Aggregate Technician Course

Lake Land College

2015-2016

Illinois Department of Transportation
Bureau of Materials & Physical Research

AGGREGATE TECHNICIAN COURSE

DEDICATION

This workbook is dedicated to the memory of Cyrus "Cy" McMasters, Area Supervisor, Illinois Department of Transportation, Division of Highways, District Two Bureau of Materials.

ACKNOWLEDGMENTS

The Aggregate Technician Course was developed jointly by the Illinois Department of Transportation (IDOT) and the Illinois Association of Aggregate Producers (IAAP).

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- Crusher details were provided by Ed Faynor of Barber-Greene Company per the Crusher and Portable Plant Association (CAPPA) booklet, "Crusher Terminology" (Appendix D herein).
- The series, "Stockpiling of Materials" (Appendix E herein), was reproduced with the permission of *Rock Products Magazine*.

AGGREGATE TECHNICIAN COURSE SCHEDULE

The following times are approximate and the schedule can be altered to accommodate the class.

Monday

8:00 am		Registration and Introduction Information
10:30 am	Ch. 1	General Geology of Illinois
12:00 pm		Lunch (1 hour)
1:00 pm	Ch. 2	Aggregate Production and Beneficiation
3:00 pm	Ch. 3	Quality and Use
5:00 pm		Finish for the day

Tuesday

8:00 am	Ch. 7	QC/QA Responsibilities Policy
10:00 am	Ch. 8	Aggregate Gradation Control System Policy
12:00 pm		Lunch (1 hour)
1:00 pm	Ch. 9	Aggregate Producer Control Chart Procedure Policy
5:00 pm		Finish for the day

Wednesday

8:00 am		Control Chart Homework
9:00 am	Ch. 4	Stockpiling and Handling
10:00 am	Ch. 5	Field Gradation Sampling
12:00 pm		Lunch (1 hour)
1:00 pm	Ch. 6	Gradation Testing Procedures & Calculations
5:00 pm		Finish for the day

Thursday

8:00 am	Lab	**Group 1** – Sample Splitting and Gradation Homework
	Lab	**Group 2** – Hands-on Gradation Procedure
12:00 pm		Lunch (1 hour)
1:00 pm	Lab	**Group 1** – Hands-on Gradation Procedure
	Lab	**Group 2** – Sample Splitting and Gradation Homework
5:00 pm		Finish for the day

Friday

8:00 am	Testing – Written, Calculation & Proficiency (See schedule for test times)

NOTE: This manual is also used for the CET027 Mixture Aggregate Technician Upgrade class. The above schedule does not apply to the CET027 Mixture Aggregate Technician Upgrade class.

Attendance Policy:

Students are now REQUIRED to present photo identification on the first day of class and prior to undertaking any test (written, calculation, practical and/or retest)

Students are required to attend all class sessions in their entirety in order to receive a certification. The student will be required to retake any missed session **or** attend the class in its entirety, per the discretion of the instructor, before receiving a class certification. This includes **being on time** to all class sessions. **No exceptions** will be made to this policy!

*Testing Policy:		Aggregate Technician	Mixture Aggregate Upgrade
Course Prerequisite:		None	Mixture Aggregate Technician
Written Test (Part 1)	**Open** Book	**Time Limit** – 1 1/2 hours **Minimum grade** – 70% (Retest **cannot** be taken on the same day as the initial test)	**Time Limit** – 1 1/2 hours **Minimum grade** – 70% (Retest **cannot** be taken on the same day as the initial test)
Calculation Test (Part 2)	**Closed** Book	**Time Limit** – 1 1/2 hours **Minimum grade** – 70% (Retest **can** be taken on the same day as the initial test)	N/A
Practical Test (Part 3)	**Closed** Book	**Time Limit** – No time limit **Minimum grade** – Pass or Fail (Retest **can** be taken on the same day as the initial test)	N/A

***Retest Policy:**

Written Retest	**Open** Book	**Time Limit** – 1 1/2 hours **Minimum grade** – 70%	**Time Limit** – 1 1/2 hours **Minimum grade** – 70%
Calculation Retest	**Closed** Book	**Time Limit** – 1 1/2 hours **Minimum grade** – 70%	N/A
Practical Retest	**Closed** Book	**Time Limit** – No time limit **Minimum grade** – Pass or Fail	N/A

*** See attendance policy above**

If the student fails **any test** the first time, a retest will be required to be completed for the failed test. All retests are required to be completed before the end of the current academic year. Lake Land College's academic year runs September 1st, 2015 to August 31st, 2016.

Example: If the original failed test was taken on December 18, 2015, the last date to retest would be the last business day up until August 31, 2016.

Failure of any retest, or failure to comply with the academic year retest time limit, will require the student to retake the class in its entirety. The student shall be required to pay all appropriate fees to retake the class.

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This page is reserved

LAKE LAND COLLEGE
INSTRUCTOR AND COURSE EVALUATION

Course (circle class attended): **Agg. Tech. Course** Section _____ Date_____

Mix. Agg. Tech. Upgrade Section _____

Lead Instructor Name: _____**Rick Watson**_____ **Lab Instructor #1's Name:**_____

Lab Instructor #2's Name:_____

PURPOSE: The main emphasis at Lake Land College is teaching. In this regard, each instructor must be continuously informed of the quality of his/her teaching and the aspects in which that teaching can be improved. As a student, you are in a position to judge the quality of teaching from direct experience, and in order to help maintain the quality of instruction at Lake Land, you are asked to complete this evaluation.

DIRECTIONS: **DO NOT SIGN YOUR NAME** (to protect your anonymity). We appreciate your fairness, honesty and frankness.

For each following items, please indicate by number, on a scale from 1 to 5, with 1 being WEAK and 5 being SUPERIOR, which seems most appropriate to you for the instructors and course that you are evaluating. You are strongly encouraged to make any comments that will clarify any particular rating in the comment sections (please refer to each item you are discussing by its number).

(1 = Weak, **2** = Needs Improvement, **3** = Average, **4** = Good, **5** = Superior)

OBJECTIVES AND APPROPRIATENESS OF THE COURSE:

1.	**Clarity of Objectives**	The objectives of the course were clearly identified and were adequately covered.	_____
2.	**Selection content**	Content was relevant and met the level of the class.	_____

ORGANIZATION AND CONTENT OF LESSONS:

			LEAD INSTR.	LAB INSTR. 1	LAB INSTR. 2
3.	**Teacher preparation**	Instructor was organized and knowledgeable in subject matter and prepared for each class.	_____	_____	_____
4.	**Organization of classes**	Classroom activities were well organized and clearly related to each other.	_____	_____	_____
5.	**Selection of materials**	Instructional materials and resources used were specific, current, and clearly related to the objectives of the course.	_____	_____	_____
6.	**Clarity of presentation**	Content of lessons was presented so that it was understandable to the students.	_____	_____	_____
7.	**Clarity of presentation**	Different point of view and/or methods with specific illustrations were used when appropriate.	_____	_____	_____

Please record any general impressions and/or comments pertaining to the **course**: _____

_____

_____

↓↓↓ **Please continue filling out the other side of this form** ↓↓↓

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LAKE LAND COLLEGE
INSTRUCTOR AND COURSE EVALUATION

(PAGE 2)

PERSONAL CHARACTERISTICS AND STUDENT RAPPORT:			**LEAD INSTR.**	**LAB INSTR. 1**	**LAB INSTR. 2**
8.	**Vocabulary**	Instructor's vocabulary level was appropriate for the class and labs.	_____	_____	_____
9.	**Pupil participation and interest**	Instructor encouraged students to ask questions and actively participate in class and labs when practical.	_____	_____	_____
10.	**Personal attributes**	Instructor indicated an interest and enthusiasm for teaching the subject matter.	_____	_____	_____
11.	**Personal attributes**	Instructor was familiar with current industry practices.	_____	_____	_____
12.	**Personal**	Instructor's mannerisms were appropriate for the class.	_____	_____	_____
13.	**Instructor-student rapport**	Instructor indicated a willingness to help students in times of difficulty.	_____	_____	_____
14.	**Instructor-student rapport**	Instructor was fair and impartial in dealings with students.	_____	_____	_____

Please record any general impressions and/or comments pertaining to the **instructors**:

Lead Instructor _____

_____

_____

Lab Instructor #1 _____

_____

_____

Lab Instructor #2 _____

_____

_____

SUMMARY:

15.	Considering everything, how would you rate each instructor?	_____	_____	_____
16.	Considering everything, how would you rate this course?	_____		

EXAMINATION:

17.	**Exam**	The exam correlated to the materials being covered in class.	_____

INTRODUCTION

Quality Management Program

Quality Control / Quality Assurance (QC/QA)

The Illinois Department of Transportation (IDOT) started the Quality Management Program in 1991. Three segments of the construction industry were chosen to implement the QC/QA process as part of the Quality Management Program: Hot Mix Asphalt, Portland Cement Concrete, and the aggregates used in asphalt and concrete.

Philosophy of QC/QA:

Under the Quality Management Program, the contractor is responsible for Quality Control and Quality Assurance is the responsibility of IDOT. Some people feel that it is a direct conflict of interest for the contractor or aggregate producer to be doing the testing of his own product and be in charge of his own quality control. This is a major departure from the way the construction industry and IDOT have always done things in Illinois. In reality, this process is used throughout the nation, not only in the road building industry, but in other segments of industry. This movement has been encouraged by the FHWA because it provides for a significantly increased amount of testing and quality monitoring which leads to a significant improvement in the quality of the finished product. In reality, it is easier for the contractor to control quality than some outside source, such as IDOT. The contractor has direct control over those things that go into making up a quality product such as the personnel, the equipment, and the materials being used. When QC/QA is talked about, many people hone in on the Quality Control and forget about the Quality Assurance. The QA is IDOT's part of the program. Under this program, IDOT does not control the quality, but must take all the necessary actions to assure that the contractor is controlling quality. These assurance processes are detailed in the various special provisions and specifications. They include some parallel testing of the materials, observing the contractor's personnel performing tests to see that the tests are being run correctly, and, in general, monitoring the contractor's quality control process.

Aggregate Requirements:

One of the basic requirements in the QC/QA program is that the aggregates that are used in Hot Mix Asphalt (HMA) and Portland Cement Concrete (PCC) must be produced under the Aggregates Gradation Control System (AGCS). In this system, the aggregate producer is responsible for his gradation control and certifies that the aggregates meet the gradation and quality requirements when shipped. In addition, tighter gradation requirements are placed on the critical sieve of the coarse aggregate being produced. There are currently over 500 approved aggregate sources in the AGCS system. A current list of approved sources can be found at IDOT's following webpage:

http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Specialty-Lists/Highways/Materials/Materials-&-Physical-Research/Aggregate/approvedaggregatesources.pdf

The A.G.C.S. Program was originally designed to control the production of coarse aggregates and manufactured sands used in PCC and HMA mixtures on IDOT QC/QA Projects.

The A.G.C.S. Program has since been expanded to include the following products on the date indicated:

Effective July 1, 2000

Coarse Aggregate for All PCC and Class I/Superpave HMA Projects
Manufactured Sand for All PCC and Class I/ Superpave HMA Projects
Natural Sand for All PCC and HMA Projects

Effective July 1, 2001

Coarse Aggregate and Manufactured Sand for All Non-Class I/ Superpave HMA Projects
Aggregate Surface Course
Granular Shoulders
Granular Subbase
Granular Base
Granular Embankment Special
Cover/Seal Coat

Hot Mix Asphalt

The chart below shows the progression of QC/QA in the production of hot mix asphalt. IDOT started with six projects in 1991. By August of 1994, a total of 255 jobs had been built, which used approximately 6,000,000 tons of hot mix. Currently, all of the Districts in the state are practically 100% QC/QA for hot mix production.

DISTRICT	Number of Asphalt QC/QA Contracts Let				Total # of Jobs	Estimated Total Tons
	1991	1992	1993	As of 8/31/94		
1	0	1	2	0	3	62,633
2	2	3	4	21	30	969,765
3	0	4	3	16	23	462,992
4	0	4	5	16	25	896,563
5	1	4	12	14	31	1,076,378
6	0	4	11	24	39	648,796
7	0	2	8	22	32	475,041
8	0	6	11	15	32	862,739
9	3	2	8	27	40	559,610
Totals	**6**	**30**	**64**	**155**	**255**	**6,013,287**

Portland Cement Concrete

The Portland Cement Concrete QC/QA program started in 1992. It is a little more complex than the Hot Mix Asphalt (HMA) program because typically the concrete mix is produced by a ready mix producer and placed by the contractor. HMA is normally produced and placed by only the contractor. Currently the QC/QA process for concrete is being used on the larger projects throughout the state, and almost 100% in District 1.

Program Training Requirements:

IDOT has mandated that the personnel involved in the program be properly trained. They have developed the following courses which are required under the Quality Management program. All of the following classes are available through Lake Land College except the Gradation Technician which is available through the BMPR.

CET 020 Mixture Aggregate Technician (3 days)

CET 021 Aggregate Technician (5 days)

CET 027 Mixture Aggregate Technician Upgrade (2 days)

CET 029 Level I Hot Mix Asphalt (5 days)

Prerequisite: CET 020 3-Day Aggregate for Mixtures **or**
CET 021 5-Day Aggregate Technician

CET 023 Level II Hot Mix Asphalt (5 days)

Prerequisite: CET 029 Level I Hot Mix Asphalt

CET 031 Level III Hot Mix Asphalt (5 days)

Prerequisite: CET 023 Level II Hot Mix Asphalt

CET 026 Half-Day Nuclear Density

CET 030 Level I Portland Cement Concrete

CET 024 * Level II Portland Cement Concrete

CET 039 ** Level III Portland Cement Concrete

Prerequisites:		* **	CET 020 3-Day Aggregate for Mixtures
	or	* **	CET 021 5-Day Aggregate Technician
	and	* **	CET 030 Level I Portland Cement Concrete
	and	**	CET 024 Level II Portland Cement Concrete

Concrete Tester

Gradation Technician

NOTE: The CET 032 AGCS Technician Course has been eliminated. Previous CET 032 AGCS Technician training is still recognized and valid.

Wonder what IDOT QC/QA training you need? The following may help in determining what classes you should take:

AGGREGATES	
Task	***Required Training Course for Certification***
Quality Control Manager	Aggregate Technician (CET 021) [1/]
Visual Inspections	Aggregate Technician (CET 021 [1/]
Aggregate Sampling	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020)
Splitting and Gradation Testing	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020) **or** Gradation Technician (IDOT class) [2/]
HOT MIX ASPHALT	
Quality Control Manager	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020) and Bituminous Concrete Level I (CET 029) and Bituminous Concrete Level II (CET 023)
Aggregate Sampling and Gradation Testing	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020) [2/ 4/] and/or Bituminous Concrete Level I (CET 029)
HMA Sampling and Testing	Bituminous Concrete Level I (CET 029)
HMA Mix Design	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020) and Bituminous Concrete Level I (CET 029) and Bituminous Concrete Level II (CET 023) and Bituminous Concrete Level III (CET 031)
PORTLAND CEMENT CONCRETE	
Quality Control Manager	Aggregate Technician (CET 021) **or** Mixture Aggregate Technician (CET 020) and PCC Level I Field Technician (CET 30) and PCC Level II Plant Technician (CET 24)
Job Site Mix Sampling & Testing	PCC Level I (CET 030) **or** Concrete Tester (Concrete Tester Course) [3/]
Concrete Plant Control & Testing	PCC Level I Field Technician (CET 30) and PCC Level II Plant Technician (CET 24) [2/ 3/]
PCC Mix Design	PCC Level I Field Technician (CET 30) and PCC Level II Plant Technician (CET 24) and PCC Level III (CET 039)
Precast	**Must have current A.C.I. card (no IDOT certification is required)**

Notes
1/ Combined certifications of a Mixture Aggregate Technician (CET 20) **AND** Mixture Aggregate Technician Upgrade (CET 027) meets the requirement for an Aggregate Technician (CET 021)
2/ A Gradation Technician must be supervised by a Mixtures Aggregate Technician or an Aggregate Technician. **Under supervision**, a Gradation Technician may perform gradation testing at a PCC or HMA mix plant. Contact the BMPR for information on how to attain a Gradation Technician certification.
3/ A Concrete Tester is required to be supervised by a PCC Level I or a PCC Level II Technician. Training for the Concrete Tester is available through Lake Land College.
4/ Aggregate Technicians and Mixture Aggregate Technicians may perform aggregate sampling and gradation testing at a PCC or HMA mix plant, except they **can not** sample hot bins at a batch style HMA plant.

Metrification

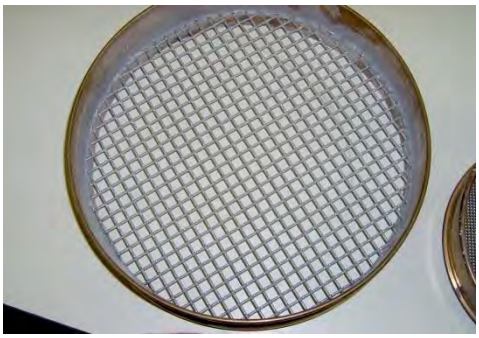
In the spring of 2000, the Illinois Department of Transportation decided to return to English units. All jobs proposed after April 2000 would be designed in English units. All manuals are published with both units of measurement, English (Metric).

Sieve Designations

The following are the English and Metric-equivalent sieve designations commonly used when testing aggregate materials:

SIEVE CONVERSIONS

ENGLISH		**METRIC**	
3"	----------	75 mm	
2.5"	----------	63 mm	
2"	----------	50 mm	
1.75"	----------	45 mm	
1.5"	----------	37.5 mm	
1"	----------	25 mm	
3/4"	----------	19 mm	
5/8"	----------	16 mm	
1/2"	----------	12.5 mm	
3/8"	----------	9.5 mm	
1/4"	----------	6.3 mm	Coarse Aggregate
#4	**----------**	**4.75 mm**	
#8	**----------**	**2.36 mm**	Fine Aggregate
#10	----------	2.00 mm	
#16	----------	1.18 mm	
#30	----------	600 μm	
#40	----------	425 μm	
#50	----------	300 μm	
#80	----------	180 μm	
#100	----------	150 μm	Fine Aggregate
#200	**----------**	**75 μm**	Dust



Gradation Terms & Codes:

The following terms are used to identify the gradation of an aggregate:

CA	**C**oarse **A**ggregate	Standard Specifications
CAM	**C**oarse **A**ggregate **M**etric	Standard Specifications
CM	**C**oarse **M**odified	Modified Standard Specifications
CMM	**C**oarse **M**odified **M**etric	Modified Standard Specifications
FA	**F**ine **A**ggregate	Standard Specifications
FAM	**F**ine **A**ggregate **M**etric	Standard Specifications
FM	**F**ine **M**odified	Modified Standard Specifications
FMM	**F**ine **M**odified **M**etric	Modified Standard Specifications

These terms are used in conjunction with numerical codes which indicate specific gradations and uses of material as shown in the following example. The following information is obtained in part from the Standard Specifications for Road and Bridge Construction, adopted on April 1, 2016.

The following is an example of determining material use from aggregate material codes:

Aggregate Material Codes

Inspected Material	Quality Level	Type of Material	Aggregate Type	Specification	Gradation Number	Superstructure Quality Concrete
0 = Aggregates	0 = No Quality 1 = No Quality 2 = A quality 3 = B quality 4 = C quality 5 = D quality 6 = D Quality Stabilized	0 = Gravel 1 = Crushed Gravel 2 = Crushed Stone 3 = ACBF Slag 7 = Natural Sand 8 = Stone Sand 9 = Special Aggregate	C = Coarse Aggregate F = Fine Aggregate	A = Standard Specification M = Modified Specification	Standard Specifications Article 1003.01(C) or Article 1004.01(C)	01

Example: **032CM16**

0	3	2	C	M	16
Aggregate	**'B' Quality**	**Crushed Stone**	**Coarse Aggregate**	**Modified Specification**	**Gradation**

A modified 'B' quality crushed stone coarse aggregate 16 gradation

Class Example:

Pages 7 & 8 are excerpts from the 2016 Standard Specifications:

Art. 1003.01 (10) (c) Fine Aggregate Gradation Table

FINE AGGREGATE GRADATIONS											
Grad No.	Sieve Size and Percent Passing										
	3/8	No. 4	No. 8 4/	No. 10	No. 16	No. 30 5/	No. 40	No. 50	No. 80	No. 100	No. 200 1/
FA 1	100	97±3			65±20			16±13		5±5	
FA 2	100	97±3			65±20			20±10		5±5	
FA 3	100	97±3		80±15			50±20		25±15		3±3
FA 4 7/	100				5±5						
FA 5	100	92±8								20±20	15±15
FA 6		92±8 2/								20±20	6±6
FA 7		100		97±3			75±15		35±10		3±3
FA 8			100				60±20			3±3	2±2
FA 9			100					30±15		5±5	
FA 10				100			90±10		60±30		7±7
FA 20	100	97±3	80±20		50±15			19±11		10±7	4±4
FA 21 3/	100	97±3	80±20		57±18			30±10		20±10	9±9
FA 22	100	6/	6/		8±8						2±2

1/ Subject to maximum percent allowed in Fine Aggregate Quality Table.

2/ 100 percent shall pass the 1 in. (25 mm) sieve, except that for bedding material 100 percent shall pass the 3/8 in. (9.5 mm) sieve. If 100 percent passes the 1/2 in. (12.5 mm) sieve, the No. 4 (4.75 mm) sieve may be 75 ± 25.

3/ For all HMA mixtures. When used, either singly or in combination with other sands, the amount of material passing the No. 200 (75 µm) sieve (washed basis) in the total sand fraction for mix design shall not exceed ten percent.

4/ For each gradation used in HMA, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of ±15 percent. The midpoint shall not be changed without Department approval.

5/ For each gradation used in HMA, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of ±13 percent. The midpoint shall not be changed without Department approval.

6/ For the fine aggregate gradation FA 22, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of ±10 percent. The midpoint shall not be changed without Department approval.

7/ When used as backfill for pipe underdrains, Type 3, the fine aggregate shall meet one of the modified FA 4 gradations shown in the following table.

FA 4 Modified		
Sieve Size	Percent Passing	
	Option 1	Option 2
3/8 in. (9.5 mm)	100	100
No. 4 (4.75 mm)		97 ± 3
No. 8 (2.36 mm)		5 ± 5
No. 10 (2 mm)	10 ± 10	
No. 16 (1.18 mm)	5 ± 5	2 ± 2
No. 200 (75 µm)	1 ± 1	1 ± 1

Art. 1004.01 (10) (c) Coarse Aggregate Gradation Table

	COARSE AGGREGATE GRADATIONS												
Grad No.	Sieve Size and Percent Passing												
	3 in.	2 1/2 in.	2 in.	1 1/2 in.	1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	N0. 8	No. 16	No. 50	No. 200 1/
CA 1	100	95±5	60±15	15±15	3±3								
CA 2		100	95±5		75±15		50±15		30±10		20±15		8±4
CA 3		100	93±7	55±20	8±8		3±3						
CA 4			100	95±5	85±10		60±15		40±10		20±15		8±4
CA 5				97±3 2/	40±25		5±5		3±3				
CA 6				100	95±5		75±15		43±13		25±15		8±4
CA 7				100	95±5		45±15 7/		5±5				
CA 8				100	97±3	85±10	55±10		10±5		3±3 3/		
CA 9				100	97±3		60±15		30±15		10±10		6±6
CA 10					100	95±5	80±15		50±10		30±15		9±4
CA 11					100	92±8	45±15 4/7/		6±6		3±3 3/ 5/		
CA 12						100	95±5	85±10	60±10		35±10		
CA 13						100	97±3	80±10	30±15		3±3 3/		
CA 14							90±10 6/	45±20	3±3				
CA 15							100	75±15	7±7		2±2		
CA 16							100	97±3	30±15		2±2 3/		
CA 17	100								65±20		45±20	20±10	10±5
CA 18	100				95±5				75±25		55±25	10±10	2±2
CA 19	100				95±5				60±15		40±15	20±10	10±5
CA 20							100	92±8	20±10	5±5	3±3		

1/ Subject to maximum percent allowed in Coarse Aggregate Quality table.

2/ Shall be 100 percent passing the 1 3/4 in. (45 mm) sieve.

3/ When used in HMA (High and Low ESAL) mixtures, the percent passing the No. 16 (1.18 mm) sieve for gradations CA 8, CA 11, CA 13, or CA 16 shall be 4 ± 4 percent.

4/ When using gradation CA 11 for IL-19.0 and IL-19.0L binder, the percent passing the 1/2 in. (12.5 mm) sieve may also be 15±10.

5/ The No. 16 (1.18 mm) requirement will be waived when CA11 is used in the manufacture of Portland cement concrete.

6/ Shall be 100 percent passing the 5/8 in. (16 mm) sieve.

7/ When Class BS concrete is to be pumped, the coarse aggregate gradation shall have a minimum of 45 percent passing the 1/2 in. (12.5mm) sieve. The Contractor may combine two or more coarse aggregate sizes, consisting of CA 7, CA 11, CA 13, CA 14, and CA 16, provided a CA 7 or CA 11 gradation is included in the blend.

Note: When CA 7, CA 8, CA 11, CA 13, CA 14, CA 15, or CA 16 are used under paved median, notes 3, 4, 5, 6, and 6 shall apply.

AGCS Program Highlights

Gradation of Standard Specifications versus AGCS gradations

Under the AGCS, the aggregate producer, with the approval of the Department, is allowed to establish their own targets for gradations. As a part of this process, the producer must also use the master band concept. With the master band concept, the critical sieve is designated by IDOT for each coarse aggregate gradation. The producer then sets a master band target for that sieve. A major factor that needs to be emphasized is that the approved gradation still needs to be compatible with other gradations to produce acceptable mix designs for asphalt and concrete mixtures.

The following are excerpts from the AGCS Policy Memorandum:

Gradation Specifications

Sieve limits for each sieve/each product under the Aggregate Gradation Control System shall be as specified in the Department's Standard Specifications and/or as amended herein. The special critical sieve criteria for certain designated products as described in QC/QA Procedure, "Aggregate Producer Control Chart Procedure" located in the current "Manual of Test Procedures for Materials" are also required.

The midpoint/tolerance range of a designated critical sieve shall be developed from an average as shown in QC/QA Procedure, "Aggregate Producer Control Chart Procedure," noted above. The average shall be a historical average or a production average derived from start-of-production samples that is agreed to by the Department. Critical sieve limits shall take precedence over Standard Specification limits. Requests for critical sieve limits shall be submitted in writing to the District Materials Engineer for approval.

For sieves other than the top and bottom specifications sieves, sieve limits may be developed based on historical or average production values. These sieve limits may be different from those in the Standard Specifications. These modifications are also allowed for fine aggregate. Changes in the top sieve or any No. 200 sieve ranges will not be permitted. In cases where the bottom sieve is other than the No. 200 sieve, a variance in limits may be granted if the Bureau determines the minus No. 200 material to be within acceptable limits. The Source shall request in writing to the District Materials Engineer approval of limits other than those in the Standard Specifications, but the range of the limits shall remain the same as the Standard Specifications.

Although the Department reserves the right to reject unacceptable material at any point prior to incorporation into the final product, the agreed upon gradation limits shall apply at the final point of shipping within the Source's control.

Development of Gradation Bands on Incoming Aggregate at Mix Plants

The aggregate user may use the gradation limits supplied by the producer or may choose to modify the gradation limits in accordance with the Department's "*Development of Gradation Bands on Incoming Aggregate at Mix Plants"* found in Appendix B of this manual. In general, this policy allows the user to shift the control limits of all sieves, except the top and bottom sieve, upwards a maximum of 3% due to the potential for degradation of some materials during shipping and handling. If the user elects to use this procedure, the new gradation limits must be approved by the District Materials Engineer. Once adopted, the new user limits are then used in place of the aggregate source limits for all gradation tests at the users' site.

Master Band/Warning Band and Critical Sieve Designations

Gradation	Critical Sieve*	Master Band (%)	Warning Band (%)
CA/CM 5	**1" (25 mm)**	**± 8**	**± 6**
CA/CM 7	**1/2" (12.5 mm)**	**± 8**	**± 6**
CA/CM 11	**1/2" (12.5 mm)**	**± 8**	**± 6**
CA/CM 13	**No. 4 (4.75 mm)**	**± 8**	**± 6**
CA/CM 14	**3/8" (9.5 mm)**	**± 8**	**± 6**
CA/CM 16	**No. 4 (4.75 mm)**	**± 8**	**± 6**

* Critical sieves for coarse aggregate gradations are established per Specification 201 "Aggregate Gradation Sample Size Table & Quality Control Sieves" document located in the current Manual of Test Procedures.

Master Band requirements for FA 20/21/22 aggregate gradations are established per Specification 201 "Aggregate Gradation Sample Size Table & Quality Control Sieves" document located in the current Manual of Test Procedures.

AGGREGATE GRADATION CONTROL SYSTEM

There are two methods by which aggregates can be certified for IDOT use when using the Aggregate Gradation Control System (AGCS).

Method 1 covers aggregate producers who employ their own “trained technicians” and furnish their own “approved laboratory” to control production of aggregates under the Aggregate Gradation Control System.

Method 1 allows an aggregate producer to furnish certified aggregates on a continuing basis to any number of contractors for IDOT contracts as long as the source meets all requirements of the Aggregate Gradation Control System.

Use of Method 1 will allow the aggregate source to be listed as a Certified Source on the Approved Aggregate Source list.

Method 2 is a variation of Method 1 where the aggregate producer utilizes the services of an engineering consultant to perform the required testing of the Aggregate Gradation Control System. The consultants must use “trained technicians” and have an “approved laboratory”.

Under Method 2, the aggregate producer may furnish certified aggregates on a continuing basis to any number of contractors for IDOT contracts as long as the producer and the retained consultant continue to meet the requirements of the Aggregate Gradation Control System.

Use of Method 2 will allow the aggregate source to be listed as a Certified Source on the Approved Aggregate Source list.

NOTE: “Trained technicians” indicate employees who have successfully completed the Illinois Department of Transportation “Aggregate Technician Course”.

“Approved laboratory” indicates a laboratory that has been inspected and approved by the Illinois Department of Transportation District Materials office.

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1.0 GENERAL GEOLOGY OF ILLINOIS

There 2 main aggregate products used in Illinois, **sand and gravel materials** which were created and deposited by the glaciers or water run-off and **crushed stone** which typically comes from carbonate rock formations

Glacial coverage

1.1 **Sand and Gravel Geology**. Sand and gravel is mined in Illinois from erosional deposits consisting of a heterogeneous mixture of igneous, metamorphic, and sedimentary rock. Most sand and gravel deposits in Illinois are related to the advance and retreat of continental glaciers that periodically moved from Canada into Illinois until approximately 10,000 years ago. Some of this material was also reworked by the processes of rivers, lakes, and winds to become our present-day sand and gravel deposits.

In order to provide a more extensive background, the two types of sand and gravel deposits in Illinois will be discussed in more detail:

- Glacial deposits
- Fluvial (river) deposits

1.1.1 **Glacial Deposits** - Although there are three types of glaciers (valley glaciers, piedmont glaciers and continental glaciers) that can produce glacial deposits, this discussion will focus on continental glaciers.

The continental glaciers were the main type of glaciation that helped to develop Illinois' sand and gravel deposits.

Continental glaciers (ice sheets) are large accumulations of ice that moved, due to the force of gravity, to cover large areas (hundreds to hundreds of thousands of square miles). They were normally thousands of feet thick. A prime example is the last continental glacier to cover Chicago (about 10,000 years ago) that was calculated to be 3,050 m (10,000 ft) thick at its maximum thickness.

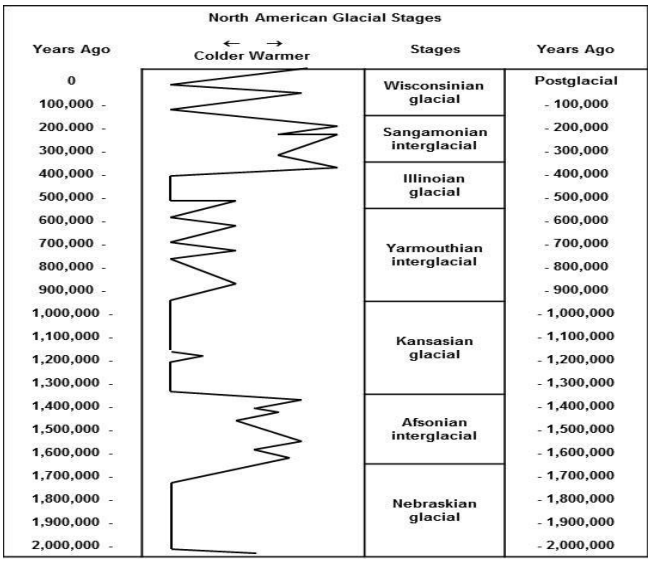
Glaciers

Continental glaciers, in order to grow, require low temperatures and an adequate snowfall over long periods of time (thousands of years). The continental glaciers affecting Illinois all originated in far-northern Canada.

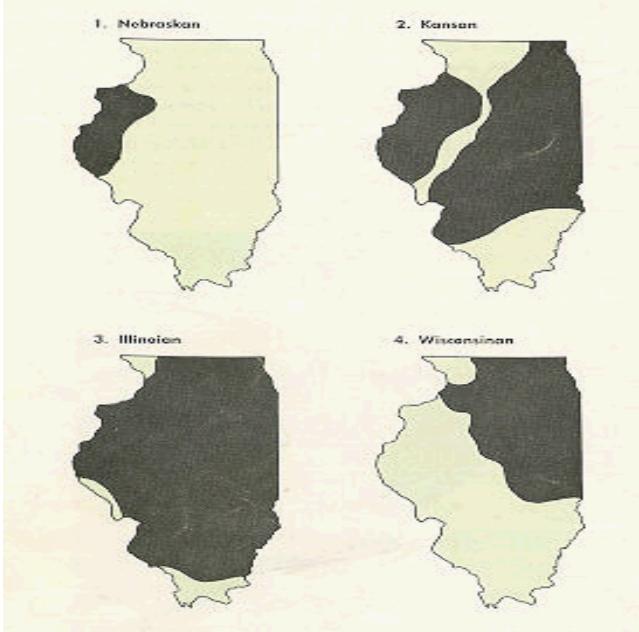
Continental glaciers deposited sand and gravel in Illinois during at least four major advancements. During the two oldest glaciation periods, continental glaciers moved across Illinois, scouring up large amounts of deeply weathered material and various types of bedrock as they advanced as far south as the St. Louis area. However, the large amounts of material scoured up and deposited during these glacial periods were removed during subsequent glacial periods and are not generally part of current sand and gravel deposits.

In the second youngest period, the Illinoisan, glaciers penetrated into Illinois as far south as the Shawnee Hills, at one time covering approximately 90% of the state. This time, large amounts of material were scoured and deposited across Illinois and are represented in some Illinois sand and gravel deposits.

The Wisconsinian glacier, the youngest, reached only into Central Illinois but, again, incorporated materials from the previous glacier, as well as scouring up new material, thus creating most of the current deposits presently being worked. The mechanics of glacial movement and glacial sand/gravel deposition are relatively simple. As a glacier accumulates more and more snow and ice under appropriate climatic conditions, it begins to advance or move. As the glacier advances, it plucks, scours, grinds, and pushes rock, trees, and anything else in its way (similar to a bulldozer). Even large boulders can be ground into sand and gravel-size material under the glacier as it moves.

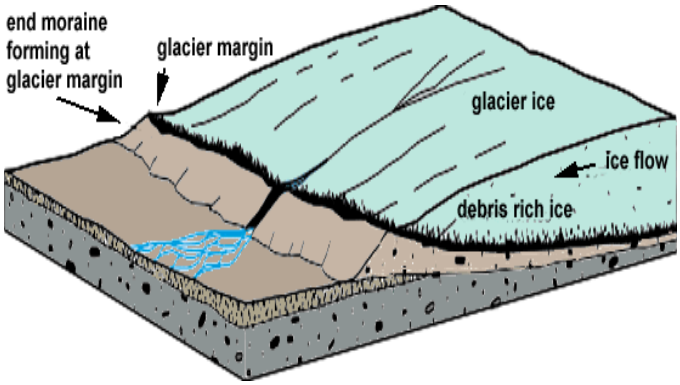


North American glacial stages



Illinois glaciation periods

This material is carried mainly in the base and sides of the glacier. The glacier continues to advance until the temperature at its leading edge is sufficiently high to cause melting to take place faster than its forward motion. When this condition occurs, it is known as "glacial retreat".



End moraine of a glacier

Sand and gravel deposition takes place as the glacier advances and retreats. A number of different types of sand and gravel deposits are left by a glacier and its melt waters. These can be divided into two main categories: (1) unstratified drift, or till, which is deposited directly by the glacier and (2) stratified drift which is deposited by the glacier's melt waters. The difference between these two is apparent in their names. Unstratified drift is a poorly sorted hodgepodge of material, whereas stratified drift is a well sorted, layered deposit.

Till deposit

Under these two general categories there are several different types of deposits. Each of these types of deposits, listed below, will be discussed in the following paragraphs.

Unstratified Drift (Glacial)	Stratified Drift (Melt Water)
Erratics	Outwash, valley trains
Moraines	Eskers
Drumlins	Kames

Boulder train

1.1.1.1 **Unstratified drift**

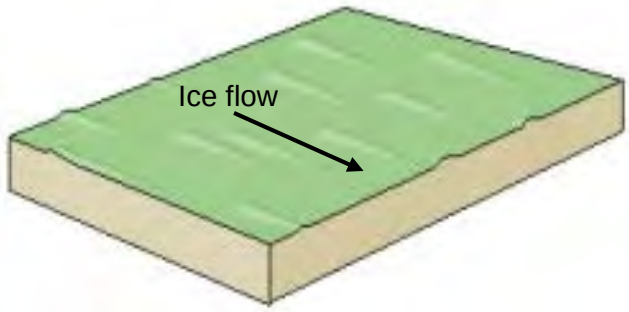
(1) Erratics and boulder trains. An erratic is a stone or boulder that has been carried from its place of origin by a glacier and left stranded on or surrounded by completely different types of material. Because of their unusually large size, most erratics have either traveled only a short distance or are very resistant rock which makes them look out of place. A boulder train is simply a series of erratics.

Erratics

(2) Moraines. "Moraine" is a general term that is used to describe many of the glacial landforms composed of till. A terminal or end moraine is a ridge of till that marks the limit of the glacier's advance. It forms when the glacier is melting back as fast as it advances. New ice continues to advance and melt at the glacier's front edge, providing an almost limitless supply of new debris (till). Recessional moraines are smaller ridges of till that mark places where the glacier was only temporarily in equilibrium. These lie at various locations behind the terminal moraine. Ground moraine is till that has been laid down by the main body of the glacier. It can vary in thickness from a thin layer of material on up to a thickness of hundreds of meters (feet).

Moraine

(3) Drumlins. Drumlins are smooth, elongated hills composed of till. They average approximately 30 m (100 ft) in height and are usually between 1/2 and 3/4 km (1/3 and 1/2 mile) long. Drumlins formed when till was deposited in a depression on the protected side of a rock hill. As the glacier advanced, it eroded the rock hill but was forced to glide over the drumlin. After the ice retreated, the drumlin became the high point in the area.



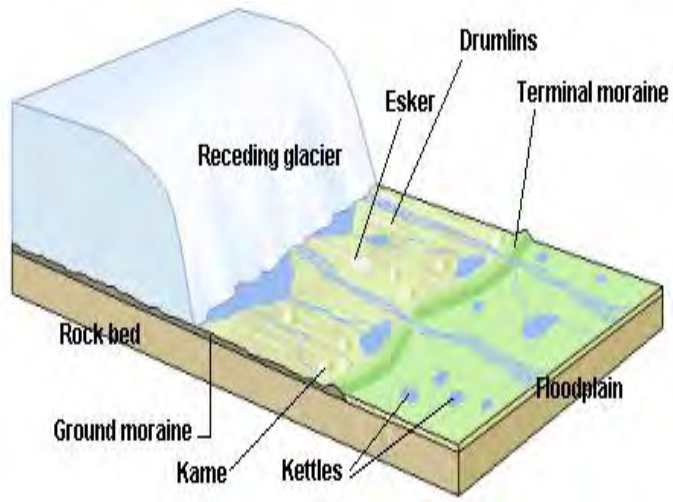
Drumlins

1.1.1.2 **Stratified drift**

(1) Outwash and valley trains. Outwash is the sand and gravel that is carried outward by the melt waters from the front of a glacier. As the glacier melts, it unleashes torrents of water that transport large amounts of debris. These streams of water rapidly lose their velocity and deposit their load of debris as they flow away from the ice sheet. As is usually the case, the larger particles fall out of suspension first, and as the water flow decreases, the smaller material begins to settle out. The process is known as sorting. Most of the large boulder gravel deposits in the Chicago area are outwash deposits. If the glacier happens to be melting in a valley, then this type of outwash deposit is called a “valley train”.

Outwash

(2) Eskers. Another stratified deposit is an esker. An esker is composed of a layer of gravel beneath a mound of sand and silt. It is a snake-shaped deposit that was formed when streams eroded a tunnel out of stagnant ice. This tunnel was then filled or partially filled with material deposited by the streams. As the glacier melted, it deposited the material in the tunnel as a steep-walled ridge of sand and gravel. Eskers range from 3 to 15 m (10 to 50 ft) in height, and 3/4 to 16 km (1/2 to 100 miles) in length but are usually only tens of meters (feet) wide.



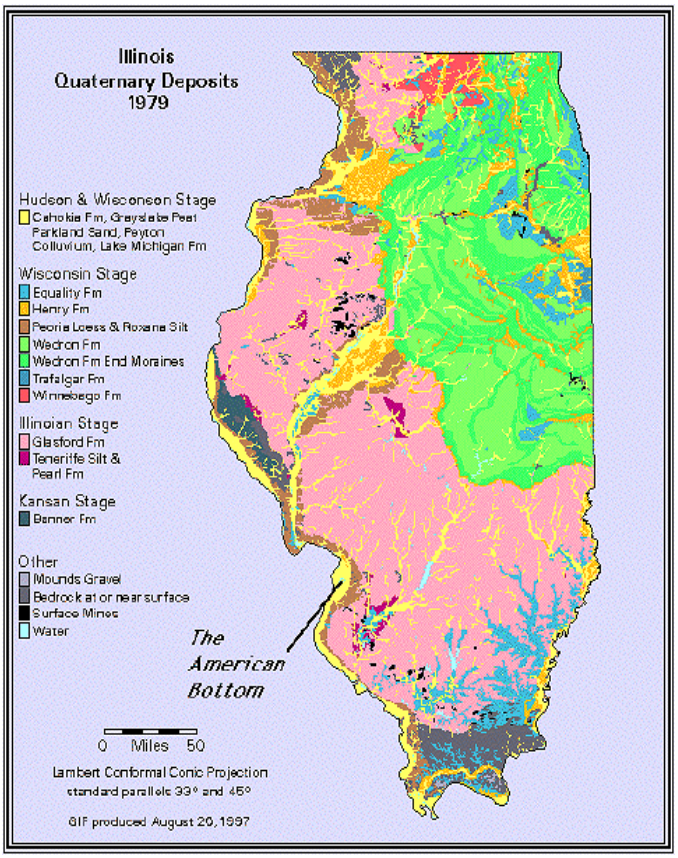
Different components of a glacier

(3) Kames. Kames are low steep-sided hills of stratified material. They are stream deposits that are left in a hole or crevasse in a block of stagnant ice. When the ice melts, the kames become the highest point in the area.

1.1.2 **Fluvial (River) Deposits** - After the glaciers had completely retreated from Illinois, they left behind the sand and gravel deposits that have just been discussed, but they also left many rivers and streams. These rivers and streams continued to flow over and through these glacial deposits, slowly eroding them down to the bedrock. While eroding the glacial sand and gravel, the rivers and streams also reworked, resorted, transported, and then redeposit this material in new deposits downstream.

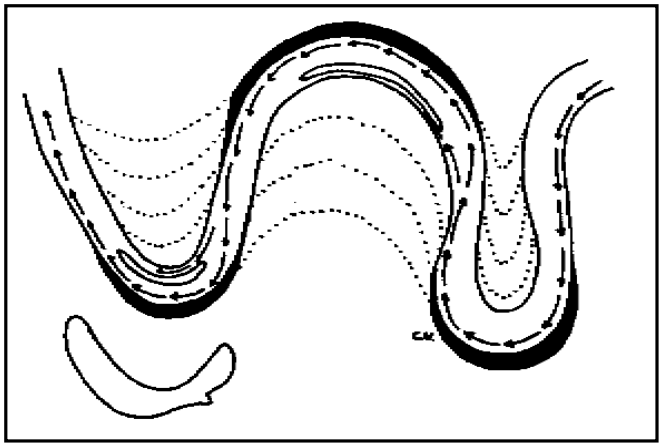
For this course, the discussion will center on two types of river deposits:

- Bar deposits
- Overbank / Flood-plain deposits

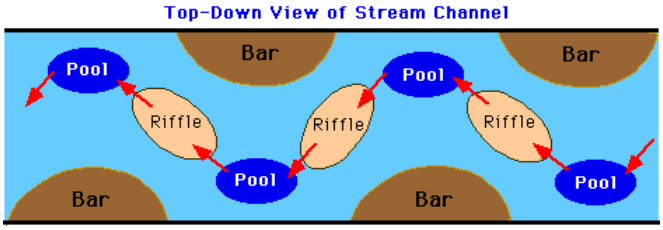


Illinois quaternary period deposits

1.1.2.1 **Bar deposits**: As a river flows, it tends to erode laterally or meander back and forth across the valley. This erosion takes place on the outside of the river bends. The river then deposits this suspended material in slower moving water on the inside of the next bend. These deposits are known as "point bars". Mining can take place in one bar if it is large enough, or an operation can move up and down the river, mining multiple bars. These deposits are usually well sorted, very clean, and contain a heterogeneous mixture of glacial sand and gravel and new material eroded by the river.

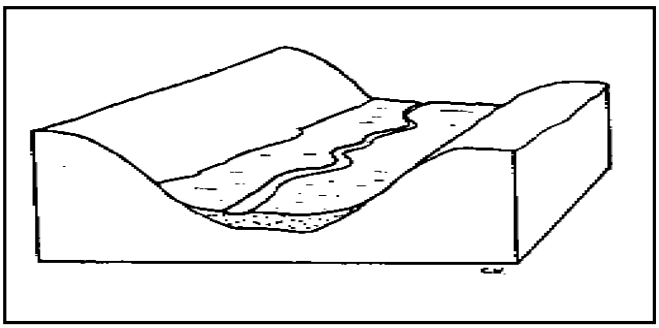


Stream Channel Deposits



Bar Deposits

1.1.2.2 **Overbank / Flood-plain deposits**: As a river overflows its banks, it loses energy, dropping its coarse particles quickly. However, large amounts of fine sand, silt, and clay remain suspended; these are deposited as the river's flow loses velocity while it extends onto the flood plain. Flood-plain deposits typically are used for backfill sand, but some are coarse enough for concrete and bituminous sand.



Flood-Plain

1.1.3 **Characteristics of a Sand and Gravel Deposit** - Now that the actual deposition of sand and gravel in certain types of deposits has been discussed, this article will focus on three characteristics that are common to all sand and gravel deposits:

- Size distribution
- Sorting
- Mineral composition

Gravel

When evaluating a potential deposit, knowledge of these characteristics can help determine whether economic mining is possible. These characteristics can also help explain quality and production problems associated with sand and gravel. Size distribution controls what products can be produced. Whether a deposit is sorted or unsorted can identify potential production problems up-front. Mineral composition plays the main role in the quality of the deposit. Each of these characteristics will be discussed in detail.

1.1.3.1 **Size distribution of a deposit**: Size distribution of a deposit simply means the amount of each different size fraction in the deposit. Material sizes range from boulders to clay. Glacial gravels, particularly the large boulder gravels in the Chicago area, tend to be considerably coarser than river deposits. Glaciers are able to carry large size material for great distances, whereas rivers, lacking the water velocity of the melting glaciers, do not have the ability to carry large boulders for long distances.

Size distribution of a deposit can also limit its uses. Some sources have enough coarse gravel to produce a full range of products, whereas others may be able to produce only pea gravel and sand. At the fine end of the spectrum, some deposits are limited entirely to fine sand production.

Gravel Deposits

Size distribution can play a big part in determining the potential of a deposit. A deposit that has a size distribution that is not desirable is probably not worth opening. On the other hand, some size ranges are so valuable in certain areas of the state that a deposit may be economic to operate even though large amounts of its materials might be unusable.

Oversize is another property that has a significant effect on the quality, physical characteristics, and size of a product. Successive crushing of oversize particles will, in general, provide quality levels exceeding that of the parent uncrushed gravel. Oversize will also provide all crushed particles (new angular fractures) in the final product. This property can be very valuable for end uses, such as hot mix asphalt.

Gravel Deposit

1.1.3.2 **Sorted / Poorly sorted deposit**: Not only is the size distribution of a deposit important, but whether each size is layered in relation to other sizes is also important. Earlier in this discussion, glacial sand and gravel was divided into unstratified and stratified deposits. Essentially, that is the same as unsorted and sorted. Glaciers, by themselves, are not able to sort material by size. When they directly deposit sand and gravel, they simply dump it all at once. All different sizes, from boulders to clay, are mixed together without any layering. On the other hand, melt waters and rivers tend to sort particles by size. As water velocity decreases, heavier or larger particles fall out first, later followed by finer material. This gives the resulting sand and gravel deposit a layered look. Most water-deposited sand and gravel deposits have numerous sequences of stratified material, grading from coarse to fine.

Boulder-train

Unsorted deposits, like moraines and other tills, can create problems when being mined. The main problem is excessive clay. This means washing is usually required to produce good aggregate. Selective mining is difficult because slugs of bad material can appear at any time. On the other hand, sorted deposits usually cause fewer problems because fine material is layered and can either be removed or processed with other material through the plant.

Poorly sorted deposit

1.1.3.3 **Mineral composition**: Sand and gravel deposits associated with glaciation contain material characteristic of the ancient bedrock that the ice sheets crossed, plus any material from older glaciers. For example, the deposits from the last part of the youngest glacier, which reached only into the Chicago area, contain mostly un-weathered material from rock located in Northeastern Illinois; the states of Wisconsin and Michigan; and Canada. These deposits consist mainly of dolomite and small amounts of igneous and metamorphic rocks.

TYPES OF MINERALS/ROCKS FOUND IN ILLINOIS GRAVELS
Sedimentary Rocks
Dolomite Laminated dolomite Silty dolomite Pyritic dolomite Limestone Cherty carbonate Chert Weathered carbonate Ironstone Shale Sandstone-Siltstone
Igneous Rocks
Mafic Weathered mafic Coarse felsic Weathered coarse felsic Fine felsic Massive quartz
Metamorphic Rocks
Gneissic Weathered gneissic Schistose Weathered schistose Metasdimentary Weathered metasdimentary Metagraywacke Tillite Quartzite

Older glaciers which moved farther south picked up more weathered material and deleterious particles from bedrock in Central Illinois. This material was deposited in Central and Southern Illinois. The deleterious materials largely consist of chert, sandstone, siltstone, ironstone concretions, coal, wood, and some weathered limestone and igneous rocks. In addition, these older deposits have experienced more weathering in-place.

In general terms, sand and gravel deposits in Northeastern Illinois are better quality than those in Central and Southern Illinois. Later in the course, IDOT's quality tests will be discussed. Two of these tests highlight the quality differences between Chicago area gravels and downstate gravels. The deleterious count, a petrographic examination, actually shows that, as a whole, there are more deleterious particles in downstate gravels. Also, the freeze-thaw test, a simulation of concrete performance in a freeze-and-thaw environment, has shown that gravels from the Chicago area perform better than downstate gravels in concrete pavement. This is mainly due to the increased amounts of chert and ironstone in downstate deposits.

General Classification of rocks		
Class	Type	Family
Sedimentary	Calcareous	Limestone Dolomite
	Siliceous	Shale Sandstone Chert Conglomerate Braccia
Metamorphic	Foliated	Gneiss Schist Amphibolite Slate
	Nonfoliated	Quartzite Marble Serpentinite
Igneous	Intrusive (coarse-grained)	Granite Syenite Diorite Gabbro Periodotite Pyroxenite Hornblendite
	Extrusive (fine-grained)	Obsidian Pumice Tuff Rhyolite Trachyte Andesite Basalt Diabase

1.1.4 **Below-Water and Above-Water Deposits** - Sand and gravel deposits can be located above the water table and below the water table. Some deposits are operated above and below water at the same time. Each of these types of deposits has merits as well as problems.

Wind-blown sand deposit

1.1.4.1 **Below-water - wet**: Sand and gravel deposits that lie below the water table are usually gray in color and are generally less weathered than their counterparts above water. Since they are less weathered, these deposits are usually better quality aggregate than above-water gravel. The drawback of below-water mining is the expense of actually extracting the material. Costly draglines or dredges usually must be used.

Below-water deposit

1.1.4.2 **Above-water - dry**: Sand and gravel deposits above the water table commonly are brown or reddish brown in color. This color can be attributed to the oxidation of the ironstone particles in the deposits. Because the gravel has been exposed to the elements for long periods of time, it is much more weathered and contains more deleterious particles than below-water gravel. Above-water gravels are usually of lower quality than below-water material. The exception to this rule is the boulder gravels in the Chicago area that are mined above water. These gravels are relatively young, geologically speaking, and have not undergone long periods of weathering. Also, they lack large amounts of deleterious particles that cause quality problems. Dry sand and gravel is usually mined with an end loader that digs into an exposed bank.

Above-water deposit

1.4.3 **Above-water / below-water**: Mining above-water and below-water sand and gravel concurrently has one major problem: inconsistent quality. Blending above- and below-water gravels is not recommended due to their potential quality differences.

1.2 **Crushed Stone Geology**

1.2.1 In Illinois most of the crushed stone aggregate used is produced from carbonate rock formations. The two classes of carbonate rock involved in Illinois aggregate production are limestone and dolomite.

1.2.1.1 **Limestone** ($CaCO_3$): Limestone is deposited as a lime mud. The mud is compacted by layers of other material deposited on top of it until it is transformed into limestone. Limestone may contain fossils or may be all fossils.

The main mineral in limestone is calcite. Pure limestone would be 100% of the mineral calcite, or calcium carbonate.

1.2.1.2 **Dolomite** ($CaMg(CO_3)_2$): Very little dolomite is virgin dolomite. Most of it was originally limestone. The shallow seas that deposited the limestone sometimes became rich in the element, magnesium. The magnesium-rich water, when circulated through the lime mud, replaced some of the calcium in the limestone molecules with magnesium. This process is the same as a conventional water softener which replaces calcium in water with sodium.

The main mineral in dolomite is dolomite. Pure dolomite would be 100% of the mineral dolomite, or calcium magnesium carbonate.

1.2.1.3 In this world, very few things are pure, and rock is not one of them. There is a lot of grading between pure limestone and pure dolomite. IDOT defines limestone as carbonate rock containing less than 11.0% magnesium oxide (MgO). Dolomite is then defined as that carbonate rock containing 11.0% or more MgO. This MgO content is determined by IDOT's Chemistry Lab, using an atomic absorption spectrophotometer. IDOT differentiates between limestone and dolomite as part of its Bituminous Friction Policy. (Found in Chapter 3.0 of this manual)

CARBONATE ROCK

LIMESTONE

DOLOMITE

LIMESTONE

- $CaCO_3$
- Deposited as lime mud
- Contains fossils of plant and animal life
- Formed in shallow seas
- Calcite or calcium carbonate

Dolomite

- $CaMg(CO_3)_2$
- Originated as limestone
- Saturated with magnesium-rich water
- Formed on the reefs of shallow seas
- Dolomite is the main ingredient
- Similar to the water-softening process

Carbonate Rock Magnesium Percentage Definition
Limestone < 11.0 % magnesium oxide (MgO)
Dolomite $\geq$ 11.0 % magnesium oxide (MgO)

1.2.2 **Physical/Chemical Characteristics**

1.2.2.1 Calcite generally is white or light gray. If there is enough clay present, it might even be dark gray or black. Other impurities, such as iron, can discolor it, turning it tan or brown.

Calcite has a specific gravity of approximately 2.700, or a unit weight of 2,700 kg/m^3 (169 lbs/ft^3), and a Mohs hardness of 3. Mohs hardness is a relative scale of 1 to 10 showing the hardness of a mineral, or its resistance to scratching, where 1 is soft (talc) and 10 is hard (diamond).

1.2.2.2 Dolomite is the same colors as calcite and also may be affected by impurities, such as iron. It has a specific gravity of 2.700 to 2.800 and a Mohs hardness of 3 to 4. Dolomite can be considered slightly harder than calcite.

1.2.2.3 Distinguishing between limestone and dolomite in the field is difficult. Usually dolomite has a sugary or grainy look and is more porous or vesicular than limestone.

A standard field test for identifying limestone from dolomite involves putting a few drops of HCl (hydrochloric acid) on the unknown rock. Limestone will fizz very violently. Dolomite usually will not fizz at all unless it is scraped to produce a fine powder and then the HCl applied.

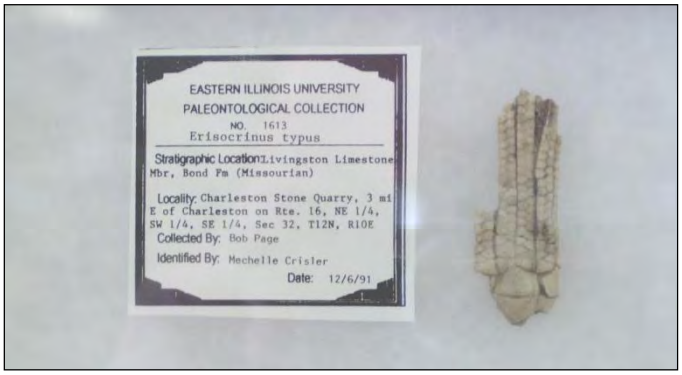
1.2.3 **Textural Characteristics** - There are several textural characteristics that are common to carbonate rocks. "Texture" is defined as the kind, size, shape, and arrangement of the component particles making up a rock, such as fossils, oolites, and crystallinity (grain size).

Limestone	
Parameter	Attribute
Color	White to light grey but can be dark grey to black
Specific Gravity	2.600 to 2.700
Hardness – Mohs scale	3
Dolomite determination	fizzing reaction

Dolomite	
Parameter	Attribute
Color	Similar to limestone
Specific Gravity	2.700 to 2.800
Hardness – Mohs scale	3 - 4
Dolomite determination	No fizzing reaction

Crushed Limestone Product

1.2.3.1 **Fossils**: Fossils are the skeletons or remains of previously living animals or plants that have been preserved in rock. Examples of fossils in Illinois rocks are carbon imprints, coral sponges, various shells, or crinoids (Indian beads).



Fossil from Charleston Stone Co. – Coles County

1.2.3.2 **Oolites**: Oolites are small spherical or rounded particles usually consisting of a quartz center surrounded by multiple layers of calcite. Oolitic limestone is limestone consisting of oolites bound together in a calcite matrix or paste.

1.2.3.3 **Crystallinity**: Crystallinity is one of those words that is hard to define. It usually means the orderly arrangement or structure of mineral grains or crystals.

Fossils from Rapatee, IL.

1.2.3.4 **Grain size**: Grain size is used in relation to crystallinity. There are many different sizes, but a standard classification is as follows:

(1) <u>Lithographic limestone</u> (less than 0.004 mm grain size diameter). This is an extremely fine crystalline rock that is of uniform character and free of coarse particles. A hand lens or microscope is needed to view these crystals.

(2) <u>Fine-grained</u> (0.004 mm to 1 mm grain size diameter)

(3) <u>Medium-grained</u> (1 mm to 5 mm grain size diameter)

(4) <u>Coarse-grained</u> (greater than 5 mm grain size diameter)

Oolites

1.2.4 **Impurities in Carbonate Rock** - Limestone and dolomite commonly have impurities which are usually non-carbonate minerals. Some of these are chert, clay, shale, sand, or pyrite. Most of these impurities produce quality problems when the carbonate rock is used as aggregate.

Impurities found in Carbonate Rock
Chert Clay Shale Sand Pyrite

1.2.4.1 **Chert** (silica dioxide (SiO_2)): Chert has the same chemical formula as glass or quartz. Most chert occurs as tiny pockets or nodules. When abundant, chert will appear as layers.

Chert – SiO_2 – Silica dioxide	
Parameter	Attribute
Color	Varies
Specific Gravity	2.050 to 2.680
Hardness – Mohs scale	7
Texture	Chalky to Glassy
Appearance	Nodules or Layers
Workability	Very abrasive
Problems	Causes pop-outs

Chert has a Mohs hardness of 7. Due to its high Mohs hardness, it is very abrasive and damaging to crushing equipment.

The specific gravity of chert is usually less than the limestone or dolomite, somewhere between 2.050 and 2.680. Lightweight chert becomes a serious problem in P.C. concrete due to its pop-out potential. (Discussed further in Chapter 3.0 of this manual)

Chert Gravel

Chert varies in color from white to black or dark gray, even green, due to impurities in its crystalline structure. The texture of chert varies from a soft, porous, chalky material to a very glassy-looking, angular rock.

1.2.4.2 **Clay and shale**: Clay and shale are common impurities in Illinois carbonates. Clay occurs as thin partings between the beds of carbonate rock. It also can occur as small particles scattered throughout the rock's crystalline structure.

Clay Balls

Shale is essentially compacted and hardened clay. Normally, shale is identified by its visible laminations. It occurs in layers of variable thickness. Its color ranges from red-to-black to gray-to-green due to impurities.

1.2.4.3 Some other non-carbonate impurities are sand particles, which are essentially quartz grains. Pyrite ("fool's gold") and marcasite are also found in carbonate rock.

1.2.5 **Stratigraphy** - Having covered the basic characteristics of carbonate rocks, the stratigraphy of the rock in Illinois will be discussed. Stratigraphy can be defined as the branch of geology that studies the sequence in which the rock formations were deposited.

1.2.5.1 In order to understand the stratigraphy of Illinois, a number of concepts need to be defined. These concepts or terms are often used when running a total quality control program at a quarry.

(1) Lithology. Lithology is defined as the physical characteristics of a rock, otherwise known as the structure and composition of the rock formation. In simple terms, lithology means "rock type", i.e., shale, limestone, sandstone, etc.

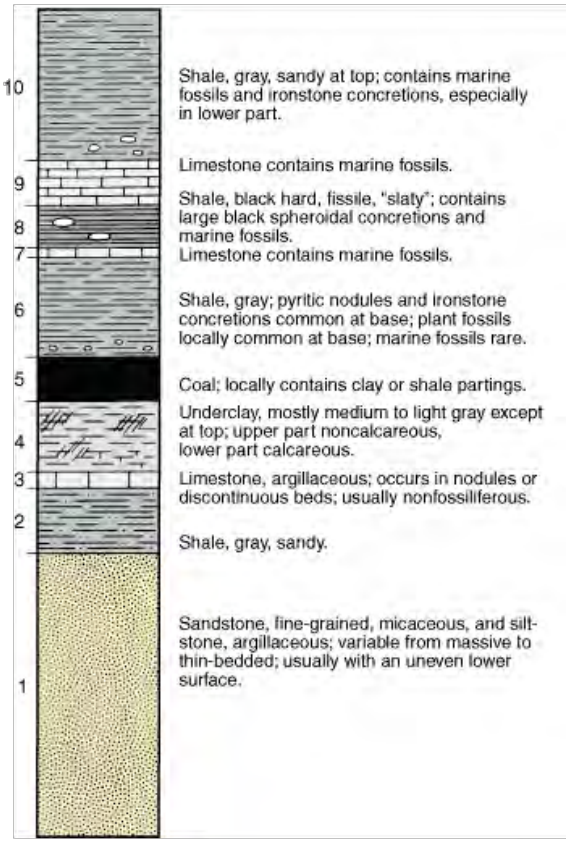
(2) Formation. A formation is a rock layer that is distinctly different than the material adjacent to it. Also, it is the primary unit used to describe rock, and it is composed of members and beds.

(3) Member. A member is a division of a formation differentiated due to its distinct lithology (physical characteristics). An example is a limestone formation that has a small shale member in it.

(4) Bed. A bed is a division in a formation or member that is a more-or-less well-defined, divisional plane between the rock above and below.

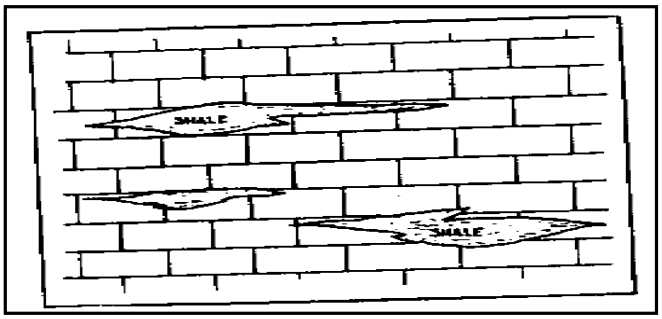
To be classified as any one of the last three, a rock type, or lithology, has to be a fairly continuous layer over considerable distance. These next several geological features have much smaller geographical boundaries.

Definitions
Stratigraphy: The study of rock formations
Lithology: The physical characteristics of a rock
Formation: A distinctively different layer of rock
Member: A physically different part of a formation
Bed: A well-defined division of a formation
Lense: A surrounded member in a formation
Tongue: A wedge of material between members
Pinch-out: Similar to the tongue
Lateral variation: Horizontal change in a formation
Joint: A fracture or crack in a formation
Fault: A fracture caused by movement
Strike: Direction of layering to a plane
Dip: The angle of layering to a plane



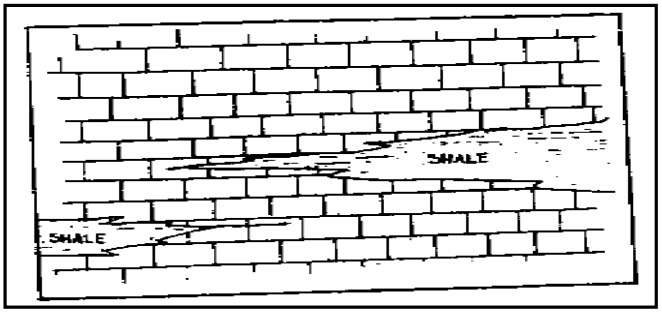
Pennsylvanian Geological Formation

(5) Lense. A lense is a geographically restricted member that terminates on all sides within a formation.



Lenses

(6) Tongue or pinch-out. A tongue or pinch-out occurs when a certain bed, member, or formation wedges out in one direction between rock with a different lithology.

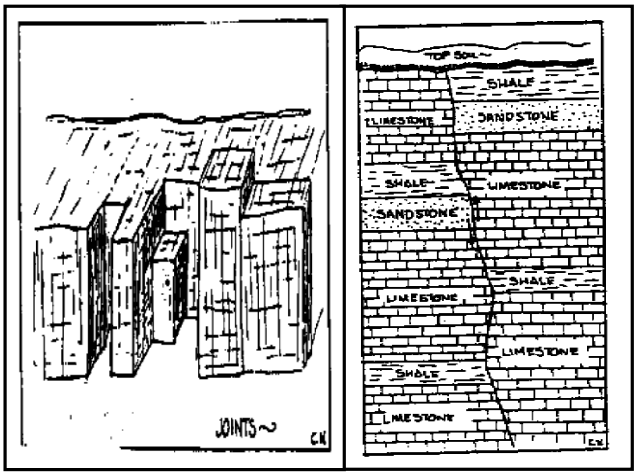


Tongues or Pinch-outs

(7) Lateral variation. Lateral variation is horizontal variation in a particular rock formation. This variation can occur in mineral composition, grain size, cementation of the grains, and crystalline structure. An example would be a grading of clean limestone into a limestone containing increased amounts of clay in the crystalline structure.

Several additional features which can be directly related to individual quarries should also be defined.

(8) Joint. A joint is a fracture or crack in rock resulting from breakage due to stress. Generally they show very little movement. Usually joints are vertical and occur in sets.

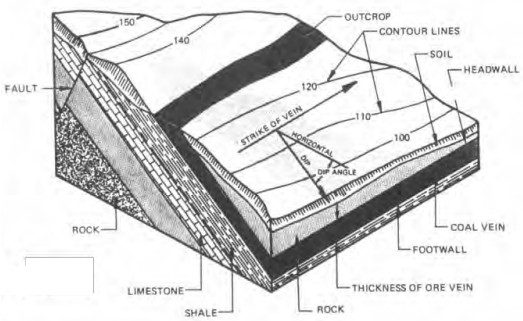


Joints Fault line

(9) Fault. A fault is a fracture or group of fractures along which there has been actual movement of rock layers -- horizontally, vertically, or both.

(10) Strike. Strike is the direction of an imaginary line formed by the intersection of the bedding and a horizontal plane.

(11) Dip. Dip is the angle between the bedding and the horizontal plane. It is always measured at right angles to the strike.



Dip and Strike

1.2.5.2 **Stratigraphy and quality** -- This section will take another look at the above-defined features but from an aggregate quality standpoint.

(1) Lithology (formations, members, and beds). Any time change in lithology occurs; a change in quality is possible.

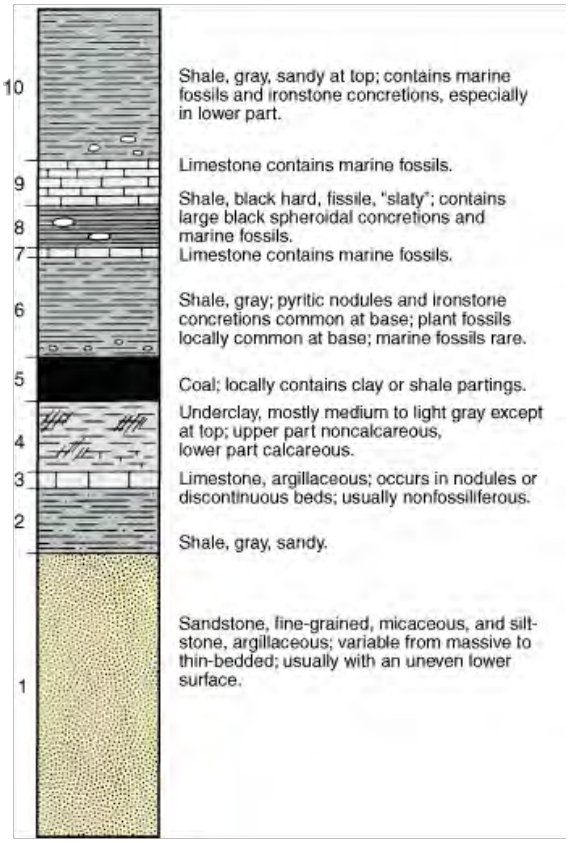
An example could be bed thickness changes. This could mean a quality change. In addition, thinner beds mean more bedding planes which usually mean more clay.

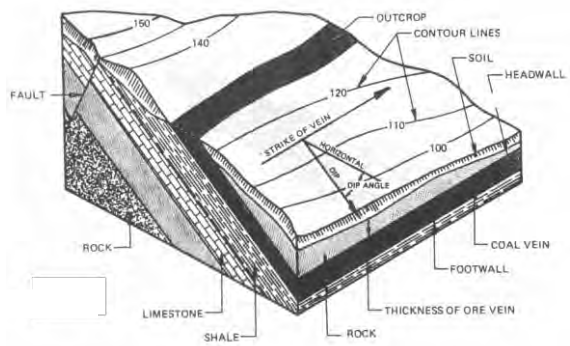
(2) Lenses, tongues. It is fairly obvious how these affect quality. Anytime material is added to or removed from the normal working ledge, quality problems can occur.

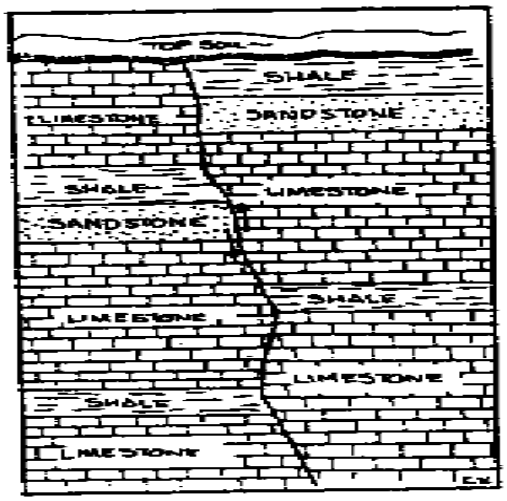
(3) Lateral variation. This is a big problem in Illinois. A gradual change in rock lithology might be missed over several years of production. However, quality tests can identify this lithology change. As an example, test results could start to rise or fall as the working ledge moves in a certain direction. The change in the physical characteristics of the face is not normally discernible. This sometimes can be seen under close observation by trained geologists.

(4) Joints, faults. Quality problems can exist whenever these are present. Both joints and faults allow more water into the rock and allow more exposure to weathering. Also with faults, due to an extreme amount of built-up stress that causes faulting, heat is generated. This heat alters the rock and allows for more severe weathering.

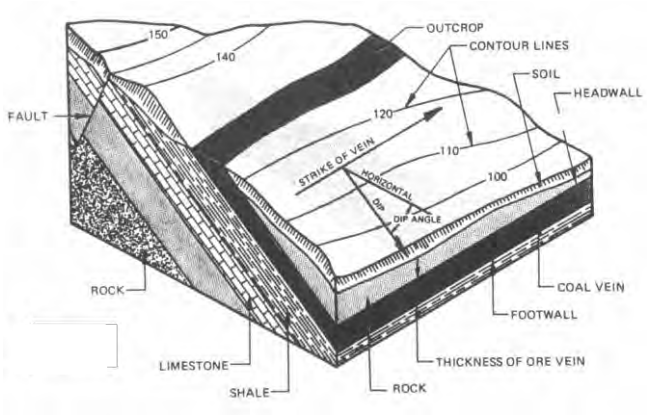
Additionally with faulting, if there has been any vertical movement and subsequent erosion, then the beds are no longer lined up horizontally, and this can cause quality problems.







(5) Strike, dip. Most quarry operators try to maintain a level quarry floor. This is good mining procedure, but what if the rock is dipping? Most rock formations dip if only slightly. In this case, the operators always try to mine up dip so water flows to the sump hole. However, by mining up dip, the footage or the location in the formation changes. This can mean a serious change in quality.



Dip and Strike

1.2.6 **Classification** - Rocks are classified using many different systems that were devised by many different people. Most of the classifications are not worth memorizing. There are three general ways to classify rock:

- Rock type (lithology)
- Fossils
- Time or age

1.2.6.1 **Lithology**: Lithology has already been discussed. Basically, rock is grouped by physical characteristics.

1.2.6.2 **Fossils**: The rock is defined and given a relative age based on what fossils it contains. No concern is given to physical features. Usually as fossils grow more complex, the rock is younger. All present applications are built on earlier work.

1.2.6.3 **Time or age**: This is usually the rock's relative age based on its vertical placement in a sequence of rock. Any distinct lithologic feature is used, such as an unconformity or marker bed. For actual numerical age, radio-carbon dating or other isotopic dating is used.

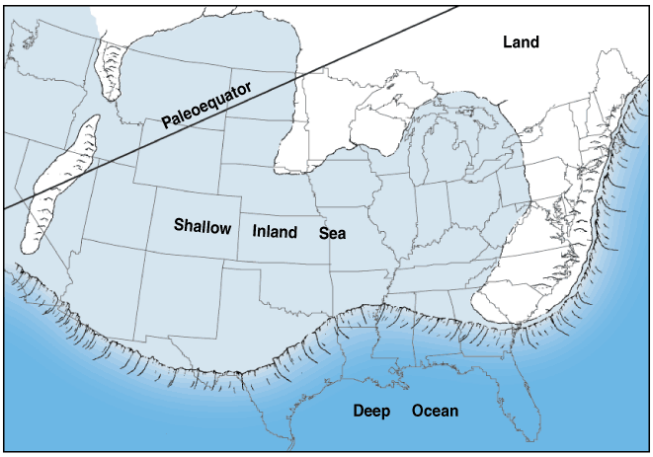
General Age Chart – Youngest to Oldest		
		Age (millions of years)
Cenozoic	Quaternary	1 or less
	Tertiary	1 - 63
Mesozoic	Cretaceous	63 - 135
	Jurassic	135 - 181
	Triassic	181 - 230
Paleozoic	Permian	230 - 280
	Pennsylvanian	280 - 310
	Mississippian	310 - 345
	Devonian	345 - 405
	Silurian	405 - 425
	Ordovician	425 - 500
	Cambrian	500 - 600
Pre-Cambrian		more than 600

Geological Age Chart

Illinois Fossils

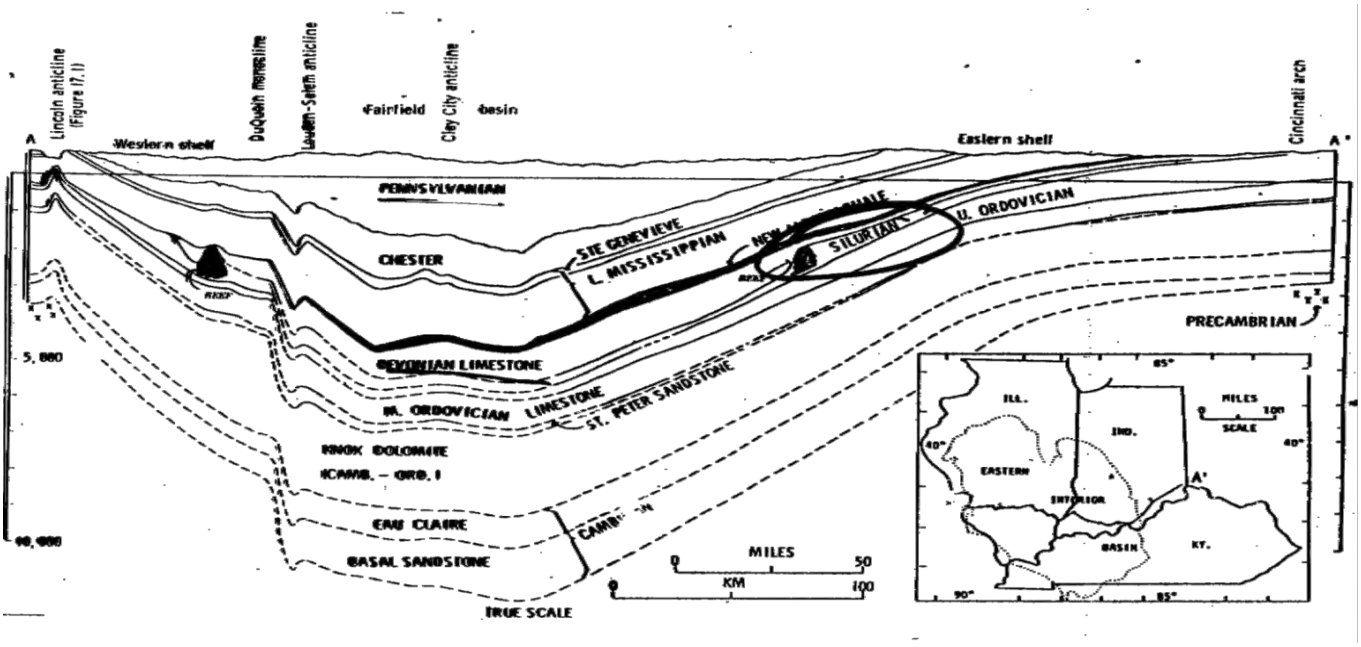
1.2.7 **General Carbonate Geology** - Illinois rock lies in a broad, oval-shaped depression, or basin, called the Illinois Basin, that is elongated north to south. This basin covers all of Illinois except the northern part. Northern Illinois geology is connected with the Michigan Basin.

In the Illinois Basin the rocks are all Paleozoic, ranging from Upper Cambrian to Pennsylvanian. The youngest rocks exist in the middle of the basin. As you progress outward, older rocks outcrop at the surface. The deepest part of the basin is located in southern Illinois and northern Kentucky. The rock is 4,600 m (15,000 ft) thick.



Mississippian Period Sea

Illinois Basin from the Pennsylvanian Period



Profile view of the Illinois Basin

1.2.8 **Production areas in Illinois.** Illinois can be divided into five general stone producing areas as follows:

(1) Northeastern Area:

Silurian dolomites from the Niagaran Series

Large-size gravel deposits

Abundance of Dolomite deposits

(2) Northwestern Area:

Ordovician, Silurian, and Devonian dolomites

Similar to the Northeastern area materials

(3) Western Area:

Mississippian limestone
Northern Part -- Lower Mississippian
Southern Part -- Upper Mississippian

Plentiful fluvial sand and gravel deposits

(4) Central Area:

Pennsylvanian limestone

Sand and small-sized gravel plentiful

(5) South Eastern:

Deeper deposits, lower qualities

Finer sand deposits with little oversize gravel

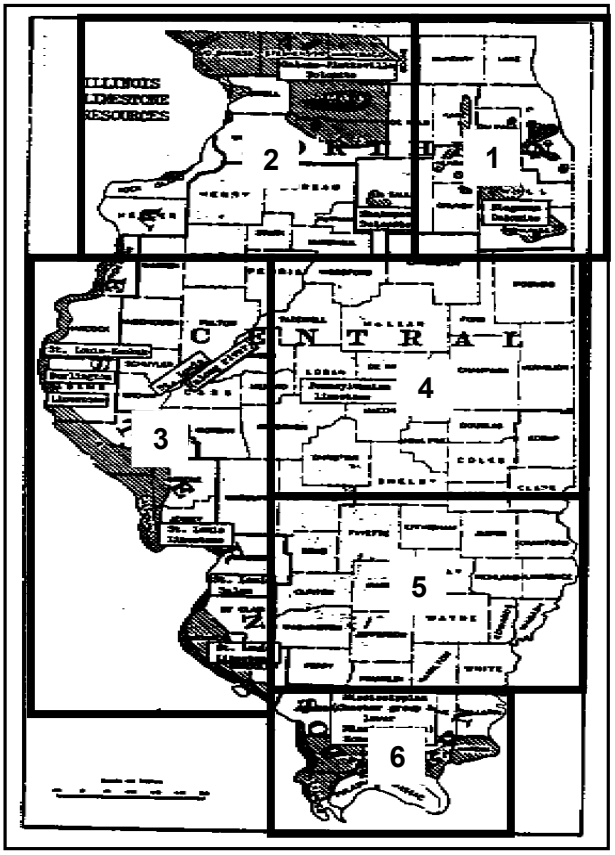
(6) Southern Area:

Upper Mississippian limestone

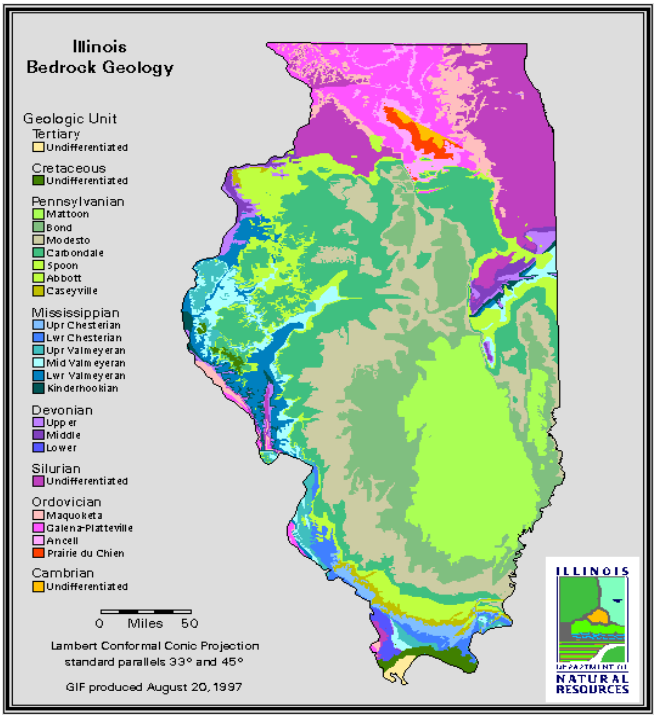
Limestone materials are usually shipped down the Mississippi River

Plentiful fluvial sand and gravel deposits

NOTE: For more detailed information, refer to the Illinois State Geological Survey (ISGS) Bulletin #95, "Handbook of Illinois Stratigraphy".



Aggregate producing areas of Illinois



Illinois Bedrock Geology

1.3 **Special Aggregates**. The major aggregate types used for highway construction in Illinois are gravel, crushed gravel, limestone, and dolomite. However, there are a number of other aggregate types, both natural and manufactured, which are also used by the construction industry. The following discussion details the aggregate types, production methods, and various physical properties that affect their use. The special aggregates that will be discussed are crushed sandstone, chert gravel, novaculite, trap rock, fly ash, wet-bottom boiler slag, air-cooled blast furnace slag, steel slag, crushed concrete, synthetic products, and copper slag.

Special Aggregates used in Illinois
Crushed Sandstone
Chert Gravel
Novaculite
Trap Rock
Fly Ash
Slag
Synthetic Products
Copper Slag

1.3.1 **Crushed Sandstone** - Sandstone is cemented sediment composed predominantly of sand-size quartz grains. The grains are cemented together by a carbonate gel which is not as strong as the quartz grains.

Sandstone deposit

Sandstone is used as a high-friction aggregate due to several special properties. The quartz particles in sandstone are continually broken out of the cementing matrix by traffic, leaving a fresh, angular quartz grain in their place. This provides a constantly renewable surface. This is why crushed sandstone is such a good friction aggregate. In contrast, when a carbonate aggregate breaks down, the particles become rounded, leaving a smooth texture and little friction potential. The rougher the texture, the higher the friction level of the aggregate.

The only sandstone IDOT can currently use comes from the Cave-In-Rock area in District Nine. This sandstone is called the "Rosiclare Sandstone". Crushed sandstone is used for HMA Superpave mixtures E & F, which are the two highest friction mixes currently being used in Illinois.

Sandstone

Manufacturing sandstone is like any regular aggregate. The ledge is shot, and the material is crushed and screened to a set gradation. The major problem in production is the high wear in the crushing and screening equipment.

1.3.2 **Chert Gravel** - Chert gravel deposits are found in very few regions of the state. The parent material for this gravel was the nodular chert found in ancient limestone formations. In the past, these chert-bearing limestones were eroded, and the chert became concentrated in gravel deposits. To be classified as chert gravel, the deposit must contain 75% chert or similar siliceous material.

Chert

Chert gravel is found basically in western Illinois and eastern Missouri. IDOT uses chert gravel from deposits at Barry, Illinois, in District Six and from the Meramec River area in Missouri, in District Eight.

Chert gravel is normally a Class B or lower quality aggregate used in HMA base mixtures and in HMA Superpave surface mixtures used at intersections, ramps, and where skid resistance is needed. When used in HMA mixtures, chert gravel must be crushed.

Trap Rock deposit

1.3.3 **Trap Rock** - Trap rock is defined as a dark-colored, iron-bearing igneous rock. There has been only one true trap rock previously used by IDOT. This deposit is located in Dresser, Wisconsin. IDOT's District Eight currently uses a material called trap rock which is actually mine tailings.

The mine tailings consist of hematite, magnetite, and granite. Another source in the area supplies an igneous rock, rhyolite, as a trap rock. These materials are Class A quality materials and are used in bituminous mixes and some bridge decks. The cost of using and shipping these materials is normally too expensive for most road work uses. These materials are good friction aggregates but, once again, the cost has to be considered.

Trap Rock

1.3.4 **Fly Ash** - Fly ash is the minute burnt and unburnt particles from gases created during the combustion of ground or powdered coal. It is used as mineral filler in HMA mixtures, as a pozzolanic binder in stabilized soil subbases, and as a replacement for cement in concrete.

There are two types of fly ash used in concrete: Type C and Type F. Type C is highly cementitious when used as a cement in concrete. It has a high content of calcium and has at least 50% of silicon, iron, and aluminum. Type C fly ash comes from burning western coals.

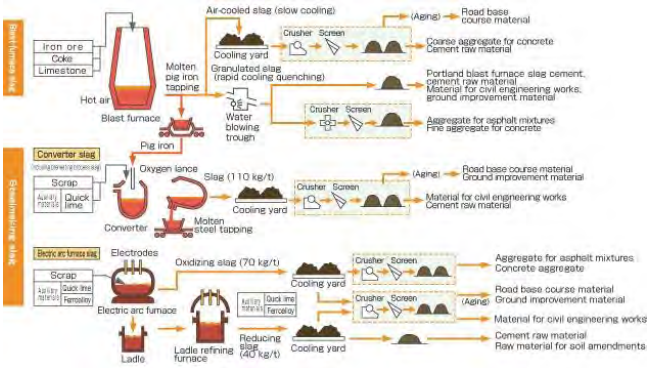
Type F has very low reactivity as a cement material. It has a lower content of calcium and at least 70% of silicon, iron, and aluminum. Type F comes from burning Illinois coals high in sulfur content.

Most of Illinois' fly ash comes from the Chicago area (District One). All fly ash is produced from coal-powered generating plants located in Illinois and surrounding states.

1.3.5 **Wet-Bottom Boiler Slag** - Wet-bottom boiler slag is a coarser, angular product from combustion of coal in wet-bottom boilers. This material is produced at the same time as fly ash. The material is mostly glassy in appearance. It can contain long and thin or teardrop-shaped particles. It is used primarily for seal coat, blotter aggregate, and as a salt extender and abrasive for snow and ice control.

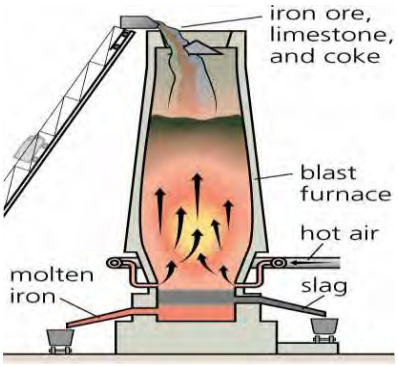
1.3.6 **Air-Cooled Blast Furnace Slag** - Air-cooled blast furnace (ACBF) slag is a nonmetallic product consisting of silicates and aluminosilicates of calcium and other bases. It develops in a molten condition simultaneously with iron in a blast furnace. The slag consists primarily of the silica and alumina from the original iron ore combined chemically with calcium and magnesium oxides from the flux stone.

Fly Ash



Slag Production Processes

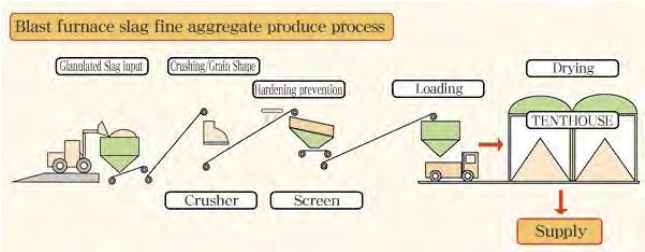
Un-Processed Wet-Bottom Boiler Slag



The American Heritage® Dictionary of the English Language

Blast Furnace

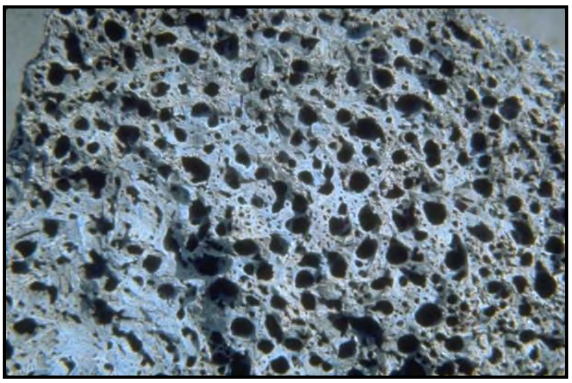
The molten slag is cooled under atmospheric conditions. Cooling may be accelerated by water sprays on the solidified mass. After it is cooled enough to be handled, the slag is dug, crushed, and screened to desired aggregate size. It is called air-cooled blast furnace, or ACBF, slag.



The solidified slag has a vesicular structure with many non-connected cells. This rough vesicular nature of slag gives it the ability to polish unevenly. This characteristic provides ACBF slag with extremely high friction potential when used in high-type bituminous surface mixtures.

Slag Pour-off

The bulk specific gravity range is 2.00 to 2.20. The smaller the size, the higher the specific gravity. The unit weight varies with size and grading of ACBF slag, method of measuring, and bulk specific gravity. The typical unit weight (compacted), graded as ordinarily used in concrete, usually ranges from 1120 kg/m^3 to 1360 kg/m^3 (70 lbs/ft^3 to 85 lbs/ft^3). Absorption is usually in the range of 1% to 6% by weight. This high and variable absorption is directly related to slag's vesicular nature. High and variable absorption, as in ACBF slag, can cause problems in producing good bituminous mixtures. A bituminous mixture's performance relies on consistent air voids and asphalt film thickness on the aggregate particles. High absorption aggregates like ACBF slag require high asphalt content in the mixture. Any variability in the absorption, different from the absorption of the aggregate used in the mix design, will cause either an excess of asphalt cement in the mixture (flushing) or a lack of asphalt cement (raveling -- not enough asphalt for the aggregate to stick together). Both conditions produce major problems in bituminous mixtures.



Air-Cooled Blast Furnace Slag

ACBF slag is used in graded aggregate bases for pavements, concrete (plain and reinforced), bituminous pavements, skid resistant surfaces, macadam surfaces and bases, railroad ballast, backfill, etc.

Slag Material Properties

Type	Bulk Sp. Gr.	Absorption (%)
Wet-Bottom	2.30 – 2.90	0.3 – 1.1
ACBF	2.00 – 2.20	1 – 6
Steel	3.00 – 3.40	2 – 5
Copper	3.69 – 4.04	Low – 0.5
Synthetic	Will vary with the different products	Will vary with the different products

1.3.7 **Steel Slag** - Steel slag is the nonmetallic product or slag developed in molten condition with steel in an open hearth furnace, basic oxygen furnace, or electric furnace. Its formation is very similar to that just described for ACBF slag. It is a very heavy aggregate with high absorption. Steel slag's bulk specific gravity ranges from 3.0 to 3.4, while its absorption ranges from 2.0% to 5.0%. Steel slag also has expansion potential due to the presence of possible free calcium or magnesium oxide created during its formation in the furnace. This material will hydrate and expand. Steel slag is similar to air-cooled blast furnace slag in its vesicular texture, high friction potential, and high absorption. Steel slag, however, does not have as variable absorption as ACBF slag.

Steel Slag

Steel slag used in Illinois comes from the District One area, including Indiana; District Four at Peoria; and District Eight at Granite City. Steel slag is used by IDOT only in HMA surface mixtures and seal coat. Due to its expansion potential, it is not allowed for use in any area that confines it.

A special provision covers the use of slag materials by IDOT. See the “Crushed Slag Producer Certification and Self-Testing Program (9-08.1)” and “Slag Producer Self-Testing Program (13-08.1)” Both of these documents can be found in Appendix C of this manual.

Uncrushed & Crushed Recycled Concrete

1.3.8 **Crushed Concrete** - Crushed concrete results from the process of recycling concrete by crushing concrete to the desired size and reusing the crushed concrete as a construction aggregate.

A special provision covers the use of crushed concrete by IDOT. Material produced at a central recycling plant is differentiated from material produced on a specific state project. (See “Recycling Portland Concrete Cement into Aggregate (07-08.2)” This document can be found in Appendix C of this manual.

Rubblized In-place Concrete

1.3.9 **Synthetic Products** - Synthetic products result from the recrystallization of expanded shale and clay in a kiln. This produces a lightweight aggregate, such as lakelite, Materialite, etc.

Expanded Shale Product

Lightweight synthetic aggregate is not allowed in concrete for IDOT use. A lightweight synthetic aggregate may cause some freeze-thaw problems in concrete. Synthetic products also may be no good as friction aggregates because, based on IDOT experience, the mixes do not hold together. There are problems with quality and determining what tests to run on the material. IDOT has had major problems resulting from contamination, friable mortar, and durability. There is some question whether the soundness test is valid for synthetic products.

Product Comparisons

At present, there are no synthetic products produced in Illinois.

1.3.10 **Copper Slag** - Copper slag is the nonmetallic product or slag developed in a molten state with copper in a smelter. Like steel slag, copper slag is a heavy material with a dry specific gravity (bulk) ranging from 3.69 to 4.04. Unlike steel slag, copper slag is essentially non-vesicular and has a lower absorption, averaging 0.5%.

Copper Slag Particles

The material is produced by only one company located in Hartford, Illinois, in District Eight.

Copper slag can be used in all construction uses. However, due to its high specific gravity, the economics of hauling it should be considered.

2.0 AGGREGATE PRODUCTION AND BENEFICIATION

Aggregate and Beneficiation Processes
Stripping
Drilling
Blasting
Loading & Hauling
Scalping
Crushing Operations
Beneficiation Processes
Screening
Sand Production
Stockpiling & Handling

This chapter covers the basics of how aggregate is produced. Some of these basics may not apply to all the aggregates produced in Illinois, especially some of the ones discussed in Chapter 1.0, Section 1.3 “Special Aggregates” (slag materials, crushed concrete, etc.), but will apply to most of them. While covering the basic production methods, the discussion will also cover how or if aggregate can be beneficiated by a change in the method.

The areas to be discussed are as follows:

- Stripping
- Drilling
- Blasting
- Loading and Hauling
- Scalping
- Crushers (compression and impact)
- Beneficiation Processes
- Screening
- Sand Production
- Stockpiling and Handling

2.1 **Stripping**. Stripping is a basic operation in a sand and gravel pit or a quarry. The overburden material between the surface and the product (gravel or stone) must be removed before production can begin.

Stripping is a process that can affect quality and gradation from the beginning of production. Not cleaning all the overburden off, or maintaining too narrow or steep a cut which allows overburden to slide down on the production material, introduces contamination into the raw feed. Many production plants cannot handle the contamination, and acceptable materials then become unacceptable.

Stripping operations

2.2 **Drilling**. After stripping the overburden off, stone must be drilled and blasted to produce the raw feed for the production plant. Drilling is also important in quality control. Production ledges, once established, need to be maintained. Quality is directly affected by drilling control which can vary the ledge footage in an area which has unacceptable material above or below the production ledge.

Drilling a ledge

This is also where the concepts of strike and, especially, dip come into play. (See Chapter 1.0, Article 1.2.5.1 (11) or Article 1.2.5.2 (5) of this manual) Unless these concepts are taken into account when drilling and shooting, identifying a particular ledge footage as a production ledge and running quality tests on it for acceptance is meaningless.

Drilled charge hole

2.3 **Blasting**. Blasting obviously reduces solid rock to various sized pieces to provide raw feed to the production plant. Each quarry decides on the drilling pattern and blasting force to suit its crusher feed. In fact, the drilling pattern in individual ledges may vary due to differing physical characteristics of the rock.

The blasting may also be adjusted to produce riprap and other erosional protection material.

Quality may be improved by blasting finer to get more initial breakage along planes of weakness. Of course, vibration and sound from blasting can environmentally limit the use of larger charges and big shots.

Blasting

2.4 Loading and Hauling

2.4.1 **Loading** - There are several ways to load the raw feed out of the pit or quarry for hauling to the production plant. Gravel operations can have both wet and dry load-out. In the wet operation, most producers use either drag line or a dredge. Dry operations in the gravel pit normally use a front endloader to dig the material. Most quarries, also, use the front endloader to load the shot rock. Several of the biggest quarries use an electric shovel.

Quality can be affected by how loading at the face is done. If the ledge had some bad material in a horizontal seam or a pocket, digging back and forth across the front of the shot could result in the bad material being concentrated in a slug of material going through the plant and out into the stockpile.

2.4.2 **Hauling** - Hauling the material to the production plant is usually accomplished in large haul trucks. However, a number of quarries set up their primary crusher in the quarry and haul to it by front endloader. The crushed product is then belted up and out of the pit to the production plant.

Sand and gravel pumping operation

Truck hauling

2.5 **Scalping**. Scalping separates out an oversize material from smaller material somewhere in the production process and allows the oversize to be crushed and processed separately. It can be done by a grizzly before primary crushing or by a screen deck elsewhere in the process.

Scalping is a definite beneficiation process that, in certain cases, removes the worst material in the smaller sizes and allows the oversize to be crushed for the better quality material.

2.5.1 **Surge Piles**. A surge pile is used to even out the flow of raw feed in the plant and maintain a constant feed essential for good crushing and screening. It also allows the continued operation of separate sections of the production plant without the total plant being in operation. For example, loading and hauling to the primary crusher and crushing material into the surge pile can continue even though the secondary and tertiary plants are not operating. Also, the primary plant can be shut down while feed from the surge pile goes to the secondary and tertiary plants for processing.

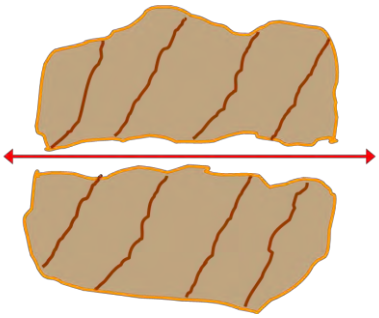
The Screen Machine Ind. 107D Scalper

Grizzly scalping screen

Conveyor scalping wheels

Surge pile

2.6 **Crushers**. Crushers are obviously important, especially in crushed stone, to reduce big rocks to small rocks so that they can be screened into a usable gradation. Crushers also upgrade the quality of the aggregate by reducing the bad rock to fines where it usually does not cause a problem. How much crushing upgrades the aggregate material is dependent upon the physical characteristics of rock and the type of crusher used.



Compression crushers break in one direction

Discussion will center on a number of different types of crushers. All fall into two categories:

- Compression crushers
- Impact crushers

Gyratory crusher

2.6.1 **Compression Crushers** - These crushers direct the rock's vertical position in the crushing chamber. Some upgrading or beneficiation occurs with this type of crusher, but not as much as can be achieved with impact crushing.

Portable Gyratory crusher

2.6.1.1 **Gyratory crusher**: This crusher is used as a primary crusher normally in the biggest quarries. It provides a large crushing capacity to service a large volume secondary plant.

The crushing action occurs as the crushing head (inverted cone shape) oscillates in a small circular path due to an eccentric. The compression crushing occurs as the crushing head progressively approaches and recedes from each point of the cone-shaped crushing chamber's inner surface.

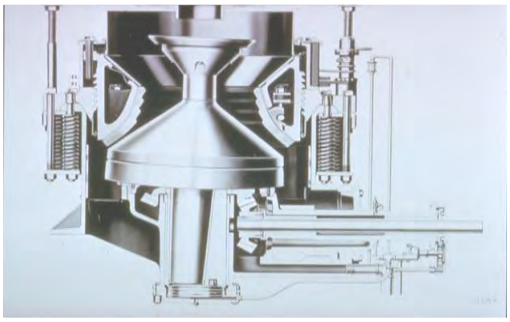
Cone crusher

The gyratory crusher is normally very large and requires a fairly large and tall infrastructure for support.

2.6.1.2 **Jaw crusher**: The jaw crusher, like the gyratory, is used mainly as a primary crusher. It is used infrequently as a secondary crusher.

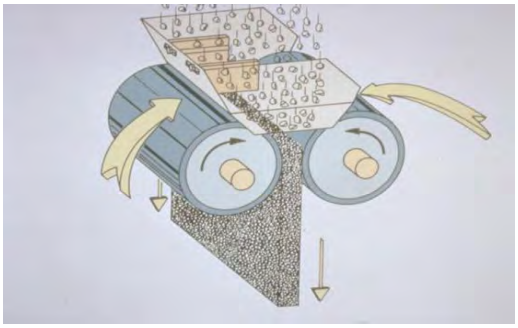
Jaw crusher

The jaw crusher employs the same crushing principle as the gyratory, that is, reciprocating pressure-crushing. This is achieved through the use of an eccentric which oscillates a flat swing-jaw against a stationary plate. The motion of the swing-jaw is greatest at the discharge opening and gradually decreases toward the upper part of the crushing chamber. The crusher is made in portable models and also with a double jaw configuration.



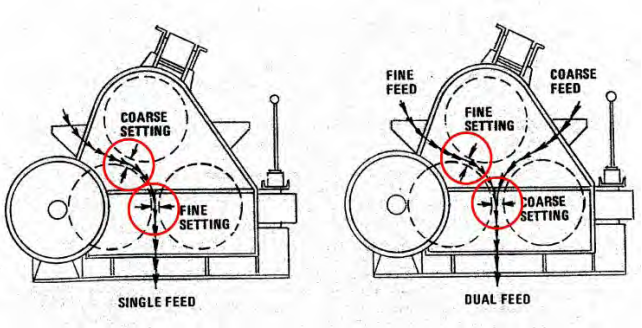
Cone crusher

2.6.1.3 **Cone crusher**: The cone crusher is a relatively high-speed gyratory crusher incorporating a flatter head angle. The number of gyrations employed in crushing is approximately twice that used in a primary gyratory crusher. Cone crushers are normally used as secondary, tertiary, or quaternary crushers in the production plant.

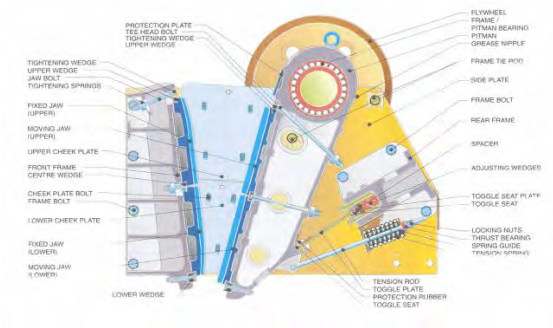


Double roll crusher

2.6.1.4 **Roll crusher**: The last of the major compression crushers is the roll crusher. A double roll crusher has two rolls mounted in the same plane which revolve toward each other, thus crushing the material between them. A triple roll crusher has a third roll added to create two separate crushing chambers, increasing the crusher's ratio of reduction. The crusher is usually used as a secondary, tertiary, or quaternary crusher.

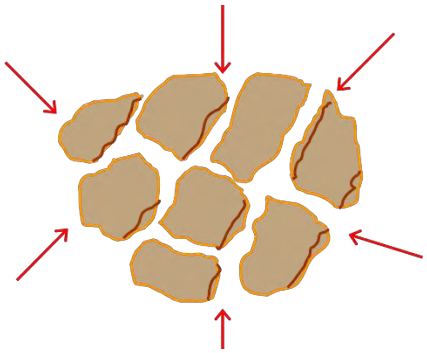


Triple Roll crusher



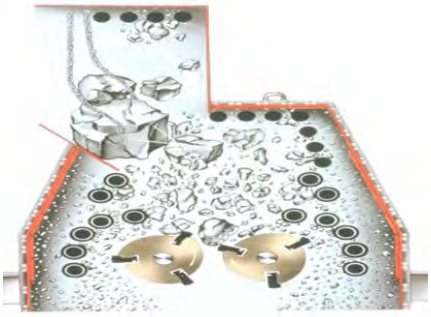
Single jaw crusher

2.6.2 **Impact Crushers** - This type of crusher obviously uses impact rather than compression to crush material. Impact crushers do beneficiate most materials. Whereas compression crushing normally causes breakage parallel to the compression force, impact crushing normally causes breakage across zones of weakness in the material, no matter at what orientation the material comes through the crusher. One unfortunate aspect of impact crushing is the increased production of fines. There are four types of impact crushers that will be discussed.



Better beneficiation
Impact crusher

2.6.2.1 **Horizontal Impactor**: A horizontal impact crusher contains a horizontal rotor with impeller bars which rotates at extremely high rpm's. Material is fed into the crushing chamber and falls onto the high-speed rotor. The impeller bars both impact and hurl the material against breaker bars and plates lining the crushing chamber. Breakage occurs from both the impact of the impeller bars and the impact against the breaker bars/plates. Some rock-on-rock breakage may also occur.



Horizontal shaft impact crusher

The horizontal impactor can perform as a primary, secondary, tertiary, or quaternary crusher.

Vertical shaft impact crusher

2.6.2.2 **Vertical Shaft Impactor**: The vertical shaft impactor (VSI) contains a vertical rotor, instead of a horizontal rotor, on which a feed plate is mounted. The rotor is turned at high rpm's and the material is dropped on top of the rotating feed plate. The feed plate flings the rock outward against breaker plates. Breakage occurs against the plates and possibly some rock-on-rock breakage. There are also several strictly rock-on-rock VSI crushers currently on the market. The VSI does not give the double impact breakage as in the horizontal impactor.

Vertical shaft impact crusher

The VSI is usually a secondary, tertiary, or quaternary crusher.

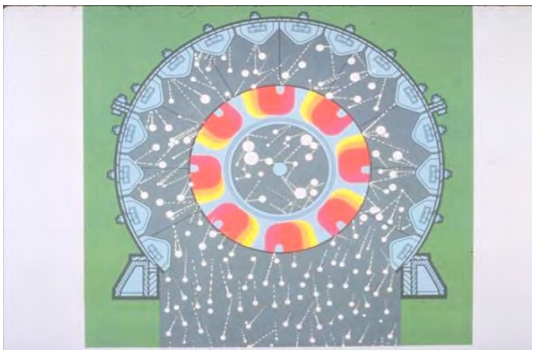
2.6.2.3 **Hammermill**: The hammermill contains a horizontal rotor, rotated at high rpm's, on which are mounted hammers, normally free-swinging. The crushing chamber is equipped with grates at the bottom. Crushing is achieved by impact from the hammers and by shear and attrition from the hammers forcing the rock through the grates.

Hammermill impact crusher

The hammermill is usually considered a tertiary or quaternary crusher (maybe a secondary in certain situations). The hammermill is sometimes used to make ag lime.

Cage mill impact crusher

2.6.2.4 **Cage mill**: The cage mill contains a high-rpm, vertically rotating cage which has breaker bars mounted in it. Material is fed into the center of the cage, and the material is then hit and broken by the breaker bars. It is also thrown against breaker plates lining the outside of the crushing chamber.



Cage mill impact crusher

The cage mill is normally used as a secondary, tertiary, or quaternary crusher. Do to the potential to create excessive fines; the cage mill crusher is not used very much in Illinois except to produce sand products or AG lime material.

2.6.3 Crusher Advantages vs. Disadvantages

Crusher type	Compression	Impact
Advantages	Less dust	Better beneficiation
	Lower cost to operate	Better particle shape
		More portable
Disadvantages	Elongated particles	More fines
	Deposits will crush differently	Higher cost to operate

2.7 **Beneficiation Processes**.
Beneficiation of rock by impact crushing is one proven method. Several other proven beneficiation processes should also be discussed.

2.7.1 **Heavy Media** - The heavy media process involves dropping the production feed into a conical tank containing a slurry of water and iron-based particles. The slurry is continually agitated in the tank by paddles thus keeping the particles suspended. This creates a slurry of a known specific gravity that can be adjusted. The material dropped into the slurry either sinks or floats due to its difference in specific gravity from that of the slurry. The float, or deleterious material, is skimmed off the top while the good material is drawn off the bottom of the tank. The iron particles are washed off the rock and recovered for use.

There is at least one heavy media plant operating in Illinois at the present time.

2.7.2 **Logwasher** - Use of a logwasher, preferably a double logwasher, is also a beneficiation process. The production material and water is introduced into the bottom end of the logwasher, and large horizontal shafts with paddles agitate, grind, and auger the material up and out the logwasher. Soft material, especially clay and soft shale, is broken down and washed away with the water.

The logwasher will not, unfortunately, eliminate excessive amounts of the hard, unsound rock.

Heavy media process

Twin-shaft logwasher

Logwasher unit

2.7.3 **Attrition Mill** – Attrition mills perform similarly to logwashers except usually on sand. Paddles agitate the material, allowing attrition, or breakdown, by particle grinding against particle.

2.7.4 **Magnet** – Magnets perform a beneficiation process in the production of ACBF and steel slags. Iron and steel particles are removed from the slags before their sale for aggregate.

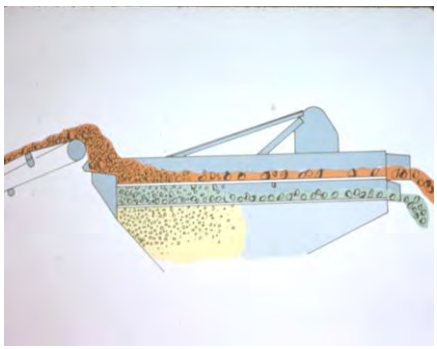
2.8 **Screening**. Screening obviously separates the material into separate sizes for a gradation or for recombining into a gradation. Screen decks (either double or triple decks) allow different sized screen wire to be mounted to separate the material into sizes. Some decks even have spray bars mounted to facilitate fines or clay removal.

The adjacent figure provides a good illustration of how the eccentric vibration applied to the decks helps separate into sizes. Then, these individual sizes can be either recombined and crushed further, or otherwise processed into specific aggregate gradations. Some sand, both natural and manufactured, can be produced without screening.

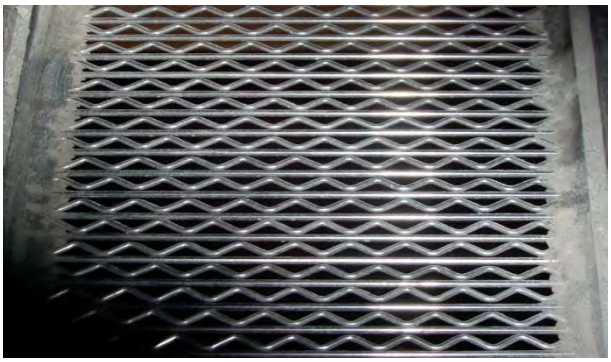
Inclined Vibrating Screening Unit

Magnetic Belt Screening Unit

Dual Screening Unit



Screening unit Operation



Self-cleaning screen

2.9 **Sand Production**. Sand classifiers, using rising currents of water and gravity separation of various size ranges, can be used to produce a sand gradation.

Sometimes a producer does not need equipment as elaborate as a classifier. There are some sand deposits that need only the fines removed. Most producers use a simple sand screw to float out the fines; most FA20 manufactured sand is produced this way. Of course, the sand screw is also used to dewater the sand prior to stockpiling.

Classifier

2.10 **Stockpiling and Handling**. Stockpiling and handling are the last processes in the production of aggregate. Stockpiling and handling then become very important because all the effort prior to stockpiling can be for nil if the material becomes segregated. This is discussed in greater detail in Chapter 4.0 “Stockpile and Handling” of this manual.

Flooded classifier

Sand & gravel production plant

Sand screw

This page is reserved

3.0 QUALITY AND USE

The Central Bureau of Materials and Physical Research (BMPR) will perform the required quality testing on the aggregate used for on IDOT projects throughout Illinois. Quality samples are taken at each source by District inspectors and then transported to the BMPR in Springfield for testing.

There are four main quality classes of aggregate used by IDOT. These classes are listed below with typical examples of their use. Actual classification is determined by the Standard Specifications and aggregate usage.

NOTE: Aggregate used for a specific quality class has to meet quality specification requirements for that particular class.

Common Aggregate Uses	
Quality Class	**Use**
"A" Highest Quality	Portland Cement Concrete (PCC)
"B"	HMA – High ESAL D, E & F Surface mixtures
"C"	HMA – High & Low ESAL C Surface & Binder mixtures Seal/cover coat (oil & chip)
"D" Lowest Quality	Stabilized subbase & shoulders including HMA usage

Aggregate materials cannot be sold and/or used in applications that demand a higher quality requirement than what the material has been approved.

Aggregate quality tests used to evaluate aggregate properties for a quality determination are as follows:

- **Sodium Sulfate Soundness***
- **Los Angeles Abrasion***
- **Deleterious Count / Heavy Media***

* Main quality tests performed on most aggregates used for IDOT purposes.

Other tests ran for material-specific purposes include:

- Freeze-Thaw Expansion Test (PCC)
- Hydrometer (HMA and PCC)
- Colorimetric/Mortar Strength (PCC)
- Dolomite Determination (Friction)

In addition to the three main quality tests, IDOT has implemented the Micro Duval testing system.

The Micro Duval test is being used to further evaluate the main aggregate properties of materials used for HMA and PCC materials. The test helps to complement the Sodium Sulfate Soundness and Los Angeles Abrasion tests.

Micro Duval Test

A number of tests are run simply to provide physical characteristics of aggregate used in the concrete/HMA mixture design process. Two of these tests are:

- Friction Characteristics
- Specific Gravity and Absorption

All the tests listed previously are used for either coarse aggregate, fine aggregate, or both. The following discussion will cover the importance of each test, the procedure, and whether it applies to coarse or fine aggregate.

All the tests start in a breakdown room at IDOT's central aggregate laboratory where the field samples are reduced down to test size samples.

IDOT BMPR breakdown room

Material is mixed into a sample pad

The field technician acquires the samples

The material is reduced to test sample size

A coarse aggregate mechanical splitter for reducing aggregates to sample size

Material is fractionalized

3.1 **Sodium Sulfate Soundness**. The sodium sulfate soundness test is run on both coarse and fine aggregate. The soundness test is designed to measure an aggregate's resistance to weathering.

Over the course of the 5-cycle test, sodium sulfate crystals are built up in the pore structure of the aggregate particles. The stress caused by the formation of these salt crystals breaks the weaker particles. This breakdown is calculated as percent loss.

IDOT follows the ITP 104 test procedure.

3.1.1 A generalized version of the sodium sulfate soundness test method is as follows (pictures are shown on the following page of this manual):

3.1.1.1 Each sample is washed, dried back to a constant weight, and sieved into individual sizes.

3.1.1.2 A specified amount of sized material is placed in bread pans for testing. The amount of material and the number of bread pans used depend on the gradation of the sample. It should be noted that IDOT uses pans instead of the 8” (200 mm) diameter sieves prescribed in T 104.

3.1.1.3 To start the first cycle, the samples and pans are put in the environmental chamber and covered with sodium sulfate solution to at least 1/2” (12.5 mm) above the sample. Lids are applied to keep any moisture inside the cabinet from dripping into the pans and diluting the saturated solution.

The temperature maintained inside the cabinet is 70° ± 1° F (21° ± 0.5° C), and the relative humidity is approximately 100%. The soaking temperature is considered critical. The samples are left soaking in the chamber for 16 to 18 hours.

3.1.1.4 After the samples have soaked for at least 16 hours, the solution is poured off, and the pans are put in the oven to dry at a temperature of 230° ± 9° F (110° ± 5° C) to a constant weight. After cooling, the samples have completed one cycle in the test. The samples are ready to start another cycle. Since this is a 5-cycle test, 4 more cycles, as just described, are run on the sample.

3.1.1.5 After the fifth cycle, the samples are washed free of the sodium sulfate crystals. After drying to constant weight, the coarse aggregate samples are sieved over the next size smaller sieve than the one on which they were made up. Fine aggregate is sieved over the same sieve on which it was made up. Any particles that fall through the sieves are considered "loss".

3.1.1.6 The total percent loss for the sample is calculated by taking a percentage of each pan loss and adding them together.

3.1.2 The Standard Specifications for the soundness test are as follows:

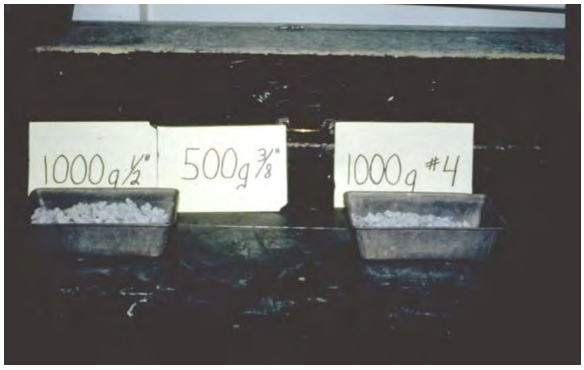
Quality Test	Class	Maximum Loss
Coarse Aggregate:	“A”	15%
	“B”	15%
	“C”	20%
	“D”	25% [2/]
Fine Aggregate:	“A”	10%
	“B”	15%
	“C”	20%

[2/] For aggregate surface course and aggregate shoulders, the maximum percent loss shall be 30.

1) Sample is washed

2) Sample is dried to a constant weight

3) Sample is sieved into individual fractions



4) Sample size is based on the gradation

5) Solution is added & sample is put into a controlled temperature environment

6) Sample is rinsed of the solution & dried

7) The process is repeated 4 more times

8) A gradation test is performed

3.2 **Los Angeles Abrasion**. The Los Angeles abrasion test is run only on coarse aggregate according to AASHTO T 96. It measures the aggregate's ability to resist wear and gives an indication of the degradation potential of the aggregate. It is not a true abrasion test. The Los Angeles abrasion test is more of an impact test.

Abrasions are not run on large aggregate gradations such as CA01, CA03 and CA05 because the results on the large stone [(+1 1/2" (+37.5 mm)] do not correlate well with tests run on the smaller sized gradations.

3.2.1 The Los Angeles abrasion test is run as follows (pictures are shown on the following page of this manual):

3.2.1.1 The test sample is initially washed, dried back to a constant weight, and sieved into separate sizes.

3.2.1.2 The test sample of 5,000 grams is made up according to the gradation of the material. The gradation also determines the number of steel balls (abrasive charge) that are added to the test sample. The number of steel balls used for the test is determined by the quality level being tested (12 for “A” quality, 11 for “B” quality and 8 for “C” quality aggregate)

3.2.1.3 The sample and the balls are put in the Los Angeles machine. The machine is then mechanically rotated at 30 rpm to 33 rpm for a total of 500 revolutions. The machine is a cylindrical steel drum that is 28” (710 mm) in diameter and 20” (508 mm) wide. A steel shelf sticks perpendicular to the wall inside the machine. The shelf dimensions are 3 1/2" x 1" x 20" (90 mm x 25 mm x 508 mm).

3.2.1.4 After 500 revolutions the sample is dumped from the machine and sieved over a No. 12 (1.70-mm) sieve. The material passing the No. 12 (1.70-mm) sieve is considered loss and is calculated as a direct percentage of the original test sample's weight.

Los Angeles Abrasion Machine

3.2.2 The Standard Specifications for the Los Angeles abrasion test are as follows:

Quality Test	Class	Maximum Loss
Coarse Aggregate:	“A”	40 [3/]
	“B”	40 [4/]
	“C”	40 [5/]
	“D”	45

[3/] For PCC – maximum loss is 45
[4/] Doesn’t apply to steel or crushed slag
[5/] For HMA binder mixtures except as surface mixtures – maximum loss is 45

1) Sample is washed

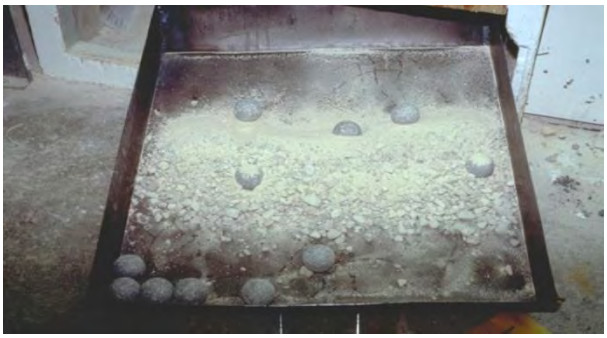
2) Sample is dried to a constant weight

3) Sample is sieved into individual fractions

4) Material is weighed based on size

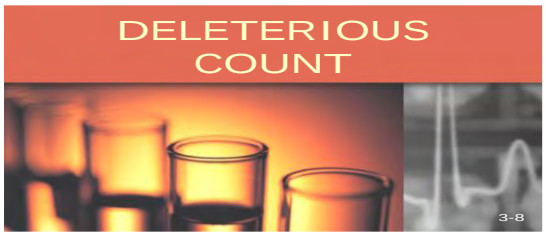
5) Steel balls are added based on quality

6) Material is placed in the LA Abrasion machine



7) Removed after 500 revolutions

8) A gradation test is performed



3.3 **Deleterious Count**. This test is a petrographic examination of an aggregate sample to identify material that has been determined to be deleterious in highway construction use. It applies to both natural sand fine aggregate (only) and coarse aggregate.

3.3.1 For coarse aggregate, the deleterious count test procedure is as follows:

3.3.1.1 The material is split and screened over a No. 4 (4.75-mm) sieve. Each test sample ranges from 1,000 grams to 5,000 grams, depending on the size of the aggregate.

3.3.1.2 Lab personnel hand-examine each particle to determine if it is deleterious. The deleterious particles of different composition are kept in separate pans. A tool is used to detect the soft particles and chert.

Maximum limits have been established by specification for several different types of deleterious particles. These limits will change for Classes “A” through “C” quality.

For Class “A” quality coarse aggregate, the following maximum limits have been set:

Quality Test	% Maximum
Shale	1.0
Clay lumps	0.25
Coal and Lignite	0.25
Soft and unsound	4.0
Other deleterious	4.0 [9/]
Total deleterious	5.0

[9/] Includes deleterious chert

Each piece of material is hand-inspected

Material is classified by deleterious type

In Class “A” quality samples, deleterious chert is picked out as "other deleterious". Since not all chert is considered deleterious, all the chert picked out is soaked for 16 hours and run in a heavy media set-up. The heavy media is a solution of zinc bromide and water. Two stainless steel tanks contain this mixture -- one set at a specific gravity of 2.350 for identifying deleterious chert in gravel, and one set at 2.550 for deleterious chert in crushed stone. If the chert is lighter than the gravity of the solution in which it is placed, it will float and is considered deleterious.

Heavy media test

For Classes “B” and “C” quality coarse aggregate, the main emphasis is on shale, clay lumps, and soft and unsound particles.

Classes “B” and “C” quality samples are not checked for deleterious chert because chert does not cause problems in HMA mixtures like it does in concrete. Chert gravel is required to be crushed when used in HMA mixtures.

Quality Test	Class “B” Quality % Maximum	Class “C” Quality % Maximum
Shale	2.0	4.0
Clay lumps	0.5	0.5
Soft and	6.0	8.0
Other	2.0	2.0
Total	6.0	10.0

Material specification % Max limits

3.3.1.3 Three other counts done on coarse aggregate, for informational purposes only, are as follows:

(1) Carbonate count (for Variable Speed Friction Testing). All carbonate rock is picked out of gravel samples.

(2) Siliceous count (District Six Special Provision). All siliceous rock (chert, quartzite, etc.) is counted out of a chert gravel sample.

(3) Crushed particle count. Particles having a fresh, mechanically fractured face are counted out.

Note: See the Policy Memorandum “Crushed Gravel Producer Self-Testing Program” (12-08.1). This document can be found in Appendix C of this manual.

Crushed particle count test

3.3.2 The deleterious count on fine aggregate is run only for Classes A and B qualities. A sample is split out, dried, and sieved over a 600-µm (No. 30) sieve. Next, the sample is split or quartered down to 100 grams. The sample is then examined either under a microscope or with the naked eye. Deleterious particles that are picked for Classes A and B quality sands include the following:

Quality Test	**Class "A" Quality % Maximum**	**Class "B" Quality % Maximum**
Shale	3.0	3.0
Clay lumps	1.0	3.0
Coal, Lignite, and shells	1.0	1.0
Conglomerate	3.0	3.0
Other deleterious	3.0	3.0
Total deleterious	3.0	5.0

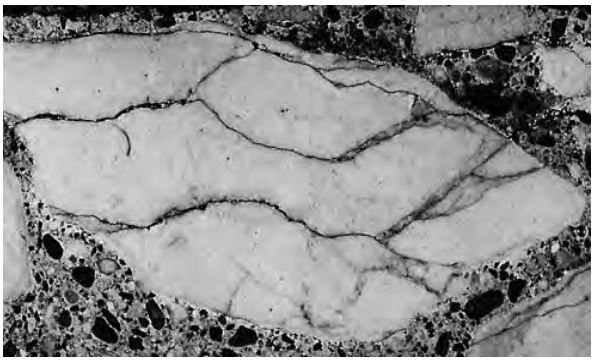
By far, the most common deleterious particle in natural sand is shale.

The deleterious particles that are removed are weighed, and a percentage of the total sample is calculated.

Fine aggregate deleterious count

3.4 Freeze-Thaw Expansion Test

3.4.1 The freeze-thaw expansion test is used to identify aggregate that causes D-cracking in P.C. concrete. "D-cracking" is defined as "the disintegration cracking of P.C. concrete due to freeze-thaw failures of its aggregate particles and surrounding mortar". The term also refers to the crack pattern which forms on the surface.



Aggregate D-cracking

D-cracking is initiated in the lower levels of a pavement slab and at any cracks or joints where moisture readily accumulates and saturates exposed aggregate particles. Water can exert 10,000 psi of pressure by expanding 9% of its volume when frozen. The cycle of freezing and thawing breaks the rock particles and surrounding mortar. This distress progresses upward and outward, destroying the pavement. Thus the concrete is reduced to rubble.

Pavement damage from D-cracking

IDOT has identified three conditions necessary to cause D-cracking. If one of these conditions is eliminated then D-cracking can be eliminated in concrete pavements:

- Freeze-thaw environment
- Water
- Susceptible aggregate

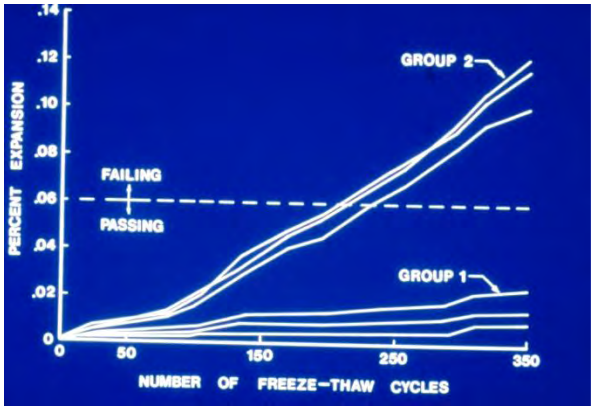
Pavement damage from D-cracking

Nothing can be done about the freeze-thaw environment. While IDOT is working on eliminating water, the majority of water is still not removed from under the pavement. IDOT decided in 1979 that the best approach and only approach was to identify D-cracking aggregates and eliminate their use in P.C. concrete pavements.

3.4.2 To identify D-cracking aggregates, IDOT has tested and continues to test all concrete aggregates in three different sizes in the Rapid Freeze-Thaw Test, ASTM C 666, Method B (rapid freezing in air -- thawing in water). This test consists of separating the coarse aggregate into individual sieve sizes and soaking the material for 18 hours; then combining the sizes in specific amounts with standard sand, cement, and admixtures; and making up a concrete mix. Keeping everything standard allows the evaluation of only the coarse aggregate for D-cracking.

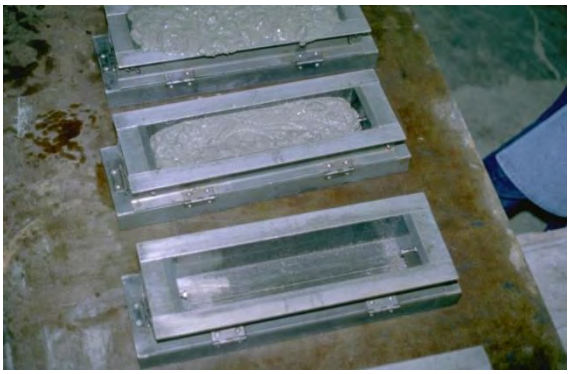
Three (3) beams are made up which have steel bolts embedded in the ends of the beams. After a 14-day cure, the initial length of each beam is read on the comparator, and the beams are run through 350 cycles of rapid freeze-thaw. Approximately once per week (25 to 50 cycles) the beams are removed from the cabinets and measured for length change. These length changes are plotted on a graph. The IDOT failure criterion is no more than 0.06% length change.

A list of what each producer can supply size-wise, or if the source is totally rejected for use in P.C. concrete pavements, is available at each IDOT District Materials office. This is strictly limited to aggregates for on-grade concrete pavements, concrete base course, and concrete base course widening.

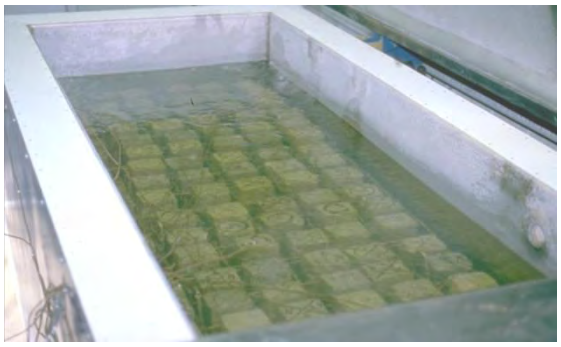


Freeze-Thaw Test Results

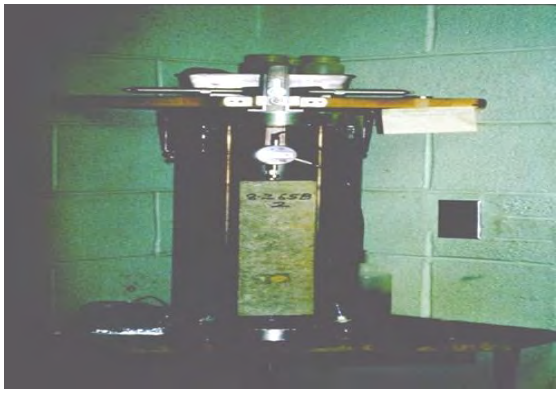
Materials are mixed together



Test beams are produced & cured



Test beams are run through 350 cycles



Test beams are evaluated

3.5 **Hydrometer**. As part of IDOT's acceptance program for fine aggregate, products with high amounts of fines, 12% or more. The hydrometer test is run to determine the percentage of clay-sized particles. Clay-size content is checked because excessive minus No. 200 (minus 75-µm) material, especially clay, is detrimental to concrete and bituminous mixes.

3.5.1 The procedure for the hydrometer test is as follows:

3.5.1.1 A sample is split out, oven-dried, and dry-sieved over a No. 10 (2.00-mm) sieve.

It should be pointed out that a separate gradation is run on the sample, and the hydrometer sample is made up and tested only if the gradation is in-spec.

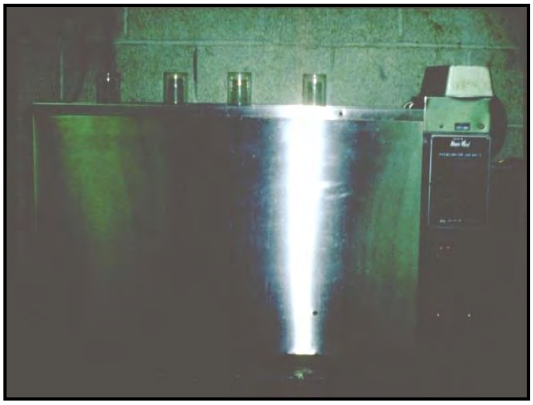
3.5.1.2 A sodium hexametaphosphate solution is added to 100 grams of the fine aggregate. This mixture is allowed to sit overnight. The sodium hexametaphosphate is a dispersing agent that acts to break apart any clay lumps.

3.5.1.3 The sample is added with distilled water to a graduated cylinder. The cylinder is placed in a temperature-regulated bath and allowed to reach 68° F (20° C). The cylinder is removed, hand-shaken for one minute, and returned to the bath.

Readings as the sample settles out and temperatures of the bath are taken at the 1, 5, 15, 30, 60, 90, 120, 250 and 1,440 minute intervals.

Sample is split & dried

Sample is mixed with hexametaphosphate solution and sits overnight



Readings are taken at intervals while in a controlled environment

3.5.1.4 The readings are plotted on logarithmic graph paper, adjusting the results for moisture content and temperature. Part of the original sample was oven-dried to determine the correction for moisture. A curve is drawn through the readings. On the graph, the percentage of clay is the point on the curve at 540 minutes. The percentage of clay is adjusted for the percentage passing the No. 10 (2.00-mm) sieve in the original gradation and reported.

3.5.2 The Standard Specifications restrict the hydrometer test to Classes “A” and “B” quality fine aggregate. A maximum of 3% clay as determined by the test is allowed.

3.6 **Colorimetric / Mortar Strength**

3.6.1 The colorimetric, or color, test is used to determine the amount of organic particles in Class “A” quality sands because organics reduce concrete strengths.

IDOT uses the AASHTO T 21 test procedure. A sample is soaked for 24 hours in a 3% sodium hydroxide solution. The solution is then compared to a standard color chart. The sodium hydroxide solution will dissolve any organic material, therefore coloring the solution. If the color exceeds the color test standard of 11, the mortar strength test has to be run.

3.6.2 The mortar strength test (AASHTO T 71 as revised by IDOT) is designed to actually test the strength of the suspect sand by comparing it in mortar to a standard sand mortar. The test consists of making up cubes of cement and a sample sand. Standard sand cubes are also made up. After curing in a moist room for 14 days, the cubes are crushed to determine their strength. The sample cube's strength must be at least 95% of the standard sand cube.

This test determines whether the organic particles in the sand will cause any strength loss in the concrete.

3.7 **Dolomite Determination**. This test looks at the chemical properties of carbonate rock.

3.7.1 The dolomite determination is run using the following procedure:

3.7.1.1 Several grams of a pulverized crushed stone sample are dissolved in hydrochloric acid. The liquid is filtered. Any solids are dried and become insoluble residue.

3.7.1.2 The liquid is put in a test tube and tested on the atomic absorption spectrophotometer. This machine determines the percentage of magnesium oxide in the sample.

Dolomite Determination

3.7.1.3 The Standard Specifications define limestone and dolomite as follows:

- Limestone -- < 11.0% MgO
- Dolomite -- $\geq$ 11.0% MgO

This test is used for IDOT's friction specifications and the Variable Speed Friction Testing program to differentiate carbonate crushed stone as limestone or dolomite materials.

3.8 Friction Specifications and Tests

3.8.1 Friction Tests

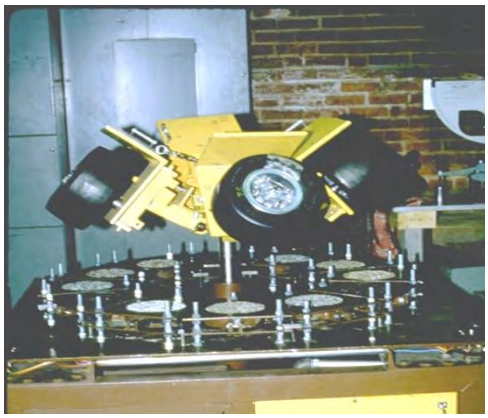
3.8.1.1 **Friction Trailer**: Many overlays (both new and old) are continually checked in the field by IDOT's ASTM friction trailer. This device is pulled at 40 mph (64 km/hr) on the pavement and uses water and a locked, full-size tire procedure to measure the pavement's friction potential. This friction potential is expressed as a Friction Number (FN).

3.8.1.2 **Variable Speed Friction Test**: IDOT can also evaluate the friction potential of the raw aggregates and combinations of aggregates in the laboratory by using its Small-Wheeled Circular Track and Variable Speed Friction Tester (VST). These devices, developed by North Carolina State University in the late 1970's, consist of a polishing track and a pendulum friction tester.

The Small-Wheeled Circular Track consists of four go-cart tires that revolve around on the aggregate samples at 30 rpm. The tires on the track are alternately toed in and toed out to provide a scrubbing or polishing action on aggregate samples.

These aggregate samples consist of aggregate particles placed in a steel mold with cement paste added, and a retarder on the mold surface. The cement paste hardens, holding the particles in place, except for the cement paste at the surface. The surface is scrubbed clean of the cement paste, leaving exposed only the aggregate to be tested.

Portable friction testing trailer



Small-wheeled circular track

Preparing a sample for the circular track

The VST drops a pendulum and tire across a wet sample and measures the energy lost. The measurement is run after 8 hours of polishing on the Small-Wheeled Circular Track and is called the Variable Speed Number (VSN).

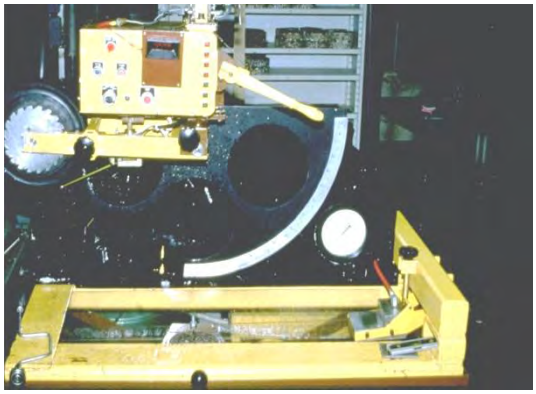
The Department has run every Class “B” quality aggregate in the VST and determined its VSN. Aggregates in Illinois are now ranked by their
VSN. The adjacent graph shows that the slags, novaculite chert, and sandstone are among the best friction aggregates.

It also shows that the decision made in 1975 that limestone polishes too easily was, on the average, correct. It substantiates the aggregates required for HMA Mixture classes C, D, E and F.

3.8.2 **Friction Specifications** - The coarse aggregate portion of any bituminous mixture provides the major friction characteristics for that mixture. Both the macro-texture (the overall surface texture of the bituminous mat) and the micro-texture (the wear pattern of the individual rock particles) are largely controlled by the coarse aggregate. In 1975, IDOT established its first special provision on high-friction pavements. In that special provision, the Department identified which aggregates could be used in the surface bituminous mix to provide a certain level of friction on the highway.

IDOT's current friction program is called the "Skid Accident Reduction Program". This program, or policy, looks at two specific procedures when overlaying a section of highway.

First, all spot locations or high-accident sites are identified, and specific remedies are selected to improve these sites. This may include changes in signing, geometrics of the roadway, or use of special high-friction mixes, such as open-graded friction course or sand seals



VST Testing Equipment

VSN Graph

Second, the normally scheduled rehabilitation of the rest of the section of highway is decided. Here, IDOT decides what level of high-friction HMA mixture is required. One of three HMA surface mixtures can be used based on the average daily traffic (ADT) of the road.

In 2000 IDOT made significant changes in the friction specifications. The new specification is on the following pages.

Skid Accident Reduction Program looks at two areas:
1. Spot locations including high accident areas
2. Normally scheduled highway rehabilitation

Beginning of the Standard Specification Article 1004.01 (a) (4) in part

"(4) Crushed Stone. Crushed stone shall be the angular fragments resulting from crushing undisturbed, consolidated deposits of rock by mechanical means. Crushed stone shall be divided into the following, when specified.

a. Carbonate Crushed Stone. Carbonate crushed stone shall be either dolomite or limestone. Dolomite shall contain 11.0 percent or more magnesium oxide (MgO). Limestone shall contain less than 11.0 percent magnesium oxide (MgO).

b. Crystalline Crushed Stone. Crystalline crushed stone shall be either metamorphic or igneous stone, including but not limited to, quartzite, granite, rhyolite and diabase."

End of the Standard Specification Article 1004.01 (a) (4) in part

Beginning of the Standard Specification Article 1004.03 (a)

"1004.03 Coarse Aggregate for Hot Mix Asphalt (HMA). *The aggregate shall be according to Article 1004.01 and the following.*

(a) Description. The coarse aggregate for HMA shall be according to the following table.

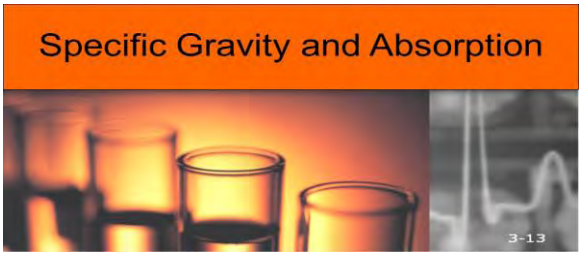
Use	*Mixture*	*Aggregates Percent (%) Allowed by Volume*
Class A	*Seal or Cover*	*Allowed Alone or in Combination* [5/]: *Gravel* *Crushed Gravel* *Carbonate Crushed Stone* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag* *Crushed Concrete*
HMA Low ESAL	*Stabilized Subbase or Shoulders*	*Allowed Alone or in Combination* [5/]: *Gravel* *Crushed Gravel* *Carbonate Crushed Stone* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag*[1/] *Crushed Concrete*

Use	*Mixture*	*Aggregates Percent (%) Allowed by Volume*	
HMA *High ESAL* *Low ESAL*	*Binder* *IL-19.0* *or IL-19.0L* *SMA Binder*	*<u>Allowed Alone or in Combination</u> [5/]:* *Crushed Gravel* *Carbonate Crushed Stone[2/]* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Concrete[3/]*	
HMA *High ESAL* *Low ESAL*	*C Surface and Leveling Binder* *IL-9.5 or IL-9.5L* *SMA* *Ndesign 50* *Surface*	*<u>Allowed Alone or in Combination</u> [5/]:* *Crushed Gravel* *Carbonate Crushed Stone[2/]* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag[4/]* *Crushed Concrete[3/]*	
HMA *High ESAL*	*D Surface and Leveling Binder* *IL-9.5* *SMA* *Ndesign 50* *Surface*	*<u>Allowed Alone or in Combination</u> [5/]:* *Crushed Gravel* *Carbonate Crushed Stone (other than Limestone)[2/]* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag[4/]* *Crushed Concrete[3/]*	
		<u>Other Combinations Allowed:</u>	
		Up to…	*With…*
		25% Limestone	*Dolomite*
		50% Limestone	*Any Mixture D aggregate other than Dolomite*
		75% Limestone	*Crushed Slag (ACBF) or Crushed Sandstone*

Use	*Mixture*	*Aggregates Percent (%) Allowed by Volume*	
HMA *High ESAL*	*E Surface* *IL-9.5* *SMA* *Ndesign 80* *Surface*	*Allowed Alone or in Combination* [5/]: *Crushed Gravel* *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag* *Crushed Concrete*[3/] *No Limestone.*	
		Other Combinations Allowed:	
		Up to…	*With…*
		50% Dolomite[2/]	*Any Mixture E aggregate*
		75% Dolomite[2/]	*Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag, or* *Crystalline Crushed Stone*
		75% Crushed Gravel or Crushed Concrete[3/]	*Crushed Sandstone, Crystalline Crushed Stone, Crushed Slag (ACBF), or Crushed Steel Slag*
HMA *High ESAL*	*F Surface* *IL-9.5* *SMA* *Ndesign 80* *Surface*	*Allowed Alone or in Combination* [5/]: *Crystalline Crushed Stone* *Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag* *No Limestone.*	
		Other Combinations Allowed:	
		Up to…	*With…*
		50% Crushed Gravel, Crushed Concrete[3/], *or Dolomite*[2/]	*Crushed Sandstone* *Crushed Slag (ACBF)* *Crushed Steel Slag, or* *Crystalline Crushed Stone*

1/ Crushed steel slag allowed in shoulder surface only
2/ Carbonate crushed stone shall not be used in SMA Ndesign 80. In SMA Ndesign 50, carbonate crushed stone shall not be blended with any of the other aggregates allowed alone in Ndesign 50 SMA binder or Ndesign SMA surface.
3/ Crushed concrete will not be allowed in SMA mixes.
4/ Crushed steel slag shall not be used as leveling binder.
5/ When combinations of aggregates are used, the blend percent measurements listed shall be by volume."

End of the Standard Specification Article 1004.03 (a)



3.9 **Specific Gravity and Absorption**. Specific gravity and absorption tests are run on both coarse and fine aggregates. While specific gravity and absorption are not used for acceptance, both the BMPR and the District Material Offices will use the information in the design process for HMA and Portland Cement Concrete mixtures.

Gravity and absorption also can be indications of quality and durability. Low specific gravities and a high absorption usually indicate an unsound or low quality aggregate. An aggregate with a high absorption can be expected to undergo a large volume change when saturated and dried, or frozen and thawed.

General rules for specific gravity and absorption for aggregates:

- with a specific gravity over 2.60 and an absorption under 2.0% is considered good.
- with a specific gravity between 2.60 to 2.54, inclusive, and an absorption between 2.0% and 3.0%, inclusive, is considered borderline.
- with a specific gravity under 2.54 and an absorption over 3.0% can indicate a poor aggregate.

General Specific Gravity and Absorption Rules

	Specific Gravity	Absorption
Good	over 2.600	under 2.0%
Borderline	2.600 - 2.540	2.0% to 3.0%
Poor	under 2.540	over 3.0%

There are exceptions to these rules:

Air-cooled blast furnace slag is very light, 2.00 to 2.25 specific gravity, and has a high absorption but has good strength and friction properties that are desirable as a building material.

Another exception would be a shale-laminated stone that has a high gravity and low absorption. This type of stone is considered deleterious due to the shale laminations. When exposed to the weather this material will breakdown easily making it very undesirable for use as a building material.

The procedures to determine specific gravity and absorption for coarse and fine aggregate are basically the same with the exception of determining the saturated surface dry condition. IDOT follows procedures ITP 84 for coarse aggregate and ITP 85 for fine aggregate.

Aggregate specific gravities and absorption tests have:

a. A direct correlation with certain mixture attributes that could potentially affect specification requirements when controlling the production and placement of asphalt and/or concrete products.

b. A potential for variability in testing procedures and results.

Because of this, the BMPR will perform all official aggregate specific gravity and absorption tests on aggregate materials used on Illinois contracts. The BMPR issues a statewide listing of the established specific gravity and absorption values for all aggregates used in Illinois. These listings are available on the IDOT website. A contractor can also contact their local IDOT District Materials office to obtain this information.

Aggregate producers and asphalt/concrete contractors are encouraged learn the process of running specific gravity and absorption tests on aggregates in order to perform checks from time to time when producing or using aggregate materials. These results will not replace the BMPR's established listing of aggregate specific gravities and absorption values.

There are certain times where producers and asphalt/concrete contractors are required to perform specific gravity and absorption tests. When using crushed slag products (ACBF and steel slag) to produce HMA or PCC mixtures, the slag producer and asphalt/concrete contractor is required to perform daily production control tests on slag samples to determine current specific gravity and absorption of these materials in order to make adjustments on mixtures using the slag materials.

Slag materials, especially steel slag materials, tend to have daily variations and inconsistency issues that can be detrimental to asphalt and/or concrete products. By performing these daily tests and being aware of these variations, the asphalt/concrete contractor can make adjustments to their mixtures in order to maintain mix compliance to the specifications.

When slag materials are being used in mixtures used for IDOT purposes, the IDOT BMPR or District Materials office will give instructions to producers and contractors instructing how to properly perform these tests. District Material technicians will monitor these testing procedures performed by producers and contractors in order to verify test results when producing mixtures for IDOT use.

The current Policy Memorandum detailing the "Crushed Slag Producer Certification and Self-Testing Program" (13-08.1) can be found in Appendix 'C' of this manual.

4.0 STOCKPILING AND HANDLING

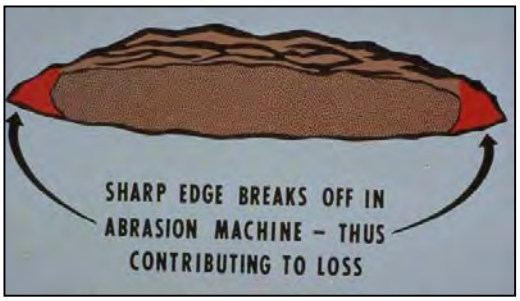
Stockpiling and handling are two of the most important aspects in the aggregate production process. Material being produced to a uniform in-specification gradation can become out-of-specification material through poor stockpiling and handling. Several factors affecting aggregate gradation in this manner are segregation and degradation.

Segregation and degradation can be defined as follows:

- Segregation is the separation of a well graded production aggregate into individual sizes due to gravity. An example is large particles rolling down an inclined pile (cone) farther than smaller particles. This leads to almost all the large particles concentrated at the bottom and a fines pipe formed in the center of the pile.

- Degradation is the actual breakdown of the individual aggregate particles due to abrasion and attrition during stockpiling and handling. This is extremely detrimental since the amount of minus 75 µm (minus No. 200) fines can be increased greatly. Increased fines create problems in most uses.

The following discussion will cover the types of stockpiling/handling, the effect of segregation and degradation on each type, and the methods normally used to eliminate or reduce their effects.

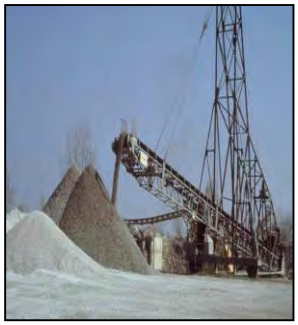


All stockpiling and handling for the Aggregate Gradation Control System shall conform to Section 40.2 of the *Manual for Aggregate Inspection* (see Appendix A, page A-3 herein).

4.1 **Conveyor Stockpiles**. One of the two most common stockpiling methods in Illinois is material being discharged from a conveyor belt to form a stockpile. There are two kinds of conveyor stockpiles:

- Cone - formed under a fixed or adjustable conveyor belt
- Elongated Cone (tent-shaped) - built by a radial (or movable) stacker or a telescopic portable radial stacker

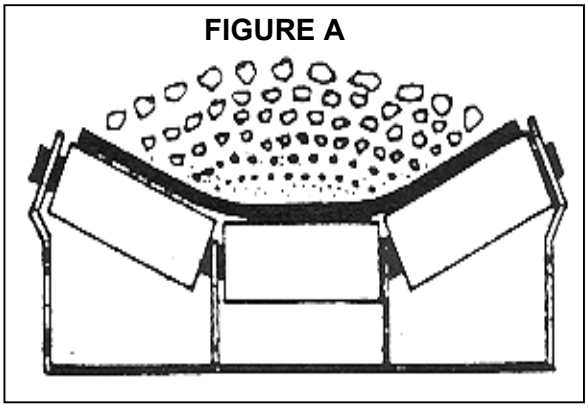
Cone Stockpile

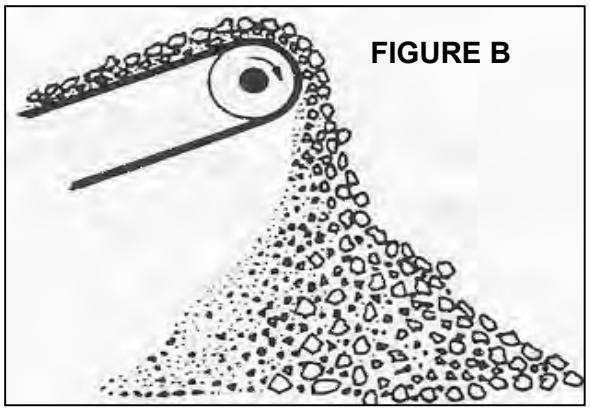


Elongated Cone Stockpiles

4.1.1 These two types of stockpiles create a high degree of segregation. A simple explanation can show the reason for segregation. As the aggregate stream is conveyed up the belt **(Figure A)**, vibration of the belt tends to layer the individual sizes and causes the fines to move to the bottom of the belt. When the material comes off the belt into the cone stockpile, the fine material clings to the belt longer and therefore drops straight down or toward the backside of the pile. The larger material falls or is thrown slightly away from the center top point of the pile. Belt speed can also be a large factor. As a result, the large particles have a tendency to roll down the front and sides of the pile and accumulate at the bottom **(Figure B)**.

FIGURE A





Several factors determine the amount of segregation in a pile. These are: belt speed, the distance of fall from the conveyor, the amount of moisture in the aggregate, the wind conditions, and the height of the pile. The distance of fall is one advantage where an adjustable stacker can produce a less segregated stockpile than a fixed belt by keeping the distance between the discharge end of the belt and the top of the pile to a minimum.

An adjustable radial stacker or an adjustable telescopic portable radial stacker can be used to build elongated tent-shaped piles. The adjustable radial stacker moves horizontally as well as vertically. The telescopic radial stacker not only moves horizonally and vertically, but also moves telescopically in and out creating a flat, instead of coned, surface. Although stockpiles using these two types of stackers also tend to segregate, they are superior to simple cone piles when built and loaded from properly. With either of these two types of stackers, the top of the pile must always be close to the end of the belt, and the stacker must be continually moved to keep the pile uniform without indentations. Load-out must be done across the end opposite the conveyor. Mixing during load-out should be done to incorporate the coarse edges with the finer center.

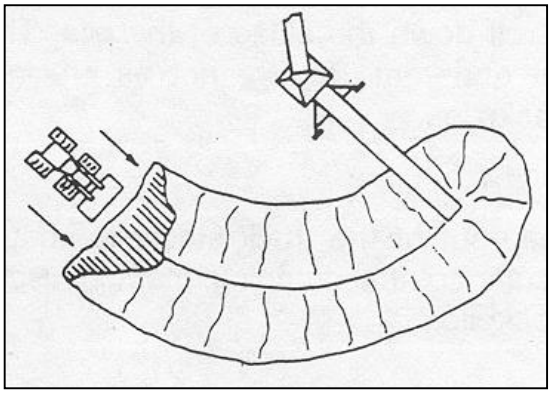
Adjustable Radial Stacker

Telescopic Portable Radial Stacker

It should be pointed out that the fall distance from the conveyor/stacker to stockpile cannot be greater than 15 feet for IDOT Class A, B, or C Quality aggregate, unless a change is approved by the Bureau of Materials and Physical Research, as specified in Section 40.2 of the Department's *Manual for Aggregate Inspection* (See Appendix A, page A-3 herein).

The source's handling/load-out procedures must adequately remix the material into an acceptable gradation when loading from cones/elongated cone piles. This explains why the endloader operator is so vitally important in most aggregate plants. A poor job of remixing means out-of-specification material being shipped.

The endloader must load perpendicular to the belt flow when loading out of fixed belt cones (see figure on cone stockpile in Section 4.1). Elongated cone stockpiles must be worked from either end rather than from points along the banana-shaped sides (see figure on elongated cone stockpiles in Section 4.1). The endloader must also remix the material when loading out. Buckets from both the center fines pipe and the fine backside of the pile must be reworked or alternated with buckets of coarse particles at the front, sides, and bottom of the pile. This remixing will help to bring the material back into gradation.



4.1.2 Degradation in cone/elongated cone stockpiles normally does not become a major problem. The main abrading action, which is minimum, is in the load-out of the stockpile.

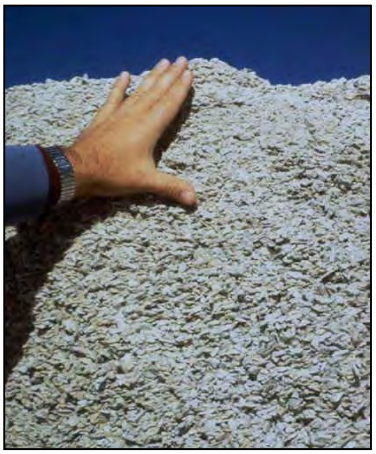
4.2 **Truck Stockpiles**. The second of the two most common stockpiling methods is using large off-road trucks. These trucks normally carry 25 to 100 metric tons per load. The method requires truck dumps to be placed next to each other, effectively building a layer of material. Material can be placed alongside the layer and pushed up by an endloader. This is considered a **single-layer/pushed stockpile.**

Most sources choose to build **multilayered truck stockpiles**. In this case, a ramp of material is constructed to allow the trucks to drive up on the just-completed layer. An endloader or a bulldozer has to level the layer before the trucks can drive on it. The trucks proceed to dump loads across the top of the layer, making sure not to dump closer than 2 to 4 feet (0.6 to 1.3 m) from the layer edge. No material dumped on the second or subsequent layers should roll down the sides of the pile. This process can be continued to build a multilayered stockpile.

4.2.1 Stockpiles built in this manner have very little segregation as long as material is not allowed to roll down the sides of the pile. Therefore, load-out and remixing are not as crucial as in coned stockpiles.

Load-out of the truck stockpile should be perpendicular to the dumping method used to build the stockpile.

4.2.2 Degradation does become a factor when building a multilayered truck stockpile. The movement of trucks on the layered material can cause sufficient abrading and attrition of the aggregate particles to produce an unacceptable amount of minus minus No. 200 (75 µm) fines.

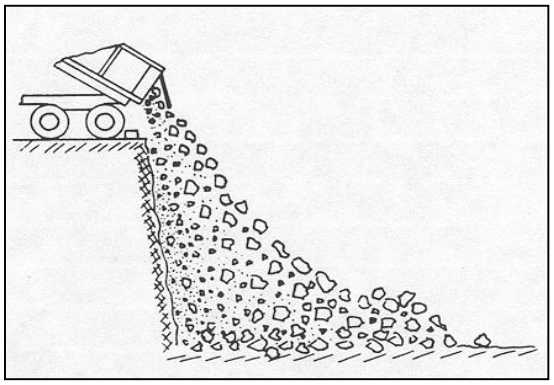


Care must be exercised when permitting trucks on a stockpile. Aggregate used where excessive fines can cause problems should not be truck-stockpiled. Stockpiles should be constantly monitored for a fines problem and, if necessary, corrective action initiated, even to the extent of halting truck-stockpiling.

4.3 **Clam Shell Stockpiles**. Very few aggregate sources use a clam shell to build a stockpile. It is used mainly to unload material from river barges. A few Illinois sources and suppliers use this method to build their stockpiles. The clam shell method casts the material that is picked up from the barge in thin layers, building one upon the other. If correctly constructed, very little material rolls down the sides of the pile.

Segregation and degradation are minimal in a clam shell stockpile. The main problem associated with this type of stockpile is the high expense in building it.

4.4 **Other Methods**. Some sources stockpile material by dumping truckloads over a quarry or pit face. (See adjacent figure.) This method, like conveyor-stockpiling, allows the material to segregate when the larger particles roll down the sloped pile. This is not a recommended stockpiling method because reclaiming normally cannot be done correctly to remix the aggregate.



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5.0 FIELD GRADATION SAMPLING

This chapter is designed to detail the correct sampling procedure to be used when taking gradation samples under the Aggregate Gradation Control System. Sampling shall conform to Illinois Test Procedure 2. **No other sampling procedures will be allowed**. Both production and stockpile sampling methods will be covered in this chapter.

5.1 **Importance of Sampling**. The *Aggregate Technician Course Manual* discusses the importance of correctly sampling aggregate for testing. Therefore, it should be sufficient to say in this chapter that knowing what is actually being produced is of prime importance in the production and utilization of aggregate. Unless gradation samples are truly **representative** of the material being produced and shipped, the test results are worthless for plant control or material acceptance.

5.2 **Production Gradation Sampling**. Production sampling is generally acknowledged as the best sampling method for plant gradation control. It also is noted for providing the most representative samples. Following is a listing of four production sampling methods. Each will be described and any limitations discussed.

- On-belt sampling
- Belt-stream sampling
- Bin-discharge sampling
  (requires IDOT approval)
- Truck-dump sampling

5.2.1 **On-Belt Sampling** - This production sampling method (illustrated on page 5-3) requires the producer to stop the production belt containing the finished product. A template (as illustrated) is inserted into the material on the belt. All the material between the template shall be removed and shall represent one of three increments making up the field sample. Extreme care shall be taken, including the use of a brush, to remove all fines on the belt between the template for inclusion into the increment. The belt shall be stopped at least three times (three increments) during approximately 10 to 15 minutes of operation to obtain a field sample. If additional material is needed beyond three increments due to the amount of material on the belt, additional template cuts may be taken during the three belt stoppages.

Samples shall be taken only during normal plant operation and when the belt is under normal load.

5.2.2 **Belt-Stream Sampling** - The sample shall be taken by cutting the stream of aggregate as it leaves the end of the production belt (see page 5-3). A sampling device is passed uniformly through the entire (width and depth) stream flow during normal production and belt load. Each sampling pass (increment) is combined with others to make up the field sample. A minimum of three increments shall be taken during a 10 to 15 minute sampling period. Enough increments shall be taken to provide the correct field sample size.

Extreme care shall be taken to make sure the sampling device passes completely and uniformly through the entire stream flow (from outside the stream on one side to outside the stream on the other side) and to ensure the device does not overflow.

On-Belt Sampling

Step 1

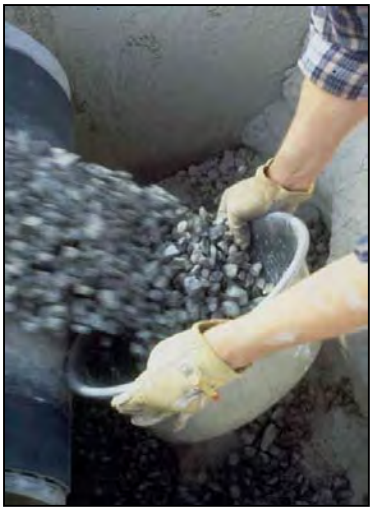
Step 2

Step 3

Step 4

Belt-Stream Sampling

Step 1



Step 2

Step 3

5.2.3 **Bin-Discharge Sampling** - Bin discharge shall be sampled in a manner similar to belt-stream sampling to get a production sample. A sampling device is passed through the entire bin discharge stream. A minimum of three increments shall be taken during a 10- to 15-minute sampling period and combined to form the field sample.

Before cutting the bin discharge stream, the bin must be emptied until such time that the stream of material entering the bin is the stream of material exiting the bin. Sampling may take place at that time.

Samples shall be taken only during normal plant operation and when the bin is being fed under normal load

The major problems associated with bin-discharge sampling involve segregated material clinging to the sides of the bin. This material can and does break loose which alters the gradation of the bin-discharge stream. This sampling procedure shall therefore be used only when approved by the District Engineer. (This technique of sampling may also be considered as another method for end-point sampling.)

5.2.4 **Truck-Dump Sampling** – Sampling from inside of transportation units is not permitted. The transportation unit shall be off-loaded and sampled by any of the sampling procedures under Illinois Test Procedure 2.

This sampling method requires taking a field sample from one or two truck dumps which are placed during the building of a stockpile or feeding of a plant. The truck dump(s) shall be cut with an endloader and two or more bucketsloads extracted. The bucketloads shall be dumped on one another to form a small pile. **The small pile shall then be mixed from two directions perpendicular to each other.** To mix the pile, the endloader shall cut into the pile along its base until approximately its midpoint. The loader bucket shall be lifted, the loader moved 1 to 2 feet forward, and the bucket dumped on the other half of the pile.

Care shall be exercised to avoid cutting below the base of the truckdumps or small pile and contaminating the material to be sampled.

After mixing twice, the endloader shall drop and angle its bucket downward on one side of the pile into a layer not less the 1 foot thick

The layer shall be sampled using a required shovel to take increments in a random "X" pattern over the layer. The shovel shall be forced vertically to its full depth when sampling each increment except that care shall be used to not dig completely through the layer. This would contaminate the sample being obtained. The equipment wheel paths and the edges of the sample layer should be avoided. Sufficient increments shall be taken to make up a correct field sample. Care shall also be exercised to retain as much material on the shovel when taking increments. Sufficient increments shall be taken to make up a correct field sample.

5.3 **Stockpile Sampling**. Stockpile sampling is needed to confirm that the material in the stockpile meets a specified gradation or can be remixed during load-out to meet a specified gradation. Care has to be taken to obtain a representative sample.

5.3.1 There are two general rules for getting samples (especially coarse aggregate) from a stockpile.

5.3.1.1 The sample shall be taken from the working face of the stockpile. The working face shall be parallel to the direction of flow used to build the stockpile. Stockpiles having not working face shall have one established prior to sampling. The working face shall have the interior of the pile exposed to permit proper reblending of the pile to eliminate segregated aggregate. If necessary, material may be brought out of the main pile's working face into a substockpile for sampling.

5.3.1.2 Take several bucketloads across the opened face of the main stockpile or substockpile with an endloader and combine them in a small pile. Care shall be exercised to avoid having the endloader cut below the base of the existing stockpile. This prevents contamination of the sample.

5.3.2 **Stockpile Sampling Procedure** – As for the actual sampling procedure (see page 5.7). The stockpile sampling procedure shall follow the truck-dump sampling procedure using an endloader. The endloader shall cut across the working face as detailed in “Truck-Dump Sampling.” Any special mixing procedure used during loading shall be used when taking any samples.

Stockpile Sampling Procedure

Step 1 – Take several bucketloads across the opened face of the main stockpile or substockpile with an endloader and combine them in a small pile.

Step 2 – The small pile shall then be mixed from two directions perpendicular to each other, always dumping back on tip of the pile.

Step 3 – After mixing, the endloader shall backdrag the pile into a layer not less than one foot thick.

Step 4 – The layer shall be sampled using a shovel to take increments in “X” pattern. Increments should be taken to the full depth of the shovel and care should be exercised to retain as much material as possible.

5.4 **Sampling Equipment**. Several pieces of sampling equipment are mentioned in the preceding parts of this chapter. This equipment - template, sampling device, and shovel - must meet certain requirements to be used for sampling. The following paragraphs describe the requirements for each piece.

5.4.1 **Template** - The template shall consist of two endplates and shall be designed to be adjustable. The distance between the end plates may therefore be changed to gather more material from the belt for each increment. The end plates shall also be machined or cut to the approximate belt size and shape.

A single template end plate may be used in the sampling procedure, if care is exercised.

5.4.2 **Sampling Device** - The sampling device used to cut the flow stream from the end of the belt or the bin discharge must be strong enough to handle the force of the flow stream. The device must also be large and deep enough to cut the entire flow stream and not overflow when passing through the stream. The device may be a bucket, a pan, or a specifically manufactured sampling container.

****Shelby tubes are not allowed as sampling devices.**

5.4.3 **Shovel** - The shovel shall be square-nosed and of a size easily handled. It shall also have built-up sides and back ***(approximately 1 1/2 inch [37.5mm])*** to facilitate the retention of material on the shovel when sampling.

5.5 Sampling Frequency / Field Sample Size

5.5.1 **Sampling Frequency** - The frequency of gradation sampling is listed in the "Aggregate Gradation Control System". This program is covered in Chapter 8.0 of the *Aggregate Technician Course Manual.*

5.5.2 **Field Sample Size** - The field sample size is detailed in the Aggregate Gradation Sample Size Table & Quality Control Sieves, effective February 1, 2014. A copy of the Aggregate Sample Size Table is located on page 6-18 herein.

SAMPLE SIZES FOR COARSE AGGREGATE

Gradation No.* †	Maximum Nominal Size	Minimum Test Sample Size‡	Minimum Field Sample Size‡
CA 6	25 mm		25 kg (55 lbs)
CA 7	25 mm (1")		25 kg (55 lbs)
CA 8	25 mm (1")	5,000 grams	25 kg (55 lbs)
CA 9	25 mm (1")	5,000 grams	25 kg (55 lbs)
CA 10	19 mm (3/4")	5,000 grams	25 kg (55 lbs)
CA 11	(3/4")	5,000 grams	25 kg (55 lbs)
CA 16	9.5 mm (3/8")	1,500 grams	11 kg (25 lbs)

Field Sample Size

5.6 **Safety**. Gradation sampling can pose one of the greatest risks to the safety of the aggregate technician/inspector. Extreme care should be used whenever around the aggregate plant and mobile equipment.

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6.0 GRADATION TESTING

The procedure for determining the gradation or particle size distribution of an aggregate is divided into five parts:

Reduction of field sample (ITP-248)

Drying of the sample (ITP 255)

Wash test (ITP-11)

Dry sieve analysis (ITP-27)

Calculation / Reporting

The following sections will describe each part of the gradation test procedure, in detail, as it is performed on a field sample brought into the laboratory.

In addition, aggregate moisture content may be run on the gradation sample prior to gradation testing or on a separate test sample, both as detailed in Article 6.6 herein.

The necessary laboratory equipment to run a gradation or aggregate moisture content is noted in Section 7.0 of the Department Policy Memorandum, “Aggregate Gradation Control System”. This equipment shall be continually monitored and frequently checked by the aggregate technician for compliance to the required Illinois Test Procedures. The producer laboratory will also be checked by the Department during initial source certification and on an annual basis thereafter.

6.1 Reduction of Field Samples. Field samples must be reduced to test sample size before testing. The test sample size for gradation testing shall conform to the Illinois Specification 201, Aggregate Gradation Sample Size Table & Quality Control Sieves, (see page 6-18 herein.) The test sample size shall be as stated in Illinois Specification 201.

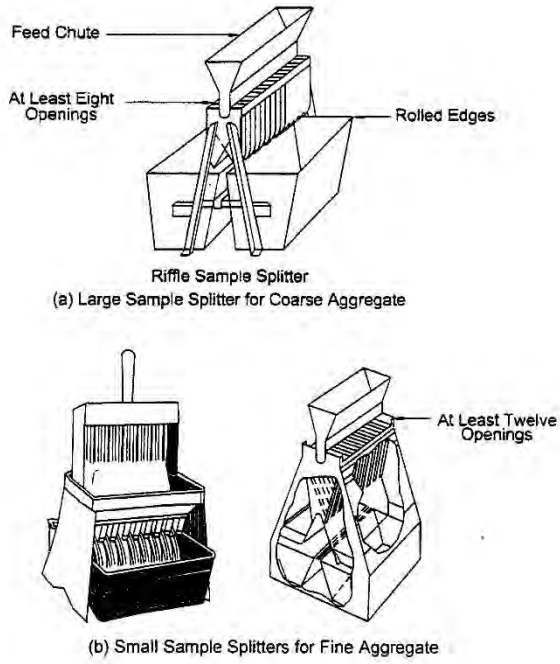
Reduction of field samples shall conform to Illinois Test Procedure 248 (see Appendix B, herein). Selection during splitting of an exact predetermined mass for the sample is not permitted.

The required splitting method for coarse aggregate in the program shall be mechanical splitters as detailed in Article 6.1.1 (following). The preferred splitting method for fine aggregate shall be mechanical splitters; however, quartering and miniature stockpile sample may be used. If a mechanical splitter is used, it shall conform to Illinois Test Procedure 248, Method 'A' (see Appendix B herein).

6.1.1 Method 'A' - Mechanical Splitters - As stated in the specification, the mechanical splitter shall have an even number of same-width chutes, directed alternately to different sides. There shall be a minimum of eight chutes for coarse aggregate and twelve chutes for fine aggregate. All chutes shall be at least 50% larger than the largest particle in the field sample. Two pans, each of which covers the entire width of the chute area, shall be used to catch the two split halves. The splitter shall be equipped with a hopper (preferred type) or a straight edged pan, either of which shall give a width equal to or slightly less than the overall width of the chutes. The splitter and accessory equipment shall be designed and operated so that the sample will flow smoothly without restriction or loss of material and can be fed at a slow, controlled rate during the splitting process.

Mechanical Splitters
Hopper Style

Mechanical Splitters
Straightedge Pan Style



Riffle Sample Splitter
(a) Large Sample Splitter for Coarse Aggregate

(b) Small Sample Splitters for Fine Aggregate

All aggregate splitters used must conform to Illinois Test Procedure 248.

The actual splitting procedure requires the field sample be placed in the hopper or pour pan and evenly distributed from edge to edge. This allows the material to be divided into approximately equal amounts by flowing through the chutes. The sample shall be introduced into the chutes in an even flow. A fast discharge or "shot-gunning" the sample into the chutes may cause material to bridge over a chute, creating a non-representative sample. One of the two splits may then be reintroduced into the hopper or pour pan for further splitting. (See page 6-4.) This procedure should be done the appropriate number of times to result in the correct test sample size.

On the <u>final</u> split, the masses of the two halves (after splitting) shall be within +/- 10% of each other. This is determined adding 10% of the mass of the smaller split to the mass of the smaller split; the larger split cannot exceed this calculated mass. If it does, both split halves shall be recombined and split until the mass comparison requirement is met.

Example problem of <u>final</u> split calculation:

Weight of 1st half is 5325 g
Weight of 2nd half is 5609 g

(Smaller split) _____ g x 10% = _____ g

(Add to smaller split) _____g + _____g = _____g

The mass of the larger split half (5609 g) cannot be larger than the calculated mass in order to be a valid split.

If the larger half exceeds the calculated mass, recombine the two halves and split again.

Mechanical Splitting

STEP 1

STEP 2

STEP 3

STEP 4

STEP 5

6.1.2 Method 'B' - Quartering - Quartering, as described in Illinois Test Procedure 248, requires the fine aggregate field sample be placed on a hard, clean, level surface or on a canvas blanket. (See page 6-6.) The sample is then thoroughly mixed by turning over the entire samples four times with a shovel, forming a small conical pile. If the canvas blanket is used, mixing may also be accomplished by alternately lifting each corner of the canvas and pulling it over the sample diagonally toward the opposite corner. This causes the material to be rolled and mixed. The mixing procedure, whether by shove or canvas, shall be repeated three times, resulting with the formation of a small conical pile. Care shall be taken not to lose material or add foreign material in either mixing procedure.

The small conical pile shall be flattened to a uniform thickness and diameter by applying the shovel to the apex of the pile. The diameter should be approximately four to eight times the thickness.

The flattened pile shall then be divided into four equal quarters with a shovel or trowel. Two diagonally opposite quarters shall be removed, including all fine material. A brush may be used to clean the cleared spaces. Remix and quarter the remaining material as many times as necessary following the above-described method to achieve the required test sample size.

On the <u>final</u> split, both split halves shall conform to the +/- 10% mass requirement detailed in Article 6.1.1 herein.

Quartering

Step 1

Step 2

Step 3

Step 4

6.1.3 Method 'C' - Miniature Stockpile – Miniature stockpile sampling may be used on only damp, fine aggregate. The material is mixed using the same procedure as just described in quartering. The small conical pile is flattened to a sampling pad of uniform thickness and diameter by applying the shovel to the apex of the pile. Each quarter section of the resulting pad will contain the material originally in it. the test sample is then obtained by selecting at least five increments in a random "X" pattern over the miniature sampling pad using a sampling thief, small scoop, or spoon. The number of increments should be sufficient to provide a sample slightly larger than the required minimum test sample size when dried to constant weight.

For all State monitor splits, the number of increments, as described above, shall be doubled to provide a sample twice the required size. This material shall then be dried to constant weight and split in accordance to Method 'A' (mechanical splitter), or, instead of drying and mechanically splitting, the material may be split in accordance to Method 'B' (quartering) of ITP 248. Both split halves shall conform to the +/- 10% weight requirement detailed in Article 6.1.1 herein.

6.2 Drying of Test Sample – The test sample shall be dried back to constant weight in conformance to the Illinois Test Procedure 255 utilizing an oven, specifically designed for drying, set at and capable of maintaining a uniform temperature of 230 +/- 9˚F (110 +/- 5˚C). Constant weight is defined as "The sample weight, at which there has not been more than a 0.5-gram weight loss during one hour". This shall be verified occasionally.

The sample may also be dried in a pan on an electric hot plate or gas burner in lieu of using an oven. Since this method can create drying temperatures greatly exceeding the allowed oven temperatures, extreme care must be used when using this drying method. The technician shall continually attend the sample on the electric hot plate or gas burner. While microwave ovens are not permitted for drying aggregate gradation samples, microwave ovens can be used when drying non-gradation test samples used for moisture determination only.

The electric hot plate and/or gas burner should be operated on a low-as-needed heat during drying. This will eliminate the popping, crackling, and/or sizzling noise which indicates potential aggregate breakdown. The heat must be turned down if these noises persist, or the sample must be constantly stirred to prevent this potential aggregate particle disintegration.

After the test sample has been dried back to constant weight, the sample shall be cooled down to room temperature. The sample shall then have its weight determined to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate on scales or a balance conforming to the *AASHTO Standard M 231, Weighing Devices Used in the Testing of Materials*. All scales or balances shall be tared before being used to determine any weight required in this chapter. This procedure provides the Total Dry Weight of the original test sample.

6.3 Wash Test – The wash test, Illinois Test Procedure 11, "Amount of Material Finer Than No. 200 [75um] Sieve in Aggregate", requires the sample be placed in a sufficiently sized pan and covered with water. (See page 6-10.) If necessary, a wetting agent, such as a detergent or dispersing solution, may be added to assure thorough separation of the fines from the coarse particles. The sample shall be agitated by the use of a **large spoon or similar instrument** to bring the fines into suspension in the water. The water is then immediately poured into a nested set of sieves. The nested set of sieves must consist of the No. 200 [75µm] sieve with an additional sieve placed directly on top. The sieve placed on top of the No. 200 (75µm) is used as a protectant sieve and can be any sieve from the #8 (2.36mm) through the No. 16 (1.18mm). Care shall be taken to avoid pouring many of the coarse particles onto the sieves. This procedure is repeated as many times as necessary until the wash water is clear. At this time, all material retained on the wash sieves is then carefully washed back into the sample.

A mechanical device, such as a Ploog washer, may be used for **coarse aggregate samples** providing its results match the manual procedure. If using a mechanical washing device, the protectant sieve needs to be an extra tall sieve (at least 6-8") to avoid loss of material due to splashing. A loss of fines due to the dripping of water from the outside edge will not be allowed and can be prevented by applying a coating of wax around the outside edge of the drum lip. If sample degradation occurs, then mechanical washing method will not be allowed.

Manual Wash Method

Mechanical Wash Method

After completing the washing, the test sample is dried back to constant weight and its weight determined. This weight is recorded as the Total Wash Weight to the nearest 1 gram for coarse aggregate and the nearest 0.1 gram for fine aggregate.

If the wash test is not required, Section 6.3 may be eliminated.

Wash Test

STEP 1

STEP 2

STEP 3

STEP 4

STEP 5

STEP 6

6.4 Dry Sieve Test – The test sample, after drying back to constant mass and having its mass determined, shall be run in the dry sieve test conforming Illinois Test Procedure 27, "Sieve Analysis of Fine and Coarse Aggregates". All equipment used shall conform to Illinois Test Procedure 27. (See page 6-13 herein for the step-by-step dry gradation procedures.)

The first step in the test procedure requires a nested set of 12" [300mm] sieves (8" [200mm] are acceptable for fine aggregate samples), be gathered and stacked. As the sieves are being stacked, they should be inspected for cracks, breaks, or any other problem which would exclude their continued use or alter test results in any way. The size of the sieves used shall conform to the gradation specifications of the aggregated tested. The No. 200 (75um) sieve is required to be part of all nested sets when running a gradation test. It is also required, when using 12" (300mm) sieves, the use of additional cutter sieves beyond the specified gradation sieves for all coarse aggregate gradations is required per Illinois Specification 201. Cutter sieves may be required for any aggregate gradation if it is determined that overloading of individual sieves occurs. Please refer to the current Illinois Specification 201-Aggregate Gradation Sample Size Table & Quality Control Sieves (See Appendix A herein) for the listing of required cutter sieves by gradation.

The sample is then introduced into the nested set of sieves and placed on or into a mechanical shaker. The shaker shall impart a vertical, or lateral and vertical, motion to the nested set. This causes the aggregate particles to bounce and turn so as to present different particle orientations to the sieves. This allows every

chance for a particle to pass a certain sized sieve.

The shaker shall be run for a minimum of 7 minutes, controlled by an automatic shut-off timer. Seven (7) minutes of shaking shall be considered the standard unless reduced shaker efficiency is demonstrated through finish hand-shaking as described in Paragraph 8.4 of Illinois Test Procedure 27 (See Appendix B herein). Shaking time shall be increased if necessary to comply with Illinois Test Procedure 27. Shaking time shall not exceed 10 minutes.

Extreme care shall be taken not to overload individual sieves or even approach the overload limits. An **overload** is defined as **several layers of particles, one on top of the other, which do not permit the top layers of particles access to the sieve openings**. Sample results which show overloading or a borderline situation are immediately suspect. If samples continually overload a sieve or sieves, then future samples shall be run in the appropriate number of portions to prevent overloading, or additional cutter sieves shall be added to the nested set to correct the problem.

After mechanical shaking, all sieves shall be finished off by hand-shaking. For hand-shaking, the largest sieve that contains material shall be removed from the stack, visually inspected for an overload, and inverted over an empty pan. While inverted, all particles shall be cleaned from the sieve. The material shall then be placed back on the same sieve and hand-shaken over an empty pan. Any amount of material that is considered to be an overload or to be approaching and overload shall be hand-shaken in at least two increments. Any appreciably large amount of particles passing a sieve may indicate poor mechanical shaking or overloading. The finish hand-shaking noted in Paragraph 8.4 of Illinois Test Procedure 27 shall then be initiated.

After hand-shaking, any retained material shall be removed from the sieve. Particles shall not be forced through the sieves. The sieve shall be inverted and lightly tapped on the sides to facilitate removal for weighing. A dowel rod or putty knife may be used to gently remove wedged particles from all sieves down through and including the No. 10 (2.00mm). A soft brass-wired brush shall be used on the No. 16 (1.18mm) through the No. 40 (425 µm) sieves, while a soft china brush shall be used the No. 50 (300 µm) sieve through the No. 200 (75µm) sieve.

Dry Sieve Test

STEP 1

STEP 2

STEP 3

STEP 4

STEP 5

STEP 6

STEP 7

STEP 8

After hand-shaking and cleaning, the material retained on each sieve shall have its mass determined and the mass recorded. All determination of mass shall start with the largest sieve in the nested set and proceed down to the pan. Determination of mass shall be to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. Any material that passed the sieve during hand-shaking shall be placed on the next smaller sieve.

After use, all sieves shall be inspected for cracks, breaks, or any other problem which would exclude their continued use.

6.5 **Calculation / Reporting** - All recording/ calculation and report shall be done on the Department's gradation form. (See page 6-21 herein.) Individual source forms may be used if approved by the District Materials Engineer. The procedure for test calculation and reporting is as follows:

6.5.1 **Calculation of Test Results** – Calculation of test results shall follow the procedure described below. Refer to the Department's gradation form on page 21 herein.

6.5.1.1 The DIFF. – No. 200 (-0.075) shall be determined by subtracting the Washed Mass (weight) from the Total Dry Mass (weight).

6.5.1.2 The "Minus" 75um (No. 200) by Washing" shall be determined by using the following formula:

$$\textbf{\% -200 (-75µm) by Washing} = \frac{\textbf{TDM-TWM}}{\textbf{TDM}} \textbf{ X 100}$$

where TDM= Total Dry Mass (weight)

and TWM = Total Wash Mass (weight)

This result shall be rounded to the nearest 0.1% and recorded on the gradation form.

6.5.1.3 Calculate the "Cumulative Mass (weight) Retained" for each sieve by adding its "Individual Mass (weight) Retained" and the "Individual Mass (weight) Retained" for each larger sieve in the nested set of sieves. Record the "Cumulative Mass (weight) Retained".

6.5.1.4 Calculate the "Maximum Gain-Loss" of the mass (weight) allowed for acceptance by using the following formula; rounding the result to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate:

$$\textbf{Maximum Gain-Loss} = 0.3\% \times \textbf{TDM}$$

where TDM = Total Dry Mass (weight)

6.5.1.5 Calculate the "Cumulative Percent Retained" for each sieve by using the following formula and record it by rounding to the nearest 0.1%.

$$\textbf{Cumulative \% Retained} = \frac{\textbf{CMR}}{\textbf{TDM}} \times 100$$

where CMR = Cumulative Mass (weight) Retained

and TDM = Total Dry Mass (weight)

6.5.1.6 Calculate the percent passing each sieve by using the following formula:

$$\textbf{\% passing} = 100 - \textbf{Cumulative \% Retained}$$

These results shall be recorded to the nearest 0.1%.

6.5.2 **Reporting** – All percent passing results except the washed minus 75um (minus No. 200) shall be reported on the gradation form as whole numbers. The washed minus No. 200 (75um) result's shall be reported to the nearest 0.1%. The gradation forms shall be completed with all required information. All forms shall be sent to the District office on a weekly basis for entry into the MISTIC system.

Rounding of values will be according to ASTM E 29.

For all sieves treated as an overload, an "S" will be notated on the worksheet next to the sieve size designation.

6.6 Aggregate Moisture Content - Aggregate moisture content may be run on the gradation sample prior to gradation testing or on a separate test sample. Field samples must be reduced to test sample size before testing according to Section 6.1 herein (according to Illinois Test Procedure 248 and shall meet the minimum sample size requirements of Illinois Specification 201, Aggregate Gradation Sample Size Table and Quality Control Sieves, effective February 1, 2014 (See Appendix A, herein).

Both field and test samples must be stored in sealable, non-absorbing plastic bags and/or plastic containers to prevent moisture loss, prior to determining the mass (weight) of the sample.

The Aggregate Technician may be required, by the source, to perform this test on an infrequent basis for information on aggregate being shipped. The Aggregate Moisture Content test is commonly required to be run at both HMA and P.C. concrete plants per QC/QA specifications. When run, all test results shall be reported on the appropriate report forms and documented in a plant diary.

6.6.1 Test Procedure - Aggregate moisture content test procedure shall conform to Illinois Test Procedure 255.

The test sample shall be initially weighed to the nearest gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate on scales or a balance conforming to AASHTO M 231. All scales shall be tared before being used for any weighing. This weighing procedure provides the "Original Sample Mass (weight), g" .The test sample shall be dried back to constant mass according to Section 6.2 herein (according to Illinois Test Procedure 255). When performing an aggregate moisture content test only, a microwave oven or heat lamp may also be used for drying purposes on a non-gradation test samples.

After the test sample has been dried to constant mass and cooled sufficiently, so as not to damage the balance or scale, the mass of the test sample will be determined as required above in this Section (6.6.1). The test sample shall have its mass determined as soon as the container can be safely handled to prevent additional moisture from being pulled from the air into the aggregate structure. This procedure provides the "Total Dry Mass (weight) g".

Calculation / Reporting - The "Aggregate Moisture Content" shall be determined by using the following formula:

$$P = \frac{(OSM - TDM)}{TDM} \times 100$$

Where P = Aggregate Moisture Content (%),

OSM = Original Sample Mass (weight), g,

and TDM = Dried Sample Mass (weight), g

Test results shall be rounded to the nearest 0.1%.

Example:

With the following given information calculate the percent moisture for a sample of CM11 material:

OSM = 3,200 g
TDM = 3,095 g

$$P = \frac{(3{,}200-3{,}095)}{3{,}095} \times 100$$

P = _____

Illinois Specification 201

Illinois Department of Transportation (IDOT)

AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES

Effective: February 1, 2014

COARSE AGGREGATE GRADATION TABLE																			
CA(CM)[1,2]	**Minimum Field Sample Size [3]**	**Minimum Test Sample Size[3]**	**3"**	**2 1/2"**	**2"**	**1 3/4"**	**1 1/2"**	**1"**	**3/4"**	**5/8"**	**1/2"**	**3/8"**	**1/4"**	**#4**	**#8**	**#16**	**#40**	**#50**	**#200**
CA01	110 lbs (50 kg)	10,000 g	X	X[MN]	X		X	X											X
CA02	110 lbs (50 kg)	10,000 g		X	X[MN]		XC	X	XC		X			X		X	X		X
CA03	110 lbs (50 kg)	10,000 g		X	X[MN]		X	X			X								X
CA04	110 lbs (50 kg)	10,000 g			X		X[MN]	X	XC		X	XC		X		X	X		X
CA05[5]	110 lbs (50 kg)	10,000 g				X	X[MN]	X[MB,6]	XC		X			X[6]					X
CA06	55 lbs (25 kg)	5,000 g					X	X[MN]	XC		X	XC		X		X	X		X
CA07[5]	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X[MB,6]	XC	XC	X[6]					X
CA08	55 lbs (25 kg)	5,000 g					X	X[MN]	X	XC	X	XC	XC	X		X			X
CA09	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X	XC	XC	X		X			X
CA10	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X	XC	XC	X		X	X		X
CA11[5]	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X[MB,6]	XC	XC	X		X[6]			X
CA12	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X	XC	X	X		X
CA13[5]	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X[MB,6]	XC	X[6]			X
CA14[5]	35 lbs (16 kg)	2,000 g								X	X[MN]	X[MB,6]	XC	X[6]					X
CA15	35 lbs (16 kg)	2,000 g									X	X[MN]	XC	X	XC	X			X
CA16[5]	25 lbs (11 kg)	1,500 g									X	X[MN]	XC	X[MB,6]	XC	X[6]			X
CA17	35 lbs (16 kg)[4]	4,000 g[4]	X		XC			XC			XC	XC		X[MN, 4]		X		X	X
CA18	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X		X	X
CA19	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X	X	X	X
CA20	25 lbs (11 kg)	2,000 g									X	X[MN]	XC	X	X	X			X

Note: See footnotes below Fine Aggregate Gradation Table for explanation of symbols.

Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES

Effective: February 1, 2014

FINE AGGREGATE GRADATION TABLE															
FA(FM)[1,2]	**Minimum Field Sample Size [3]**	**Minimum Test Sample Size[3]**	**1"**	**1/2"**	**3/8"**	**#4**	**#8**	**#10**	**#16**	**#30**	**#40**	**#50**	**#80**	**#100**	**#200**
FA01	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA02	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA03	25 lbs (11 kg)	500 g			X	X[MN]		X			X		X		X
FA04	25 lbs (11 kg)	500 g			X				X[MN]						
FA05	25 lbs (11 kg)	500 g			X	X[MN]								X	X
FA06	25 lbs (11 kg)	500 g	X	X	X	X[MN]								X	X
FA07	25 lbs (11 kg)	100 g				X		X[MN]			X		X		X
FA08	25 lbs (11 kg)	100 g					X				X[MN]			X	X
FA09	25 lbs (11 kg)	100 g					X					X[MN]		X	X
FA10	25 lbs (11 kg)	100 g						X			X[MN]		X		X
FA20[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[6]
FA21[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[6]
FA22[5]	25 lbs (11 kg)	500 g			X	X[MB]	X[MB, 6]		X						X[6]

Notes below apply to Fine and Coarse Aggregate Gradation Tables Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
MB = Master Band Sieves for Category I & II Coarse Aggregate for PCC and HMA Mixes; Bituminous use only for fine aggregate.
MN = Maximum Nominal Sieve for Crushed Gravels – Maximum Nominal Size is defined as the first specification sieve in the product gradation on which material may be retained.
1 = CA = Coarse Aggregate; CM = Coarse Aggregate, Modified; FA = Fine Aggregate; FM = Fine Aggregate, Modified
2 = CM and FM gradations shall be sampled and tested the same as the corresponding CA and FA gradations.
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = Will vary with the gradation of the material being used
5 = Control Charts Required
6 = Required Sieve for Control Charts

Illinois Specification 201

Illinois Department of Transportation (IDOT)

AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES

Effective: February 1, 2014

LARGE SIZED AGGREGATE GRADATION TABLE										
CS/RR[1,2]	**Minimum Test Sample Size[3]**	**8"**	**6"**	**4"**	**3"**	**2"**	**1 ½"**	**1"**	**½"**	**#4**
CS01	20,000 g	X	X	X	XC	X		XC	XC	X
CS02	15,000 g		X	X	XC	X		XC	XC	X
RR01	10,000 g				X	XC	X	XC	XC	X
RR02	10,000 g			X	XC	X	XC	XC	XC	X

Notes below apply to Large Sized Aggregate Gradation Table Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
1 = CS = Coarse Aggregate Subgrade; RR/RRM = Rip Rap
2 = Dry Gradations Only
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = A round nosed shovel may be used for sampling.
5 = Metal plates with precisely sized square holes by be used for the gradation
6 = Test sample size shall be taken in the field. No splitting is required.

Illinois Department of Transportation

Field / Lab Gradations

I.D. Number(1) _____

Inspector No.(2) _____ Inspector Name(3) _____ Date Sampled(4) _____ Seq. No.(5) _____

Mix Plant No.(6) _____ Mix Plant Name(7) _____ *Contract No.(8) _____ *Job No.(9) _____

Responsible Loc.(10) _____ Lab(11) _____ Lab Name(12) _____ Source Name(13) _____

Source(14)	Mat. Code #(15)	Type Test(16)	Orig. I.D. #(17)	Insp. Qty(18).	Spec.(19)	Article(20)	Sampled From(21)	Wash/Dry(22)

(23)

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200(24) _____ PI Ratio(25) _____ Test Results(26) _____ Remarks(27) _____

Sieve CA	Sieve FA	Indiv. Wt. Retained(28)	Cumul. Wt. Retained(29)	Cumul. % Retained(30)	Percent % Passing(31)	Spec. Range % Passing(32)
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)					
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)					
12.5 (1/2)	0.6 (#30)					
9.5 (3/8)	0.425 (#40)					
6.3 (1/4)						
4.75 (#4)	0.3 (#50)					
2.36 (#8)						
1.18 (#16)	0.18 (#80)					
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)					
Pan						
Total Dry Mass (33)						
Total Washed Mass (34)						
Diff. -0.075(-#200)(35)						

Max Gain/Loss= _____

% Washed - #200(36) _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
(37)0.425 _____

(Mix Plant Only)

Lot(38) _____
Bin(39) _____

Copies(40): _____ Tester(41) _____

Agency(42) _____

MISTIC INPUT
Date Entered(43) _____
Initials(44) _____

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Field / Lab Gradations

I.D. Number(1) _____

Inspector No.(2) _____ Inspector Name(3) _____ Date Sampled(4) _____ Seq. No.(5) _____

Mix Plant No.(6) _____ Mix Plant Name(7) _____ *Contract No.(8) _____ *Job No.(9) _____

Responsible Loc.(10) _____ Lab(11) _____ Lab Name(12) _____ Source Name(13) _____

Source(14)	Mat. Code #(15)	Type Test(16)	Orig. I.D. #(17)	Insp. Qty(18).	Spec.(19)	Article(20)	Sampled From(21)	Wash/Dry(22)

(23)																	
CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200(24) _____ PI Ratio(25) _____ Test Results(26) _____ Remarks(27) _____

Sieve CA	Sieve FA	Indiv. Wt. Retained(28)	Cumul. Wt. Retained(29)	Cumul. % Retained(30)	Percent % Passing(31)	Spec. Range % Passing(32)
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)					
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)					
12.5 (1/2)	0.6 (#30)					
9.5 (3/8)	0.425 (#40)					
6.3 (1/4)						
4.75 (#4)	0.3 (#50)					
2.36 (#8)						
1.18 (#16)	0.18 (#80)					
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)					
Pan						
Total Dry Mass (33)						
Total Washed Mass (34)						
Diff. -0.075(-#200)(35)						

Max Gain/Loss= _____

% Washed - #200(36) _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075 / (37)0.425 _____

(Mix Plant Only)

Lot(38) _____

Bin(39) _____

Copies(40): _____ Tester(41) _____

Agency(42) _____

MISTIC INPUT

Date Entered(43) _____

Initials(44) _____

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Field / Lab Gradations

I.D. Number(1) (1)

Inspector No.(2) (2) Inspector Name(3) (3) Date Sampled(4) (4) Seq. No.(5) (5)

Mix Plant No.(6) (6) Mix Plant Name(7) (7) *Contract No.(8) (8) *Job No.(9) (9)

Responsible Loc.(10) (10) Lab(11) (11) Lab Name(12) (12) Source Name(13) (13)

Source(14)	Mat. Code #(15)	Type Test(16)	Orig. I.D. #(17)	Insp. Qty(18).	Spec.(19)	Article(20)	Sampled From(21)	Wash/Dry(22)
(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)

(23)

CA	75 (3) or	63 (2.5)	50 (2)	45 (1.75)	37.5 (1.5)	25 (1)	19 (3/4)	16 (5/8)	12.5 (1/2)	9.5 (3/8)	4.75 (4)	2.36 (8)	1.18 (16)	0.6 (30)	0.3 (50)	0.15 (100)	.075 (200)
FA	6.3 (1/4)		25 (1)	9.5 (3/8)	4.75 (4)	2.36 (8)	2 (10)	1.18 (16)	0.6 (30)	0.425 (40)	0.3 (50)		0.18 (80)		0.15 (100)		.075 (200)
	(23)																

Wash - #200(24) (24) PI Ratio(25) (25) Test Results(26) (26) Remarks(27) (27)

Sieve CA	Sieve FA	Indiv. Wt. Retained(28)	Cumul. Wt. Retained(29)	Cumul. % Retained(30)	Percent % Passing(31)	Spec. Range % Passing(32)
63 (2.5)		(28)	(29)	(30)	(31)	(32)
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)					
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)					
12.5 (1/2)	0.6 (#30)					
9.5 (3/8)	0.425 (#40)					
6.3 (1/4)						
4.75 (#4)	0.3 (#50)					
2.36 (#8)						
1.18 (#16)	0.18 (#80)					
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)					
Pan						
Total Dry Mass (33)		(33)				
Total Washed Mass (34)		(34)				
Diff. -0.075(-#200)(35)		(35)				

Max Gain/Loss= _____

% Washed - #200(36) (36)

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
(37)0.425

(Mix Plant Only)

Lot(38) _____

Bin(39) _____

Copies(40): (40) Tester(41) (41)

Agency(42) (42)

MISTIC INPUT

Date Entered(43) (43)

Initials(44) (44)

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FIELD/LAB GRADATIONS

MI 504M

(Revised 11/20/12)

1. **I.D. NUMBER:** MISTIC test identification number. Leave blank, because the MISTIC system will generate the test identification number.

2. **INSPECTOR NO.:** Identify the individual who took the sample. For split samples, the same inspector number should be used for both halves of the sample**.**

   a) IDOT personnel should enter their MISTIC inspector number.

   b) Contractor, Subcontractor, Producer, should use a "9", the District number, and seven zeroes (0's).
   Example: (960000000) for District 6.

   c) Consultant personnel enter their company's MISTIC inspector number.

   d) Local agency personnel are to enter a "9"; followed by the District number, which is repeated until field is filled.
   Example: (966666666) for District 6 local agency.

3. **INSPECTOR NAME:** Enter the name of the inspector who took the sample.

4. **DATE SAMPLED:** Enter the date the sample was taken as month, day, and year in mmddyy format. Example: (103112)

5. **SEQ. NO.:** Sequence number. May be any combination of letters and/or numbers up to 6 characters in length. It is used to differentiate multiple samples of the same gradation, taken on the same day. For a split sample, both halves of the split shall have "**SPLIT**" in this field.

6. **MIX PLANT NO.:** The MISTIC code number for the P.C. Concrete or Hot Mix Asphalt Producer. Only one plant may be shown on one report.

7. **MIX PLANT NAME:** Name of mix plant.

8. **CONTRACT NO.:** Leave blank unless the gradation has been sampled at a jobsite for a specific contract. Enter the 5 digit contract number. If it is a local agency contract without a 5 digit number, then enter the 16 or 17 character MFT (Motor Fuel Tax) contract number.

9. **JOB NO.:** Leave blank unless gradation sampled at the jobsite for a specific contract. Enter the 8 character number that corresponds with the 5 digit contract number. If the contract number is not 5 digits, leave this field blank.

10. **RESPONSIBLE LOC.:** Enter the District identification number as a "9" followed by the District number. Example: 96 for District 6

11. LAB: Enter the 2 letter MISTIC lab code.

Laboratory Locations	MISTIC Lab Codes
Producer Plant Site Laboratory	PP
Producer Non-Plant Site Laboratory	PL
Producer Construction Site	PC
Producer Quarry Laboratory	PQ
Independent Plant Site Laboratory	IP
Independent Non-Plant Site Laboratory	IL
Independent Construction Site	IC
Independent Quarry Laboratory	IQ
Independent Laboratory	IN
IDOT/Local Agency Plant Site Laboratory	FP
IDOT/Local Agency Construction Site	FC
IDOT/Local Agency Quarry Laboratory	FQ
DISTRICT LABORATORY	DI
DISTRICT SATELLITE LABORATORY	DS

NOTE: A Contractor, Subcontractor, and Producer are to use one of the “Producer” lab codes. An IDOT Consultant, Contractor Consultant, Subcontractor Consultant, and Producer Consultant are to use one of the “Independent” lab codes.

12. LAB NAME: Enter the name of the company which cannot exceed 20 characters.

13. SOURCE NAME: Enter the name of the aggregate producer.

14. SOURCE: Enter the MISTIC code number of the aggregate producer.
Example: 50912-02

15. MAT. CODE NO.: Material code for the aggregate product. Enter the 8 to 10 character code number of the material being tested.

The following information will help you determine if you have the correct material code number.

- The first space is a “0” to indicate the material is an aggregate.

- The second space indicates the QUALITY LEVEL of the aggregate. Concrete coarse and fine aggregates are always “A” quality. Cement aggregate mixture II coarse aggregate is “D” quality “stabilized”, and fine aggregate is “A” quality. Controlled low-strength material fine aggregate is “A” quality, unless alternate fine aggregate materials are used. Hot mix asphalt surface coarse and fine aggregates are generally “B” quality. Hot mix asphalt binder coarse aggregates are generally ”C” quality and fine aggregates are “B” quality. (see below).
- The third space indicates the Type of Material (see below).
- The fourth space indicates the Aggregate Type (see below).
- The fifth space indicates the SPECIFICATION of the aggregate (see below).
- The sixth space is always a “M” to indicate **Metric**.
- The seventh and eighth spaces are the Gradation Number of the aggregate. See Articles 1003.01(c) and 1004.01(c) of the Standard Specifications.
- The ninth and tenth spaces indicate superstructure quality aggregate for concrete use. Always enter “01” if testing superstructure quality aggregate.

QUALITY LEVEL	TYPE OF MATERIAL	AGGREGATE TYPE
0 & 1 Have No Quality	0 = Gravel	C = Coarse Aggregate
2 = A Quality	1 = Crushed Gravel	F = Fine Aggregate
3 = B Quality	2 = Crushed Stone	
4 = C Quality	3 = ACBF Slag	
5 = D Quality	7 = Natural Sand	
6 = D Quality Stabilized	8 = Stone Sand	
	9 = Special Aggregate	

SPECIFICATION

A = Standard Specification
M = Modified or QC/QA Specification

16. TYPE INSP: Type of inspection (see below). For additional information see Attachment 4 in the Project Procedures Guide.

AGENCY	QC/QA	NON QC/QA
Contractor/Producer/ Consultant	PRO	-----
IDOT/Consultant at Aggregate Source	IND (split), INV	PRO
IDOT/Consultant at Mix Plant	IND (split), INV	IND (split-share), INV

17. ORIG. I.D. #: Original identification number. Use for resample tests only. Enter the original MISTIC test identification number of the failing test.

18. INSP. QTY.: Inspected Quantity. Leave blank. IDOT personnel may enter the quantity that is represented by the gradation test but it is not required.

19. **SPEC.:** Specification. Leave blank. IDOT aggregate personnel should enter the master band ranges under a "PRE" test at the beginning of each production season.
Example: MB2036

20. **ARTICLE:** Leave blank. IDOT aggregate personnel should enter the warning band ranges under a "PRE" test at the beginning of each production season. Example: WB2234

21. **SAMPLED FROM:** Enter the 2 character designation in the first two spaces. Refer to "Sampled From Codes" box, which is on the form.

22. **WASH/DRY:** Enter if the test was a "W" for a washed gradation, or "D" for a dry gradation.

23. **GRADATION RESULTS INPUT TABLE:** Enter the percent passing test results, "percent % passing", from the calculation table for all sieves. All test results shall be reported to the nearest 1%, except for the 0.075 mm (or 75µm)(-#200) sieve, which shall be reported to the nearest 0.1%.

24. **WASH - 0.075 (-#200):** Enter the washed minus .075 mm (#200) value from the calculation table to the nearest 0.1%.

25. **PI RATIO:** Plasticity index ratio. Leave blank. IDOT personnel, when appropriate, should enter the PI ratio value.

26. **TEST RESULTS:** Enter "APPR" for results meeting specifications or "FAIL" for failure to meet specifications. Show under "Remarks" action taken for samples not meeting specifications. For example, retest, checked equipment, test method incorrect, will monitor.

27. **REMARKS:** This space should be used to record any comments about the aggregates, or the stockpiling and handling methods used.

For "IND" inspection, a comparison remark is required, because the assurance test is from a split sample. For an acceptable comparison, enter the following:

- Enter "C" when tests compare within acceptable limits of precision.
- Enter date of comparison.
- Enter initials for "IND" inspector.
- If the sample was witnessed by the "IND" inspector, indicate as "ws".
- Example: C - 100197 TCS ws.

For an unacceptable comparison, enter the following:

- Enter "X" when tests do not compare within acceptable limits of precision.
- Enter date of comparison.
- Enter initials for "IND" inspector.

- If the sample was witnessed by the “IND” inspector, indicate as “ws”.
- Explain reason for unacceptable comparison.
- Examples are: Contractor obtained sample incorrectly; IDOT equipment required repair; Contractor performed test method incorrectly; problem was not identified, will investigate further if problem continues.
- Example: X - 100297 TCS ws Contractor obtained sample incorrectly.

28. INDIV. WT. RETAINED: Enter the weight of aggregate on each sieve individually, starting with the largest sieve first. Weigh coarse aggregate to the nearest 1 gram, and fine aggregate to the nearest 0.1 gram. If the **sieve was overloaded** and split into two or more portions to hand sieve, then write a “S” outside the table on that row (right or left side).

29. CUMUL. WT. RETAINED: Cumulative Weight Retained. Add the weight on each sieve, to the weight on any larger sieve(s), and enter that value.

30. CUMUL. % RETAINED: Cumulative Percent Retained. Divide the cumulative weight retained by the total dry weight, and multiply by 100, for each sieve. Round to the nearest 0.1%, and enter that value.

31. PERCENT % PASSING: Subtract the cumulative percent retained, from 100, for each sieve. Record to nearest 0.1%, and enter that value

32. SPEC. RANGE % PASSING: Enter the specification range for all appropriate sieves. These may be Standard Specifications, or modified Standard Specification, or master band limits.

33. TOTAL DRY MASS: Enter the weight of the sample after it has been dried to a constant weight. Weigh coarse aggregate to the nearest 1 gram, and fine aggregate to the nearest 0.1 gram.

34. TOTAL WASHED MASS: Enter the weight of the sample after it has been washed, and dried back to a constant weight. Weigh coarse aggregate to the nearest 1 gram, and fine aggregate to the nearest 0.1 gram.

35. DIFF. -0.075 (-200): Subtract total washed weight from the total dry weight, and enter that value.

36. % WASHED -0.075: Divide the “Diff. - 0.075” by the “Total Dry Wt.” and multiply by 100. Round to the nearest 0.1%, and enter that value.

37. 0.075 / 4.25: Leave blank. IDOT personnel, when appropriate, enter the ratio of the percent passing the .075 mm (#200) sieve and the .425 mm (#40) sieve.

38. LOT: Leave blank. IDOT mix plant personnel use if performing individual hot bin “IND” tests. Enter the lot corresponding to the Daily Plant Output (MI 305). Also, enter this in the remarks.

39. <u>BIN:</u> Leave blank. IDOT mix plant personnel use if performing individual hot bin "IND" tests. Enter the appropriate hot bin number. Also, enter this in remarks.

40. <u>COPIES:</u> Enter the distribution of this report. The normal distribution for mix plant results is the **original** goes to the District Engineer, a copy goes to the Resident Engineer(s), and a copy goes to the QC Manager(s). The distribution for aggregate source tests is the original goes to the District Engineer and a copy goes to the source's QC manager. Non-QC/QA – Same as above, except that the file copy stays with the tester or the individual who completed the report.

41. <u>TESTER:</u> Print the name of the individual who tested the aggregate. The individual's signature is also required. If the test is run by a Gradation Technician, then the supervisor should sign here also.

42. <u>AGENCY:</u> Enter the tester's employer.

43. <u>DATE ENTERED:</u> Leave blank. IDOT will enter the date the results are entered into MISTIC as month, day and year n mmddyy format.

44. <u>INITIALS:</u> Leave blank. IDOT will enter initials of the person entering the test results into MISTIC.

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Revised: January 1, 2011

7.0 QUALITY CONTROL (QC) MANAGER / AGGREGATE TECHNICIAN / AGCS TECHNICIAN / MIXTURE AGGREGATE TECHNICIAN / IDOT INSPECTOR / GRADATION TECHNICIAN RESPONSIBILITIES

The Quality Control (QC) Manager, Aggregate Technician, AGCS Technician, Mixture Aggregate Technician, IDOT Aggregate Inspector, and the Gradation Technician have specific responsibilities under the Aggregate Gradation Control System. Many of these responsibilities are similar, including gradation sampling/testing and visual inspection of production. Several are limited to the QC Manager, the Aggregate Technician, or the IDOT Aggregate Inspector. It should be noted that only the Aggregate Technician or the AGCS Technician may also be the QC Manager.

The following table denotes the responsibilities and the person responsible.

	QC Manager	Aggregate Tech.	AGCS Tech.	Mixture Agg. Tech.	IDOT Inspector	Gradation Tech.
• Knowledge of Specs	X	X	X		X	
• Quality Sampling					X	
• Visual Inspection	X	X	X		X	
• Gradation Sampling	X	X	X	X	X	
• Gradation Testing	X **Note 2**	X		X	X	X **Note 1**
• Plant Diary	X	X	X			
• Aggregate Certification	X					
• Safety	X	X	X	X	X	X

Note 1: Only under direct supervision of Aggregate Technician or Mixture Aggregate Technician
Note 2: Not allowed for AGCS Technician

Each responsibility is discussed below.

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7.1 **Knowledge of Current Specifications**. The QC Manager, the Aggregate Technician, the AGCS Technician, and the IDOT Aggregate Inspector must maintain up-to-date knowledge of the specifications that apply to the aggregate products currently being produced at the Source. The Aggregate Technician and the AGCS Technician shall have available at the Source a copy of the current Standard Specifications, any applicable supplemental specifications, and the *Manual of Test Procedures for Materials*. All four individuals shall be aware of any special provisions which change current aggregate specifications. This applies to both quality and gradation specifications. A copy of the current Standard Specifications, Sections 1003 and 1004, and the supplemental specifications for Sections 1003 and 1004 are located in the Appendix.

7.2 **Quality Sampling / Testing**. IDOT will continue to sample and test all aggregates for quality. The IDOT Aggregate Inspector shall sample any certified stockpile at the frequency designated in the *Manual for Aggregate Inspection*. All quality samples are sent to the Central Bureau of Materials and Physical Research for testing. The tests run were discussed previously in Chapter 3.0 herein. Any certified stockpile must meet the designated quality before shipment. Willful shipment of out-of-specification material shall be handled according to Section 11.2 of the Department's current Policy Memorandum, "Aggregate Gradation Control System (AGCS)", in Chapter 8.0.

Although the Aggregate Technician/AGCS Technician will not be sampling or testing for quality, he/she will be notified when sampling occurs and may witness the sampling. The Aggregate Technician/AGCS Technician should obtain and maintain quality information on specific ledges, production methods, and the certified stockpiles. Shipment of approved material remains the responsibility of the Source.

A Consultant, hired by the Department to perform duties of an Aggregate Inspector, shall not be allowed to take any quality or Freeze-Thaw samples at an aggregate source.

7.3 **Visual Inspection**. The responsibility of visually inspecting an aggregate Source's process on a frequent basis falls on the Aggregate Technician, the AGCS Technician, and the IDOT Aggregate Inspector. Visual inspection can be defined as observing the processing or production area, the stockpiling methods, and the loading/handling operation, as well as the condition of the aggregate in the flow stream or stockpiles.

7.3.1 For the Aggregate Technician/AGCS Technician, visual inspections shall be a daily occurrence—**several** (three or more) inspections spread uniformly throughout the production day—while producing certified aggregate. Visual inspections by the IDOT Aggregate Inspector may be at a reduced frequency.

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Most Aggregate/AGCS Technicians/Inspectors will establish an inspection route when they enter the Source. As an example, the inspection route will take them past the ledge face to verify from where the raw feed is coming. This also allows for visual examination of the face for contamination or the intrusion of poor quality material into the ledge.

The production plant, from the primary crusher to the final screening/logwashing, is visited next. This stop verifies that the correct production method is being used to produce the required quality and gradation. Problems with equipment, such as screen cloth, etc., can be observed and corrected.

Finally, the stockpiling/load-out area can be observed. Segregation, degradation, or contamination can be readily identified and proper steps taken to eliminate the problems.

7.3.2 This quick type of inspection helps the Aggregate Technician/AGCS Technician/ Inspector "keep a handle on" the aggregate being produced. It does not take away from actual testing of the aggregate but enhances the inspection to ensure quality aggregate.

Remember, it is an Aggregate/AGCS Technician's/Inspector's responsibility to observe the overall aggregate operation to detect segregation, degradation, and contamination that is detrimental to the quality of the aggregate product. These observations should be communicated immediately to the QC Manager for corrective action if necessary.

7.4 **Gradation Sampling**. Quality or gradation sampling involves taking a small, representative portion of a finished product for quality/gradation control or compliance testing. The word "representative" is perhaps the most important word in that definition, especially in conjunction with gradation testing. It is imperative that the sample accurately represents the material being produced. Inaccurate samples can lead to acceptable material being rejected or to non-acceptable material being used. In either case, non-representative sampling often results in higher construction/maintenance costs.

7.4.1 Under the Aggregate Gradation Control System, the Aggregate Technician, the AGCS Technician, the Mixture Aggregate Technician, and the IDOT Aggregate Inspector must know how to correctly sample aggregate for gradation testing. The Aggregate Technician/AGCS Technician/Mixture Aggregate Technician will have to sample at a specified frequency from both production and stockpiles. They may choose one of the approved production sampling methods described in Illinois Test Procedure 2, (Chapter 5.0 of the AGCS). The stockpile sampling method noted in Chapter 5.0 is the only method allowed for sampling a stockpile.

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The IDOT Aggregate Inspector will sample on a very infrequent basis. Most of the IDOT monitor samples will be split samples taken and split by the Aggregate Technician/AGCS Technician/Mixture Aggregate Technician. However, the IDOT Aggregate Inspector may take a sample at any time under the program.

7.4.2 The frequency of sampling for the Aggregate Technician/AGCS Technician/Mixture Aggregate Technician, and the IDOT Aggregate Inspector is covered in the Department's current Policy Memorandum, "Aggregate Gradation Control System (AGCS)", in Chapter 8.0. The high number of samples required, especially by the Aggregate Technician/AGCS Technician/Mixture Aggregate Technician, makes it imperative that the technician/ inspector takes the time and has the knowledge to accurately sample for gradation testing. The overall program relies on accurate results to supply in-gradation aggregate to IDOT construction projects.

7.5 **Gradation Testing**. Illinois Test Procedure 11 / Illinois Test Procedure 27 (Chapter 6.0 of the AGCS) describes the correct and acceptable method to run a gradation test. As with gradation sampling, inaccurate results hurt both the aggregate producer as well as IDOT. It is therefore the responsibility of the Aggregate Technician, the Mixture Aggregate Technician, the Gradation Technician, and the IDOT Aggregate Inspector to correctly run the gradation test. The AGCS Technician is not allowed to split or run gradation tests under the AGCS.

7.6 **Plant Diary**. The Aggregate Technician/AGCS Technician is required to maintain a plant diary when producing certified material under the program. This diary shall detail samples taken, pass/fail results, corrective action, plant/ledge changes, etc., on a daily basis. The diary must be kept at the Source for periodic checking by the IDOT Aggregate Inspector. See Example on [following page (page 7-6 of Aggregate Technician Course Manual)].

The IDOT Aggregate Inspector is required to keep a personal diary on his/her daily inspection trips. Much of the same information required for the Aggregate Technician/AGCS Technician diary is noted by the IDOT Aggregate Inspector.

7.7 **Aggregate Certification**. The previous discussions on numerous individual responsibilities focus attention on the QC Manager's/Aggregate Technician's/AGCS Technician's/Inspector's overall responsibilities. The Source's QC Manager has the overall responsibility of certifying that material being placed on the certified stockpile is produced under and conforms to the Aggregate Gradation Control System. The production or quarry supervisor, if not the QC Manager, also assumes some of the responsibility for assuring that in-specification material is being made and shipped to IDOT projects.

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The IDOT Aggregate Inspector, through his/her monitoring activities (sampling/ testing, visual observation, etc.), must verify the continued compliance to the Aggregate Gradation Control System. Any lack of compliance, as noted by the IDOT Aggregate Inspector, will be grounds for Source decertification under the program and shall be communicated to the QC Manager as expediently as possible for correction.

7.8 **Safety**. It is the responsibility of the QC Manager, the Aggregate Technician, the AGCS Technician, the Mixture Aggregate Technician, the IDOT Aggregate Inspector, and the Gradation Technician to perform their respective duties in a safe manner. To assure that this condition is met, the QC Manager, the Aggregate Technician, the AGCS Technician, the Mixture Aggregate Technician, and the IDOT Aggregate Inspector should be familiar with any and all safety regulations in force. Great care should be taken when sampling around moving equipment, e.g., conveyor belts, screen decks, hopper grates, etc. Due to poor visibility and large truck/equipment traffic, caution should also be used when driving around the plants and stockpiles.

The QC Manager, the Aggregate Technician, the AGCS Technician, the Mixture Aggregate Technician, and the IDOT Aggregate Inspector must have a knowledge of applicable Mine Safety and Health Administration (MSHA) regulations. The IDOT Aggregate Inspector is also regulated by Departmental policies covered in the "Employee Safety Code" handbook.

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EXAMPLE

Company Name: _____

Aggregate / AGCS Technician Plant Diary

Date:	
Plant Name:	
Weather:	
Ledge Information:	
Material Being Produced:	

VISUAL INSPECTION:	1ST VISIT	2ND VISIT	3RD VISIT	ADDITIONAL VISITS
Time:				
Stockpile/Loadout:				
Degradation	YES/NO	YES/NO	YES/NO	YES/NO
Segregation	YES/NO	YES/NO	YES/NO	YES/NO
Contamination	YES/NO	YES/NO	YES/NO	YES/NO
Plant:				
Pit Area:				
Graph(s):				
Samples Taken:				
Production				
Loadout:				
Resample:				
SIGNATURE:				

Problems: (Init./Time)	
Action Taken: (Init./Time)	
Comments:	

State of Illinois
Department of Transportation
Bureau of Materials and Physical Research

POLICY MEMORANDUM

Revised: March 1, 2014	11-08.4
This Policy Memorandum supersedes number 11-08.3 dated June 1, 2012	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: AGGREGATE GRADATION CONTROL SYSTEM (AGCS)

1.0 SCOPE

1.1 This program shall apply to all Sources that supply certified aggregate for uses identified in this program to projects let under the jurisdiction of the Illinois Department of Transportation (includes local agency projects). All aggregate shipped for program-designated uses on these projects shall be from a Certified Source.

2.0 PURPOSE

2.1 To establish a procedure of certification whereby Sources shall supply aggregate for designated use meeting test properties cited by the Bureau.

2.2 To set forth the conditions for Source certification and revocation of certification.

3.0 DEFINITIONS

3.1 **AGCS Technician** - A technician at the Source who has successfully completed the Department's AGCS Technician Course. This individual may perform all duties of the Aggregate Technician under the Gradation Control Program except gradation testing. Gradation testing (including splitting) must be performed by an Aggregate Technician or a Mixture Aggregate Technician. This training course is no longer available.

3.2 **Aggregate Inspector** - District materials inspector who has successfully completed the Department's Aggregate Technician Course and is responsible for inspection at an aggregate Source. A Consultant, hired by the Department to perform the duties of an Aggregate Inspector, shall not be allowed to take any quality or Freeze-Thaw samples at an aggregate source.

3.3 **Aggregate Technician** - Sampling and testing technician at the Source who has successfully completed the Department's Aggregate Technician Course and is responsible for the Gradation Control Program at the Source.

3.4 **Approved Aggregate Source List** - A list maintained by the Department identifying aggregate sources certified to supply aggregate to Department/Local Agency projects.

3.5 **Bureau** - The Bureau of Materials and Physical Research, of the Illinois Department of Transportation, located in Springfield, Illinois.

3.6 **Department** - Illinois Department of Transportation.

3.7 **District** - Materials Office located at each Illinois Department of Transportation highway district office.

3.8 **Failing Gradation Sample** - A gradation sample which, when tested, exceeds the established Master Band on the critical sieve and/or exceeds the specification ranges on the other sieves for that gradation.

3.9 **Gradation Technician** - A technician who has successfully completed the Department's Gradation Technician Course and is responsible only for testing gradation samples. The Gradation Technician shall be monitored on a daily basis by the Aggregate Technician.

To be certified as a Gradation Technician go to: http://www.dot.il.gov/materialforms.html and fill our form BMPR AGG04.

Complete the application and email to dot.bmpr.gradtrain@illinois.gov or Fax to (217) 782-2572, Attn. Scott Hughes.

3.10 **Manual** - Illinois Department of Transportation *Manual for Aggregate Inspection*.

3.11 **Mixture Aggregate Technician** - A technician who has successfully completed the Department's 3-day Aggregate for Mixtures course and is responsible only for sampling and testing gradation.

3.12 **Monitor Sample** - Gradation sample taken from the Source, Terminal, Supplier Yard, or mix plant and tested by the Department to monitor the gradation being produced by the Source under its Gradation Control Program. This sample shall also be used to evaluate the adequacy of procedures and equipment used by the Source in its Gradation Control Program.

3.13 **Outlying (OS) Source** – A certified aggregate source located out-of-state which is specifically designated by the inspecting District and the Bureau and required to run the requirements listed in Section 8.0 herein.

3.14 **Quality Control (QC) Manager** - The Aggregate Technician or the AGCS Technician designated by the Source who shall be responsible for compliance with the requirements of the Aggregate Gradation Control System. The QC Manager shall have successfully completed the Department's Aggregate Technician Course or the AGCS Technician Course.

3.15 **Source** - Individual aggregate source, i.e., a specific quarry or pit location supplying a specific product or products.

3.16 **Source Classification** - Under this program, a Source will be classified as Certified, De-Certified, or Non-Certified.

3.16.1 **Certified Source** - A Source that has met the requirements for certification and is allowed to supply aggregate for Department/Local Agency projects.

3.16.2 **De-Certified Source** - A Source that has had its Certified Source status revoked because requirements warranting certification have not been maintained. A De-Certified Source shall not be allowed to supply aggregate to Department/Local Agency projects.

3.16.3 **Non-Certified Source** - A Source that does not initially meet certification requirements or has not applied for certification.

3.17 **Source QC Plan** - A QC Plan detailing how a source designated as Outlying will comply with the AGCS.

3.18 **Standard Specifications** - Current edition of the Illinois Department of Transportation *Standard Specifications for Road and Bridge Construction.*

3.19 **Supplier Yard** – A Yard which buys aggregate from an AGCS or IDOT-inspected source and resells the aggregate from the yard for use on IDOT contracts (including local agency).

3.20 **Terminal** – A location owned by, leased to, or provided to an AGCS or IDOT-inspected source from which the source ships aggregate for use on IDOT contracts (including local agency).

4.0 GENERAL RESPONSIBILITIES

4.1 The Bureau shall maintain an Approved Aggregate Source List identifying certified sources. Only Certified Sources shall supply material to Department/Local Agency projects. Each Certified Source shall maintain its own Gradation Control Program unless producing Category IV aggregate only. Aggregate shipped from a Certified Source shall be certified to meeting the quality and gradation requirements in the Standard Specifications. However, if approved by the District, the Source may choose to certify and supply other than standard Department gradations as established by the criteria in Article 6.2 herein.

4.2 A Supplier Yard shall meet the requirements of the AGCS on all aggregates which will be used on IDOT contracts (including local agency). Start-of-Production (6.3.1) and Normal-Production (6.3.2) sampling/testing shall be waived. Incoming aggregate sampling/testing shall be run. The sampling/testing shall be according to the current Department QC/QA document, Model Annual Quality Control (QC) Plan for Hot-Mix Asphalt (HMA) Production, Section B. Materials, 1. Aggregates, b. Incoming Aggregate Gradation Samples.

4.3 A Terminal shall meet all the requirements of the AGCS on all aggregates which will be used on IDOT contracts (including Local Agency). Start-of-Production (6.3.1) and Normal-Production (6.3.2) sampling/testing shall be waived.

5.0 REQUIREMENTS FOR SOURCE CERTIFICATION

5.1 A Certified Source shall have been checked using the procedures set forth in Section 9.0 herein and found to meet the requirements for Source certification. Any Source subsequently found not meeting these or any other requirements of this program shall be removed from the Approved Aggregate Source List based on the procedure detailed in Section 11.0. The requirements for Source certification are as follows:

5.1.1 Gradation Control Program - Gradation samples shall be taken and tested as per Section 6.0 herein.

Gradations and their ranges established per Article 6.2 herein which do not meet the Standard Specifications shall be submitted to the District for approval prior to production.

5.1.2 Stockpiling and Handling - Stockpiling and handling procedures of material for Department use shall be as noted in QC/QA Procedure, “Stockpiling and Handling of Aggregate,” located in the current “Manual of Test Procedures for Materials”.

Materials certified under this program shall be stockpiled separately and identified by signs. Signs shall have a minimum of 3” lettering. Each individual sign shall be free-standing and moveable. Any changes made to signing must be pre-approved by the district.

5.1.3 Approved Laboratory - Laboratory facilities and equipment must conform to Section 7.0 herein. Laboratories shall be checked by District personnel and reapproved on an annual basis. One (1) laboratory may be used as an approved laboratory for more than one (1) Source as long as no problems occur in maintaining each Source’s Gradation Control Program.

5.1.4 Aggregate Technicians - Sampling and testing personnel (including consultants and contractors) at the Source shall be Aggregate Technicians.

The Source may use an AGCS Technician to perform all duties of an Aggregate Technician except splitting and gradation testing. When an AGCS Technician is used, splitting and gradation testing must be performed by an Aggregate Technician or a Mixture Aggregate Technician.

The Source may use Gradation Technicians for gradation testing only. The Gradation Technician shall be under the direct supervision of the Aggregate Technician when testing gradation samples. The source may also use Mixture Aggregate Technicians for sampling and gradation testing only. The Mixture Aggregate Technician shall be under the supervision of the Aggregate Technician or the AGCS Technician. The Aggregate Technician, when supervising a Gradation Technician or Mixture Aggregate Technician, shall demonstrate gradation testing proficiency to the Aggregate Inspector on a quarterly basis.

A mixture QC/QA Technician shall not be allowed to concurrently perform the duties of an Aggregate Technician, an AGCS Technician, or a Mixture Aggregate Technician in the *AGCS.*

6.0 GRADATION CONTROL PROGRAM

6.1 The Gradation Control Program shall be run by an Aggregate Technician or an AGCS Technician as defined in Section 3.0 herein. The QC Manager shall assume responsibility for compliance with the Aggregate Gradation Control System and specifically shall ensure that the Aggregate Technician, AGCS Technician, or Mixture Aggregate Technician is performing all the required duties under the Aggregate Gradation Control System.

All communication concerning the Aggregate Gradation Control System shall be directed to the QC Manager.

Primary duties of the Aggregate Technician shall include frequent visual inspection, gradation sampling and testing, documentation, etc., as detailed herein and in QC/QA Procedure, “Quality Control (QC) Manager / Aggregate Technician / AGCS Technician / IDOT Inspector / Gradation Technician Responsibilities”, located in the current ”Manual of Test Procedures for Materials.” The AGCS Technician may perform the same duties as the Aggregate Technician except gradation testing. Gradation testing shall be performed by an Aggregate Technician or a Mixture Aggregate Technician.

6.2 **Gradation Specifications** - Sieve limits for each sieve/each product under the Aggregate Gradation Control System shall be as specified in the Department’s Standard Specifications and/or as amended herein. The special critical sieve criteria for certain designated products as described in QC/QA Procedure, “Aggregate Producer Control Chart Procedure” located in the current ”Manual of Test Procedures for Materials” are also required.

The midpoint/tolerance range of a designated critical sieve shall be developed from an average as shown in QC/QA Procedure, “Aggregate Producer Control Chart Procedure,” noted above. The average shall be a historical average or a production average derived from start-of-production samples that is agreed to by the Department. Critical sieve limits shall take precedence over Standard Specification limits. Requests for critical sieve limits shall be submitted in writing to the District Materials Engineer for approval.

For sieves other than the top and bottom specification sieves, sieve limits may be developed based on historical or average production values. These sieve limits may be different from those in the Standard Specifications. These modifications are also allowed for fine aggregate. Changes in the top sieve or any No. 200 sieve ranges will not be permitted. In cases where the bottom sieve is other than the No. 200 sieve, a variance in limits may be granted if the Bureau determines the minus No. 200 material to be within acceptable limits.

The Source shall request in writing to the District Materials Engineer approval of limits other than those in the Standard Specifications, but the range of the limits shall remain the same as the Standard Specifications.

Although the Department reserves the right to reject unacceptable material at any point prior to incorporation into the final product, the agreed upon gradation limits shall apply at the final point of shipping within the Source's control.

6.3 **Sampling and Testing** - Gradation samples shall be reduced to testing size by Illinois Test Procedure 248. Minimum Field Sample Size and Minimum Test Sample Size shall be as noted in the Sample Size table, Illinois Specification 201. All sampling and gradation testing shall conform to Illinois Test Procedure 2, Illinois Test Procedure 11, and Illinois Test Procedure 27. The Illinois Test Procedures noted above are located in the current "Manual of Test Procedures for Materials."

Sampling and testing frequencies (including washed tests) by category/use shall be as noted in Table 1. Definitions of each frequency are as follows:

6.3.1 **Start-of-Production Frequency** - After a seasonal shutdown of production or when first producing a new product, the sampling and testing of start-up production or of the new product at each production point shall be at start-of-production frequencies/requirements noted in Table 1.

6.3.2 **Normal-Production Frequency** - During normal production, the minimum production sampling and testing frequency/requirements as noted in Table 1 shall be maintained at each production point.

6.3.3 **Stockpile Frequency** - During loadout of stockpiles, the minimum stockpile sampling and testing frequency/requirements as noted in Table 1 shall be maintained for each stockpile.

6.3.4 **Production Changes (Short-Term Shutdown, Screen Change, Crusher Modification, Different Feed Rate, New Products, etc.)** - If a production change is made, a washed gradation sample shall immediately be run on all affected products. The start-of-production sampling frequency shall be implemented if the result on any critical sieve in that sample exceeds the Master Band limits on the critical sieve or if any results fail any specified sieve limits.

6.4 **Documentation** - Gradation results shall be charted on control charts, if required in Table 1, according to QC/QA Procedure, "Aggregate Producer Control Chart Procedure", located in the current "Manual of Test Procedures for Materials". Within one (1) working day of sampling, all gradation results shall be charted, posted, or entered into a source computer, each of which shall be located at the source and/or approved laboratory, at the District's option. Computer-maintained charting must be approved by the Department and accessible in a timely manner during any Department inspection.

Computer-maintained charts shall be printed and displayed once per week or at the request of the Department. Control charts are the property of the Department and shall not be removed or altered in any manner. The Aggregate Inspector shall check the control charts on a regular basis. Source gradation computation sheets shall be maintained by the Department for a minimum of three (3) years after the date run.

A Source diary shall be maintained by the Aggregate Technician or the AGCS Technician. The Aggregate Technician or the AGCS Technician will log all actions taken during the production day, such as new product production, sampling, resampling, screen changes, separate stockpiling, visual inspections, etc., as noted in QC/QA Procedure, "Quality Control (QC) Manager / Aggregate Technician / AGCS Technician / IDOT
Inspector / Gradation Technician Responsibilities." in the current "Manual of Test Procedures for Materials."

The Source shall immediately notify the District whenever new products are being produced at the Source under its Gradation Control Program.

6.5 **Failing Gradation Samples** - Any Failing Gradation Sample (start-of-production, normal-production, or stockpile) shall be evaluated according to the following procedure and, if necessary, immediate action taken to correct the failing gradation.

If a gradation sample fails, one (1) resample from the same sampling location shall immediately be taken and tested. If the resample passes, the testing frequency being run prior to the failure shall be resumed. If the resample fails, a second resample shall immediately be taken.

If the second resample passes, the start-of-production sampling frequency shall be initiated. All samples in the series must pass before the normal production or stockpile sampling frequency for that location can be restarted.

If the second production resample fails, production of that specified aggregate shall not be incorporated in the approved stock, or, in the case of the second stockpile resample failing, shipment from that stockpile shall cease. Corrective action shall be initiated by the Source. No material shall be placed on or, in the case of stockpile problems, shipped from the certified stock until a passing gradation sample is taken and tested. The start-of-production frequency shall then be run at that location. All samples in the series must pass before the normal-production or stockpile sampling frequency for that location can be restarted.

All resamples shall be washed gradation tests except as stated under Note 2 in Table 1.

Any action taken, such as resampling, screen changes, separate stockpiling, etc., shall be noted on the bottom of the failing test computation sheet and in the Source diary.

The Aggregate Technician or the AGCS Technician shall monitor the corrective action. Failure to comply with Article 6.5 herein shall cause the Source to be removed from the Approved Aggregate Source list as per Section 11.0 herein.

6.6 **Failing Monitor Gradation Samples** - Any Source's failing Monitor gradation sample taken and tested by the Department and determined to be a source problem per Section 9.6 shall be considered a Failing Gradation Sample under the Source's Gradation Control Program and shall cause the Source to enact Article 6.5 herein.

7.0 APPROVED LABORATORY

7.1 An approved Source laboratory shall have the following equipment or alternatives approved by the Bureau (see "Aggregate Laboratory Equipment" in the current *Manual of Test Procedures for Materials*:

7.1.1 Current Manual of Test Procedures for Materials.

7.1.2 Balance - meeting the current AASHTO M 231, "General Purpose Balances and Scales".

7.1.3 Rainhart Shaker (305-mm [12"] Sieves) - for coarse aggregate testing.

7.1.4 Rainhart Shaker (305-mm [12"] Sieves) - for fine aggregate testing.

7.1.5 Sieves or Screens - meeting ASTM 11, "Sieves for Testing Purposes".

7.1.6 Drying Oven - of appropriate size, built specifically for drying, and capable of maintaining a uniform temperature of 110 ± 5° C (230 ± 9° F). An electric hot plate, gas burner, or comparable heat source (microwaves are not allowed) may be substituted provided that no indication of variation in the test results occurs due to overheating of the material. Hot plates, gas burners, or comparable heat sources shall be continually attended by the Aggregate Technician or the Mixture Aggregate Technician during drying.

7.1.7 Sample Splitters - meeting Illinois Test Procedure 248.

7.2 If a mixture QC laboratory is used for AGCS testing, the following additional equipment is required for use only on AGCS aggregate samples:

- One set of nested sieves for coarse and/or fine aggregate.
- One set of wash sieves.
- One coarse and/or fine aggregate splitter.

All equipment listed above shall be as specified "Aggregate Laboratory Equipment" in the current *Manual of Test Procedures for Materials.*

8.0 OUTLYING (OS) SOURCE REQUIREMENTS

8.1 Each district may designate in writing to the Bureau a certified aggregate source located out-of-state which shall follow specific requirements in running the AGCS, listed herein. The District shall detail the criteria used to select the source for the Outlying designation. The Source QC plan tentatively approved by the District shall accompany the District request.

The Bureau shall notify the District Materials Engineer in writing as to whether the aggregate source has met the Outlying criteria, the Source QC Plan is acceptable, and the Source will be designated as an Outlying (OS) Source.

8.2 The OS Source shall follow all requirements of the AGCS program unless otherwise noted within this section. A Source QC plan shall be submitted for department approval to the inspecting District. Other states' QC/QA programs or parts thereof may be substituted for the Illinois AGCS program, if approved by the Bureau. All substitutions/changes shall be noted in the Source QC Plan. The minimum sampling frequencies noted in the Illinois AGCS program shall be met regardless of frequencies listed in the other state programs.

8.3 The District will, at least annually, visit each Source to obtain quality/gradation samples, observe program procedures, and inspect the AGCS laboratory. Laboratory inspections conducted under other states' programs may be used if the OS Source has been approved to use the other states' QC/QA program.

These inspections may be unannounced.

8.4 The District will inspect, sample, and test incoming aggregate at the specified AGCS monitor frequency at Illinois sites (job sites, mix plants, terminals, or supplier yards). Split sample, load-out, and comparison requirements noted in Section 9 herein shall be waived.

The District shall communicate the test results to the QC Manager at the aggregate Source for appropriate action, including any corrective action. In addition, the District shall communicate the test results to any QC Manager or Resident Engineer at the jobsite, mix plant, terminal, or supplier yard, for appropriate action, including corrective action.

8.5 Outlying Sources shall notify their inspecting District of all scheduled AGCS shipments/production (including shipments to mix plants, terminals, and supplier yards) prior to the shipment/production.

8.6 Once designated as an Outlying Source, all aggregate, including Category I, II, III, and IV, shipped to Illinois Department of Transportation projects (including all Local Agency projects) shall be produced under the AGCS program. Category IV shall be run at the Category III frequency.

9.0 DEPARTMENT RESPONSIBILITIES

9.1 Sampling and testing for quality shall remain the responsibility of the Department. A Consultant, hired by the Department to perform the duties of an Aggregate Inspector, shall not be allowed to take any quality or Freeze-Thaw samples at an aggregate source.

9.2 Monitor gradation samples at the Source shall be taken, by or in the presence of an Aggregate Inspector, from each aggregate being produced for designated use at each Certified Source. All Monitor samples shall be split samples of a Source's gradation sample taken as per the Source's Gradation Control Program.

Additionally, the Department does reserve the right to sample Monitor samples at any time. At least two (2) out of every five (5) Monitor samples shall be taken from the stockpile's loadout face once loadout procedures have started. The Monitor samples shall be tested by District personnel on Department testing equipment according to the first paragraph of Section 6.3 herein. All Monitor samples shall be washed gradation tests unless Note 2 in Table 1 is applicable. Each Monitor sample shall be identified as to sampling location and gradation test procedure used.

9.3 Sampling and testing frequency for the Monitor gradation samples shall be a minimum of one (1) sample per every twenty (20) production days for each gradation being produced for designated use.

9.4 All Monitor gradations run shall be reported in the MISTIC system. Computation sheets shall be retained for a minimum of three (3) years in the Department's Source file.

9.5 The Inspector shall compare both the Monitor sample and the Source's split sample for validity as defined by the Department's "Guideline for Sample Comparison" (see Appendix A of the current "Manual of Test Procedures for Materials"). The reason for any significant difference between the two (2) samples shall be determined and corrected.

9.6 All Monitor gradations shall be communicated to the QC Manager. All failing monitor gradations shall be investigated by the Department. Any failing gradations, which are determined to be a Source problem not already corrected by the Producer, shall cause Article 6.6 herein to be enacted by the Source. The Aggregate Inspector shall compare the failing gradation to the Source's control charts and/or split sample computation sheet. If the control chart indicates that the Source is aware of the problem and is taking corrective action, normal Monitor sampling shall resume.

The Aggregate Inspector shall continue to visually monitor the problem and the Source's corrective action. If the control chart indicates the Source is not aware of the problem, a split sample of the Source's next sample as specified in Article 6.5 shall be tested. Failure of the Source to follow Article 6.6 shall result in the Source being removed from the Approved Aggregate Source list per Section 11.0 herein.

9.7 A copy of all correspondence between the District and the Certified Source shall be sent to the Bureau for inclusion in the aggregate Source file.

10.0 SOURCE CERTIFICATION PROCEDURE

10.1 The certification procedure shall follow the Department's "Producer Start-Up for the Aggregate Gradation Control System". An aggregate Source wishing to become certified shall verbally contact the District. A preliminary meeting may be held to discuss requirements of the program. After the initial contact or the preliminary meeting, a written request for certification shall be submitted to the District Materials Engineer.

10.2 An evaluation team composed of two (2) District personnel and one (1) Bureau representative (if possible) shall conduct an inspection of the Source for compliance to the certification checklist for all sources producing Category I, II, and III aggregate. A formal meeting with the Source's management, QC Manager, and quality control personnel shall be held to discuss the Source's Gradation Control Program requirements, if applicable, and any problems noted in the certification checklist. The Source shall submit a certification letter as designated by the Department. Each Source shall provide and maintain a listing of current certified gradations being produced under the Aggregate Gradation Control System. The certification letter, a copy of the checklist, and the evaluation team's recommendations, shall be forwarded to the Bureau along with a memorandum from the District requesting certification.

10.3 The Bureau shall notify the District Materials Engineer in writing whether or not the aggregate Source has met the certification criteria and has been added to the Approved Aggregate Source list.

10.4 Each Certified Source shall be reevaluated on an annual basis by District personnel. The reevaluation shall be a complete evaluation of the Source's laboratory and technician(s). A copy of the reevaluation checklist and comments shall be forwarded to the Bureau. Failure to comply with the certification criteria shall result in the Source's certification being revoked as per the procedure detailed in Section 11.0 and the Source will be classified as De-Certified and removed from the Approved Aggregate Source list.

10.5 Only during the initial certification procedure and at the request of the aggregate Source, existing IDOT-approved stockpiles at the Source may be approved as certified AGCS aggregate for Category II and Category III use only under the AGCS. This request, including identification and location of the stockpiles, shall be included in the written letter requesting certification submitted to the District Materials Engineer. The Engineer shall review the gradations representing the stockpiles for compliance to the specifications. If acceptable, the stockpiles shall be considered AGCS aggregate at such time as the aggregate source is certified. Any Category I aggregate may be grandfathered into the AGCS using the Department's current Policy Memorandum, "Use of Non-certified Aggregate Stockpiles Under the Aggregate Gradation Control System (AGCS)", located in the current "Manual of Test Procedures for Materials."

10.6 If at any time a Certified Source does not maintain the proper QC personnel, the source will be given one (1) month to comply by either hiring a new QC person or by contracting with a qualified consultant. If after one (1) month the source does not have the proper QC personnel; the source's Certification will be revoked by the BMPR. Section 11.0 will not apply to this type of Revocation. The source will be reinstated as an Approved Aggregate Source once the proper QC personnel are acquired.

As an option to this type of Revocation, a source may utilize a Gradation Technician for gradation testing as long as the following criteria are met:

- The Source must inform the district, in writing, of the QC personnel change.

- The source must have an Aggregate Technician visit the source a minimum of three (3) times a day to oversee the Gradation Technician.

- The source must have the proper personnel trained and in place as soon as possible.

11.0 REVOCATION OF A SOURCE'S CERTIFICATION

11.1 The Department may revoke a Source's Certification for any of the following reasons:

- Failing to follow the procedures and requirements of the Aggregate Gradation Control System (AGCS) Policy Memorandum.

- Misrepresentation of materials or products.

- Failing to follow the approved Quality Control Plan, if applicable.

11.2 Before removal, the District Materials Engineer shall detail, in a non-conformance letter to the Source's QC Manager, why the Department is seeking to revoke the Source's Certification. The Source has within two weeks to reply. The Source shall not place materials in question on certified stockpiles during the two-week period. If the Department's reasons warrant, the Source may be required to stop shipment of any and all products to Department and/or Local Agency projects.

11.3 Within this two-week period, the Source's QC Manager shall reply, in writing, outlining the steps the Source is taking to address the issues outlined within the Department's non-conformance letter.

11.4 After receipt of the Source's letter, the District will schedule a meeting with the Source to discuss the proposed revocation and the Source's response. After such meeting, the District Materials Engineer will either (1) conclude the steps taken by the Source's QC Manager are adequate and terminate the revocation process, or (2) conclude the Source's response does not address the issues outlined in the Department's non-conformance letter and recommend in writing to the Bureau of Materials and Physical Research the Source be taken off the Approved Aggregate Source List. The recommendations shall include details and District/Source comments concerning the proposed revocation. Copies of all correspondence, including meeting minutes, shall be sent to the Bureau and the Source.

11.5 If requested by the Source within seven days of the District's recommendation to revoke the Certification, the Bureau will schedule a meeting with the Source's QC Manager and the District. After such meeting, the Bureau will either terminate the revocation process or proceed with removing the Source from the Approved Aggregate Source List.

The Bureau's decision to revoke the Source's Certification is a final agency decision of the Illinois Department of Transportation.

11.6 The Bureau shall notify the District Materials Engineer and Source in writing when a Source's Certification has been revoked and the Source has been removed from the Approved Aggregate Source List as a De-Certified Source. The Source may not provide aggregate materials or products for Department and/or Local Agency projects until such time as the Source's Certification has been reinstated.

11.7 The QC Manager, at any time, may inform the District in writing that the Source is no longer producing or shipping a specific certified gradation. This action shall terminate any revocation process against the source concerning that certified gradation. Production of that gradation for the AGCS shall not be restarted unless the District concurs that corrective action has been completed by the Source. If the revocation process is based on misrepresentation of materials or products, and/or failure to follow the overall general requirements of this policy, 11.7 does not pertain

12.0 REINSTATEMENT OF A SOURCE'S CERTIFICATION

12.1 The Source may re-apply for reinstatement of its certification at the end of the revocation period. Re-application shall be in writing to the Bureau of Materials and Physical Research and include the specific steps to be taken to correct the cause for loss of certification.

Aaron A. Weatherholt, P.E.
Acting, Engineer of Materials
and Physical Research

SAB/jy

Illinois Department of Transportation
AGGREGATE GRADATION CONTROL SYSTEM (AGCS)
TABLE 1
August 16, 2012

Category	Use	Start of Production	Normal Production	Stockpile/ Loadout	Control Charts	Masterband
I Notes 1 & 5	Coarse Aggregate and Manufactured Sand Used in QC/QA HMA and PCC Coarse Aggregate for Pavement Drainage Coarse Aggregate for All PCC and Class I/Superpave HMA Projects	5@1000T (all wash)	1@2000T 2 per day max (wash 1/3 coarse agg.) (wash all manufactured sand)	2/week (all wash) (Note 3)	Yes	Yes (Note 8)
II Notes 1 & 5	Coarse Aggregate and Manufactured Sand for All Non-Class I / Superpave HMA Projects	3@1000T (all wash) (Note 2)	1@5000T 2 per day max 1 per week min (all wash) (Note 2)	1/week (all wash) (Notes 2 & 7)	Yes	Yes (Note 8)
III Notes 1 & 5	Natural Sand for All PCC and HMA Projects Aggregate Surface Course Granular Shoulders Granular Sub-base Granular Base Granular Embankment Special Cover/Seal Coat Sand Bedding Porous Granular Embankment and Bedding Sand Backfill for Underdrains French Drains Membrane Waterproofing Mortar Sand Blotter Granular Embankment Aggregate Subgrade (Note 9)	2@2000T (all wash) (Note 2)	1@10,000T 2 per day max 1 per week min (all wash) (Note 2 & 6)	1/week (all wash) (Notes 2 & 7)	No	No
IV Note 4	Rock Fill Erosion and Sediment Control Rip-Rap Bedding Ice Control Abrasives Trench Backfill	Department Testing				

Note 1: A producer may adjust gradation bands for any product in accordance with Article 6.2 of the AGCS.

Note 2: Wash only products used for HMA, PCC, Seal/cover coat and products with #200 sieve requirements.

Note 3: No loadout tests for quantities under 500 tons or less shipped weekly. When loadout occurs but no weekly loadout test is run, the tonnage shipped shall be accumulated from the start of that week. When the accumulated tonnage exceeds 500 tons, a loadout sample shall be run.

Note 4: Testing to be performed by IDOT personnel.

Note 5: Testing frequency may be reduced based on conformance to QC requirements, consistency in meeting sieves' midpoints, statistical consistency, etc.

Note 6: Minimum of 1 per week after the first 10,000 tons of production per week for aggregate surface course, granular shoulders, granular subbase, granular base, and granular embankment special; minimum of 1 every 2 weeks if producing less than 10,000 tons per 2-week period.

Note 7: No loadout tests for quantities under 1,000 tons or less shipped weekly. When loadout occurs but no weekly loadout test is run, the tonnage shipped shall be accumulated from the start of that week. When the accumulated tonnage exceeds 1,000 tons, a loadout sample shall be run.

Note 8: Refer to current QC/QA Procedure, “Aggregate Producer Control Chart Procedure” for required gradations.

Note 9: Only Normal Production test shall apply.

Illinois Department of Transportation

Aggregate Producer Control Chart Procedure
(Chapter 9, Aggregate Technician Course Manual)
Appendix A3

Effective: November 1, 1995
Revised: March 1, 2013

9.0 AGGREGATE PRODUCER CONTROL CHART PROCEDURE

Gradation control charts provide an effective way to monitor the aggregate production process and can present a graphical record of aggregate gradation during continuous production and stockpiling. Specific changes or gradual trends in a product's gradation can be readily identified before major trouble occurs. Other benefits may also be realized by using control charts including but not limited to:

- Decreased product variability
- Established production capabilities
- Permanent record of gradation quality
- Increased sense of "quality awareness" at the Source

For these reasons, an Aggregate Producer Control Chart Procedure is an important requirement in the Gradation Control Program at certified aggregate Sources in Illinois.

Under the Illinois Aggregate Producer Control Chart Procedure, all gradation test results (percent passing) for each required gradation/production point tested shall be recorded on a control chart within one working day of sampling. The control chart/s for any gradation in the program must therefore have each required sieve represented on the chart.

The gradation control charts are to be readily accessible at the source and/or approved laboratory and available for inspection upon request by the Aggregate Inspector or a representative of the Department. Computer-maintained charts are the property of the Department and shall not be removed or altered in any manner. The Aggregate Inspector shall check the control charts on a regular basis.

The “Illinois Specification 201 Aggregate Gradation Sample Size Table & Quality Control Sieves” document from the “Manual of Test Procedures for Materials” designates the required sieves for coarse and fine aggregate gradations.

9.1 Definitions

9.1.1 **Average**: The sum of a series of test results or measurements divided by the number of values or measurements included in the sum, also, known as the arithmetic mean.

9.1.2 **Check Samples**: Samples taken for a specific purpose, other than required by Table 1. This information may be used to verify an observation or conclusion, or as a means of confirmation of corrective action, other than required by Table 1. Such samples are permitted under any circumstances except to replace samples required by Table 1.

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(Chapter 9, Aggregate Technician Course Manual)
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Effective: November 1, 1995
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9.1.3 **Control Charts**: A visual representation of test results, observations, or measurements arranged in an orderly sequence in respect to time. Control charts provide the means of measuring the effectiveness of process control, detecting lack of control, directing a course of action to restore control, and increased sense of "quality awareness".

9.1.4 **"Master Band" or Control Limits**: Mathematical limits placed on gradations, based on established Master Band limits, which when exceeded initiate action by those responsible for process control, and/or acceptance of aggregate products. These limits may be established on the basis of previous historical experience or by start of production results.

9.1.5 **Sample Testing Frequency**: As per Table 1.

9.1.6 **Table 1**: Table 1 of the current Bureau of Materials and Physical Research's Policy Memorandum, "Aggregate Gradation Control System (AGCS)" found in the "Manual of Test Procedures for Materials".

9.1.7 **Trend**: When two or more points move away from the mid-point target values in either direction (±), thus producing either a steep angled line or three points moving with a gradual angle. This is usually associated with the moving average points but can also be determined from individual test points. Trends are indications that a problem(s) are or will be present if corrective action is not taken.

9.1.8 **"Warning Band" or Moving Average**: The average of 5 consecutive values (sample results) obtained per Table 1 requirements, based on established Warning Band limits. Such values always represent the most recently obtained test results or measurements within the prescribed group of observations. These limits may be established on the basis of previous historical experience or by start of production results.

9.2 **Control Chart Paper / Size**: Control Charts for the Gradation Control Program, when created by hand, must be placed on 10x10 cross-sectional graph paper measuring 420 mm x 280 mm (16-1/2" x 11") or 216 mm x 280 mm (8-1/2" x 11"). Graph paper used for this purpose, can be ordered through office supply specialty stores, companies dealing in drafting materials or ordered through the internet. An example of a control chart is found on the last page of this document.

9.3 **Chart Preparation**: At the top of the control chart, the aggregate product material code and the Master Band (when known) will be noted.

Lines corresponding to the upper and lower percent-passing Standard Specification limits for each required sieve/gradation shall be drawn horizontally across the graph.

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The vertical distance between these lines must accurately represent the difference between the upper and lower limits for each sieve using a vertical scale of one division (square) which will equal one percent (1%) passing on all sieves except the 75-µm (No. 200), see Article 9.3.1.

On the left side of the control chart, the upper and lower specification lines of each sieve shall be connected by a drawn vertical double arrow.

The specification limits for the each sieve, e.g., 45% for upper limit and 15% for lower limit, must be indicated at the top (for upper limit) and bottom (for lower limit) of the arrow. The sieve size, e.g., 4.75 mm (No. 4), shall also be indicated between the limits on the far left side of the chart.

The vertical scale [(1% = 1 division (square) or 0.1% = 1 division (square)] shall be noted below each required sieve.

Each test value will be spaced horizontally every 1/2” or 5 horizontal divisions (squares).

9.3.1 The 75-µm (No. 200) sieve, when plotted, shall be plotted for washed tests only.

9.3.2 Master Bands and Warning Bands shall be drawn across the graph for the critical sieve, when required, as defined in Article 9.5.1 herein. Master Band limits, once known, shall be represented by a solid line and the Warning Band limits shall be represented by a broken line.

9.4 **Plotting of Test Values**. The Gradation Control Program allows the producer to run both washed and dry gradation tests. The percent passing results for each different kind of gradation test run shall be plotted on the control chart using specific symbols. All symbols must measure approximately 2.5 mm (1/10”) on each side/diameter.

9.4.1 The symbols to be used for each test type are as follows:

Type of Gradation Test	Symbol	
Washed Production	Open Circle	O
Dry Production	Circled X	⊗
Stockpile (can be plotted on separate chart)	Asterisk	✱
Moving Average	Open Square	□

9.4.2 In addition to the required symbols, line-types are used to further facilitate proper interpretation of the plotted information. Washed production test results will be connected with a broken line while moving average results are to be connected with a solid line.

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9.4.3 The moving average will be calculated and plotted on the last five consecutive washed production test values on each critical sieve and is only plotted when a new washed production test is ran.

The moving average will be started by taking the fifth test value after the start of yearly production, or production restarted after a protracted shutdown, and averaging it with the four preceding test values. Once the moving average is established, the moving average will be calculated and plotted each time a new washed production test value is ran and plotted.

9.4.4 Each individual test result that is ran and plotted will have the following information located at the bottom of the chart below the respective plotted test result.

- Date the sample was taken (e.g. 07/15/11)
- Time the sample was taken (e.g. 10:15 am)
- Every resample was taken (An ‘R’ shall be placed under the test result that it represents)
- Initials of the Aggregate technician plotting the test results
- All individual test symbols shall have the numerical value written just below the symbol.

9.4.5 Stockpile load out test results may be plotted or summarized on a separate control chart, graph, or table. The reporting format may be developed by the Source. The reporting format shall include the information required in this article (sample type, time, and date).

The control limits and deviation from the established Master Band shall be identified.

9.5 **Master Band/Warning Band**. During Start of Production, Master Bands/Warning Bands must be developed and placed on the control chart after five tests or within the first 9,100 metric tons (10,000 tons), whichever occurs first, for each product's critical sieve, when required. Any production or equipment change after development of a Master Band may necessitate the development of a new Master Band.

Historical data from washed production samples may also be used, at the Source's request, to establish Master Band targets. The average, rounded to the nearest whole number, used to establish the Master Band shall be based only on washed production critical sieve test results.

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9.5.1 Master Bands/Warning Bands will be drawn plus/minus using the below-listed percentages from a rounded average for each listed coarse aggregate sieve/gradation.

If the critical sieve and the plus/minus percentages for coarse aggregates is not listed, this information will be assigned by the Bureau of Materials and Physical Research on an as-needed basis.

Gradation	Sieve	Master Band (%)	Warning Band (%)
CA/CM 5	25 mm (1")	± 8	± 6
CA/CM 7	12.5 mm (1/2")	± 8	± 6
CA/CM 11	12.5 mm (1/2")	± 8	± 6
CA/CM 13	4.75 mm (No. 4)	± 8	± 6
CA/CM 14	9.5 mm (3/8")	± 8	± 6
CA/CM 16	4.75 mm (No. 4)	± 8	± 6

Sand Producers – Refer to Illinois Specification 201 for gradation requirements.

9.5.2 When a production change is made, a vertical line shall be drawn through the Master Band. The change shall be noted on the chart and documented in the Source plant diary.

9.5.3 A Master Band, when established, shall take precedence over the Standard Specification limits set for that sieve/gradation.

9.6 **Test Values at Master Band/Warning Band Limits**. When an individual test value on a Master Band **exceeds** the Master Band limits, the producer must treat that test result as a failure. Article 6.5 of the current Aggregate Gradation Control System Department Policy Memorandum shall be enacted. Article 6.5 of the AGCS requires resamples/corrective action be taken in response to the initial failing test.

The situation of the moving average hitting or exceeding a Warning Band is different than a failing individual test and Master Bands. When the moving average **hits or exceeds** the Warning Bands, the Source must decide whether to take corrective action to bring the gradation back within the Warning Bands or to develop a new Master Band.

The Source must notify the District what action was taken.

If a new Master Band is developed, the material shall be stockpiled separately from the previous production.

The development of a new Master Band may necessitate new HMA or PCC mix designs.

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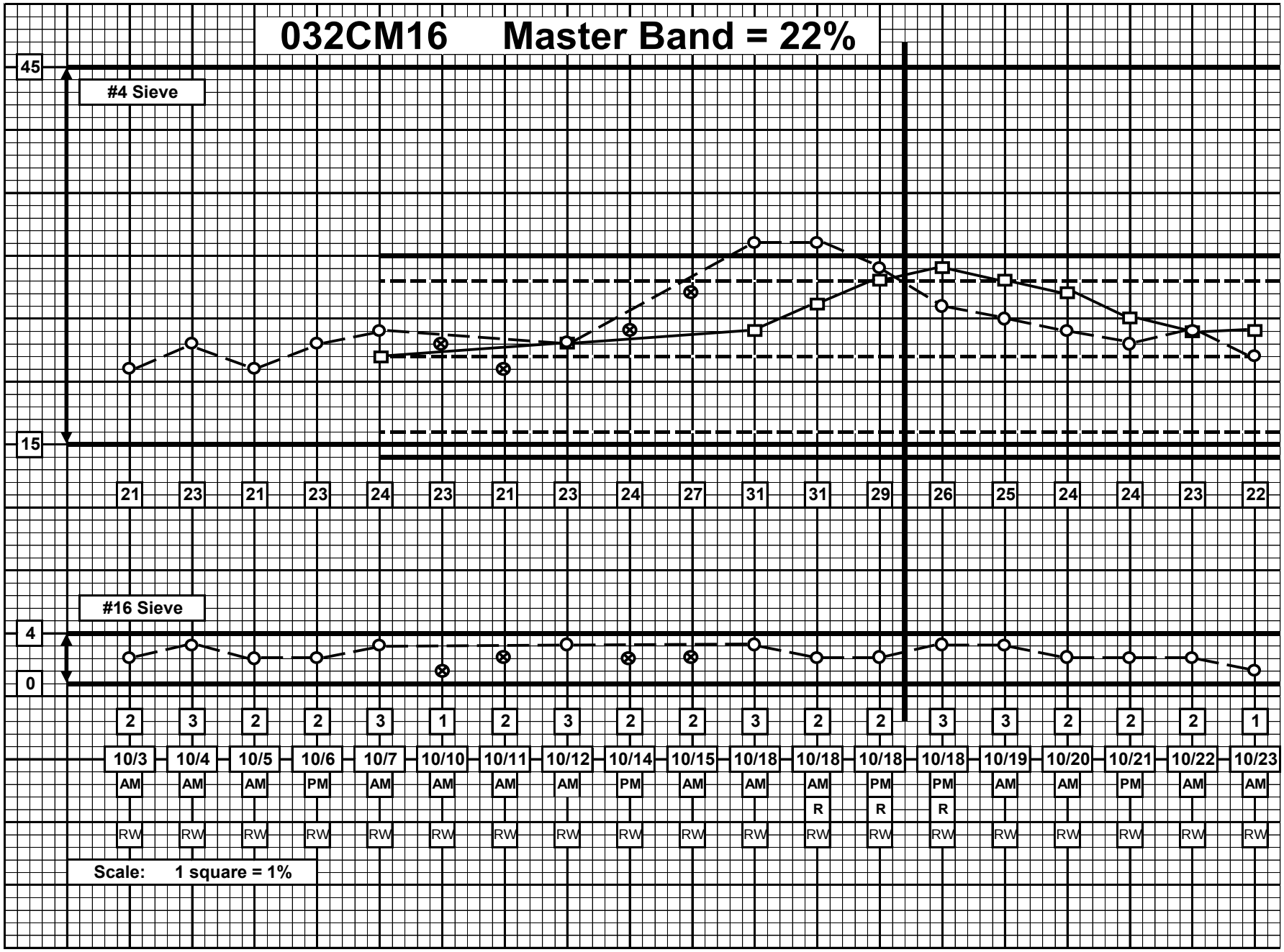
032CM16 Master Band = 22%
#4 Sieve
45
15
21 23 21 23 24 23 21 23 24 27 31 31 29 26 25 24 24 23 22
#16 Sieve
4
0
2 3 2 2 3 1 2 3 2 2 3 2 2 3 3 2 2 2 1
10/3 10/4 10/5 10/6 10/7 10/10 10/11 10/12 10/14 10/15 10/18 10/18 10/18 10/18 10/19 10/20 10/21 10/22 10/23
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Scale: 1 square = 1%

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Note: The following pages have been added to this manual to better facilitate teaching the concepts of control charts and **is not part of or found in** the "Aggregate Producer Control Chart Procedure" document located in the Manual of Test Procedures.

Calculating Averages

A technician obtains "n" (5) consecutive test values: 59 61 58 55 60

What is the average of these five test values?

Solution: The sum of the data values: 61 + 55 + 58 + 59 + 60 = 293

The average is: $\frac{\text{Sum of Data}}{\text{Number of Data}} = \frac{293}{5} = 58.6$ or 59

The value of 59 would then be the average for these five test values. (Answers should always reflect the required precision based on the given information).

Example: All reported aggregate **percent** values are rounded to the nearest whole percent except the 75-µm (No. 200 material). The 75-µm (No. 200) **percent** values are rounded to the nearest tenth of a percent. This applies to percent only and is not to be confused when working with **weights (**coarse and fine aggregate materials).

"Moving" Average Calculation

A technician obtains 15 consecutive test values (n):

5l 46 50 53 49 48 56 47 49 48 43 52 56 44 49

Determine the moving average for the 5th, 7th, 10th and the 15th tests?

Solution for the 5th test value: **5l 46 50 53 49** 48 56 47 49 48 43 52 56 44 49

5l + 46 + 50 + 53 + 49 = 249

249 ÷ 5 = **49.8** = **50** (50 would then be plotted for the 5th test moving average value)

Solution for the 6th test value: 5l **46 50 53 49 48** 56 47 49 48 43 52 56 44 49

46 + 50 + 53 + 49 + 48 = 246

246 ÷ 5 = **49.2** = **49** (49 would then be plotted for the 6th test moving average value)

Solve for the 10th test value: 5l 46 50 53 49 48 56 47 49 48 43 52 56 44 49

Solve for the 15th test value: 5l 46 50 53 49 48 56 47 49 48 43 52 56 44 49

Note: The official Illinois Specification 201 "Aggregate Gradation Sample Size Table & Quality Control Sieves" document is found in the "Manual of Test Procedures" and **is not part of** the "Aggregate Producer Control Chart Procedure" document. The Illinois Specification 201 document is placed here as an aid to help facilitate the discussion on Control Charts.

Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES
Effective February 1, 2014

COARSE AGGREGATE GRADATION TABLE																			
CA(CM)[1, 2]	Minimum Field Sample Size[3]	Minimum Test Sample Size[3]	3"	2 1/2"	2"	1 3/4"	1 1/2"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	#4	#8	#16	#40	#50	#200
CA01	110 lbs (50 kg)	10,000 g	X	X[MN]	X		X	X											X
CA02	110 lbs (50 kg)	10,000 g		X	X[MN]		XC	X	XC		X			X		X	X		X
CA03	110 lbs (50 kg)	10,000 g		X	X[MN]		X	X			X								X
CA04	110 lbs (50 kg)	10,000 g			X		X[MN]	X	XC		X	XC		X		X	X		X
CA05[5]	110 lbs (50 kg)	10,000 g				X	X[MN]	X[MB,6]	XC		X			X[6]					X
CA06	55 lbs (25 kg)	5,000 g					X	X[MN]	XC		X	XC		X		X	X		X
CA07[5]	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X[MB,6]	XC	XC	X[6]					X
CA08	55 lbs (25 kg)	5,000 g					X	X[MN]	X	XC	X	XC	XC	X		X			X
CA09	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X	XC	XC	X		X			X
CA10	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X	XC	XC	X		X	X		X
CA11[5]	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X[MB,6]	XC	XC	X		X[6]			X
CA12	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X	XC	X	X		X
CA13[5]	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X[MB,6]	XC	X[6]			X
CA14[5]	35 lbs (16 kg)	2,000 g								X	X[MN]	X[MB,6]	XC	X[6]					X
CA15	35 lbs (16 kg)	2,000 g									X	X[MN]	XC	X	XC	X			X
CA16[5]	25 lbs (11 kg)	1,500 g									X	X[MN]	XC	X[MB,6]	XC	X[6]			X
CA17	35 lbs (16 kg)[4]	4,000 g[4]	X		XC			XC			XC	XC		X[MN, 4]		X		X	X
CA18	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X		X	X
CA19	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X	X	X	X
CA20	25 lbs (11 kg)	2,000 g									X	X[MN]	XC	X	X	X			X

Note: See footnotes below Fine Aggregate Gradation Table for explanation of symbols

Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES
Effective February 1, 2014

FINE AGGREGATE GRADATION TABLE															
FA(FM)[1, 2]	Minimum Field Sample Size[3]	Minimum Test Sample Size[3]	1"	1/2"	3/8"	#4	#8	#10	#16	#30	#40	#50	#80	#100	#200
FA01	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA02	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA03	25 lbs (11 kg)	500 g			X	X[MN]		X			X		X		X
FA04	25 lbs (11 kg)	500 g			X				X[MN]						
FA05	25 lbs (11 kg)	500 g			X	X[MN]								X	X
FA06	25 lbs (11 kg)	500 g	X	X	X	X[MN]								X	X
FA07	25 lbs (11 kg)	100 g				X		X[MN]			X		X		X
FA08	25 lbs (11 kg)	100 g					X				X[MN]			X	X
FA09	25 lbs (11 kg)	100 g					X					X[MN]		X	X
FA10	25 lbs (11 kg)	100 g						X			X[MN]		X		X
FA20[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[5]
FA21[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[5]
FA22[5]	25 lbs (11 kg)	500 g			X	X[MB]	X[MB, 6]		X						X[5]

Notes below apply to Fine and Coarse Aggregate Gradation Tables Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
MB = Master Band Sieves for Category I & II Coarse Aggregate for PCC and HMA Mixes; Bituminous use only for fine aggregate.
MN = Maximum Nominal Sieve for Crushed Gravels – Maximum Nominal Size is defined as the first specification sieve in the product gradation on which material may be retained.
1 = CA = Coarse Aggregate; CM = Coarse Aggregate, Modified; FA = Fine Aggregate; FM = Fine Aggregate, Modified
2 = CM and FM gradations shall be sampled and tested the same as the corresponding CA and FA gradations.
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = Will vary with the gradation of the material being used
5 = Control Charts Required
6 = Required Sieve for Control Charts

Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES
Effective February 1, 2014

LARGE SIZED AGGREGATE GRADATION TABLE										
CS/RR[1, 2]	Minimum Test Sample Size[3]	8"	6"	4"	3"	2"	1 ½"	1"	½"	#4
CS01	20,000 g	X	X	X	XC	X		XC	XC	X
CS02	15,000 g		X	X	XC	X		XC	XC	X
RR01	10,000 g				X	XC	X	XC	XC	X
RR02	10,000 g			X	XC	X	XC	XC	XC	X

Notes below apply to Large Sized Aggregate Gradation Table Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
1 = CS = Coarse Aggregate Subgrade; RR/RRM = Rip Rap
2 = Dry Gradations Only
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = A round nosed shovel may be used for sampling
5 = Metal plates with precisely sized square holes may be used for the gradation
6 = Test sample size shall be taken in the field. No splitting is required.

The following are the gradation tables taken from the 2016 Standard Specifications:

Art. 1004.01 (10) (c) Coarse Aggregate Gradation Table

Grad No.	COARSE AGGREGATE GRADATIONS												
	Sieve Size and Percent Passing												
	3 in.	2 1/2 in.	2 in.	1 1/2 in.	1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	N0. 8	No. 16	No. 50	No. 200 1/
CA 1	100	95±5	60±15	15±15	3±3								
CA 2		100	95±5		75±15		50±15		30±10		20±15		8±4
CA 3		100	93±7	55±20	8±8		3±3						
CA 4			100	95±5	85±10		60±15		40±10		20±15		8±4
CA 5				97±3 2/	40±25		5±5		3±3				
CA 6				100	95±5		75±15		43±13		25±15		8±4
CA 7				100	95±5		45±15 7/		5±5				
CA 8				100	97±3	85±10	55±10		10±5		3±3 3/		
CA 9				100	97±3		60±15		30±15		10±10		6±6
CA 10					100	95±5	80±15		50±10		30±15		9±4
CA 11					100	92±8	45±15 4/7/		6±6		3±3 3/ 5/		
CA 12						100	95±5	85±10	60±10		35±10		
CA 13						100	97±3	80±10	30±15		3±3 3/		
CA 14							90±10 6/	45±20	3±3				
CA 15							100	75±15	7±7		2±2		
CA 16							100	97±3	30±15		2±2 3/		
CA 17	100								65±20		45±20	20±10	10±5
CA 18	100				95±5				75±25		55±25	10±10	2±2
CA 19	100				95±5				60±15		40±15	20±10	10±5
CA 20							100	92±8	20±10	5±5	3±3		

Art. 1003.01 (10) (c) Fine Aggregate Gradation Table

Grad No.	FINE AGGREGATE GRADATIONS										
	Sieve Size and Percent Passing										
	3/8	No. 4	No. 8 4/	No. 10	No. 16	No. 30 5/	No. 40	No. 50	No. 80	No. 100	No. 200 1/
FA 1	100	97±3			65±20			16±13		5±5	
FA 2	100	97±3			65±20			20±10		5±5	
FA 3	100	97±3		80±15			50±20		25±15		3±3
FA 4 7/	100				5±5						
FA 5	100	92±8								20±20	15±15
FA 6		92±8 2/								20±20	6±6
FA 7		100		97±3			75±15		35±10		3±3
FA 8			100				60±20			3±3	2±2
FA 9			100					30±15		5±5	
FA 10				100			90±10		60±30		7±7
FA 20	100	97±3	80±20		50±15			19±11		10±7	4±4
FA 21 3/	100	97±3	80±20		57±18			30±10		20±10	9±9
FA 22	100	6/	6/		8±8						2±2

CHAPTER 6 – HOMEWORK

READ ALL OF THE FOLLOWING INSTRUCTIONS ON PAGES HM-1 AND HM-2, BEFORE COMPLETING THE HOMEWORK. THE INSTRUCTIONS ARE FOR THE CALCULATIONS HOMEWORK PROBLEMS 1 THRU 6, WHICH ARE LOCATED ON PAGES HM-3 TO HM-13.

Problem No. 1

- Calculate the Percent Passing.
- Show all weights and percents calculated.
- Report Percent % Passing on the Report line.
- Calculate Max Loss.

Problem No. 2

- Calculate the Percent Passing.
- Show all weights and percents calculated.
- Report Percent % Passing on the Report line.
- Calculate the % Washed -200.
- Calculate Max Loss.

Problem No. 3

- Calculate the Percent Passing.
- Show all weights and percents calculated.
- Report Percent % Passing on the Report line.
- Calculate the % Washed -200.
- Calculate Max Loss.

OVER – (HOMEWORK CONTINUED)

CHAPTER 6 – HOMEWORK (Cont'd)

Problem No. 4

- Calculate the percent passing
- Show all weights and percents calculated.
- Report Percent % Passing on the Report line.
- Calculate the % Washed -200.
- Calculate Max Loss.
- Use given information below and complete as much of the form as possible. (Directions for filling out the form are located in Chapter 6 on pages 6-23 thru 6-31.)

GIVEN: **Matt Sparks is the Quality Control Manager for Miller Construction Company (923-02). Matt took a sample of 032CM16 from a stockpile located at Miller Construction's asphalt plant site on August 10, 2015. Josie Peters, a Mixture Aggregate Technician, who also works for Miller Construction, ran a washed gradation (Seq. No. 003) on this material the same day. The testing took place on site in the Miller Construction's laboratory. The stone came from Cleary Materials. (50612-01). Miller Construction's plant and laboratory is located in District 5.**

Problem No. 5

- Calculate the Percent Passing.
- Show all weights and percents calculated.
- Report Percent % Passing on the Report line.
- Calculate the % Washed -200.
- Calculate Max Loss.

Problem 6 - Sample Comparison Problem

- Transfer the producer % passing from each sieve to this worksheet. (from Problem No. 5)
- Calculate the monitor's and producer's fraction, fraction difference, and write in the applicable tolerance.
- Specify the proper disposition (ok or out)

Illinois Department of Transportation

HOMEWORK - PROBLEM 1

Field / Lab Gradations

I.D. Number _____

Inspector No. _____ Inspector Name _____ Date Sampled _____ Seq. No. _____

Mix Plant No. _____ Mix Plant Name _____ *Contract No. _____ *Job No. _____

Responsible Loc. _____ Lab. _____ Lab Name _____ Source Name _____

Source	Mat. Code #	Type Insp.	Orig I.D. #	Insp. Qty.	Spec.	Article	Sampled From	Wash/Dry
	042CM11							**D**

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200 _____ PI Ratio _____ Test Results _____ Remarks _____

Sieve CA	Sieve FA	Indiv. Wt. Retained	Cumul. Wt. Retained	Cumul. % Retained	Percent % Passing	Spec. Range % Passing
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)	**0**				
19 (3/4)	2 (#10)	**565**				
16 (5/8)	1.18 (#16)	**762**				
12.5 (1/2)	0.6 (#30)	**1448**				
9.5 (3/8)	0.425 (#40)	**1146**				
6.3 (1/4)		**525**				
4.75 (#4)	0.3 (#50)	**318**				
2.36 (#8)						
1.18 (#16)	0.18 (#80)	**195**				
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)	**68**				
Pan		**8**				
Total Dry Mass		**5034**				
Total Washed Mass						
Diff. -0.075(- #200)			% Washed - #200			

Max Gain/Loss = _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
0.425 _____

(Mix Plant Only)

Lot _____
Bin _____

Copies: _____ Tester _____

_____ Agency _____

MISTIC INPUT
Date Entered _____
Initials _____

/FOR DTY03504
MI 504M (Rev. 11/20/12)

Is this a valid test? _____

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Illinois Department of Transportation

HOMEWORK - PROBLEM 2

Field / Lab Gradations

I.D. Number _____

Inspector No. _____ Inspector Name _____ Date Sampled _____ Seq. No. _____

Mix Plant No. _____ Mix Plant Name _____ *Contract No. _____ *Job No. _____

Responsible Loc. _____ Lab. _____ Lab Name _____ Source Name _____

Source	Mat. Code #	Type Insp.	Orig I.D. #	Insp. Qty.	Spec.	Article	Sampled From	Wash/Dry
	038FM20							**W**

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200 _____ PI Ratio _____ Test Results _____ Remarks _____

Sieve CA	Sieve FA	Indiv. Wt. Retained	Cumul. Wt. Retained	Cumul. % Retained	Percent % Passing	Spec. Range % Passing
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)	**0.0**				
37.5 (1.5)	4.75 (#4)	**5.6**				
25 (1)	2.36 (#8)	**248.2**				
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)	**358.6**				
12.5 (1/2)	0.6 (#30)	**231.3**				
9.5 (3/8)	0.425 (#40)					
6.3 (1/4)						
4.75 (#4)	0.3 (#50)	**141.8**				
2.36 (#8)						
1.18 (#16)	0.18 (#80)					
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)	**81.3**				
0.15 (#100)						
0.075 (#200)	0.075 (#200)	**35.4**				
Pan		**2.3**				
Total Dry Mass		**1144.9**				
Total Washed Mass		**1097.5**				
/Diff. -0.075(- #200)			% Washed - #200			

Max Gain/Loss = _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
0.425 _____

(Mix Plant Only)
Lot _____
Bin _____

Copies: _____ Tester _____

_____ Agency _____

MISTIC INPUT
Date Entered _____
Initials _____

/FOR DTY03504
MI 504M (Rev. 11/20/12)

Is this a valid test? _____

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Illinois Department of Transportation

HOMEWORK - PROBLEM 3

Field / Lab Gradations

I.D. Number

Inspector No. _____ Inspector Name _____ Date Sampled _____ Seq. No. _____

Mix Plant No. _____ Mix Plant Name _____ *Contract No. _____ *Job No. _____

Responsible Loc. _____ Lab. _____ Lab Name _____ Source Name _____

Source	Mat. Code #	Type Insp.	Orig I.D. #	Insp. Qty.	Spec.	Article	Sampled From	Wash/Dry
	038FM20							**W**

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200 _____ PI Ratio _____ Test Results _____ Remarks _____

Sieve CA	Sieve FA	Indiv. Wt. Retained	Cumul. Wt. Retained	Cumul. % Retained	Percent % Passing	Spec. Range % Passing
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)	**0.0**				
37.5 (1.5)	4.75 (#4)	**4.4**				
25 (1)	2.36 (#8)	**179.9**				
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)	**287.3**				
12.5 (1/2)	0.6 (#30)	**188.2**				
9.5 (3/8)	0.425 (#40)					
6.3 (1/4)						
4.75 (#4)	0.3 (#50)	**116.8**				
2.36 (#8)						
1.18 (#16)	0.18 (#80)					
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)	**67.4**				
0.15 (#100)						
0.075 (#200)	0.075 (#200)	**28.5**				
Pan		**1.9**				
Total Dry Mass		**911.2**				
Total Washed Mass		**871.9**				
Diff. -0.075(- #200)			% Washed - #200			

Max Gain/Loss = _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
0.425

(Mix Plant Only)

Lot _____
Bin _____

Copies: _____ Tester _____

Agency _____

MISTIC INPUT
Date Entered _____
Initials _____

/FOR DTY03504
MI 504M (Rev. 11/20/12)

Is this a valid test? _____

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Illinois Department of Transportation

HOMEWORK - PROBLEM 4

Field / Lab Gradations

I.D. Number _____

Inspector No. _____ Inspector Name _____ Date Sampled _____ Seq. No. _____

Mix Plant No. _____ Mix Plant Name _____ *Contract No. _____ *Job No. _____

Responsible Loc. _____ Lab. _____ Lab Name _____ Source Name _____

Source	Mat. Code #	Type Insp.	Orig I.D. #	Insp. Qty.	Spec.	Article	Sampled From	Wash/Dry
	032CM16							**W**

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200 _____ PI Ratio _____ Test Results _____ Remarks _____

Sieve CA	Sieve FA	Indiv. Wt. Retained	Cumul. Wt. Retained	Cumul. % Retained	Percent % Passing	Spec. Range % Passing
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)					
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)					
12.5 (1/2)	0.6 (#30)	**0**				
9.5 (3/8)	0.425 (#40)	**72**				
6.3 (1/4)		**427**				
4.75 (#4)	0.3 (#50)	**789**				
2.36 (#8)		**578**				
1.18 (#16)	0.18 (#80)	**47**				
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)	**34**				
Pan		**2**				
Total Dry Mass		**2015**				
Total Washed Mass		**1952**				
Diff. -0.075(- #200)			% Washed - #200			

Max Gain/Loss = _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
0.425 _____

(Mix Plant Only)

Lot _____
Bin _____

Copies: _____ Tester _____

_____ Agency _____

MISTIC INPUT
Date Entered _____
Initials _____

/FOR DTY03504
MI 504M (Rev. 11/20/12)

Is this a valid test? _____

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Illinois Department of Transportation

HOMEWORK - PROBLEM 5

Field / Lab Gradations

I.D. Number _____

Inspector No. _____ Inspector Name _____ Date Sampled _____ Seq. No. _____

Mix Plant No. _____ Mix Plant Name _____ *Contract No. _____ *Job No. _____

Responsible Loc. _____ Lab. _____ Lab Name _____ Source Name _____

Source	Mat. Code #	Type Insp.	Orig I.D. #	Insp. Qty.	Spec.	Article	Sampled From	Wash/Dry
	032CM16							**W**

CA FA	75 (3) or 6.3 (1/4)	63 (2.5)	50 (2) 25 (1)	45 (1.75) 9.5 (3/8)	37.5 (1.5) 4.75 (4)	25 (1) 2.36 (8)	19 (3/4) 2 (10)	16 (5/8) 1.18 (16)	12.5 (1/2) 0.6 (30)	9.5 (3/8) 0.425 (40)	4.75 (4) 0.3 (50)	2.36 (8)	1.18 (16) 0.18 (80)	0.6 (30)	0.3 (50) 0.15 (100)	0.15 (100)	.075 (200) .075 (200)

Wash - #200 _____ PI Ratio _____ Test Results _____ Remarks _____

Sieve CA	Sieve FA	Indiv. Wt. Retained	Cumul. Wt. Retained	Cumul. % Retained	Percent % Passing	Spec. Range % Passing
63 (2.5)						
50 (2)	25 (1)					
45 (1.75)	9.5 (3/8)					
37.5 (1.5)	4.75 (#4)					
25 (1)	2.36 (#8)					
19 (3/4)	2 (#10)					
16 (5/8)	1.18 (#16)					
12.5 (1/2)	0.6 (#30)	**0**				
9.5 (3/8)	0.425 (#40)	**89**				
6.3 (1/4)		**460**				
4.75 (#4)	0.3 (#50)	**920**				
2.36 (#8)		**737**				
1.18 (#16)	0.18 (#80)	**80**				
0.6 (#30)						
0.425 (#40)						
0.3 (#50)	0.15 (#100)					
0.15 (#100)						
0.075 (#200)	0.075 (#200)	**36**				
Pan		**2**				
Total Dry Mass		**2380**				
Total Washed Mass		**2323**				
Diff. -0.075(- #200)			% Washed - #200			

Max Gain/Loss = _____

Sampled From Codes			
BR	Barge	RD	Road
BE	Belt Stream	SI	Silo/Bin
CF	Cold Feed	SP	Stockpile
HB	Hot Bin	TD	Truck Dump
OB	On Belt (Stopped)	TK	Truck
PR	Production	WB	Weigh Belt
CR	Rail Car		

0.075
0.425

(Mix Plant Only)

Lot _____
Bin _____

Copies: _____ Tester _____

_____ Agency _____

MISTIC INPUT
Date Entered _____
Initials _____

/FOR DTY03504
MI 504M (Rev. 11/20/12)

Is this a valid test? _____

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HOMEWORK PROBLEM 6

SAMPLE COMPARISON DATA

If the comparison has no out-of-tolerance fractions, both sample results are considered valid. If an out-of-tolerance situation has been identified, both the producer certified technician and the State inspector shall immediately investigate the splitting procedure, test equipment, test method, and calculations for possible equipment failure or procedure errors. The State Monitor Sample shall always take precedence unless shown to be invalid during investigation.

032CM16	1/2" (12.5 mm)	3/8" (9.5 mm)	1/4" (6.3 mm)	#4 (4.75 mm)	#8 (2.36 mm)	#16 (1.18 mm)	#200 (75 µm)
Monitor, % Passing	100	97	73	33	10	5	2.0
Producer, % Passing							

Comparison Data

Consecutive Sieve Sizes	Monitor Fraction	Producer Fraction	Fraction Difference	Applicable Tolerance	Disposition
1/2" and 3/8" (12.5 mm and 9.5 mm)					
3/8" and 1/4" (9.5 mm and 6.3 mm)					
1/4" and #4 (6.3 mm and 4.75 mm)					
#4 and #8 (4.75 mm and 2.36 mm)					
#8 and #16 (2.36 mm and 1.18mm)					
#16 and #200 (1.18 mm and 75 µm)					
#200 and Pan (75 µm and Pan)					

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5-Day Aggregate Technician Chapter 9

Control Chart Homework

Create a control chart for a Category I 042CM11 aggregate product with a Master Band set at 47%, then:

A) Plot the following information on the control chart
B) Identify all required retest and/or corrective action situations

Sampling Frequency	Date	Time	Critical Sieve	Bottom Sieve	Gradations Wash	Gradations Dry
Start of Production Frequency	06/05	am	45	4	X	
	06/05	pm	44	6	X	
	06/06	am	45	3	X	
	06/06	pm	49	4	X	
	06/07	am	45	4	X	
Normal Production Frequency	06/10	am	42	2		X
	06/10	pm	41	1		X
	06/11	am	35	2	X	
	06/12	am	38	1	X	
	06/12	am	41	3	X	
	06/12	pm	39	2	X	
	06/13	am	49	3	X	
	06/13	pm	45	5	X	
	06/14	am	47	4	X	
	06/14	pm	48	7	X	
	06/14	pm	46	3	X	
	06/17	am	48	4	X	
	06/17	pm	45	3	X	
	06/18	am	45	2	X	

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MTP = Manual of Test Procedures for Materials
IDOT = Illinois Department of Transportation
BMPR = Bureau of Materials and Physical Research

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Illinois Department of Transportation

Stockpiling and Handling of Aggregate
(Section 40.2, *Manual for Aggregate Inspection*)
Appendix A4

Effective Date: March 4, 1980
Revised: November 25, 1996

40.2 **Classes A, B, and C Quality Coarse Aggregate and Manufactured Sand**
Degradation is of primary concern in handling Classes A, B, and C Quality coarse aggregates (and manufactured sand). Steel-tracked equipment shall not be permitted on stockpiles of Classes A, B, and C Quality (Class I binder and seal/cover coat) aggregate (and manufactured sand). Free-fall from conveyor equipment onto load-out stockpiles shall be held to a maximum of 15 feet. The fall height requirement may be waived if the aggregate source uses a special remixing procedure or device approved by the Bureau of Materials and Physical Research. A comparison of a series of samples taken during the reclaiming or loading-out operation to those taken from the production belt should be made to estimate the effect of the aggregate-handling method on degradation.

Stockpiling and handling methods of Classes A Quality, B Quality, and C Quality (Class I binder and seal/cover coat) aggregate should be designed to hold segregation to a minimum. Coned stockpiles built with stationary or movable conveyor equipment shall not be permitted unless the reclaiming method is such that the loaded-out material will meet the requirements of Article 30.3(b)1. Radial and longitudinal conveyors or stackers shall be kept in motion to reduce coning. Where possible, a spreader chute on the stacker shall be used to broaden or flatten the wedge shape of the pile. Cascading down the sides of the pile should be held to a minimum. Material shall be reclaimed from wedge-shaped piles with an endloader or equipment having similar type loading action working from the end of the pile, with care taken to work the entire width of the pile to remix the material as much as possible. Aggregate-handling methods using tunnel conveyor systems to reclaim aggregate from coned surge piles should be checked for consistency of gradation. Consistency of the gradation should be checked according to the procedures and requirements described in Article 30.3(b) for checking uninspected stockpiles during loading-out procedures. The method of aggregate-handling and stockpiling currently in use at a particular source shall be considered satisfactory provided that the product, when checked at a loading-out point, meets the gradation requirements described in Article 30.3(b)1.

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State of Illinois
Department of Transportation
Bureau of Materials and Physical Research

POLICY MEMORANDUM

Revised: July 1, 2015	6-08.2
This Policy Memorandum supersedes number 6-08.1 dated June 6, 2014	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS
AGGREGATE, HOT-MIX ASPHALT (HMA), AND
PORTLAND CEMENT CONCRETE (PCC) PRODUCERS

SUBJECT: MINIMUM PRIVATE LABORATORY REQUIREMENTS FOR
CONSTRUCTION MATERIALS TESTING OR MIX DESIGN

1.0 DEFINITIONS

AASHTO R 18 - The American Association of State Highway and Transportation Officials (AASHTO) Standard for "Establishing and Implementing a Quality System for Construction Materials Laboratories." The principles of AASHTO R 18 are used by the Bureau of Materials and Physical Research (BMPR) to administer the qualified laboratory program for **District** and **Private Laboratories**.

ACCREDITED LAB – A laboratory that is currently accredited by the AASHTO Accreditation Program (AAP) or other accrediting body recognized by FHWA.

BMPR LABORATORY - The Department's central laboratory maintained and operated by the Bureau of Materials and Physical Research (BMPR). The BMPR Laboratory administers the qualified laboratory program for **District** and **Private Laboratories**.

CONSULTANT - A Private firm which performs construction materials testing for the **Department**, **Producer**, or **Contractor**. **Department** prequalification and AASHTO accreditation requirements apply where **Department** construction testing is performed directly for the **Department** under a **Department** contract or subcontract.

CONTRACTOR - The individual, firm, partnership, joint venture, or corporation contracting with the **Department** for performance of prescribed work.

DEPARTMENT – Illinois Department of Transportation (IDOT), including its Districts and Central Bureau offices.

DISTRICT LABORATORY - A **Department** laboratory that is operated by a District.

FIELD TESTS – Tests that may be performed outside of a laboratory, for example, a portland cement concrete (PCC) or hot-mix asphalt (HMA) test performed at the jobsite.

HMA MIX DESIGN LABORATORY – Any **Private Laboratory** that has a **Department** approved HMA mix design lab. Consultants that are prequalified with the **Department** for HMA Mix Design must be capable of performing the tests listed in Table 1 under HMA Design.

PRIVATE LABORATORY - Any construction materials testing or design laboratory not operated by the **Department**. This includes **Contractor**, **Producer**, or **Consultant** laboratories performing Quality Control (QC), Quality Assurance (QA), acceptance, independent assurance, or any other required or contracted testing on a **Department** project.

PRODUCER - An individual or business entity providing materials for performance of prescribed work.

QUALIFIED LABORATORIES – Laboratories that are inspected and approved by the **Department**. FHWA's Construction regulations (23 CFR 637.203) define these as *Laboratories that are capable as defined by appropriate programs established by each state transportation department. As a minimum, the qualification program shall include provisions for checking test equipment, and the laboratory shall keep records of calibration checks.*

QUALIFIED PERSONNEL - Personnel with demonstrated and documented capability to perform the applicable inspection and testing. The minimum requirement for aggregate, hot-mix asphalt (HMA) or Portland cement concrete (PCC) testing is successful completion of the prescribed **Department** Quality Control/Quality Assurance (QC/QA) Trained Technician classes. (Note: Additional personnel or experience requirements may apply to labs performing professional service work for the **Department**, e.g. Professional Engineer (P.E.) registrations, resumes, documented experience. When required, such notice will be provided in the prequalification process or solicitation notice.)

QUALITY ASSURANCE TESTING CONSULTANT – A Professional Engineering firm that is prequalified by the **Department** to perform field and/or laboratory tests for the **Department**. Required tests for quality assurance testing consultants are listed in Table 2.

QUALITY ASSURANCE LABORATORY - Any laboratory used for Quality Assurance (QA) testing (**Department** tests) required by the **Department**. Required tests for quality assurance laboratories are listed in Table 2.

QUALITY CONTROL LABORATORY - Any laboratory used for Quality Control (QC) testing (**Contractor** or **Producer** tests) required by the **Department**. Required tests for quality control laboratories are listed in Table 1.

QUALITY CONTROL (QC) MANAGER – An employee (or **Consultant**) of a **Contractor** or **Producer** who is responsible for compliance with the QC/QA requirements in a **Department** contract or policy.

TECHNICAL MANAGER - The individual with responsibility for the overall operations, condition, and maintenance of the **Private Laboratory**. The Technical Manager shall be identified in writing. The Technical Manager is not required to be the **QC Manager** defined in the contract. However, the Technical Manager shall be familiar with the Quality Control (QC) testing requirements and the specified equipment.

2.0 SCOPE

This policy governs the minimum qualifications for materials **Quality Control** and **Quality Assurance Laboratories** operated by **Contractors**, **Producers** and **Consultants**. It applies to aggregate, hot-mix asphalt (HMA) and Portland cement concrete (PCC) testing laboratories.

3.0 PURPOSE

- To ensure that **Private Laboratories** are equipped and maintained at a uniform and high level of quality.
- To establish a uniform procedure for evaluating and approving **Private Laboratories**.
- To maintain a uniform standard for inspecting test equipment and test procedures.

4.0 AUTHORITY

Federal regulations (23 CFR Part 637) require the **Department** to establish a program for "qualifying" construction laboratories involved in tests which are used for acceptance. Under the **Department's** QC/QA specifications, **Contractor/Producer** test results are used in the acceptance process.

5.0 REFERENCE DOCUMENTS

- IDOT *Standard Specifications for Road and Bridge Construction.*
- IDOT *Manual of Test Procedures for Materials.*
- IDOT QC/QA Specifications for Hot-Mix Asphalt and Portland Cement Concrete.
- AASHTO, ASTM, and IDOT Test Procedures.
- Code of Federal Regulations (23 CFR Part 637).
- **Department** Policy MAT-15, "Quality Assurance Procedures for Construction."

6.0 PRIVATE LABORATORY REQUIREMENTS

6.1 Personnel Qualifications/Responsibilities

6.1.1 All testing for **Department** contracts shall be performed by **Qualified Personnel** as specified in the contract.

6.1.2 The **Department** will maintain a computer database of **Qualified Personnel** who have successfully passed the appropriate QC/QA classes.

6.2 Facilities and Equipment

6.2.1 The **Department** shall approve all **Private Laboratories** used on **Department** projects.

6.2.2 Each **Private Laboratory** shall maintain the equipment and facilities necessary to perform the tests as appropriate for the product to be tested. A list of required **Private Laboratory** tests is provided in Tables 1 and 2.

6.2.3 Each **Private Laboratory** shall have adequate floor space to efficiently conduct required tests. Suggested minimum floor space is provided under "Model Quality Control Plans" in the Manual of Test Procedures for Materials.

6.2.4 Each **Private Laboratory** shall have HVAC equipment capable of maintaining a room temperature of 20 to 30º C (68-86º F). A **Private Laboratory** that performs only aggregate gradation and/or aggregate moisture testing is exempt from this requirement.

6.2.5 All equipment shall be as specified in the current Manual of Test Procedures for Materials.

7.0 QUALITY SYSTEM CRITERIA

7.1 AASHTO R 18

Each **Quality Assurance Private Laboratory** shall establish and implement a quality system which meets the criteria from **AASHTO R 18**. Accredited Laboratories shall comply with all of **AASHTO R 18** for AMRL and ASTM C 1077 for CCRL, with the exception of Sections 6.1.7.4 and Section 6.1.7.5 of ASTM C 1077. The **Quality Assurance Private Laboratory** shall document staff technical proficiency in line with the requirements of AASHTO R 18 section 5.5.2.

7.2 Technical Manager

Each **Private Laboratory** shall have a **Technical Manager** (however titled) who has overall responsibility for the technical operations of the **Private Laboratory**. The **Technical Manager** shall be responsible for equipment maintenance and calibration, maintaining records, and ensuring that current test procedures are utilized. If the **Private Laboratory** is prequalified in a Professional **Consultant** service category, a licensed Illinois Professional Engineer shall have direct supervision of the laboratory.

7.3 Equipment Calibration and Verification

The **Quality Control Private Laboratory** shall calibrate or verify all testing equipment associated with tests performed by the **Quality Control Private Laboratory** according to Table 3 which includes the maximum interval for calibrating most laboratory equipment. Heavy use or specific test requirements may justify more frequent checks. **Department** verification of **Quality Control Private Laboratory** equipment shall not be construed as part of, or substitute for, the equipment calibration requirement, except for **Department** verification of the gyratory compactor using the DAV-2 and **Department** verification of the gyratory molds using the bore gauge.

The **Quality Assurance Private Laboratory** shall calibrate, standardize, and check all significant equipment associated with tests the laboratory performs according to AASHTO R 18 for AMRL and ASTM C 1077 for CCRL in addition to Table 3 which may include equipment required for Illinois Modified Tests or Illinois Test Procedures.

7.4 Proficiency Testing

Private Laboratory qualifications may include round-robin proficiency testing conducted by the **Department**. Results of proficiency testing may be considered in the overall evaluation of the **Private Laboratory** to conduct specific tests.

7.5 Records

7.5.1 Test Records – Each **Private Laboratory** shall maintain test records which contain sufficient information to permit verification of any test report.

7.5.2 Records Retention - Each **Private Laboratory** shall maintain documentation of the internal quality controls. At a minimum, the records shall include:

- Documentation of assignment of personnel responsible for internal quality controls.
- Documentation of equipment calibration.
- Logs of sample pick-up shall be maintained for a minimum period of three years.
- All documentation shall be maintained and available to **Department** inspection for a period of three years.

7.5.3 Equipment Calibration and Verification Records - Calibration records shall include the minimum information listed below. **AASHTO R 18** and ASTM Standard C 1077 provide additional guidance for calibration of most testing equipment.

1. Description
2. Model & Serial Number
3. Name of person calibrating
4. Calibration equipment used
   (e.g., standard weights, proving rings, thermometers)
5. Date calibrated & next due date
6. Reference procedure used
7. Results of calibration / verification

7.5.4 Proficiency Sample Records – Each **Private Laboratory** shall retain results of participation in any proficiency sample program, including the documentation of steps taken to determine the cause of poor results and corrective action taken.

7.6 Publications

Each **Approved Private Laboratory** shall maintain current copies or electronic access to all test procedures performed and the Manual of Test Procedures for Materials.

8.0 <u>LABORATORY INSPECTIONS</u>

8.1 General

The **Department** will approve **Private Laboratories** by inspection.

- AGGREGATE LABORATORIES - Initial inspections and re-inspections will be performed by the District.

- OTHER LABORATORIES - Initial inspections are performed by the **Bureau of Materials and Physical Research**. Re-inspections are performed by the District.

8.2 AASHTO Accredited Private Laboratories

8.2.1 Current AASHTO accreditation of the **private** laboratory is a prerequisite for **Consultant** prequalification as a **Quality Assurance Testing Consultant**. Conditions for prequalification may be found in the prequalification instructions and forms.

AASHTO accreditation does not waive the right of the **Department** to conduct inspections and/or re-inspections.

AASHTO accreditation is required for **Quality Assurance Testing Consultants** prior to initial **BMPR** inspection. AMRL (AASHTO Material Reference Laboratory) shall provide assessment for HMA and Aggregates. CCRL (Cement and Concrete Reference Laboratory) shall provide assessment for Portland Cement Concrete.

8.3 Initial Inspection

- Facilities - Physical and environmental conditions.
- Equipment - Test apparatus for specification compliance.
- Documentation - Calibration and verification records.
- Personnel - A review of qualified personnel credentials.
- Observation - The **Private Laboratory** may be required to demonstrate **Required Tests**. Some test procedures, such as field tests, may be evaluated through discussion with laboratory personnel.
- Report - The **Private Laboratory** will be provided with a report listing those tests for which it is approved. The report will note deficiencies.

8.4 Initial HMA and PCC Laboratory Inspections

8.4.1 The **Private Laboratory** shall submit a written request for an inspection to the District. The request shall indicate the following:

- The location of the **Private Laboratory**.
- The type of **Private Laboratory**, i.e., QC, QA or HMA Mix Design; aggregate, HMA, PCC.
- The name of the **Technical Manager**, who will be present for the inspection.
- The date the **Private Laboratory** will be ready for inspection.

8.4.2 The District will notify the **BMPR Laboratory** of the inspection request. **BMPR** personnel will establish a tentative date to perform the inspection.

8.4.3 The District will perform an inspection approximately seven calendar days before the **BMPR** inspection. The District will verify that the **Private Laboratory** is ready for inspection and notify **BMPR**.

8.4.4 **BMPR** personnel will perform the inspection and prepare a preliminary report. Standard inspection forms and a preliminary report, developed and maintained by the **BMPR Laboratory**, will be used.

8.4.5 **BMPR** personnel will assign identification numbers to all test equipment. Unless a District has an established numbering system, the following sequences will be used.

Sieves
e.g., IL07 -1418-01
where: IL = State
07 = inspection year
1418-01 = Producer/Supplier Number

Sieves are engraved on the inside of the bottom lip directly beneath the label.

HMA Equipment
e.g., IL07B1 - 123
where: IL = State
07 = inspection year
B = hot mix asphalt (bituminous)
1 = district number
123 = sequential numbers

PCC Equipment
e.g., IL07C1 - 123
where: IL = State
07 = inspection year
C = concrete
1 = district number
123 = sequential numbers

*The numbering system prior to 2007 was IL07-123 for HMA and IL07CND1-123 for PCC. The change was made to make the numbering system more uniform.

8.4.6 **BMPR** personnel will perform a close-out with the **Technical Manager** and the District representative. The **Technical Manager** and the District will be given a copy of the preliminary report.

8.4.7 If a review of the preliminary report indicates there are no deficiencies, **BMPR** will provide written notification to the **Private Laboratory** indicating the **Private Laboratory** is now an approved **Quality Control** or **Quality Assurance Private Laboratory**. The notification will include an equipment list. A copy of the notification will be provided to the District.

8.4.8 If the preliminary report indicates there are deficiencies, **BMPR** will provide written notification to the **Private Laboratory**, indicating the deficiencies and that corrective action is required. A copy of the written notification will be provided to the District.

8.4.9 After correction of all cited deficiencies, the **Private Laboratory** shall notify the District. The District will inspect the **Private Laboratory** to verify the deficiencies have been corrected and will notify **BMPR** in writing.

8.4.10 **BMPR** will provide written notification to the **Private Laboratory**, indicating the private laboratory is now an approved **Quality Control** or **Quality Assurance Private Laboratory**. The notification will include an equipment list. A copy of the written notification will be provided to the District.

8.4.11 Uncorrected deficiencies will not be waived. Equivalent equipment specifications may be approved only with the written approval of BMPR's Engineer of Tests.

8.5 Initial Aggregate Laboratory Inspection

For an aggregate **Private Laboratory**, the procedures outlined in 8.4 shall be followed, except District personnel will perform the inspection instead of personnel from **BMPR**.

8.6 Re-Approval of Approved Private Laboratories

8.6.1 The re-inspection of **Private Laboratories** shall be conducted at intervals deemed appropriate by the District. The interval between inspections shall not exceed two calendar years. The District's evaluation may include the following:

- Physical inspection of the laboratory facility and equipment.
- Review of the **Private Laboratory's** internal quality plan and documentation in accordance with this policy and those parts of **AASHTO R 18** incorporated by this policy.
- Observations of tests performed by qualified personnel.
- Results of split sample testing between the **Private Laboratory** and the District.
- Results of proficiency sample testing programs conducted by the **Department**.
- Overall past performance and experience.

8.6.2 The District may not waive any requirements for **Private Laboratories** or test equipment for **Required Tests**.

8.6.3 The District shall issue a letter of re-approval to the **Private Laboratory**, or provide a written and itemized deficiency list. The **Private Laboratory** shall notify the District when deficiencies are corrected and ready for re-inspection.

8.6.4 At any time, if the District identifies deficiencies in the facility, equipment, or test procedures that could affect the results of any QC or QA tests, the District will require the **Private Laboratory** to take immediate action to correct the deficiency.

9.0 EXEMPTIONS – AASHTO Accreditation Program

If a **Private Laboratory** maintains current accreditation through the AASHTO Accreditation Program (AAP) for the appropriate test procedures, the District may waive the re-inspection requirements of this policy. To enact the waiver, the **Private Laboratory** must provide copies of inspection reports and proficiency sample results to the District. This waiver does not apply to the initial inspection requirements, including the required equipment list.

10.0 LABORATORY DATABASE

The **Department** will maintain a computer database to monitor the approval status of **Private Laboratories**. The database will include the following information:

- Laboratory Codes (Department, Producer, etc.)
- Responsible District
- Type Laboratory (Aggregate, HMA, PCC, Other)
- Demographics (Address, etc.)
- Date Inspected
- Approval Status

Laura R. Mlacnik, P.E.
Acting, Engineer of Materials
and Physical Research

Attachments

TABLE1
QUALITY CONTROL PRIVATE LABORATORY TESTS

	PROCEDURE		PRIVATE LAB TYPE				
	Illinois Test Procedure	ASTM	AGG	HMA QC	HMA DESIGN	PCC QC	TITLE
AGGREGATE TESTS	ITP 2	____	√	√	√	√	Sampling of Aggregates
	ITP 11	____	√	√	√	√	Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
	ITP 19	____	√[1]			√	Bulk Density ("Unit Weight") and Voids in Aggregate
	ITP 27	____	√	√	√	√	Sieve Analysis of Fine and Coarse Aggregate
	ITP 84	____	√[2]				Specific Gravity and Absorption of Fine Aggregate
	ITP 85	____	√[2]				Specific Gravity and Absorption of Coarse Aggregate
	ITP 248	____	√	√	√	√	Reducing Samples of Aggregate to Testing Size
	ITP 255	____	√	√	√	√	Total Evaporable Moisture Content of Aggregate by Drying

Note 1: Required for laboratories that test Air Cooled Blast Furnace Slag.

Note 2: Required for laboratories that run the Department's Slag Producers' Self-Testing Program

TABLE1 (CONT'D)
QUALITY CONTROL PRIVATE LABORATORY TESTS

	PROCEDURE		PRIVATE LAB TYPE				
	AASHTO (Illinois Modified)	ASTM (Illinois Modified)	AGG	HMA QC	HMA DESIGN	PCC QC	TITLE
HOT-MIX ASPHALT TESTS	T 30 (IL)			√	√		Mechanical Analysis of Extracted Aggregate
	T 164 (IL)			√[3] Or T 287 or T 308[4]	√[3]		Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
	T 166 (IL)			√	√		Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
	T 209 (IL)			√	√		Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt Paving Mixtures
	T 245 (IL)						Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus
	T 283 (IL)				√		Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
	T 287 (IL)			√ Or T 164 or T 308[4]			Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method
	T 308 (IL)			√ Or T 164 or T 287[4]	√		Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
	T 312 (IL)			√	√		Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
	_____	D 2950 (IL)		√			Determination of Density of Bituminous Concrete in Place by Nuclear Methods – Field Test; not observed during Lab Inspection

Note 3: Method A or B shall be used for quantitative extraction. Method A or E shall be used to recover binder for qualitative analysis. If a QC HMA Mix Design laboratory does not have the ability to perform AASHTO T 164 (IL), outsourcing the test to a qualified QC or QA laboratory will be permitted.

Note 4: Determined by which piece of equipment is more appropriate for the lab to determine asphalt content.

TABLE1 (CONT'D)
QUALITY CONTROL PRIVATE LABORATORY TESTS

	PROCEDURE		PRIVATE LAB TYPE				TITLE
	AASHTO (Illinois Modified)/Illinois Test Procedure	ASTM (Illinois Modified)	AGG	HMA QC	HMA DESIGN	PCC QC	
PORTLAND CEMENT CONCRETE TESTS	R 39 (IL)					Required if developing mix designs.	Making and Curing Concrete Test Specimens in the Laboratory
	R 60 (IL)					√	Sampling Freshly Mixed Concrete
	T 22 (IL)					√[5] Either T 22 or T 177	Compressive Strength of Cylindrical Concrete Specimens
	T 23 (IL)					√	Making and Curing Concrete Test Specimens in the Field
	T 119 (IL)					√	Slump of Hydraulic Cement Concrete
	T 121 (IL)					√	Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
	T 152 (IL)					√	Air Content of Freshly Mixed Concrete by the Pressure Method - Type A or B Air Meter
	T 177 (IL)					√[5] Either T 22 or T 177	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
	T 196 (IL)						Air Content of Freshly Mixed Concrete by the Volumetric Method
	T 231 (IL)					Either T 231 or C 1231	Capping Cylindrical Concrete Specimens
		C 1064 (IL)				√	Temperature of Freshly Mixed Hydraulic Cement Concrete
		C 1231 (IL)				Either T 231 or C 1231	Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
	ITP 301	____					Fine Aggregate Moisture Content by the Flask Method
	ITP 302	____					Aggregate Specific Gravity and Moisture Content by the Dunagan Method
	ITP 303	____					Fine or Coarse Aggregate Moisture Content by Pycnometer Jar Method
	ITP 306	____				Required if developing mix designs.	Voids Test of Coarse Aggregate for Concrete Mixtures

Note 5: For an exception to the strength testing requirement of performing compressive or flexural testing (Example: Labs at Concrete Producer Plants), refer to the Department's "Required Sampling and Testing Equipment for Concrete" document and check with district for approval of exception.

TABLE 2
REQUIRED TESTS – QUALITY ASSURANCE TESTING CONSULTANTS [1,2]

	PROCEDURE		REQUIRED FOR PREQUALIFICATION			TITLE
	Illinois Test Procedure/ AASHTO	ASTM	IDOT QA	AAP On-Site Assessment	AAP Proficiency Assessment	
AGGREGATE	ITP 2		√			Sampling of Aggregates
	ITP 11		√			Materials Finer Than 75-µm (No. 200)Sieve in Mineral Aggregates by Washing
		T 11		√	√	
	ITP 19		√			Bulk Density ("Unit Weight") and Voids in Aggregate
		T 19		√		
	ITP 27		√			Sieve Analysis of Fine and Coarse Aggregates
		T 27		√	√	
	ITP 84[3]		√			Specific Gravity and Absorption of Fine Aggregate
		T 84		√	√	
	ITP 85[3]		√			Specific Gravity and Absorption of Coarse Aggregate
		T 85		√	√	
	ITP 248		√			Reducing Samples of Aggregate to Testing Size
		T 248		√		
	ITP 255		√			Total Evaporable Moisture Content of Aggregate by Drying
		T 255		√		

Note 1: Compliance with IDOT test methods will be required for IDOT QA lab inspections. However, AMRL or CCRL lab inspections shall require compliance with the corresponding AASHTO or ASTM test methods.

Note 2: QA labs have the option to be HMA/AGG or PCC/AGG approved.

Note 3: Required for laboratories that run the Department's Slag Producers' Self-Testing Program.

TABLE 2 (CON'T)
REQUIRED TESTS – QUALITY ASSURANCE TESTING CONSULTANTS [1, 2]

	PROCEDURE		REQUIRED FOR PREQUALIFICATION			TITLE
	Illinois Modified/A AASHTO	ASTM Illinois Modified	IDOT QA	AAP On-Site Assessment	AAP Proficiency Assessment	
HOT-MIX ASPHALT	T 30 (IL)		√			Mechanical Analysis of Extracted Aggregate
	T 164 (IL)		√			Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
	T 164			√		
	T 166 (IL)		√			Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
	T 166			√	√	
	T 209 (IL)		√			Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt Paving Mixtures
	T 209			√	√	
	T 245 (IL)					Resistance of Plastic flow of Asphalt mixtures Using Marshall Apparatus
	T 283 (IL)		√			Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
	T 283			√		
	T 287 (IL)		√[4]			Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method
	T 308 (IL)		√			Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
	T 308			√	√	
	T 312 (IL)		√			Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
	T 312			√	√	
		D 2950 (IL)	√			Density of Bituminous Concrete in Place by Nuclear Method – Field Test

Note 1: Compliance with IDOT test methods will be required for IDOT QA lab inspections. However, AMRL or CCRL lab inspections shall require compliance with the corresponding AASHTO or ASTM test methods.

Note 2: QA labs have the option to be HMA/AGG or PCC/AGG approved.

Note 4: Requirement determined on case to case basis by district in which lab is located.

TABLE 2 (CON'T)
REQUIRED TESTS – QUALITY ASSURANCE TESTING CONSULTANTS [1, 2]

	PROCEDURE		REQUIRED FOR PREQUALIFICATION			TITLE
	Illinois Modified/ AASHTO/Illinois Test Procedure	ASTM/Illinois Modified	IDOT QA	AAP On-Site Assessment	AAP Proficiency Assessment	
PORTLAND CEMENT CONCRETE		C 192			√	Making and Curing Concrete Test Specimens in the Laboratory
	R 60 (IL)	C 172	√	√		Sampling Freshly Mixed Concrete
	T 22 (IL)	C 39	√	√	√	Compressive Strength of-Cylindrical Concrete Specimens
	T 23 (IL)	C 31	√	√	√	Making and Curing Concrete Test Specimens in the Field
	T 119 (IL)	C 143	√	√	√	Slump of Hydraulic Cement Concrete
	T 121 (IL)	C 138	√	√	√	Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
	T 152 (IL)	C 231	√	√	√	Air Content of Freshly Mixed Concrete by the Pressure Method-Type A or B Air Meters
	T 177 (IL)	C 78	√	√[5]		Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
	T 196 (IL)	C 173	[6]	[6]	[8]	Air Content of Freshly Mixed Concrete by the Volumetric Method
	T 231 (IL)	C 617	[6]	[6]		Capping Cylindrical Concrete Specimens
		C 1064 (IL) C 1064	√	√		Temperature of Freshly Mixed Hydraulic Cement Concrete
		C 1231 (IL) C 1231	√	√		Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
	ITP 301		[6]			Fine Aggregate Moisture Content by the Flask Method
	ITP 302		[6]			Aggregate Specific Gravity and Moisture Content by the Dunagan Method
	ITP 303		[6]			Fine or Coarse Aggregate Moisture Content by Pycnometer Jar Method
	ITP 306		[7]			Voids Test of-Coarse Aggregate for Concrete Mixtures

Note 1: Compliance with IDOT test methods will be required for IDOT QA lab inspections. However, AMRL or CCRL lab inspections shall require compliance with the corresponding AASHTO or ASTM test methods.

Note 2: QA labs have the option to be HMA/AGG or PCC/AGG approved.

Note 5: The AAP on-site assessment is not required for Illinois type portable beam breakers but is required for all other types of beam breakers. Additional information regarding use of portable PCC labs and their approval is provided in Department Policy MAT-15, "Quality Assurance Procedures for Construction".

Note 6: Test equipment must be presented during an inspection if the consultant lab has the ability to perform the test.

Note 7: Test equipment must be presented during an inspection if consultant lab has the ability to verify PCC mix designs.

Note 8: Test must be performed if consultant lab has the ability to perform the test.

TABLE 3[1]
EQUIPMENT CALIBRATION SCHEDULE

EQUIPMENT	REQUIREMENT	MAXIMUM INTERVAL (MONTHS)
AGGREGATE & GENERAL		
Unit Weight Measures	Standardize	12
General Purpose Balances, Scales	Commercial Service or Verification using standardized NIST traceable Masses	12
Standard Masses	Standardize	12
Mechanical Shakers	Check Sieving Thoroughness	12
Ovens	Standardize Thermometric Device	12
Coarse Sieves (Openings ≥ 4.75 mm)	Check Physical Condition and Dimensions of Openings	12
Fine Sieves (Openings <4.75 mm)	Check Physical Condition	12
Working Thermometers	Standardize with calibrated NIST traceable Reference Thermometer	12
Reference Thermometer	Calibrate	60
Timers	Check Accuracy	12
Calipers and Micrometers	Standardize	12
Caliper Checker (Gauge Blocks or Caliper Master)	Calibrate	60
HOT MIX ASPHALT		
Gyratory Compactor	Verify Angle, Pressure, Height	Once a month during use
	Verify Angle using a DAV-2	12
Plates, Ram Face, Molds	Check Critical Dimensions	12
Marshall Hammer	Check Physical Condition	12
	Standardize	36
Ignition Furnace	Standardize	Each Mix
Vacuum Pump	Check Pressure	12
Tensile Strength Machine	Standardize	12
Breaking Heads	Check Critical Dimensions	12
Pycnometers	Standardize Volume	12
Mixers	Check Physical Condition	12
Water Baths	Standardize	12
Extraction Equipment	Check Physical Condition	12
Residual Pressure Manometer	Standardize	12
Bore Gauge	Standardize	Each Use
Master Ring	Calibrate	60
Hamburg Wheel-Track		
Water Temperature	Verify	12
Speed	Verify	12
Wheel Weight	Verify	12
LVDT'S	Verify	12

Note 1: See AASHTO R18 for equipment calibration terminology definitions.

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EQUIPMENT	REQUIREMENT	MAXIMUM INTERVAL (MONTHS)
PORTLAND CEMENT CONCRETE		
Air Meters (Pressure Type)	Standardize During Use	3 (Type B)
	Standardize	12 (Type A)
Air Meters (Volumetric Type)	Standardize	12
Compression & Flexural Testing Machine	Calibrate	12
Capping Material	Check Strength	3 or New Shipment
Slump Cones	Check Critical Dimensions	12
Reusable Molds	Check Critical Dimensions	12
Single Use Molds	Check Dimension	Each Shipment
Neoprene Pads	Check Physical Condition	Track Usage
Metal Retainers	Check Critical Dimensions	3
Metal Stem Thermometers	Standardize with calibrated NIST traceable Reference Thermometer	12
Moist Room/Storage Tanks Recording Thermometer or Max/Min Thermometer	Standardize with calibrated NIST traceable Reference Thermometer	12

Note 1: See AASHTO R 18 for equipment calibration terminology definitions.

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Illinois Department of Transportation

Aggregate Laboratory Equipment
Appendix D3

Effective Date: October 1, 1995
Revised: June 1, 2012

All equipment listed is required unless noted otherwise. This list recommends 12" sieves and 12" shakers. Individual needs may vary for the specific products. Eight-inch sieves and other alternate equipment may be substituted provided they conform to Illinois Test Procedure or ASTM requirements and are approved by the Engineer.

Quantity	Description
1	Mechanical Sieve Shaker – 12" sieve capacity
1	Coarse Aggregate Sample Splitter (Illinois Test Procedure 248, Method A)
4	Splitter pans, for coarse aggregate
1	Fine Aggregate Sample Splitter (as required)
4	Splitter pans, for fine aggregate
1	Sink and clear Water Supply
1	Oven, electric drying, capable of maintaining a uniform temperature of 110± 5 ˚C (230 ± 9 ˚F) Optional – see Hot Plate
2	Hot plate, electric, or Burner, gas – in lieu of oven if approved by the Engineer
1	Gloves, pair, insulated
1	Balance, electronic, 8,000-gram capacity, 0.1-gram readability
15	Sample Pans, (constructed to minimize loss of material during testing)
5	Pans, holding, typical round – 12 in. minimum diameter
2	Spoon, stainless steel, 15 in. minimum
1	Brush, stencil
1	Brush, brass
1	Knife, putty
2	Thermometers, - 18 to 150 ˚C (0 to 300 ˚F), readable to 0.5 ˚C (1.0 ˚F) to verify oven temperature.
1	Set (11) Fine Aggregate Sieves, brass, 8 in. 12 in. diameter, with brass or stainless cloth, -- 9.5 mm, 4.75 mm, 2.36 mm, 2.00 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 180 µm, 150 µm, 75 µm (3/8 in., No. 4, No. 8, No. 10, No. 16, No. 30, No. 40, No. 50, No. 80, No. 100, No. 200), according to ASTM E 11.
1	Lid for 12 in. sieve
1	Pan, catch, bottom, 12 in.
1	Set (11) Coarse Aggregate Sieves, brass, 12 in. diameter, with brass or stainless cloth, -- 37.5 mm, 25 mm, 19 mm, 16 mm, 12.5 mm, 9.5 mm, 6.3 mm, 4.75 mm, 2.36 mm, 1.18 mm, 75 µm (1 1/2 in., 1 in., 3/4 in., 5/8 in., 1/2 in., 3/8 in., No. 4, No. 8, No. 16, No. 200), according to ASTM E 11.
1	Additional 12 in. brass sieves are required for testing larger coarse aggregate. (e.g. A 1 3/4 in. sieve is required for CA05 testing.)
1	Wash Sieve, 12 in. diameter, No. 200, recommended 3 1/4 in. nominal height*
1	Wash Sieve, 12 in. diameter, No. 16, recommended 3 1/4 in. nominal height*

*Distance from the top of the frame to the sieve cloth surface.

Illinois Department of Transportation

Aggregate Laboratory Equipment
Appendix D3
(continued)

Effective Date: October 1, 1995
Revised: June 1, 2012

VENDOR LIST – For information only

Baxter Healthcare Corp.
One Baxter Parkway
Deerfield, IL 60015-4625
Phone: 800-422-9837

Curtin Matheson Scientific, Inc. (CMS)
1225 North Michael Drive
Wood Dale, IL 60191
Phone: 800-323-6572

Gilson Company, Inc.
P.O. Box 200
Lewis Center, OH 43035-200
Phone: 800-444-1508

Greco Sales, Inc.
901 East Adams Street
Springfield, IL 62708
Phone: 800-252-8522
217-528-2548

Humboldt Scientific, Inc.
3801 North 25th Avenue
Schiller Park, IL 60176
Phone: 800-544-7220

Rainhart Co.
604 William Street
P.O. Box 4533
Austin, TX 78765
Phone: 800-628-0021

VWR Scientific
3850 North Wilke Road
Suite 300
Arlington Heights, IL 60004
Phone: 847-463-1233

Illinois Department of Transportation
QC/QA PROCEDURE
Procedure for Sample Comparison
Appendix A5

Effective Date: November 10, 1997
Revised Date: June 1, 2012

Precision Comparison Table*
State Monitor vs. Producer

	Size Fraction Between Consecutive Sieves	*Tolerance (%)*
Coarse Aggregate:	0 to 3.0	2
	3.1 to 10.0	3
	10.1 to 20.0	5
	20.1 to 30.0	6
	30.1 to 40.0	7
	40.1 to 50.0	9
Fine Aggregate:	0 to 3.0	1
	3.1 to 10.0	2
	10.1 to 20.0	3
	20.1 to 30.0	4
	30.1 to 40.0	4

* Split Samples only (reported values)

† The State Monitor Sample shall be used to pick tolerances.

Comparison Method

Calculate size fraction between consecutive sieves, including cutter sieves, for both the State Monitor and Producer test results (% Passing).

Show the fraction retained between consecutive sieves for both gradations, the fraction difference on each consecutive sieve grouping between the Monitor and Producer gradation, the applicable tolerance (if coarse aggregate, use coarse aggregate tolerances and, if fine aggregate, use fine aggregate tolerances- If size fraction between consecutive sieves exceeds largest fraction shown, use tolerance for largest size fraction), and whether they are in-tolerance or out-of-tolerance.

Illinois Department of Transportation
QC/QA PROCEDURE
Procedure for Sample Comparison
Appendix A5
(continued)
Effective Date: November 10, 1997
Revised Date: June 12, 2012

If the comparison has no out-of-tolerance fractions, both sample results are considered valid. If an out-of-tolerance situation has been identified, both the producer certified technician and the State inspector shall immediately investigate the splitting procedure, test equipment, test method, and calculations for possible equipment failure or procedure errors. The State Monitor Sample shall always take precedence unless shown to be invalid during investigation.

Example:

CA11	1" (25 mm)	3/4" (19 mm)	5/8" (16 mm)	1/2" (12.5 mm)	3/8" (9.5 mm)	1/4" (6.3 mm)	#4 (4.75 mm)	#16 (1.18 mm)	#200 (75 µm)
Monitor, % Passing	100	87	67	36	13	4	2	1	0.7
Producer, % Passing	100	89	67	44	14	5	3	2	1.3

Comparison Data

Consecutive Sieve Sizes	Monitor Fraction	Producer Fraction	Fraction Difference	Applicable Tolerance	Disposition
1" and 3/4" (25 mm and 19 mm)	13	11	2	5	OK
3/4" and 5/8" (19 mm and 16 mm)	20	22	2	5	OK
5/8" and 1/2" (16 mm and 12.5 mm)	31	23	8	7	OUT
1/2" and 3/8" (12.5 mm and 9.5 mm)	23	30	7	6	OUT
3/8" and 1/4" (9.5 mm and 6.3 mm)	9	9	0	3	OK
1/4" and #4 (6.3 mm and 4.75 mm)	2	2	0	2	OK
#4 and #16 (4.75 mm and	1	1	0	2	OK
#16 and #200 (1.18 mm and 75 µm)	0.3	0.7	0.4	2	OK
#200 and Pan (75 µm and Pan)	0.7	1.3	0.6	2	OK

GUIDELINE FOR COMPARISON

Example:

CM 11

If the comparison has no out-of-tolerance fractions, both sample results are considered valid. If an out-of-tolerance situation has been identified, both the producer certified technician and the State inspector shall immediately investigate the splitting procedure, test equipment, test method, and calculations for possible equipment failure or procedure errors. The State Monitor Sample shall always take precedence unless shown to be invalid during investigation.

Example:

CM11	1" (25 mm)	3/4" (19 mm)	5/8" (16 mm)	1/2" (12.5 mm)	3/8" (9.5 mm)	1/4" (6.3 mm)	#4 (4.75 mm)	#16 (1.18 mm)	#200 (75 µm)
Monitor, % Passing	100	95	70	40	20	11	4	3	1.9
Producer, % Passing									

Comparison Data

Consecutive Sieve Sizes	Monitor Fraction	Producer Fraction	Fraction Difference	Applicable Tolerance	Disposition
1" and 3/4" (25 mm and 19 mm)					
3/4" and 5/8" (19 mm and 16 mm)					
5/8" and 1/2" (16 mm and 12.5 mm)					
1/2" and 3/8" (12.5 mm and 9.5 mm)					
3/8" and 1/4" (9.5 mm and 6.3 mm)					
1/4" and #4 (6.3 mm and 4.75 mm)					
#4 and #16 (4.75 mm and 1.18mm)					
#16 and #200 (1.18 mm and 75 µm)					
#200 and Pan (75 µm and Pan)					

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Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES

Effective: February 1, 2014

COARSE AGGREGATE GRADATION TABLE																			
CA(CM)[1,2]	**Minimum Field Sample Size [3]**	**Minimum Test Sample Size[3]**	**3"**	**2 1/2"**	**2"**	**1 3/4"**	**1 1/2"**	**1"**	**3/4"**	**5/8"**	**1/2"**	**3/8"**	**1/4"**	**#4**	**#8**	**#16**	**#40**	**#50**	**#200**
CA01	110 lbs (50 kg)	10,000 g	X	X[MN]	X		X	X											X
CA02	110 lbs (50 kg)	10,000 g		X	X[MN]		XC	X	XC		X			X		X	X		X
CA03	110 lbs (50 kg)	10,000 g		X	X[MN]		X	X			X								X
CA04	110 lbs (50 kg)	10,000 g			X		X[MN]	X	XC		X	XC		X		X	X		X
CA05[5]	110 lbs (50 kg)	10,000 g				X	X[MN]	X[MB,6]	XC		X			X[6]					X
CA06	55 lbs (25 kg)	5,000 g					X	X[MN]	XC		X	XC		X		X	X		X
CA07[5]	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X[MB,6]	XC	XC	X[6]					X
CA08	55 lbs (25 kg)	5,000 g					X	X[MN]	X	XC	X	XC	XC	X		X			X
CA09	55 lbs (25 kg)	5,000 g					X	X[MN]	XC	XC	X	XC	XC	X		X			X
CA10	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X	XC	XC	X		X	X		X
CA11[5]	55 lbs (25 kg)	5,000 g						X	X[MN]	XC	X[MB,6]	XC	XC	X		X[6]			X
CA12	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X	XC	X	X		X
CA13[5]	35 lbs (16 kg)	2,000 g							X		X[MN]	X	XC	X[MB,6]	XC	X[6]			X
CA14[5]	35 lbs (16 kg)	2,000 g								X	X[MN]	X[MB,6]	XC	X[6]					X
CA15	35 lbs (16 kg)	2,000 g									X	X[MN]	XC	X	XC	X			X
CA16[5]	25 lbs (11 kg)	1,500 g									X	X[MN]	XC	X[MB,6]	XC	X[6]			X
CA17	35 lbs (16 kg)[4]	4,000 g[4]	X		XC			XC			XC	XC		X[MN, 4]		X		X	X
CA18	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X		X	X
CA19	35 lbs (16 kg)[4]	4,000 g[4]	X					X[MN, 4]			XC	XC		X		X	X	X	X
CA20	25 lbs (11 kg)	2,000 g									X	X[MN]	XC	X	X	X			X

Note: See footnotes below Fine Aggregate Gradation Table for explanation of symbols.

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Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES
Effective: February 1, 2014

FINE AGGREGATE GRADATION TABLE															
FA(FM)[1,2]	**Minimum Field Sample Size [3]**	**Minimum Test Sample Size[3]**	**1"**	**1/2"**	**3/8"**	**#4**	**#8**	**#10**	**#16**	**#30**	**#40**	**#50**	**#80**	**#100**	**#200**
FA01	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA02	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB]		X		X	X
FA03	25 lbs (11 kg)	500 g			X	X[MN]		X			X		X		X
FA04	25 lbs (11 kg)	500 g			X				X[MN]						
FA05	25 lbs (11 kg)	500 g			X	X[MN]								X	X
FA06	25 lbs (11 kg)	500 g	X	X	X	X[MN]								X	X
FA07	25 lbs (11 kg)	100 g				X		X[MN]			X		X		X
FA08	25 lbs (11 kg)	100 g					X				X[MN]			X	X
FA09	25 lbs (11 kg)	100 g					X					X[MN]		X	X
FA10	25 lbs (11 kg)	100 g						X			X[MN]		X		X
FA20[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[6]
FA21[5]	25 lbs (11 kg)	500 g			X	X[MN]	X[MB]		X	X[MB, 6]		X		X	X[6]
FA22[5]	25 lbs (11 kg)	500 g			X	X[MB]	X[MB, 6]		X						X[6]

Notes below apply to Fine and Coarse Aggregate Gradation Tables Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
MB = Master Band Sieves for for Category I & II Coarse Aggregate for PCC and HMA Mixes; Bituminous use only for fine aggregate.
MN = Maximum Nominal Sieve for Crushed Gravels – Maximum Nominal Size is defined as the first specification sieve in the product gradation on which material may be retained.
1 = CA = Coarse Aggregate; CM = Coarse Aggregate, Modified; FA = Fine Aggregate; FM = Fine Aggregate, Modified
2 = CM and FM gradations shall be sampled and tested the same as the corresponding CA and FA gradations.
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = Will vary with the gradation of the material being used
5 = Control Charts Required
6 = Required Sieve for Control Charts

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Illinois Specification 201
Illinois Department of Transportation (IDOT)
AGGREGATE GRADATION SAMPLE SIZE TABLE & QUALITY CONTROL SIEVES
Effective: February 1, 2014

LARGE SIZED AGGREGATE GRADATION TABLE										
CS/RR[1,2]	**Minimum Test Sample Size[3]**	**8"**	**6"**	**4"**	**3"**	**2"**	**1 ½"**	**1"**	**½"**	**#4**
CS01	20,000 g	X	X	X	XC	X		XC	XC	X
CS02	15,000 g		X	X	XC	X		XC	XC	X
RR01	10,000 g				X	XC	X	XC	XC	X
RR02	10,000 g			X	XC	X	XC	XC	XC	X

Notes below apply to Large Sized Aggregate Gradation Table Only

X = Required Gradation Specification Sieves
XC = Required Cutter Sieves
1 = CS = Coarse Aggregate Subgrade; RR/RRM = Rip Rap
2 = Dry Gradations Only
3 = Slag should be adjusted accordingly due to its lighter or heavier mass.
4 = A round nosed shovel may be used for sampling.
5 = Metal plates with precisely sized square holes by be used for the gradation
6 = Test sample size shall be taken in the field. No splitting is required.

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MTP = Manual of Test Procedures for Materials
IDOT = Illinois Department of Transportation
BMPR = Bureau of Materials and Physical Research

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ILLINOIS TEST PROCEDURE 2

SAMPLING OF AGGREGATES

Effective Date: April 1, 2012
Revised Date: February 1, 2014

1 SCOPE

1.1 This procedure covers sampling of coarse and fine aggregates for the following purposes.

1.1.1 Preliminary investigation of the potential source of supply.

1.1.2 Control of the product at the source of supply.

1.1.3 Control of the operations at the site of use.

1.1.4 Acceptance or rejection of the materials.

Note 1 – Sampling plans and acceptance and control tests vary with the type of construction in which the material is used.

1.2 The text of this standard references notes which provide explanatory material. These notes (excluding those in tables and figures) shall not be considered as requirements of the procedure.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the procedure.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 2 – The quality of the results produced by this procedure are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used.

2 REFERENCED DOCUMENTS

2.1 Illinois Specification:

- Illinois Specification 201 Aggregate Gradation Sample Size Table

3 TERMINOLOGY

3.1 *Definitions*:

3.1.1 *maximum size of aggregate, n*—in specifications for, or descriptions of aggregate—the smallest sieve opening through which the entire amount of aggregate is required to pass.

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SAMPLING OF AGGREGATES

Effective Date: April 1, 2012
Revised Date: February 1, 2014

3.1.2 *maximum aggregate size, (Superpave) n*—in specifications for , or descriptions of aggregate—one size larger than the nominal maximum aggregate size.

3.1.3 *nominal maximum aggregate size (of aggregate), n*—in specifications for, or descriptions of aggregate—smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

3.1.4 *nominal maximum aggregate size (Superpave), n*—in specifications for, or descriptions of aggregate—one size larger than the first sieve that retains more than 10% aggregate.

3.1.4.1 *Discussion*—These definitions in 3.1.2 and 3.1.4 apply to hot mix asphalt (HMA) mixtures designed using the Superpave system only.

3.1.4.2 *Discussion* -Specifications on aggregates usually stipulate a sieve opening through which all the aggregate may, but need not, pass so that a slated maximum portion of the aggregate may be retained on that sieve. A sieve opening so designated is the nominal maximum size.

4 SIGNIFICANCE AND USE

4.1 Sampling is equally as important as the testing, and the sampler shall use every precaution to obtain samples that will show the nature and condition of the materials which they represent.

5 APPARATUS

5.1 *Template* – The template shall be designed with two end plates and shall be adjustable. The distance between the end plates may therefore be changed to gather more material from the belt for each increment. The end plates shall also be machined or cut to the approximate belt size and shape.

A single template end plate may be used in the sampling procedure, if care is exercised.

5.2 *Sampling Device* – The sample device used to cut the flow stream from the end of the belt or the bin discharge must be strong enough to handle the force of the flow stream. The device must also be large and deep enough to cut the entire flow stream and not overflow when passing through the stream. The device may be a bucket, a pan, or a manufactured sampling container.

Shelby tubes are not allowed as sampling devices.

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5.3 *Shovel* – The shovel shall be square-nosed and of a size easily handled. It shall also have built-up sides and back (approximately 1 ½" [37.5mm]) to facilitate the retention of material on the shovel when sampling.

6 SECURING SAMPLES

6.1 *General* – Where practicable, samples to be tested for quality shall be obtained from the finished product. Samples from the finished product to be tested for abrasion loss shall not be subject to further crushing or manual reduction in particle size in preparation for the abrasion test unless the size of the finished product is such that it requires further reduction for the testing purposes.

6.2 *Inspection* – The material shall be inspected to determine discernible variations. The seller shall provide suitable equipment needed for proper inspection and sampling.

6.3 *Sampling Procedure* – Aggregate production sampling shall be accomplished by one of the following procedures:

1. belt-stream sampling
2. bin-discharge sampling (requires IDOT approval)
3. on-belt sampling
4. truck-dump or stockpile sampling

Aggregate stockpile sampling shall be accomplished by any of the procedures notes above.

No other sampling procedures will be permitted.

6.3.1 *Sampling from Belt-Stream Discharge or from Bins:*

Belt-Stream Sampling – The sample shall be taken by cutting the stream of aggregate as it leaves the end of the production belt. A sampling device is passed uniformly through the entire width and depth stream flow during normal production and belt load. Each sampling pass (increment) is combined with others to make up the field sample. A minimum of three increments shall be taken during a 10 to 15 minute sampling period. Enough increments shall be taken and combined to provide the correct field sample size.

Extreme care shall be taken to make sure the sampling device passes completely and uniformly through the entire stream flow (from outside the stream on one side to outside the stream on the other side) and to ensure the device does not overflow.

Bin Sampling – Bin discharge shall be sampled in a manner similar to belt-stream sampling. A sampling device is passed through the entire bin discharge stream. A minimum of three increments shall be taken during a 10 to 15 minute sampling period and combined to form the field sample.

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SAMPLING OF AGGREGATES

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Before cutting the bin discharge stream, the bin must be emptied until such time that the stream of material entering the bin is the stream of material exiting the bin. Sampling may take place at that time.

Extreme care shall be taken to make sure the sampling device passes completely and uniformly through the entire stream flow (from outside the stream on one side to outside the stream on the other side) and to ensure the device does not overflow.

Samples shall be taken only during normal plant operation and when the bin is being fed under normal load.

The major problems associated with bin-discharge sampling involve segregated material clinging to the sides of the bin. This material can and does break loose which alters the gradation of the bin-discharge stream. The sampling procedure shall therefore be used only when approved by the District Engineer.

6.3.2 *On-Belt Sampling* – The sample shall be taken by stopping the belt containing the finished product. A template shall be inserted into the material on the belt. All the material between the template shall be removed and shall represent one of the three increments (minimum) making up the field sample. Extreme care shall be taken, including the use of a brush, to remove all fines on the belt between the template for inclusion in the increment. The belt shall be stopped at least three times (three increments) during approximately 10 to 15 minutes of operation to obtain a field sample. If additional material is needed beyond three increments due to the amount of material on the belt, additional template cuts may be taken during the three belt stoppages. Automatic samplers may be used as long as the gradations compare to samples taken with the sample template. Contact BMPR for further guidance.

Samples shall be taken only during normal plant operation and when the belt is under normal load.

6.3.3 *Sampling from Truck-Dumps or from Stockpiles* – Sampling from inside of transportation units is not permitted. The transportation unit shall be off-loaded and sampled by any of the sampling procedures listed, herein.

Truck-Dump Sampling – The sample shall be taken by placing one or two truck dumps together. This may occur during the building of a stockpile or feeding of a plant. The truck dump(s) shall be cut with an end loader and two or more bucket loads extracted. The bucket loads shall be dumped on one another to form a small pile. The small pile shall then be mixed from two directions perpendicular to each other. To mix the pile, the end loader shall cut into the pile along its base until approximately its midpoint. The loader bucket shall be lifted, the loader moved 1 to 2 feet forward, and the bucket dumped on the other half of the pile. Care shall be exercised to avoid cutting below the base of the truck dumps or small pile and contaminating the material to be sampled.

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After mixing twice, the end loader shall drop the angle of its bucket downward on one side of the pile and back drag the pile into a layer not less than 1 foot thick.

The layer shall be sampled using a required shovel to take increments in a random "X" pattern over the layer. The shovel shall be forced vertically to its full depth when sampling each increment except that care shall be used to not dig completely through the layer. This would contaminate the sample being obtained. Care shall also be exercised to retain as much material on the shovel as possible when taking increments. Sufficient increments shall be taken to make up a correct field sample.

Stockpile Sampling – The sample shall be taken from the working face of the stockpile. The working face shall be parallel to the direction of flow used to build the stockpile. Stockpiles having no working face shall have one established prior to sampling. The working face shall have the interior of the pile exposed to permit proper re-blending of the pile to eliminate segregated aggregate. If necessary, material may be brought out of the main pile's working face into the sub-stockpile for sampling.

The stockpile sampling procedure shall follow the truck-dump sampling procedure using an end loader. The end loader shall cut across the working face as detailed in "Truck-Dump Sampling." Any special mixing procedure used during loading shall be used when taking any samples.

6.4 *Number and Masses of Field Samples*:

6.4.1 The number of field samples (obtained by one of the methods described in 5.3) required depends on the criticality of, and variation in, the properties to be measured. Designate each unit from which a field sample is be obtained prior to sampling. The number of field samples from the production should be sufficient to give the desired confidence in test results.

6.4.2 *Field Sample Sizes* – The field sample size shall meet the minimum requirements as detailed in the Illinois Specification 201.

7 Shipping Samples

7.1 Transport aggregates in bags or other containers so constructed as to preclude loss or contamination of any part of the sample, or damage to the contents from mishandling during shipment.

7.2 Shipping containers for aggregate samples shall have a LM-5 envelope attached to the container. Written on the outside of the LM-5 shall be the following information: producer number, test id# (including suffix), material code, ledge description. The required information to be written on the outside of the LM-5 shall also be written on the outside of the sample container. Inside the LM-5 shall contain a fully completed LM-6 form. The LM-6 form shall be the most recent version of the Bureau of

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Materials and Physical Research online template (no other LM-6 forms will be accepted).

8 Red Tag Samples – Used for Quality Samples only.

8.1 The Bureau of Materials and Physical Research has established a procedure which allows the producer the opportunity to delivering their quality samples directly to the Springfield testing facility.

Your sample, taken by the district, will be sampled following the procedures outlined in this test procedure. Upon completion of the sampling the District shall "Red Tag" the sample containers. During the tagging process the District shall write the "Red Tag" serial number on the LM-6 form. If the serial number is not indicated on the LM-6 form the samples will not be accepted.

Once the sample containers are tagged and the documentation has been completed the producer will then be allowed to deliver the samples to the Bureau.

9 Keywords

9.1 aggregates; exploration of potential sources; aggregates; number and sizes needed to estimate character; aggregates; sampling

8

ILLINOIS TEST PROCEDURE 11

MATERIALS FINER THAN No. 200 (75-µm) SIEVE IN MINERAL AGGREGATES BY WASHING

Effective Date: April 1, 2012
Revised Date: February 1, 2014

1 SCOPE

1.1 This test procedure covers the determination of the amount of material finer than a No. 200 (75µm) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

1.2 There are two methods. Method A uses only water for the operation. Method B includes the use of a wetting agent to assist in the loosening of the material finer than the No. 200 (75µm) sieve from the coarser material. A wetting agent such as detergent or dispersing solution is recommended.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2 REFERENCED DOCUMENTS

2.1 Illinois Test Procedures (ITP):

- ITP 2, Sampling of Aggregates
- ITP 27, Sieve Analysis of Fine and Coarse Aggregates
- ITP 248, Reducing Samples of Aggregate to Testing Sizes

2.2 Illinois Specifications:

- Illinois Specification 201, Aggregate Gradation Sample Size Table

2.3 *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials

2.4 ASTM Standards:

- E 11, Woven Wire Test Sieve Cloth and Test Sieves
- E 29 (Illinois Modified), Using Significant Digits in Test Data to Determine Conformance with Specifications

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MATERIALS FINER THAN No. 200 (75-µm) SIEVE IN MINERAL AGGREGATES BY WASHING

Effective Date: April 1, 2012
Revised Date: February 1, 2014

3 SUMMARY OF METHOD

3.1 A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a No. 200 (75µm) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a No. 200 (75µm) sieve by washing.

4 SIGNIFICANCE AND USE

4.1 Material finer than the No. 200 (75µm) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than No. 200 (75µm) in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving in accordance with ITP 27. The results of this test method are included in the calculation in ITP 27, and the total amount of material finer than the No. 200 (75µm) by washing, plus that obtained by dry sieving the same sample, is reported with the results of ITP 27. Usually the additional amount of material finer than No. 200 (75µm) obtained in the dry-sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked. A large amount of material could also be an indication of degradation of the aggregate.

4.2 Plain water is adequate to separate the material finer than No. 200 (75µm) from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water.

5 APPARATUS AND MATERIALS

5.1 *Balance* – The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2 *Sieves* – A nest of two sieves, the lower being a No. 200 (75µm) sieve and the upper being a sieve with openings in the range of No. 8 (2.36mm) to No. 16 (1.18mm), both conforming to the requirement of ASTM E 11.

5.3 *Container* – A pan or vessel of a sufficient size to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5.4 *Oven* – An oven of sufficient size, capable of maintaining a uniform temperature of 230±9°F (110±5°C). The oven shall be specifically designed for drying. In addition, a gas burner or electric hot plate may be used. Microwave ovens are <u>not</u> permitted for drying aggregate gradation samples.

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MATERIALS FINER THAN 75-µm (No. 200) SIEVE IN MINERAL AGGREGATES BY WASHING

Effective Date: April 1, 2012
Revised Date: February 1, 2014

5.5 *Wetting Agent* – Any dispersing agent, such as liquid dishwashing detergents, that will promote separation of the fine materials

Note 1 – A mechanical device, such as a Ploog Washer, may be used for coarse aggregate samples providing its results match the manual procedure. When using a mechanical washing device, loss of fines from damage to the drum or dripping water will not be allowed. Applying wax to the rim of the drum will help prevent water from dripping down the outside of the drum.

6 SAMPLING

6.1 Field samples of aggregate shall be taken according to ITP 2. The field sample size shall meet the minimum requirements in the Illinois Specification 201.

6.2 Field samples of aggregate shall be reduced to test sample size before testing according to ITP 248.

Test sample size for gradation samples shall meet the minimum requirements found in the Illinois Specification 201.

7 PROCEDURE

7.1 The test sample shall be dried back to constant mass in an oven specifically designed for drying, set at and capable of maintaining a uniform temperature of 230±9˚F (110±5˚C). Constant mass is defined as the sample mass at which there has not been more than a 0.5 gram mass loss during 1 hour of drying. This should be verified occasionally.

The sample may also be dried to constant mass in a pan on an electric hot plate or gas burner. The technician shall continually attend the sample when drying on the electric hot plate or gas burner. The electric hot plate or gas burner should be operated on a low-as-needed heat to prevent popping, crackling, and/or sizzling noise from the aggregate during drying. If these noises occur, the heat must be turned down and/or the sample must be constantly stirred during drying to prevent potential aggregate particle breakdown.

After the test sample has been dried to constant mass and cooled down to room temperature, the sample shall have its mass determined to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. All balances or scales shall be tared before being used to determination of mass required by this test procedure. This procedure provides the “Total Dry Mass, g” (TDM) of the original test sample.

ILLINOIS TEST PROCEDURE 11

MATERIALS FINER THAN No. 200 (75-µm) SIEVE IN MINERAL AGGREGATES BY WASHING

Effective Date: April 1, 2012
Revised Date: February 1, 2014

7.2 After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the No. 200 (75µm) sieve from the coarser particles, and to bring the fine material into suspension. The use of a large spoon or other similar tool shall be used to stir and agitate the aggregate in the wash water. Once the wash water becomes clear pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

7.3 Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

Note 2 – If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.

Note 3 – A spray nozzle or a piece of rubber tubing attached to a water faucet may be used to rinse any of the material that may have fallen onto the sieves. The velocity of water, which may be increased by pinching the tubing or by use of a nozzle, should not be sufficient to cause any splashing of the sample over the sides of the sieve.

7.4 Return all material retained on the nested sieves by flushing per note 5 . Dry the washed test sample to constant mass and determine the mass of the test sample in the same manner as detailed in 8.1 herein. This procedure provides the "Total Wash Mass, g" (TWM).

Note 4 – Following the washing of the sample and flushing any material retained on the No. 200 (75µm) sieve back into the container by washing from the back of the sieve. No water should be decanted from the container except through the No. 200 (75µm) sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

8 CALCULATION

8.1 The "Percent Minus No. 200 (75µm) by Washing" shall be determined by using the following formula:

% - No. 200 (-75µm) by Washing = $\frac{TDM-TWM}{TDM} X\ 100$

where TDM = Total Dry Mass, g
and TWM = Total Wash Mass, g.

ILLINOIS TEST PROCEDURE 11

MATERIALS FINER THAN 75-µm (No. 200) SIEVE IN MINERAL AGGREGATES BY WASHING

Effective Date: April 1, 2012
Revised Date: February 1, 2014

9 REPORT

9.1 The test results shall be rounded to the nearest 0.1 percent and recorded on the Illinois Department of Transportation (IDOT) gradation form. All rounding shall be according to ASTM E 29 (Illinois Modified)

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ILLINOIS TEST PROCEDURE 27

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Effective Date: March 1, 2013

1. SCOPE

1.1 This procedure covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates, which reference this method, contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 Illinois Test Procedures (ITP):

- ITP 2, Sampling of Aggregates
- ITP 11, Materials Finer Than 75µm (No. 200) Sieve in Mineral Aggregates by Washing
- ITP 248, Reducing Samples of Aggregate to Testing Size

2.2 Illinois Specifications:

- Illinois Specification 201, Aggregate Gradation Sample Size Table

2.3 AASHTO Standards:

- M 231, Weighing Devices Used in the Testing of Materials

2.4 ASTM Standards:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- E 11, Woven Wire Test Sieve Cloth and Test Sieves

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SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Effective Date: March 1, 2013

- E 29 (Illinois Modified), Using Significant Digits in Test Data to Determine Conformance with Specifications

3 TERMINOLOGY

3.1 *Definitions* – For definitions of terms used in this standard, refer to ASTM C 125.

4 SUMMARY OF METHOD

4.1 A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

5 SIGNIFICANCE AND USE

5.1 This procedure is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2 Accurate determination of material finer than the 75µm (No. 200) sieve cannot be achieved by used of this method alone. ITP 11 for material finer than the 75µm (No. 200) sieve by washing should be employed.

6 APPARATUS

6.1 *Balance* – The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of AASHTO M 231.

6.2 *Sieves* – The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of ASTM E 11. Nonstandard sieve frames shall conform to requirements of ASTM E 11 as applicable.

When running Coarse Aggregate samples 12in (305mm) are required, if running Fine Aggregate samples 12in (305mm) or 8in (203mm) sieves are acceptable.

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SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Effective Date: March 1, 2013

6.3 *Mechanical Sieve Shaker* – A mechanical sieving device, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as the present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 8.4 is met in a reasonable time period.

6.4 *Oven* – An oven of appropriate size capable of maintaining a uniform temperature of 110±5˚C (230±9˚F). The oven shall be specifically designed for drying.

In addition, a gas burner or electric hot plate may be used. Microwave ovens are not permitted for drying aggregate gradation samples.

7 SAMPLING

7.1 Field samples of aggregate shall be taken according to ITP 2. The field sample size shall meet the minimum requirements in the Illinois Specification 201.

7.2 Field samples of aggregate shall be reduced to test sample size before testing according to ITP 248.

Test sample size for gradation samples shall meet the minimum requirements in the Illinois Specification 201.

7.3 In the event that the amount of material finer than 75µm (No. 200) sieve is to be determined by ITP 11, proceed as follows: use the procedure described in Section 7.3.1 or 7.3.2, whichever is applicable.

7.3.1 Use the same test sample for testing by ITP 11 and by this method. First test the sample according to ITP 11 through the final drying operation, and then dry-sieve the sample as stipulated in Sections 8.2 through 8.6 of this method.

7.3.2 If the test sample is not to be tested by ITP 11, follow Section 8, "Procedure."

8 PROCEDURE

8.1 If the test sample has not been subject to testing by ITP 11, the test sample shall be dried back to constant mass in an oven specifically designed for drying, set at and capable of maintaining a uniform temperature of 110±5˚C (230±9˚F). Constant mass

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Effective Date: March 1, 2013

is defined as the sample mass at which there has not been more than a 0.5 gram mass loss during 1 hour of drying. This should be verified occasionally.

The sample may also be dried to constant mass in a pan on an electric hot plate or gas burner. The technician shall continually attend the sample when drying on the electric hot plate or gas burner. Microwave ovens are not permitted for drying gradation samples.

The electric hot plate or gas burner should be operated on a low-as-needed heat to prevent popping, crackling, and/or sizzling noise from the aggregate during drying. If these noises occur, the heat must be turned down and/or the sample must be constantly stirred during drying to prevent potential aggregate particle breakdown.

After the test sample has been dried to constant mass and cooled down to room temperature, the sample shall have its mass determined to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. All balances or scales shall be tared before being used for determination of mass required by this test procedure. This procedure provides the "Total Dry Mass, g (TDM) of the original test sample._ When testing Recycled Asphalt Pavement (RAP) samples shall be air dried to a constant mass.

8.2 A nested set of sieves (203mm [8 inch] or 305mm [12 inch]) shall be gathered and stacked. As the sieves are being stacked, they should be inspected for cracks, breaks, or any other problem which would exclude their continued use. The size of the sieves used shall conform to the gradation specifications of the aggregate tested. The 75µm (No. 200) sieve is required to be part of all nested sets when running a gradation test. It is also required that 203mm (8 inch) and 305mm (12 inch) round sieves use additional cutter sieves beyond the specified gradation sieves for all coarse aggregate gradations. Some cutter sieves may be required for fine aggregate gradations if overloading of individual sieves occurs. Gradations CA/CM 7 and 11 require the 16.0mm (5/8 inch), 9.5mm (3/8 inch), and 6.3mm (1/4 inch) sieves as cutter sieves, while the gradations CA/CM 13, 14, and 16 require the 6.3mm (1/4 inch) and the 2.38mm (No. 8) sieves. Cutter sieves for other gradations can be found in Illinois Specification 201.

The sample shall then be introduced into the nested set of sieves and placed in a mechanical shaker. The shaker shall impart a vertical, or lateral and vertical, motion to the nested set. This causes the aggregate particles to bounce and turn so as to

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SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Effective Date: March 1, 2013

present different particle orientations to the sieves. This allows every chance for the particle to pass a certain sized sieve.

The shaker shall be run for 7 minutes, controlled by an automatic shut-off timer. Seven (7) minutes of shaking shall be considered the standard unless reduced shaker efficiency can be demonstrated through finish hand-shaking as described in Section 8.4. Shaking time shall be increased if necessary to comply with the finish hand-shaking procedure in Section 8.4. Shaking time shall not exceed 10 minutes.

8.3 Extreme care shall be taken not to overload individual sieves or even approach the overload limits. An overload is defined as several layers of particles, one on top of the other, which do not permit the top layers of particles access to the sieve openings. Sample results which show overloading or a borderline situation are immediately suspect. If samples continually overload a sieve or sieves, then future samples shall be run in the appropriate number of portions to prevent overloading, or additional cutter sieves shall be added to the nested set to correct the problem.

8.4 After mechanical shaking, all sieves shall be finished off by hand-shaking. When hand-shaking, the largest sieve that contains material shall be removed from the stack, visually inspected for overload, and inverted over an empty pan. While inverted, all particles shall be cleaned from the sieve. The material shall then be placed back on the same sieve and hand-shaken over an empty pan. Any amount of material that is considered to be an overload or to be approaching an overload shall be hand-shaken in a least two increments. Any appreciable amount of particles passing a sieve may indicate poor mechanical shaking or overloading. The finish hand-shaking described in the following paragraph shall then be initiated.

Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during 1 minute of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at a rate of about 150 times per minute, turn the sieve about one-sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than 4.75mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203mm (8inch) diameter sieves to verify the sufficiency of sieving.

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SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Effective Date: March 1, 2013

8.5 After hand-shaking, material shall be removed from the sieve. Particles shall not be forced through the sieves. The sieve shall be inverted and lightly tapped on the sides to facilitate removal for weighing. A dowel rod or putty knife may be used to gently remove wedged particles from all sieves down through the 2.00mm (No. 10). A soft brass-wired brush shall be used on the 1.18mm (No. 16) through the 425µm (No. 40) sieve. A soft china brush shall be used on the 300µm (No. 50) through the 75µm (No. 200) sieve. Any material that passed the sieve during hand-shaking shall be placed on the next smaller sieve. After use, all sieves shall be inspected for cracks, breaks, or any other problem which would exclude their continued use.

8.6 After hand-shaking and cleaning, the material retained on each sieve shall have its mass determined and the mass recorded. All determination of mass shall start with the largest sieve in the nested set and proceed down to the pan. Determination of mass shall be to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. The total mass of the material after sieving should check closely with original mass of samples placed on the sieves. If the amounts differ by more than 0.3 percent, based on the original dry sample mass, the results should not be used for acceptance purposes.

9 CALCULATION

9.1 Calculation of test results shall follow the procedure described below:

Calculated the "Cumulative Mass Retained" for each sieve by adding its "Individual Mass Retained" and the "Individual Mass Retained" for each larger sieve in the nested set of sieves. Record the "Cumulative Mass Retained".

Calculated the "Cumulative Percent Retained" for each sieve by using the following formula and record it by rounding to the nearest 0.1 percent:

$$\text{Cumulative \% Retained} = \frac{CMR}{TDM} \times 100$$

where CMR = Cumulative Mass Retained
and TDM = Total Dry Mass

Calculated the percent passing each sieve by using the following formula:

% = 100 – Cumulative % Retained

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Effective Date: March 1, 2013

These results shall be recorded to the nearest 0.1 percent.

9.2 Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100; 150µm (No. 100), 300µm (No. 50), 600µm (No. 30), 1.18mm (No. 16), 2.36mm (No. 8), 4.75mm (No. 4), 9.5mm (3/8 in.), 19.0mm (¾ in.), 37.5mm (1 ½ in.), and larger, increasing the ratio of 2 to 1.

10 **REPORT**

10.1 Depending upon the form of the specifications for used of the material under test, the report shall include one of the following:

10.1.1 Total percentage of material passing each sieve, or

10.1.2 Total percentage of material retained on each sieve, or

10.1.3 Percentage of material retained between consecutive sieves.

10.2 All percent passing results except the washed minus 75µm (minus No. 200) and minus 75µm (minus No. 200) shall be reported on the gradation form as whole numbers. The washed minus 75µm (minus No. 200) and minus 75µm (minus No. 200) results shall be reported to the nearest 0.1 percent. Illinois Department of Transportation (IDOT) gradation forms or forms approved by IDOT shall be used. These forms shall be competed with all required information.

10.3 Rounding shall be according to ASTM E 29 (Illinois Modified).

10.4 For all sieves that are considered overloaded and split in more than one increment. An "S" next to the sieve must be notated on the worksheet.

11 COMPARISON PROCEDURE

11.1 All comparison testing shall be conducted in accordance with the most current version of the Illinois Department of Transportation Manual of Test Procedures for Materials (Appendix A7).

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ILLINOIS TEST PROCEDURE 248

REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

Effective: June 1, 2012

1. SCOPE

1.1 This procedure covers the reduction of large samples of aggregate to the appropriate size for testing, employing techniques that are intended to minimize variations in measured characteristics between the test samples so selected and the large sample.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 Illinois Test Procedures (ITP):

- ITP 2, Sampling of Aggregates
- ITP 11, Materials Finer Than 75µm (No. 200) Sieve in Mineral Aggregates by Washing
- ITP 84, Specific Gravity and Absorption of Fine Aggregate

2.2 ASTM Standards:

- *C 125, Standard Terminology Relating to Concrete and Concrete Aggregates*

3. TERMINOLOGY

3.1 *definitions* – the terms used in this standard are defined in ASTM C 125.

4. SIGNIFICANCE AND USE

4.1 Specifications for aggregates require sampling portions of the material for testing. Other factors being equal, larger samples will tend to be more representative of the total supply. The methods described in this standard provide for reducing the large sample obtained in the field or produced in the laboratory to a convenient size for conducting a number of tests to describe the material and measure its quality. These methods are conducted in such a manner that the smaller test sample portion will be

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REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

Effective: June 1, 2012

representative of the larger sample and, thus, of the total supply. The individual test methods provide for minimum masses of material to be tested.

4.2 Under certain circumstances, reduction in size of the large sample prior to testing is not recommended. Substantial differences between the selected test samples sometimes cannot be avoided, as for example, in the case of an aggregate having relatively few large-sized particles in the sample. The laws of chance dictate that these few particles may be unequally distributed among the reduced-size test samples. Similarly, if the test sample is being examined for certain contaminants occurring as a few discrete fragments in only small percentages, caution should be used in interpreting results from the reduced-size test sample. Chance inclusion or exclusion of only one or two particles in the selected test sample may importantly influence interpretation of the characteristics of the original sample. In these cases, the entire original sample should be tested.

4.3 Failure to carefully follow the procedures in these methods could result in providing a non-representative sample to be used in subsequent testing. Selection during splitting of an exact, predetermined mass for the sample is not permitted.

5. SELECTION OF METHOD

5.1 *Fine Aggregate* – The preferred splitting method for fine aggregate shall be a fine aggregate mechanical splitter (Method A). However, quartering (Method B) and miniature stockpile sampling (Method C) may be used.

5.1.1 If the use of Method B or Method C is desired, and the sample does not have free moisture on the particle surfaces, the sample may be moistened to achieve this condition, thoroughly mixed, and then the sample reduction performed.

Note 1 – As a quick approximation of free moisture; the fine aggregate will retain its shape when molded in the hand, it may be considered to be wetter than saturated-surface-dry.

5.1.2 If the use of Method A is desired and the sample has free moisture on the particle surfaces, the entire sample may be dried to at least the surface-dry condition, using temperatures that do not exceed those specified for any of the tests contemplated, and then the sample reduction performed. Alternatively, if the moist sample is very large, a preliminary split may be made using a mechanical splitter having wide chute openings 37.5mm (1 ½ in.) or more to reduce the sample to not less than 5000g. The

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portion so obtained is then dried, and reduction to test sample size is completed using Method A.

5.2 *Coarse Aggregate and Mixtures of Coarse and Fine Aggregate* – The required splitting method for coarse aggregate and mixtures of coarse and fine aggregate shall be a coarse aggregate mechanical splitter (Method A). However, quartering (Method B) may be used for coarse aggregate moisture tests to proportion Portland cement concrete, cement aggregate mixture II, and controlled low-strength material mixtures.

6. SAMPLING

6.1 Field samples of aggregate shall be taken according to ITP 2.

METHOD A – MECHANICAL SPLITTER

7. APPARATUS

7.1 *Sample Splitter* – Sample splitters shall have an even number of equal width chutes, but not less than a total of eight for coarse aggregate, or 12 for fine aggregate, which discharge alternatively to each side of the splitter. For coarse aggregate and mixed aggregate the minimum width of the individual chutes shall be approximately 50 percent larger than the largest particles in the sample to be split (Note 2). For dry fine aggregate in which the entire sample will pass the 9.5mm (3/8 in.) sieve, the minimum width of the individual chutes shall be at least 50 percent larger than the largest particles in the sample and the maximum width shall be 19mm (3/4 in.). The splitter shall be equipped with two receptacles to hold the two halves of the sample following splitting. It shall also be equipped with a hopper or straight-edged pan, which has a width equal to or slightly less than the overall width of the assembly of chutes, by which the sample may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material (see Figure 1).

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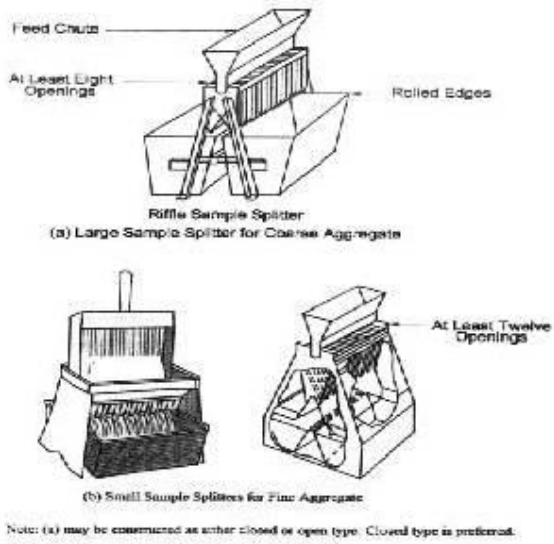

Note: (a) may be constructed as either closed or open type. Closed type is preferred.

Figure 1—Sample Splitters (Riffles)

Note 2 – Mechanical splitters are commonly available in sizes adequate for coarse aggregate having the largest particles not larger than 37.5mm (1 ½ in.).

8. PROCEDURE

8.1 Place the original sample in the hopper or pan and uniformly distribute it from edge to edge, so that when it is introduced in the chutes, approximately equal amounts will flow through each chute. The rate at which the sample is introduced shall be such as to allow free flowing through the chutes into the receptacles below. Reintroduce the portion of the sample in one of the receptacles into the splitter as many times as necessary to reduce the sample to the size specified for the intended test. The portion of the material collected in the other receptacle may be reserved for reduction in size for other tests.

On the final split, the mass of the two halves (after splitting) shall be within ±10 percent of each other. This is determined by adding 10 percent of the mass of the small split to the mass of the smaller split; the larger split cannot exceed this calculated mass. If it does, both split halves shall be recombined and split until the mass comparison requirement is met.

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REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

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METHOD B – QUARTERING

9. APPARATUS

9.1 Apparatus shall consist of a straight-edge; straight-edged scoop, shovel or trowel; a broom or brush; and a canvas blanket or tear-resistant tarp approximately 2 by 2.5m (6 by 8 ft.).

10. PROCEDURE

10.1 Use either the procedure described in Section 10.1.1 or 10.1.2, or a combination of both.

10.1.1 Mix the material thoroughly on a hard, clean, level surface by turning the entire sample over four times using the shovel. Each shovel full shall be deposited on top of the preceding one. This procedure shall be done three times, resulting in the formation of a small conical pile. Carefully flatten the conical pile to a uniform thickness and diameter by pressing down the apex with a shovel or trowel so that each quarter sector of the resulting pile will contain the material originally in it. The diameter should be approximately four to eight times the thickness. Divide the flattened mass into four equal quarters with a shovel or trowel and remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean. The two unused quarters may be set aside for later use or testing, if desired. Successively mix and quarter the remaining material until the sample is reduced to the desired size (see Figure 2).

Both halves of the final split shall meet the 10 percent comparison requirement in 8.1 herein.

10.1.2 As an alternative to the procedure in Section 10.1.1, the field sample may be placed on a canvas blanket. Mixing may be accomplished by the shovel method listed in 10.1.1 herein or by alternately lifting each corner of the canvas and pulling over the sample diagonally toward the opposite corner. This causes the material to be rolled and mixed. The material shall then be flattened and divided as required in 10.1.1. (see Figure 3) Both halves of the final split shall meet the 10 percent comparison requirement in 8.1 herein.

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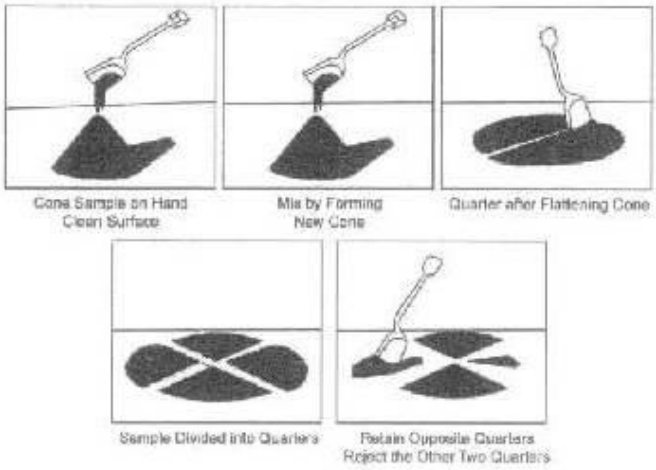

Figure 2—Quartering on a Hard, Clean, Level Surface

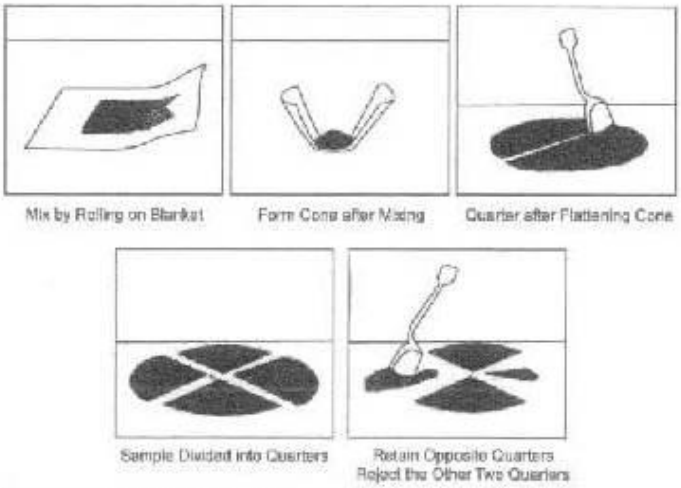

Figure 3—Quartering on a Canvas Blanket or Tear-Resistant Tarp

METHOD C – MINIATURE STOCKPILE SAMPLING (DAMP FINE AGGREGATE ONLY)

11. APPARATUS

11.1 Apparatus shall consist of a straight-edge; straight-edged scoop, shovel, or trowel for mixing the aggregate; and either a small thief, small scoop, or spoon for sampling.

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12. PROCEDURE

12.1 Mix the material thoroughly on a hard, clean, level surface as required in 10.1.1 or 10.1.2.

The test sample shall be obtained by selecting at least five increments in a random "X" pattern over the resultant miniature sample pad using a sampling thief, small scoop, or spoon. A sufficient number of increments shall be obtained to provide a test sample slightly larger than the minimum test sample size when dried to a constant mass. (see Figure 4)

For all samples from which a state monitor split will also be obtained, the number of increments shall be doubled to provide a sample twice the minimum required test size. This material shall then be dried to constant mass as specified in the current ITP 11 and split in a fine aggregate mechanical splitter according to Method A – Mechanical Splitter. Alternately, the material may also be quartered according to Method B – Quartering.

Both halves of the final split shall meet the 10 percent comparison requirement in 8.1 herein.

Figure 4 – Miniature Stockpile Method on a canvas blanket or tear resistant tarp.

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ILLINOIS TEST PROCEDURE 255

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING

Effective Date: March 1, 2013

1 SCOPE

1.1 This test procedure covers the determination of the percentage of evaporable moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate. Some aggregate may contain water that is chemically combined with the minerals in the aggregate. Such water is not evaporable and is not included in the percentage determined by this test method. Aggregate moisture content may be run on a gradation sample prior to gradation testing or on a separate test sample.

1.2 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 REFERENCED DOCUMENTS

2.1 Illinois Test Procedures (ITP):

- ITP 2, Sampling of Aggregates
- ITP 84, Specific Gravity and Absorption of Fine Aggregate
- ITP 85, Specific Gravity and Absorption of Coarse Aggregate
- ITP 248, Reducing Samples of Aggregate to Testing Size

2.2 Illinois Specifications:

- Illinois Specification 201, Aggregate Gradation Samples Size Table

2.3 AASHTO Standards:

- M 231, Weighing Devices Used in the Testing of Materials

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TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING

Effective Date: March 1, 2013

2.4 *ASTM Standards:*

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- E 29 (Illinois Modified), Using Significant Digits in Test Data to Determine Conformance with Specifications

3 TERMINOLOGY

3.1 *Definitions:*

3.2 For definitions of terms used in this test method, refer to ASTM C 125.

4 SIGNIFICANCE AND USE

4.1 This test method is sufficiently accurate for usual purposes such as adjusting batch quantities of ingredients for concrete. It will generally measure the moisture in the test sample more reliably than the sample can be made to represent the aggregate supply. In rare cases where aggregate itself is altered by heat, or where more refined measurement is required, the test should be conducted using a ventilated, controlled-temperature oven.

4.2 Large particles of coarse aggregate, especially those larger than 50mm (2 in.), will require greater time for the moisture to travel from the interior of the particle to the surface. The user of this test method should determine by trial if rapid drying methods provide sufficient accuracy for the intended use when drying large-size particles.

5 APPARATUS

5.1 *Balance* – The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of AASHTO M 231.

5.2 *Source of Heat* – A ventilated oven capable of maintaining the temperature surrounding the sample at 110±5°C (230±9°F). The oven shall be specifically designed for drying.

5.2.1 Where close control of the temperature is not required (see Section 4.1), other suitable sources of heat may be used such as an electric or gas hot plate, electric

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TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING

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heat lamps, or a ventilated microwave oven. A microwave oven or an electric or gas hot plate may be used only when drying a non-gradation test sample.

5.3 *Sample Container* – A container not affected by the heat, and of sufficient volume to contain the sample without danger of spilling, and of such shape that the depth of sample will not exceed one-fifth of the least lateral dimension.

Note 1 – Except for testing large samples, an ordinary frying pan is suitable for use with a hot plate, or any shallow flat-bottomed metal pan.

5.4 *Stirrer* – A metal spoon or spatula of convenient size.

6 SAMPLE

6.1 Sampling shall generally be accomplished in accordance with ITP 2, except the sample size shall be as stated in Illinois Specification 201.

6.2 Field samples of aggregate shall be reduced to test sample size before testing according to ITP 248.

Test samples shall be stored in sealable, non-absorbing bags or containers prior to determining mass to start the test.

7 PROCEDURE

7.1 The test sample shall have its mass determined to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. This procedure provides the "Original Sample Mass, g" (OSM).

7.2 The test sample shall be dried back to constant mass by the selected source of heat as specified herein.

7.2.1 ***Caution*** – When using a microwave oven, occasionally minerals are present in aggregates that may cause material to overheat and explode. If this occurs, it can damage the microwave oven. When a gas burner or electric hot plate is used for drying, the technician shall continually attend the sample. The gas burner or electric hot plate should be operated on a low-as-needed heat to prevent popping, crackling, and/or sizzling noise from the aggregate during drying. If these noises occur, the heat

ILLINOIS TEST PROCEDURE 255

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING

Effective Date: March 1, 2013

must be turned down and/or the sample must be constantly stirred during drying to prevent potential aggregate particle breakdown.

7.3 Constant mass is defined as the sample at which there has not been more than a 0.5-gram mass loss during a 1 hour of drying. This should be verified occasionally.

After the test sample has been dried to constant mass, the test sample shall have its mass determined as soon as the pan or container can safely be handled to prevent additional moisture from being pulled from the air into the aggregate structure.

7.4 Determine the mass of the test sample to the nearest 1 gram for coarse aggregate and to the nearest 0.1 gram for fine aggregate. .

This procedure provides the "Total Dry Mass, g" (TDM). The TDM will also be used for calculation of gradation samples.

8 CALCULATION

8.1 The "Aggregate Moisture Content" shall be determined by using the following formula:

$$P = 100(OSM - TDM) / TDM$$

where:

P = Aggregate Moisture Content (%)
OSM = Original Sample Mass, g.

and:

TDM = Dried Sample Mass g.

Results shall be reported as required and in the appropriate plant diary.

Test results shall be rounded to the nearest 0.1 percent. All rounding shall be according to ASTM E 29 (Illinois Modified)

ILLINOIS TEST PROCEDURE 255

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING

Effective Date: March 1, 2013

8.2 Surface moisture content is equal to the difference between the total evaporable moisture content and the absorption, with all values based on the mass of a dry sample. Absorption may be determined in accordance with ITP 85, Test for Specific Gravity and Absorption of Coarse Aggregate, or ITP 84, Test for Specific Gravity and Absorption of Fine Aggregate.

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Illinois Department of Transportation

Illinois Specification 101
Minimum Requirements for Electronic Balances
Appendix D5

Effective Date: April 1, 1999
Revised February 1, 2014

Electronic balances for materials testing laboratories shall be top-loading, direct-reading, with specified minimum capacity and readability per the table below. Underhooks are required for hot mix asphalt laboratories.

Purchasers are advised to specify balances that are manufactured according to AASHTO M 231. Laboratories may, at their option, provide additional balances that comply with each individual test procedure.

Electronic balances approved for Illinois Department of Transportation use prior to the effective date of this specification may be utilized until replaced.

Minimum Requirements for Laboratory Balances

QC/QA LAB TYPE	MINIMUM CAPACITY	READABILITY
AGGREGATE (AGCS, HMA, PCC)		
Moisture, Gradation, Specific Gravity		
Fine Aggregate	8 kg	0.1 g
Coarse Aggregate CA/CM 6 through 19	8 kg	0.1 g
Coarse Aggregate CA/CM 1 through 5	12 kg	0.1 g
HOT MIX ASPHALT		
Volumetric Analysis		
Mix Design Labs (Marshall and Superpave)	15 kg	0.1 g
QC, QA Labs (Marshall and Superpave)	8 kg	0.1 g
Asphalt Content		
(Nuclear AC Gauge or Ignition Furnace)	12 kg	0.1 g
PORTLAND CEMENT CONCRETE*		
Aggregate Moisture Content**	8 kg	0.1 g
Unit Weight**	†	‡
Cylinder Strength Specimens***	†	50 g maximum

* A maximum 50-gram (0.1 lb.) readability is permitted to calibrate the unit weight measure (Illinois Modified AASHTO T 121) and the air meter measuring bowl (Illinois Modified AASHTO T 152). However, if the capacity of the unit weight measure and the air meter measuring bowl is less than 0.009 cubic meter (0.3 cu.ft.), a 20-gram (0.05 lb.) or smaller readability is preferable for calibration.

** The weighing equipment may be a balance or scale, and it does not have to be electronic.

***The weighing of cylinder strength specimens prior to compressive strength testing is optional.

† Sufficient capacity.

‡ A 20-gram (0.05 lb.) or smaller readability shall be required for unit weight measures which have a capacity less than 0.009 cubic meter (0.3 cu.ft.). A 50-gram (0.1 lb.) or smaller readability shall be required for unit weight measures which have a capacity greater than or equal to 0.009 cubic meter (0.3 cu.ft.).

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Illinois Modified Test Procedure
Effective Date: February 1, 2014

Standard Method of Test
for
Using Significant Digits in Test Data to Determine Conformance with Specifications

Reference ASTM E 29-13

Note: Several test procedures reference either ASTM E 29 for rounding of test results. Results for Illinois Department of Transportation tests shall follow the "round up from five" rule, i.e.:

When the digit beyond the last place to be retained (or reported) is equal to or greater than 5, increase by 1 the digit in the last place retained.

The following modification to ASTM shall apply:

ASTM Section	***Illinois Modification***
6.4.2	Revise as follows: When the digit next beyond the last place to be retained (or reported) is equal to or greater than 5, increase by 1 the digit in the last place retained.
6.4.3	Delete.
6.4.4	Delete.

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State of Illinois
Department of Transportation
Bureau of Materials and Physical Research
Springfield

POLICY MEMORANDUM

Revised: March 1, 2014	7-08.2
This Policy Memorandum supersedes 7-08.1 dated June 1, 2012	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: RECYCLING PORTLAND CEMENT CONCRETE INTO AGGREGATE

Section 1003 and 1004 of the Standard Specifications for Road and Bridge Construction includes "crushed concrete" as an acceptable source of aggregate material. Care must be taken, however, to assure that quality and gradation requirements are not compromised when recycled concrete is used in lieu of other aggregate materials. Freeze-thaw, ASR and Chloride Content tests are required if the crushed concrete is to be recycled as Portland cement concrete. Concrete removal and crushed concrete stockpiling and handling must be performed in such a manner as to avoid contamination of the aggregate with dirt and foreign matter.

Acceptance of crushed concrete shall be determined using one of the following methods:

I. Project Acceptance
Recycling Portland cement concrete may be specified by special provision for appropriate projects. The crushed concrete shall be recycled from IDOT-specified concrete in the project. The Engineer shall approve the concrete removal method prior to crushing and continually monitor the method during crushing for unacceptable contamination.

Quality. The fact that the original aggregate in the concrete met "Class A" quality does not mean that the product resulting from the crushing of the concrete will meet "Class A" quality. Preliminary samples of existing concrete from a number of locations (minimum 3) in any potential recycling project shall be submitted to the Central Laboratory for quality testing. A period of three months is required for freeze-thaw testing if the material is to be recycled into any uses covered under 1004.02 (f) in the Standard Specifications for Road and Bridge Construction. This work shall be completed prior to advertising the project for bidding.

Quality testing shall include Illinois Test Procedures 96 "Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine" and Illinois Test Procedure 203 "Deleterious Particles in Coarse Aggregate". Standard "Class A" quality limits shall apply but Recycled Asphalt Pavement (RAP) shall be counted as Other Deleterious and shall not exceed 2.0%. RAP shall not be considered as Other Deleterious when Crushed Concrete is used as Aggregate Wedge Shoulders, Type B.

A. Gradation. Gradation sampling and testing shall conform to the Aggregate Gradation Control System (AGCS.

B. Stockpiling. Contamination in the stockpile area is as detrimental as contamination when picking up the broken concrete. Stockpile pads shall be provided and haul roads/plant area properly maintained to assure that acceptable material is not contaminated prior to use.

Stockpiling, hauling, and loading shall conform to the Aggregate Gradation Control System.

II. Central Recycling Plant

Portland Cement Concrete may be recycled by crushing at a central recycling plant.

Concrete used as raw feed at a central recycling plant shall not be contaminated with soil or foreign matter. A small amount of soil embedded in the base of the concrete slab is acceptable. A small amount of construction debris, steel, fabric, wood from forms, and a small amount of RAP leftover from milling is also acceptable. Raw feed piles shall not have excavated soil or aggregate, bricks, slabs of HMA pavement or washout from concrete trucks.

Acceptance for quality and gradation shall be on a stockpile-by-stockpile basis.

A. Quality. Each stockpile shall have one quality sample per each 10,000 tons per specific gradation submitted for quality testing. The quality samples shall be taken from stockpiled material. Since non-IDOT specified concrete may be included in recycling at central recycling plants, the crushed concrete produced at the central recycling plant is not acceptable for Class A quality use, Class B quality use, or Class C quality hot-mix asphalt mixture use, except as specified herein.

For HMA Surface courses and HMA Binder courses: Quality testing shall include Illinois Test Procedure 96 “Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine”, and Illinois Test Procedure 203 “Deleterious Particles in Coarse Aggregate”. Standard “Class B” quality limits shall apply but there will be no limit on RAP from the Deleterious Count. Illinois Test Procedure 327 “Resistance to Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus” shall also be performed and a 15.0% limit shall be applied.

For Granular Embankment Special, Granular Subbase, Stabilized Subbase, Aggregate Base, Aggregate Surface and Aggregate Shoulders: Quality testing shall include Illinois Test Procedure 96 “Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine” with standard “Class D” quality limits applied. Illinois Test Procedure 203 “Deleterious Particles in Coarse Aggregate” shall also be performed but standard “Class C” quality limits shall apply except the Other Deleterious maximum percent limit shall be 7.0%, with no more than 5.0% RAP allowed, nor more than 2.0% other material defined as Other Deleterious. RAP shall not be considered as Other Deleterious when Crushed Concrete is used as Aggregate Wedge Shoulders, Type B.

B. Gradation. Gradation sampling and testing shall comply with the Aggregate Gradation Control System.

C. Stockpiling. Stockpiling, hauling, and loading shall comply with the the Aggregate Gradation Control System. Stockpile pads shall be provided and the haul roads/plant area properly maintained to prevent contamination.

III. Recycled Returned Ready-Mix Concrete

Portland Cement Concrete may be recycled by curing returned concrete either at the Concrete Mix Plant or at a Central Recycling Plant as outlined below:

Returned concrete shall be dumped on a clean stockpile area or concrete pad. A small amount of fines scattered on the pad prior to dumping the returned concrete, will assist in removal of the cured concrete.

No water shall be added to the returned concrete before dumping.

After the concrete truck is empty, it shall then proceed to a different area to "wash out". "Wash out refers to the use of water and agitation to remove the ready-mix residue from the inside the ready-mix truck.

The returned concrete shall be cured for a minimum of 2 weeks to gain strength. Cured concrete is then broken up and placed in piles.

A. Quality. IDOT reserves the right to test this material for quality, as outlined in Section II (A), herein, if contamination is present in the stockpile.

B. Gradation. Gradation sampling and testing shall comply with the Aggregate Gradation Control System. "Wash out" material may be mechanically blended with the returned concrete during aggregate production as long as the final product still meets the required gradation.

C. Stockpiling. Stockpiling, hauling, and loading shall comply with the Aggregate Gradation Control System. Stockpile pads shall be provided and the haul roads/plant area properly maintained to prevent contamination.

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SECTION 1003. FINE AGGREGATES

1003.01 Materials. Fine aggregate materials shall be according to the following.

(a) Description. The natural and manufactured materials used as fine aggregate are defined as follows.

(1) Sand. Sand shall be the fine granular material resulting from the natural disintegration of rock. Sand produced from deposits simultaneously with, and by the same operations as, gravel coarse aggregate may contain crushed particles in the quantity resulting normally from the crushing and screening of oversize particles.

(2) Silica Sand. Silica sand shall be composed of not less than 99.5 percent silica ($Si0_2$).

(3) Stone Sand. Stone sand shall be produced by washing, or processing by air separation, the fine material resulting from crushing rock quarried from undisturbed, consolidated deposits, or crushing gravel. The acceptance and use of crushed gravel stone sand shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Crushed Gravel Producer Self-Testing Program".

(4) Chats. Chats shall be the tailings resulting from the separation of metals from rocks in which they occur.

(5) Wet Bottom Boiler Slag. Wet bottom boiler slag shall be the hard, angular by-product of the combustion of coal in wet bottom boilers.

(6) Slag Sand. Slag sand shall be the graded product resulting from the screening of air-cooled blast furnace slag. Air-cooled blast furnace slag shall be the nonmetallic product, consisting essentially of silicates and alumino-silicates of lime and other bases, which is developed in a molten condition simultaneously with iron in a blast furnace.

The acceptance and use of air-cooled blast furnace slag sand shall be according to the current Bureau of Materials and Physical Research

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Policy Memoranda, "Crushed Slag Producer Certification and Self-Testing Program" and "Slag Producer Self-Testing Program".

(7) Granulated Slag Sand. Granulated slag sand shall be the graded product resulting from the screening of granulated slag. Granulated slag shall be the nonmetallic product, consisting essentially of silicates and alumino-silicates of lime and other bases, which is developed in a molten condition simultaneously with iron in a blast furnace. Granulated slag sand is formed by introducing a large volume of water under high pressure into the molten slag.

(8) Steel Slag Sand. Steel slag sand shall be the graded product resulting from the screening of crushed steel slag. Crushed steel slag shall be the nonmetallic product which is developed in a molten condition simultaneously with steel in an open hearth, basic oxygen, or electric furnace. The acceptance and use of steel slag sand shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Slag Producer Self-Testing Program".

(9) Crushed Concrete Sand. Crushed concrete sand shall be the angular fragments resulting from crushing portland cement concrete by mechanical means. The acceptance and use of crushed concrete sand shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Recycling Portland Cement Concrete Into Aggregate".

(10) Construction and Demolition Debris Sand. Construction and demolition debris sand shall be the angular fragments resulting from mechanical crushing/screening of unpainted exterior brick, mortar, and/or concrete with small amounts of other materials. Construction and demolition debris sand shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Construction and Demolition Debris Sand as a Fine Aggregate for Trench Backfill".

(b) Quality. The fine aggregate shall meet the quality standards listed in the following table. Except for the minus No. 200 (75 µm) sieve material, all fine aggregate shall meet specified quality requirements before being proportioned for mix or combined to adjust gradation. The blended materials shall meet the minus No. 200 (75 µm) sieve requirements.

FINE AGGREGATE QUALITY			
QUALITY TEST	CLASS		
	A	B	C
Na_2SO_4 Soundness 5 Cycle, ITP 104, % Loss max.	10	15	20
Minus No. 200 (75 µm) Sieve Material, ITP 11, % max.[4/]	3	6 [1/]	10 [1/]
Organic Impurities Check, ITP 21	Yes [2/]	---	---
Deleterious Materials: [3/ 5/]			
Shale, % max.	3.0	3.0	---
Clay Lumps, % max.	1.0	3.0	---
Coal, Lignite, & Shells, % max.	1.0	3.0	---
Conglomerate, % max.	3.0	3.0	---
Other Deleterious, % max.	3.0	3.0	---
Total Deleterious, % max.	3.0	5.0	---

1/ Does not apply to Gradations FA 20 or FA 21.

2/ Applies only to sand. Sand exceeding the colorimetric test standard of 11 (ITP 21) will be checked for mortar making properties according to ITP 71, and shall develop a compressive strength at the age of 14 days when using Type I or II Cement of not less than 95 percent of the comparable standard.

3/ Applies only to sand.

4/ Fine aggregate used for hot-mix asphalt (HMA) shall not contain more than three percent clay (2 micron or smaller) particles as determined by Illinois Modified AASHTO T 88.

5/ Tests shall be run according to ITP 204.

(c) Gradation. All aggregates shall be produced according to the current Bureau of Materials and Physical Research Policy Memorandum, "Aggregate Gradation Control System".

The gradations prescribed may be manufactured by any suitable commercial process and by the use of any sizes or shapes of plant screen openings necessary to produce the sizes within the limits of the sieve analysis specified.

The gradation of the material from any one source shall be reasonably uniform and shall not be subject to the extreme percentages of gradation represented by the tolerance limits of the various sieve sizes.

The gradation numbers and corresponding gradation limits are listed in the following tables.

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FINE AGGREGATE GRADATIONS											
Grad No.	Sieve Size and Percent Passing										
	3/8	No. 4	No. 8 4/	No. 10	No. 16	No. 30 5/	No. 40	No. 50	No. 80	No. 100	No. 200 1/
FA 1	100	97±3			65±20			16±13		5±5	
FA 2	100	97±3			65±20			20±10		5±5	
FA 3	100	97±3		80±15			50±20		25±15		3±3
FA 4 7/	100				5±5						
FA 5	100	92±8								20±20	15±15
FA 6		92±8 2/								20±20	6±6
FA 7		100		97±3			75±15		35±10		3±3
FA 8			100				60±20			3±3	2±2
FA 9			100					30±15		5±5	
FA 10				100			90±10		60±30		7±7
FA 20	100	97±3	80±20		50±15			19±11		10±7	4±4
FA 21 3/	100	97±3	80±20		57±18			30±10		20±10	9±9
FA 22	100	6/	6/		8±8						2±2

FINE AGGREGATE GRADATIONS (Metric)											
Grad No.	Sieve Size and Percent Passing										
	9.5 mm	4.75 mm	2.36 mm 4/	2.00 mm	1.18 mm	600 µm 5/	425 µm	300 µm	180 µm	150 µm	75 µm 1/
FA 1	100	97±3			65±20			16±13		5±5	
FA 2	100	97±3			65±20			20±10		5±5	
FA 3	100	97±3		80±15			50±20		25±15		3±3
FA 4 7/	100				5±5						
FA 5	100	92±8								20±20	15±15
FA 6		92±8 2/								20±20	6±6
FA 7		100		97±3			75±15		35±10		3±3
FA 8			100				60±20			3±3	2±2
FA 9			100					30±15		5±5	
FA 10				100			90±10		60±30		7±7
FA 20	100	97±3	80±20		50±15			19±11		10±7	4±4
FA 21 3/	100	97±3	80±20		57±18			30±10		20±10	9±9
FA 22	100	6/	6/		8±8						2±2

1/ Subject to maximum percent allowed in Fine Aggregate Quality Table.

2/ 100 percent shall pass the 1 in. (25 mm) sieve, except that for bedding material 100 percent shall pass the 3/8 in. (9.5 mm) sieve. If 100 percent passes the 1/2 in. (12.5 mm) sieve, the No. 4 (4.75 mm) sieve may be 75 ± 25.

3/ For all HMA mixtures. When used, either singly or in combination with other sands, the amount of material passing the No. 200 (75 µm) sieve (washed basis) in the total sand fraction for mix design shall not exceed ten percent.

4/ For each gradation used in HMA, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of

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±15 percent. The midpoint shall not be changed without Department approval.

5/ For each gradation used in HMA, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of ±13 percent. The midpoint shall not be changed without Department approval.

6/ For the fine aggregate gradation FA 22, the aggregate producer shall set the midpoint percent passing, and the Department will apply a range of ± ten percent. The midpoint shall not be changed without Department approval.

7/ When used as backfill for pipe underdrains, Type 3, the fine aggregate shall meet one of the modified FA 4 gradations shown in the following table.

FA 4 Modified		
Sieve Size	Percent Passing	
	Option 1	Option 2
3/8 in. (9.5 mm)	100	100
No. 4 (4.75 mm)		97 ± 3
No. 8 (2.36 mm)		5 ± 5
No. 10 (2 mm)	10 ± 10	
No. 16 (1.18 mm)	5 ± 5	2 ± 2
No. 200 (75 µm)	1 ± 1	1 ± 1

(d) Incompatibility. Incompatibility of any of the gradations or combinations of gradations permitted resulting in unworkable mixtures, nonadherence to the final mix gradation limits, or any other indication of incompatibility shall be just cause for rejection of one or both of the sizes.

(e) Storage of Fine Aggregate. Sites for storage of all fine aggregates shall be grubbed and cleaned prior to storing the material.

Stockpiles shall be built according to the current Bureau of Materials and Physical Research Policy Memorandum, "Aggregate Gradation Control System" and the following.

(1) Fine aggregate of various gradations and from different sources shall be stockpiled separately.

(2) Stockpiles shall be separated to prevent intermingling at the base. If partitions are used, they shall be of sufficient heights to prevent intermingling.

(3) Fine aggregates for portland cement concrete and HMA shall be handled in and out of the stockpiles in such a manner that will prevent contamination, segregation, and degradation.

At the time of use, the fine aggregate shall be free from frozen material, material used to caulk rail cars, and all foreign materials which may have become mixed during transportation and handling.

(f) Shipping Tickets. Shipping tickets for the material shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Designation of Aggregate Information on Shipping Tickets".

1003.02 Fine Aggregate for Portland Cement Concrete and Mortar. The aggregate shall be according to Article 1003.01 and the following.

(a) Description. The fine aggregate shall consist of washed sand, washed stone sand, or a blend of washed sand and washed stone sand approved by the Engineer. Stone sand produced through an air separation system approved by the Engineer may be used in place of washed stone sand.

(b) Quality. The fine aggregate for portland cement concrete shall meet Class A Quality, except that the minus No. 200 (75 µm) sieve ITP 11 requirement in the Fine Aggregate Quality Table shall not apply to washed stone sand or any blend of washed stone sand and washed sand approved by the Engineer. The fine aggregate for masonry mortar shall meet Class A Quality.

(c) Gradation. The washed sand for portland cement concrete shall be Gradation FA 1 or FA 2. Washed stone sand for portland cement concrete, which includes any blend with washed sand, shall be Gradation FA 1, FA 2, or FA 20. Fine aggregate for masonry mortar shall be Gradation FA 9.

(d) Use of Fine Aggregates. The blending, alternate use, and/or substitution of fine aggregates from different sources for use in portland cement concrete will not be permitted without the approval of the Engineer. Any blending shall be by interlocked mechanical feeders at the aggregate source or concrete plant. The blending shall be uniform, and the equipment shall be approved by the Engineer.

(e) Alkali Reaction.

(1) ASTM C 1260. Each fine aggregate will be tested by the Department for alkali reaction according to ASTM C 1260. The test will be performed with Type I or II portland cement having a total equivalent alkali content (Na_2O + $0.658K_2O$) of 0.90 percent or greater. The Engineer will determine the assigned expansion value for each aggregate, and these values will be made available on the Department's Alkali-Silica Potential Reactivity Rating List. The Engineer may differentiate aggregate based on ledge, production method, gradation number, or other factors. An expansion value of 0.03 percent will be assigned to limestone or dolomite fine aggregates (manufactured stone sand). However, the Department reserves the right to perform the ASTM C 1260 test.

(2) ASTM C 1293 by Department. In some instances, such as chert natural sand or other fine aggregates, testing according to ASTM C 1260 may

not provide accurate test results. In this case, the Department may only test according to ASTM C 1293.

(3) ASTM C 1293 by Contractor. If an individual aggregate has an ASTM C 1260 expansion value that is unacceptable to the Contractor, an ASTM C 1293 test may be performed by the Contractor to evaluate the Department's ASTM C 1260 test result. The laboratory performing the ASTM C 1293 test shall be approved by the Department according to the current Bureau of Materials and Physical Research Policy Memorandum "Minimum Laboratory Requirements for Alkali-Silica Reactivity (ASR) Testing".

The ASTM C 1293 test shall be performed with Type I or II portland cement having a total equivalent alkali content (Na_2O + 0.658K_2O) of 0.80 percent or greater. The interior vertical wall of the ASTM C 1293 recommended container (pail) shall be half covered with a wick of absorbent material consisting of blotting paper. If the testing laboratory desires to use an alternate container, wick of absorbent material, or amount of coverage inside the container with blotting paper, ASTM C 1293 test results with an alkali-reactive aggregate of known expansion characteristics shall be provided to the Engineer for review and approval. If the expansion is less than 0.040 percent after one year, the aggregate will be assigned an ASTM C 1260 expansion value of 0.08 percent that will be valid for two years, unless the Engineer determines the aggregate has changed significantly. If the aggregate is manufactured into multiple gradation numbers, and the other gradation numbers have the same or lower ASTM C 1260 value, the ASTM C 1293 test result may apply to multiple gradation numbers.

The Engineer reserves the right to verify a Contractor's ASTM C 1293 test result. When the Contractor performs the test, a split sample shall be provided to the Engineer. The Engineer may also independently obtain a sample at any time. The aggregate will be considered reactive if the Contractor or Engineer obtains an expansion value of 0.040 percent or greater.

1003.03 Fine Aggregate for Hot-Mix Asphalt (HMA). The aggregate shall be according to Article 1003.01 and the following.

(a) Description. Fine aggregate for HMA shall consist of sand, stone sand, chats, slag sand, or steel slag sand. For gradation FA 22, uncrushed material will not be permitted. Fine aggregate for SMA shall consist of stone sand, slag sand, or steel slag sand.

(b) Quality. The fine aggregate for all HMA shall be Class B Quality or better.

(c) Gradation. The fine aggregate gradation for all HMA shall be FA 1, FA 2, FA 20, FA 21, or FA 22. The fine aggregate gradation for SMA shall be FA/FM 20.

For mixture IL-4.75 and surface mixtures with an Ndesign = 90, at least 50 percent of the required fine aggregate fraction shall consist of either stone sand, slag sand, or steel slag meeting the FA 20 gradation.

For mixture IL-19.0, Ndesign = 90 the fine aggregate fraction shall consist of at least 67 percent manufactured sand meeting FA 20 or FA 22 gradation. For mixture IL-19.0, Ndesign = 50 or 70 the fine aggregate fraction shall consist of at least 50 percent manufactured sand meeting FA 20 or FA 22 gradation. The manufactured sand shall be stone sand, slag sand, steel slag sand, or combinations thereof.

Gradation FA 1, FA 2, or FA 3 shall be used when required for prime coat aggregate application for HMA.

1003.04 Fine Aggregate for Bedding, Backfill, Trench Backfill, Embankment, Porous Granular Backfill, and French Drains. The aggregate shall be according to Article 1003.01 and the following.

(a) Description. The fine aggregate shall consist of sand, stone sand, chats, wet bottom boiler slag, slag sand, or granulated slag sand.

For trench backfill, crushed concrete sand and construction and demolition debris sand may be used in lieu of the above.

For pipe underdrains, Type 3, the fine aggregate shall consist of sand or crushed gravel sand.

(b) Quality. The fine aggregate shall be reasonably free from an excess of soft and unsound particles and other objectionable matter.

(c) Gradation. The fine aggregate gradations shall be as follows.

Application	Gradation
Granular Embankment, Granular Backfill, Trench Backfill, and Bedding and Backfill for Pipe Culverts and Storm Sewers	FA 1, FA 2, or FA 6 through FA 21
Porous Granular Embankment, Porous Granular Backfill, French Drains, and Bedding and Backfill for Pipe Underdrains, Type 1	FA 1, FA 2, or FA 20, except the percent passing the No. 200 (75 µm) sieve shall be 2±2
Backfill for Pipe Underdrains, Type 3	FA 4 Modified (see Article 1003.02(c))

1003.05 Fine Aggregate for Membrane Waterproofing. The aggregate shall be according to Article 1003.01 and the following.

(a) Description. The fine aggregate shall consist of sand, stone sand, wet bottom boiler slag, slag sand, or chats.

(b) Quality. The fine aggregate shall meet the Class B Quality Deleterious Count, and when subjected to ITP 104, the weighted average loss shall not be more than ten percent.

(c) Gradation. The fine aggregate shall be Gradation FA 8.

1003.06 Fine Aggregate for Controlled Low-Strength Material (CLSM). The aggregate shall be according to Article 1003.01 and the following.

(a) Description. The fine aggregate shall consist of sand.

(b) Quality. The fine aggregate shall be reasonably free from an excess of soft and unsound particles and other objectionable matter.

(c) Gradation. The fine aggregate gradation shall be FA 1 or FA 2. Blending of fine aggregate will not be permitted.

1003.07 Fine Aggregate for Select Fill Used for Retaining Wall Applications Utilizing Soil Reinforcement. The aggregate shall be according to Article 1003.01 and the following.

(a) Description. The fine aggregate shall consist of sand or stone sand.

(b) Quality. The fine aggregate shall have a maximum sodium sulfate (Na_2SO_4) loss of 15 percent according to ITP 104.

(c) Gradation. The fine aggregate shall be FA 1, FA 2, or FA 20.

(d) Internal Friction Angle. The effective internal friction angle for the fine aggregate shall be a minimum 34 degrees according to AASHTO T 236 on samples compacted to 95 percent density according to Illinois Modified AASHTO T 99. The AASHTO T 296 test with pore pressure measurement may be used in lieu of AASHTO T 236. If the Contractor's design uses a friction angle greater than 34 degrees this greater value shall be taken as the minimum required.

(e) pH. The pH shall be determined according to Illinois Modified AASHTO T 289.

(1) When geosynthetic soil reinforcement is used, the fine aggregate pH shall be 4.5 to 9.0 for permanent applications, and 3.0 to 10.0 for temporary applications.

(2) When steel reinforcement is used, the fine aggregate pH shall be 5.0 to 10.0.

(f) Corrosion Mitigation. The fine aggregates shall also meet the following when used in conjunction with steel soil reinforcement in non-temporary wall applications.

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(1) Resistivity. The resistivity according to Illinois Modified AASHTO T 288 shall be greater than 3000 ohm centimeters for galvanized reinforcement, and 1500 ohm centimeters for aluminized Type 2 reinforcement.

(2) The chlorides shall be less than 100 parts per million according to Illinois Modified AASHTO T 291 or ASTM D 4327. For either test, the sample shall be prepared according to Illinois Modified AASHTO T 291.

(3) The sulfates shall be less than 200 parts per million according to Illinois Modified AASHTO T 290 or ASTM D 4327. For either test, the sample shall be prepared according to Illinois Modified AASHTO T 290.

(4) The organic content shall be a maximum of 1.0 percent according to Illinois Modified AASHTO T 267.

(g) Test Frequency. Prior to the start of construction, the Contractor shall provide internal friction angle and pH test results to demonstrate the select fill material meets the specification requirements. Resistivity, chlorides, sulfates, and organic content test results shall also be provided if steel reinforcement is used. The laboratory performing the Illinois Modified AASHTO T 288 test shall be approved by the Department according to the current Bureau of Materials and Physical Research Policy Memorandum "Minimum Laboratory Requirements for Resistivity Testing". These test results shall be no more than 12 months old. In addition, a sample of select fill material will be obtained by the Engineer for testing and approval before construction begins. Thereafter, the minimum frequency of subsequent sampling and testing at the jobsite will be one per 40,000 tons (36,300 metric tons) of select fill.

SECTION 1004. COARSE AGGREGATES

1004.01 Materials. Coarse aggregate materials shall be according to the following.

(a) Description. The natural and manufactured materials used as coarse aggregate are defined as follows.

(1) Gravel. Gravel shall be the coarse granular material resulting from the reduction of rock by the action of the elements and having subangular to rounded surfaces. It may be partially crushed.

(2) Chert Gravel. Chert gravel shall be the coarse granular material occurring in alluvial deposits resulting from reworking by weathering and erosion of chert bearing geological formations and containing a minimum of 80 percent chert or similar siliceous material.

(3) Crushed Gravel. Crushed gravel shall be the product resulting from crushing, by mechanical means, and shall consist entirely of particles obtained by crushing gravel. The acceptance and use of crushed gravel shall be according to the current Bureau of Materials and

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Physical Research Policy Memorandum, "Crushed Gravel Producer Self-Testing Program".

(4) Crushed Stone. Crushed stone shall be the angular fragments resulting from crushing undisturbed, consolidated deposits of rock by mechanical means. Crushed stone shall be divided into the following, when specified.

a. Carbonate Crushed Stone. Carbonate crushed stone shall be either dolomite or limestone. Dolomite shall contain 11.0 percent or more magnesium oxide (MgO). Limestone shall contain less than 11.0 percent magnesium oxide (MgO).

b. Crystalline Crushed Stone. Crystalline crushed stone shall be either metamorphic or igneous stone, including but is not limited to, quartzite, granite, rhyolite and diabase.

(5) Wet Bottom Boiler Slag. Wet bottom boiler slag shall be the hard, angular by-product of the combustion of coal in wet bottom boilers.

(6) Crushed Slag. Crushed slag shall be the graded product resulting from the processing of air-cooled blast furnace slag. Air-cooled blast furnace slag shall be the nonmetallic product, consisting essentially of silicates and alumino-silicates of lime and other bases, which is developed in a molten condition simultaneously with iron in a blast furnace. It shall be air-cooled and shall have a compact weight (ITP 19) of not less than 70 lb/cu ft (1100 kg/cu m). The acceptance and use of air-cooled blast furnace slag shall be according to the current Bureau of Materials and Physical Research Policy Memoranda, "Crushed Slag Producer Certification and Self-Testing Program" and "Slag Producer Self-Testing Program".

(7) Crushed Sandstone. Crushed sandstone shall be the angular fragments resulting from crushing, by mechanical means, a cemented sand composed predominantly of quartz grains. Sandstone shall have an Insoluble Residue of 50.0 percent or higher.

(8) Crushed Concrete. Crushed concrete shall be the angular fragments resulting from crushing portland cement concrete by mechanical means. The acceptance and use of crushed concrete shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Recycling Portland Cement Concrete Into Aggregate".

(9) Chats. Chats shall be the tailings resulting from the separation of metals from the rocks in which they occur.

(10) Crushed Steel Slag. Crushed steel slag shall be the graded product resulting from the processing of steel slag. Steel slag shall be the nonmetallic product which is developed in a molten condition simultaneously with steel in an open hearth, basic oxygen, or electric furnace. The acceptance and use of crushed steel slag shall be

according to the current Bureau of Materials and Physical Research Policy Memorandum, "Slag Producer Self-Testing Program".

(b) Quality. The coarse aggregate shall be according to the quality standards listed in the following table.

COARSE AGGREGATE QUALITY				
QUALITY TEST	CLASS			
	A	B	C	D
Na_2SO_4 Soundness 5 Cycle, ITP 104 1/, % Loss max.	15	15	20	25 2/
Los Angeles Abrasion, ITP 96, % Loss max.	40 3/	40 4/	40 5/	45
Minus No. 200 (75 µm) Sieve Material, ITP 11	1.0 6/	---	2.5 7/	---
Deleterious Materials 10/				
Shale, % max.	1.0	2.0	4.0 8/	---
Clay Lumps, % max.	0.25	0.5	0.5 8/	---
Coal & Lignite, % max.	0.25	---	---	---
Soft & Unsound Fragments, % max.	4.0	6.0	8.0 8/	---
Other Deleterious, % max.	4.0 9/	2.0	2.0 8/	---
Total Deleterious, % max.	5.0	6.0	10.0 8/	---

1/ Does not apply to crushed concrete.

2/ For aggregate surface course and aggregate shoulders, the maximum percent loss shall be 30.

3/ For portland cement concrete, the maximum percent loss shall be 45.

4/ Does not apply to crushed slag or crushed steel slag.

5/ For hot-mix asphalt (HMA) binder mixtures, the maximum percent loss shall be 45.

6/ For crushed aggregate, if the material finer than the No. 200 (75 µm) sieve consists of the dust from fracture, essentially free from clay or silt, this percentage may be increased to 2.5.

7/ Does not apply to aggregates for HMA binder mixtures.

8/ Does not apply to Class A seal and cover coats.

9/ Includes deleterious chert. In gravel and crushed gravel aggregate, deleterious chert shall be the lightweight fraction separated in a 2.35 heavy media separation. In crushed stone aggregate, deleterious chert shall be the lightweight fraction separated in a

2.55 heavy media separation. Tests shall be run according to ITP 113.

10/ Test shall be run according to ITP 203.

All varieties of chert contained in gravel coarse aggregate for portland cement concrete, whether crushed or uncrushed, pure or impure, and irrespective of color, will be classed as chert and shall not be present in the total aggregate in excess of 25 percent by weight (mass).

Aggregates used in Class BS concrete (except when poured on subgrade), Class PS concrete, and Class PC concrete (bridge superstructure products only, excluding the approach slab) shall contain no more than two percent by weight (mass) of deleterious materials. Deleterious materials shall include substances whose disintegration is accompanied by an increase in volume which may cause spalling of the concrete.

(c) Gradation. All aggregates shall be produced according to the current Bureau of Materials and Physical Research Policy Memorandum, "Aggregate Gradation Control System".

The sizes prescribed may be manufactured by any suitable commercial process and by the use of any sizes or shapes of plant screen openings necessary to produce the sizes within the limits of the sieve analysis specified.

The gradation of the material from any one source shall be reasonably close to the gradation specified and shall not be subject to the extreme percentages of gradation represented by the tolerance limits for the various sieve sizes. The gradation numbers and corresponding gradation limits are listed in the following table.

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Grad No.	COARSE AGGREGATE GRADATIONS												
	Sieve Size and Percent Passing												
	3 in.	2 1/2 in.	2 in.	1 1/2 in.	1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200 1/
CA 1	100	95±5	60±15	15±15	3±3								
CA 2		100	95±5		75±15		50±15		30±10		20±15		8±4
CA 3		100	93±7	55±20	8±8		3±3						
CA 4			100	95±5	85±10		60±15		40±10		20±15		8±4
CA 5				97±3 2/	40±25		5±5		3±3				
CA 6				100	95±5		75±15		43±13		25±15		8±4
CA 7				100	95±5		45±15 7/		5±5				
CA 8				100	97±3	85±10	55±10		10±5		3±3 3/		
CA 9				100	97±3		60±15		30±15		10±10		6±6
CA 10					100	95±5	80±15		50±10		30±15		9±4
CA 11					100	92±8	45±15 4/7/		6±6		3±3 3/ 5/		
CA 12						100	95±5	85±10	60±10		35±10		9±4
CA 13						100	97±3	80±10	30±15		3±3 3/		
CA 14							90±10 6/	45±20	3±3				
CA 15							100	75±15	7±7		2±2		
CA 16							100	97±3	30±15		2±2 3/		
CA 17	100								65±20		45±20	20±10	10±5
CA 18	100				95±5				75±25		55±25	10±10	2±2
CA 19	100				95±5				60±15		40±15	20±10	10±5
CA 20							100	92±8	20±10	5±5	3±3		

Grad No.	COARSE AGGREGATE GRADATIONS (metric)												
	Sieve Size and Percent Passing												
	75 mm	63 mm	50 mm	37.5 mm	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	300 µm	75 µm 1/
CA 1	100	95±5	60±15	15±15	3±3								
CA 2		100	95±5		75±15		50±15		30±10		20±15		8±4
CA 3		100	93±7	55±20	8±8		3±3						
CA 4			100	95±5	85±10		60±15		40±10		20±15		8±4
CA 5				97±3 2/	40±25		5±5		3±3				
CA 6				100	95±5		75±15		43±13		25±15		8±4
CA 7				100	95±5		45±15 7/		5±5				
CA 8				100	97±3	85±10	55±10		10±5		3±3 3/		
CA 9				100	97±3		60±15		30±15		10±10		6±6
CA 10					100	95±5	80±15		50±10		30±15		9±4
CA 11					100	92±8	45±15 4/7/		6±6		3±3 3/ 5/		
CA 12						100	95±5	85±10	60±10		35±10		9±4
CA 13						100	97±3	80±10	30±15		3±3 3/		
CA 14							90±10 6/	45±20	3±3				
CA 15							100	75±15	7±7		2±2		
CA 16							100	97±3	30±15		2±2 3/		
CA 17	100								65±20		45±20	20±10	10±5
CA 18	100				95±5				75±25		55±25	10±10	2±2
CA 19	100				95±5				60±15		40±15	20±10	10±5
CA 20							100	92±8	20±10	5±5	3±3		

1/ Subject to maximum percent allowed in Coarse Aggregate Quality table.

2/ Shall be 100 percent passing the 1 3/4 in. (45 mm) sieve.

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3/ When used in HMA (High and Low ESAL) mixtures, the percent passing the No. 16 (1.18 mm) sieve for gradations CA 8, CA 11, CA 13, or CA 16 shall be 4±4 percent.

4/ When using gradation CA 11 for IL-19.0 and IL-19.0L binder, the percent passing the 1/2 in. (12.5 mm) sieve may also be 15±10.

5/ The No. 16 (1.18 mm) requirement will be waived when CA 11 is used in the manufacture of portland cement concrete.

6/ Shall be 100 percent passing the 5/8 in. (16 mm) sieve.

7/ When Class BS concrete is to be pumped, the coarse aggregate gradation shall have a minimum of 45 percent passing the 1/2 in. (12.5 mm) sieve. The Contractor may combine two or more coarse aggregate sizes, consisting of CA 7, CA 11, CA 13, CA 14, and CA 16, provided a CA 7 or CA 11 is included in the blend.

Note: When CA 7, CA 8, CA 11, CA 13, CA 14, CA 15, or CA 16 are used under paved median, Notes 3, 4, 5, and 6 shall apply.

(d) Incompatibility. Incompatibility of any of the gradations or combinations of gradations permitted resulting in unworkable mixtures, nonadherence to the final mix gradation limits, or any other indication of incompatibility shall be just cause for rejection of one or both of the sizes.

(e) Storage. Sites for stockpiles shall be grubbed and cleaned prior to storing the aggregates.

The stockpiles shall be built according to the current Bureau of Materials and Physical Research Policy Memorandum, "Aggregate Gradation Control System" and the following.

(1) Segregation or degradation due to improper stockpiling or loading out of stockpiles shall be just cause for rejecting the material.

(2) Separate stockpiles shall be provided for the various kinds of aggregates.

(3) Stockpiles shall be separated to prevent intermingling at the base. If partitions are used, they shall be of sufficient heights to prevent intermingling.

(4) Coarse aggregates shall be handled in and out of the stockpiles in such a manner that will prevent contamination and degradation.

(5) Crushed concrete, crushed slag, or lightweight aggregate for portland cement concrete shall be stockpiled in a moist condition (saturated surface dry or greater) and the moisture content shall be maintained uniformly throughout the stockpile by periodic sprinkling.

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At the time of use, the coarse aggregate shall be free from frozen material, material used to caulk rail cars, and all foreign material which may have become mixed during transportation and handling.

(f) Shipping Tickets. Shipping tickets for the material shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Designation of Aggregate Information on Shipping Tickets".

1004.02 Coarse Aggregate for Portland Cement Concrete. The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate shall be gravel, crushed gravel, crushed stone, crushed concrete, crushed slag, or crushed sandstone.

(b) Quality. The coarse aggregate shall be Class A quality.

(c) Gradation. The gradations of coarse aggregate used in the production of portland cement concrete for pavements and structures shall be according to Table 1 of Article 1020.04. Washing equipment will be required where producing conditions warrant.

(d) Combining Sizes. Each size shall be stored separately and care shall be taken to prevent them from being mixed until they are ready to be proportioned. Separate compartments shall be provided to proportion each size.

(1) When Class BS concrete is to be pumped, the coarse aggregate gradation shall have a minimum of 45 percent passing the 1/2 in. (12.5 mm) sieve. The Contractor may combine two or more coarse aggregate sizes, consisting of CA 7, CA 11, CA 13, CA 14, and CA 16, provided a CA 7 or CA 11 is included in the blend.

(2) If the coarse aggregate is furnished in separate sizes, they shall be combined in proportions to provide a uniformly graded coarse aggregate grading within the following limits.

Class of Concrete 1/	Combined Sizes	Sieve Size and Percent Passing						
		2 1/2 in.	2 in.	1 3/4 in.	1 1/2 in.	1 in.	1/2 in.	No. 4
PV 2/								
	CA 5 & CA 7	---	---	100	98±2	72±22	22±12	3±3
	CA 5 & CA 11	---	---	100	98±2	72±22	22±12	3±3
SI and SC 2/								
	CA 3 & CA 7	100	95±5	---	---	55±25	20±10	3±3
	CA 3 & CA 11	100	95±5	---	---	55±25	20±10	3±3
	CA 5 & CA 7	---	---	100	98±2	72±22	22±12	3±3
	CA 5 & CA 11	---	---	100	98±2	72±22	22±12	3±3

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Class of Concrete 1/	Combined Sizes	Sieve Size (metric) and Percent Passing						
		63 mm	50 mm	45 mm	37.5 mm	25 mm	12.5 mm	4.75 mm
PV 2/								
	CA 5 & CA 7	---	---	100	98±2	72±22	22±12	3±3
	CA 5 & CA 11	---	---	100	98±2	72±22	22±12	3±3
SI and SC 2/								
	CA 3 & CA 7	100	95±5	---	---	55±25	20±10	3±3
	CA 3 & CA 11	100	95±5	---	---	55±25	20±10	3±3
	CA 5 & CA 7	---	---	100	98±2	72±22	22±12	3±3
	CA 5 & CA 11	---	---	100	98±2	72±22	22±12	3±3

1/ See Table 1 of Article 1020.04.

2/ Any of the listed combination of sizes may be used.

(e) Mixing Gravel, Crushed Gravel, Crushed Stone, and Crushed Slag Coarse Aggregates. Two different specified sizes of crushed stone, gravel, and crushed gravel from one source or any two sources may be combined in any consistent ratio in a mix; but the use of alternate batches of crushed stone, gravel, or crushed gravel of any one size or combination of sizes will not be permitted. Coarse aggregates of any one size from different sources shall not be mixed without permission from the Engineer. Crushed slag shall not be combined or mixed with gravel, crushed gravel, or crushed stone aggregates.

(f) Freeze-Thaw Rating. When coarse aggregate is used to produce portland cement concrete for base course, base course widening, pavement (including precast), driveway pavement, sidewalk, shoulders, curb, gutter, combination curb and gutter, median, paved ditch, concrete superstructures on subgrade such as bridge approach slabs (excluding precast), concrete structures on subgrade such as bridge approach footings, or their repair using concrete, the gradation permitted will be determined from the results of the Department's Freeze-Thaw Test (ITP 161). A list of freeze-thaw ratings for all Class A quality coarse aggregate sources will be available. The gradations permitted for each rating shall be as follows.

Freeze-Thaw Rating (Top Size) in.	mm	Gradation Permitted
1 1/2 in.	(37.5 mm)	Combined CA 5 & CA 7, Combined CA 5 & CA 11, CA 7, or CA 11
1 in.	(25 mm)	CA 7 or CA 11
3/4 in.	(19 mm)	CA 11
1/2 in.	(12.5 mm)	CA 13, CA 14, or CA 16
NON-ACC		Not Acceptable

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Additional requirements may be placed on coarse aggregates when used in continuously reinforced concrete pavement. Such requirements will be stipulated on the most recent Freeze-Thaw Rating List.

(g) Alkali Reaction.

(1) ASTM C 1260. Each coarse aggregate will be tested by the Department for alkali reaction according to ASTM C 1260. The test will be performed with Type I or II portland cement having a total equivalent alkali content (Na_2O + 0.658K_2O) of 0.90 percent or greater. The Engineer will determine the assigned expansion value for each aggregate, and these values will be made available on the Department's Alkali-Silica Potential Reactivity Rating List. The Engineer may differentiate aggregate based on ledge, production method, gradation number, or other factors. An expansion value of 0.05 percent will be assigned to limestone or dolomite coarse aggregates. However, the Department reserves the right to perform the ASTM C 1260 test.

(2) ASTM C 1293 by Department. In some instances testing a coarse aggregate according to ASTM C 1260 may not provide accurate test results. In this case, the Department may only test according to ASTM C 1293.

(3) ASTM C 1293 by Contractor. If an individual aggregate has an ASTM C 1260 expansion value that is unacceptable to the Contractor, an ASTM C 1293 test may be performed by the Contractor according to Article 1003.02(e)(3).

If lightweight aggregate is specified for structures, it shall be according to ASTM C 330, the second paragraph of Article 1004.01(c), and Articles 1004.01(d) and 1004.01(e). Lightweight aggregate of any one size from different sources shall not be mixed without permission of the Engineer. Lightweight aggregate may be combined or mixed with gravel, crushed gravel, or crushed stone.

1004.03 Coarse Aggregate for Hot-Mix Asphalt (HMA). The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate for HMA shall be according to the following table.

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Use	Mixture	Aggregates Allowed
Class A	Seal or Cover	Allowed Alone or in Combination [5/]: Gravel Crushed Gravel Carbonate Crushed Stone Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag Crushed Concrete
HMA Low ESAL	Stabilized Subbase or Shoulders	Allowed Alone or in Combination [5/]: Gravel Crushed Gravel Carbonate Crushed Stone Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag[1/] Crushed Concrete
HMA High ESAL Low ESAL	Binder IL-19.0 or IL-19.0L SMA Binder	Allowed Alone or in Combination [5/]: Crushed Gravel Carbonate Crushed Stone[2/] Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Concrete[3/]
HMA High ESAL Low ESAL	C Surface and Leveling Binder IL-9.5 or IL-9.5L SMA Ndesign 50 Surface	Allowed Alone or in Combination [5/]: Crushed Gravel Carbonate Crushed Stone[2/] Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag[4/] Crushed Concrete[3/]
HMA High ESAL	D Surface and Leveling Binder IL-9.5 SMA Ndesign 50 Surface	Allowed Alone or in Combination [5/]: Crushed Gravel Carbonate Crushed Stone (other than Limestone)[2/] Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag[4/] Crushed Concrete[3/]

Other Combinations Allowed:

Up to...	*With...*
25% Limestone	Dolomite
50% Limestone	Any Mixture D aggregate other than Dolomite
75% Limestone	Crushed Slag (ACBF) or Crushed Sandstone

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Art. 1004.03 Coarse Aggregates

Use	Mixture	Aggregates Allowed	
HMA High ESAL	E Surface IL-9.5 SMA Ndesign 80 Surface	Allowed Alone or in Combination [5/]: Crushed Gravel Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag Crushed Concrete[3/] No Limestone.	
		Other Combinations Allowed:	
		Up to...	*With...*
		50% Dolomite[2/]	Any Mixture E aggregate
		75% Dolomite[2/]	Crushed Sandstone, Crushed Slag (ACBF), Crushed Steel Slag, or Crystalline Crushed Stone
		75% Crushed Gravel or Crushed Concrete[3/]	Crushed Sandstone, Crystalline Crushed Stone, Crushed Slag (ACBF), or Crushed Steel Slag
HMA High ESAL	F Surface IL-9.5 SMA Ndesign 80 Surface	Allowed Alone or in Combination [5/]: Crystalline Crushed Stone Crushed Sandstone Crushed Slag (ACBF) Crushed Steel Slag No Limestone.	
		Other Combinations Allowed:	
		Up to...	*With...*
		50% Crushed Gravel, Crushed Concrete[3/], or Dolomite[2/]	Crushed Sandstone, Crushed Slag (ACBF), Crushed Steel Slag, or Crystalline Crushed Stone

1/ Crushed steel slag allowed in shoulder surface only.

2/ Carbonate crushed stone shall not be used in SMA Ndesign 80. In SMA Ndesign 50, carbonate crushed stone shall not be blended with any of the other aggregates allowed alone in Ndesign 50 SMA binder or Ndesign 50 SMA surface.

3/ Crushed concrete will not be permitted in SMA mixes.

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4/ Crushed steel slag shall not be used as leveling binder.

5/ When combinations of aggregates are used, the blend percent measurements shall be by volume.

(b) Quality. For surface courses, the coarse aggregate shall be Class B quality or better. For SMA surface and binder courses the coarse aggregate shall be Class B Quality or better. For Class A (seal or cover coat), other binder courses, and surface course IL-9.5L (Low ESAL), the coarse aggregate shall be Class C quality or better.

(c) Gradation. The coarse aggregate gradations shall be as listed in the following table.

Use	Size/Application	Gradation No.
Class A-1, 2, & 3	3/8 in. (10 mm) Seal	CA 16
Class A-1	1/2 in. (13 mm) Seal	CA 15
Class A-2 & 3	Cover	CA 14
HMA High ESAL	IL-19.0 IL-9.5	CA 11 1/ CA 16 and/or CA 13 CA 16
HMA Low ESAL	IL-19.0L IL-9.5L Stabilized Subbase or Shoulders	CA 11 1/ CA 16

1/ CA 16 or CA 13 may be blended with the gradations listed.

(d) Flat and Elongated Particles. For SMA the coarse aggregate shall meet the criteria for Flat and Elongated Particles listed in Illinois Modified AASHTO M 325.

(e) Absorption. For SMA the coarse aggregate shall also have water absorption $\leq$ 2.5 percent.

1004.04 Coarse Aggregate for Granular Embankment Special; Granular Subbase; Stabilized Subbase; and Aggregate Base, Surface, and Shoulder Courses. The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate shall be gravel, crushed gravel, crushed stone, crushed concrete, crushed slag, or crushed sandstone, except gravel shall not be used for subbase granular material, Type C.

The coarse aggregate for stabilized subbase, aggregate base course, and aggregate shoulders, if approved by the Engineer, may be produced by blending aggregates from more than one source, provided the method of blending results in a uniform product. The components of a blend need not be of the same kind of material. The source of material or blending proportions shall not be changed during the progress of the work without written permission from the Engineer. Where a natural aggregate is

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deficient in fines, the material added to make up deficiencies shall be a fine aggregate of Class C quality or higher according to Section 1003 and/or mineral filler meeting the requirements of Article 1011.01.

(b) Quality. The coarse aggregate shall be Class D Quality or better.

(c) Gradation. The coarse aggregate gradation shall be used as follows.

Use	Gradation
Granular Embankment, Special	CA 6 or CA 10 1/
Granular Subbase:	
Subbase Granular Material, Ty. A	CA 6 or CA 10 2/
Subbase Granular Material, Ty. B	CA 6, CA 10, CA 12, or CA 19 2/
Subbase Granular Material, Ty. C	CA 7, CA 11, or CA 5 & CA 7 3/
Stabilized Subbase	CA 6 or CA 10 4/
Aggregate Base Course	CA 6 or CA 10 2/
Aggregate Surface Course:	
Type A	CA 6 or CA 10 1/
Type B	CA 6, CA 9, or CA 10 5/
Aggregate Shoulders	CA 6 or CA 10 2/

1/ Gradation CA 2, CA 4, CA 9, or CA 12 may be used if approved by the Engineer.
2/ Gradation CA 2 or CA 4 may be used if approved by the Engineer.
3/ If the CA 5 and CA 7 blend is furnished, proper mixing will be required either at the source or at the jobsite according to Article 1004.02(d).
4/ Gradation CA 2, CA 4, or CA 12 may be used if approved by the Engineer.
5/ Gradation CA 4 or CA 12 may be used if approved by the Engineer.

(d) Plasticity. All material shall comply with the plasticity index requirements listed below. The plasticity index requirement for crushed gravel, crushed stone, and crushed slag may be waived if the ratio of the percent passing the No. 200 (75 µm) sieve to that passing the No. 40 (425 µm) sieve is 0.60 or less.

Use	Plasticity Index - Percent 1/	
	Gravel	Crushed Gravel, Stone, & Slag
Granular Embankment, Special	0 to 6	0 to 4
Granular Subbase:		
Subbase Granular Material, Type A	0 to 9	---
Subbase Granular Material, Type B	0 to 9	---
Stabilized Subbase	0 to 9	0 to 9
Aggregate Base Course	0 to 6	0 to 4
Aggregate Surface Course:		
Type A	2 to 9	---
Type B 2/	2 to 9	---
Aggregate Shoulders	2 to 9	---

1/ Plasticity Index shall be determined by the method given in AASHTO T 90. Where shale in any form exists in the producing ledges, crushed stone samples shall be soaked a minimum of 18 hours before processing for plasticity index or minus No. 40 (425 µm) material. When clay material is added to adjust the plasticity index, the clay material shall be in a minus No. 4 (4.75 mm) sieve size.

2/ When Gradation CA 9 is used, the plasticity index requirement will not apply.

1004.05 Coarse Aggregate for Blotter, Embankment, Backfill, Trench Backfill, Bedding, and French Drains. The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate shall be gravel, crushed gravel, crushed stone, crushed concrete, crushed slag, chats, crushed sandstone, or wet bottom boiler slag.

For pipe underdrains, Type 2, the crushed stone shall be a crystalline crushed stone.

(b) Quality. The coarse aggregate shall consist of sound durable particles reasonably free of objectionable deleterious material.

(c) Gradation. The coarse aggregate gradations shall be as follows.

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Application	Gradation
Blotter	CA 15
Granular Embankment, Granular Backfill, Trench Backfill, and Bedding and Backfill for Pipe Culverts and Storm Sewers	CA 6, CA 9, CA 10, CA 12, CA 17, CA 18, and CA 19
Porous Granular Embankment, Porous Granular Backfill, and French Drains	CA 7, CA 8, CA 11, CA 15, CA 16 and CA 18
Bedding and Backfill for Pipe Underdrains, Type 2	CA 16, except the percent passing the No. 16 (1.18 mm) sieve shall be 4 ± 4 percent.

1004.06 Coarse Aggregate for Select Fill Used for Retaining Wall Applications Utilizing Soil Reinforcement. The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate shall be crushed gravel or crushed stone.

(b) Quality. The coarse aggregate shall have a maximum sodium sulfate (Na_2SO_4) loss of 15 percent according to ITP 104.

(c) Gradation. The coarse aggregate shall be CA 6 thru CA 16, except when epoxy coated steel, geosynthetic, or geotextile soil reinforcement is utilized the coarse aggregate shall be CA 12 thru CA 16.

(d) Internal Friction Angle. The effective internal friction angle for the coarse aggregate shall be a minimum 34 degrees according to AASHTO T 236 on samples compacted to 95 percent density according to Illinois Modified AASHTO T 99. The AASHTO T 296 test with pore pressure measurement may be used in lieu of AASHTO T 236. If the Contractor's design uses a friction angle greater than 34 degrees, this greater value shall be taken as the minimum required.

(e) pH. pH shall be determined according to Illinois Modified AASHTO T 289.

(1) When geosynthetic soil reinforcement is used, the coarse aggregate pH shall be 4.5 to 9.0 for permanent applications, and 3.0 to 10.0 for temporary applications.

(2) When steel reinforcement is used, the coarse aggregate pH shall be 5.0 to 10.0 according to Illinois Modified AASHTO T 289.

(f) Corrosion Mitigation. The coarse aggregates shall also meet the following when used in conjunction with steel soil reinforcement in non-temporary wall applications:

(1) Resistivity. The resistivity according to Illinois Modified AASHTO T 288 shall be greater than 3000 ohm centimeters for galvanized reinforcement, and 1500 ohm centimeters for aluminized Type 2 reinforcement. However, the resistivity requirement is not applicable to CA 7, CA 8, CA 11, CA 13, CA 14, CA 15, and CA 16.

(2) The chlorides shall be less than 100 parts per million according to Illinois Modified AASHTO T 291 or ASTM D 4327. For either test, the sample shall be prepared according to Illinois Modified AASHTO T 291.

(3) The sulfates shall be less than 200 parts per million according to Illinois Modified AASHTO T 290 or ASTM D 4327. For either test, the sample shall be prepared according to Illinois Modified AASHTO T 290.

(4) The organic content shall be a maximum of 1.0 percent according to Illinois Modified AASHTO T 267.

(g) Test Frequency. Prior to the start of construction, the Contractor shall provide internal friction angle and pH test results demonstrating the select fill material meets the specification requirements. Resistivity, chlorides, sulfates, and organic content test results shall also be provided if steel reinforcement is used. The laboratory performing the Illinois Modified AASHTO T 288 test shall be approved by the Department according to the current Bureau of Materials and Physical Research Policy Memorandum "Minimum Laboratory Requirements for Resistivity Testing". These test results shall be no more than 12 months old. In addition, a sample of select fill material will be obtained by the Engineer for testing and approval before construction begins. Thereafter, the minimum frequency of subsequent sampling and testing at the jobsite will be one per 40,000 tons (36,300 metric tons) of select fill. Testing to verify the internal friction angle will only be required when the wall design utilizes a minimum effective internal friction angle greater than 34 degrees.

Illinois Department of Transportation

Development of Gradation Bands on Incoming Aggregate at Mix Plants
Appendix A1

Effective: January 1, 1994
Revised: June 1, 2012

A. Scope

Quality Control Plans for QC/QA Contracts normally require incoming aggregate to be checked for gradation compliance before use in mix plants. Aggregate is produced to tight gradation bands at the source but will degrade during handling and shipment.

B. Purpose

Establish a procedure to modify aggregate source gradation bands to develop mix plant gradation bands for use in checking gradation compliance on incoming aggregate at mix plants. The mix plant gradation bands will also be used in checking gradation compliance for required stockpile gradation tests at the mix plant.

C. Aggregate Source Gradation Bands

The Contractor shall obtain certified aggregate gradation bands (including master band, if required) from the aggregate source for all certified aggregates prior to any shipment of material to the mix plant. Natural sand gradation bands shall be obtained from the appropriate District Materials Engineer.

D. General Procedure

The Contractor may modify the aggregate source gradation bands according to the following procedures, if necessary, to check incoming aggregate for gradation compliance at the mix plant. If not modified, the aggregate source gradation bands shall be considered the mix plant gradation bands when checking incoming aggregate.

1. Coarse Aggregate—The Contractor may shift the aggregate source master band a maximum of three percent (3%) upwards to establish a Mix Plant Master Band for each coarse aggregate used. All other aggregate source gradation bands, except for the top sieve and bottom sieve bands in the gradation specification, may also be shifted upward a maximum of three percent (3%). The top sieve and bottom sieve bands shall not be changed, except as follows:

   At portland cement concrete plants, the Contractor may increase the specification limit for the minus 75-µm (No. 200) Illinois Test Procedure 11 sieve material upwards one half percent (0.5%) if the 75-µm (No. 200) material consists of dust from fracture, or degradation from abrasion and

attrition, during stockpiling and handling (reference Article 1004.01[b] of the Department's *Standard Specifications for Road and Bridge Construction*.

2. Manufactured Sand—All aggregate source gradation bands, except the top sieve and bottom sieve bands in the gradation specification, for each certified manufactured sand may be shifted upwards a maximum of three percent (3%). The top sieve and bottom sieve bands shall not be changed.

3. Natural Sand—The gradation bands obtained from the Department for each natural sand shall not be changed.

E. Department Approval

All aggregate source gradation bands and mix plant gradation bands must be sent to the District Materials Engineer for approval prior to any shipment of aggregate to the mix plant. Once approved, the mix plant gradation bands shall not be changed without approval of the District Materials Engineer.

App C – Aggregate “BDE” and “Policy Memorandums”

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State of Illinois
Department of Transportation
Bureau of Materials and Physical Research
Springfield

POLICY MEMORANDUM

Revised: March 1, 2014 This Policy Memorandum supersedes 7-08.1 dated June 1, 2012	7-08.2

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: RECYCLING PORTLAND CEMENT CONCRETE INTO AGGREGATE

Section 1003 and 1004 of the Standard Specifications for Road and Bridge Construction includes "crushed concrete" as an acceptable source of aggregate material. Care must be taken, however, to assure that quality and gradation requirements are not compromised when recycled concrete is used in lieu of other aggregate materials. Freeze-thaw, ASR and Chloride Content tests are required if the crushed concrete is to be recycled as Portland cement concrete. Concrete removal and crushed concrete stockpiling and handling must be performed in such a manner as to avoid contamination of the aggregate with dirt and foreign matter.

Acceptance of crushed concrete shall be determined using one of the following methods:

I. Project Acceptance
Recycling Portland cement concrete may be specified by special provision for appropriate projects. The crushed concrete shall be recycled from IDOT-specified concrete in the project. The Engineer shall approve the concrete removal method prior to crushing and continually monitor the method during crushing for unacceptable contamination.

Quality. The fact that the original aggregate in the concrete met "Class A" quality does not mean that the product resulting from the crushing of the concrete will meet "Class A" quality. Preliminary samples of existing concrete from a number of locations (minimum 3) in any potential recycling project shall be submitted to the Central Laboratory for quality testing. A period of three months is required for freeze-thaw testing if the material is to be recycled into any uses covered under 1004.02 (f) in the Standard Specifications for Road and Bridge Construction. This work shall be completed prior to advertising the project for bidding.

Quality testing shall include Illinois Test Procedures 96 "Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine" and Illinois Test Procedure 203 "Deleterious Particles in Coarse Aggregate". Standard "Class A" quality limits shall apply but Recycled Asphalt Pavement (RAP) shall be counted as Other Deleterious and shall not exceed 2.0%. RAP shall not be considered as Other Deleterious when Crushed Concrete is used as Aggregate Wedge Shoulders, Type B.

A. Gradation. Gradation sampling and testing shall conform to the Aggregate Gradation Control System (AGCS.

B. Stockpiling. Contamination in the stockpile area is as detrimental as contamination when picking up the broken concrete. Stockpile pads shall be provided and haul roads/plant area properly maintained to assure that acceptable material is not contaminated prior to use.

Stockpiling, hauling, and loading shall conform to the Aggregate Gradation Control System.

II. Central Recycling Plant

Portland Cement Concrete may be recycled by crushing at a central recycling plant.

Concrete used as raw feed at a central recycling plant shall not be contaminated with soil or foreign matter. A small amount of soil embedded in the base of the concrete slab is acceptable. A small amount of construction debris, steel, fabric, wood from forms, and a small amount of RAP leftover from milling is also acceptable. Raw feed piles shall not have excavated soil or aggregate, bricks, slabs of HMA pavement or washout from concrete trucks.

Acceptance for quality and gradation shall be on a stockpile-by-stockpile basis.

A. Quality. Each stockpile shall have one quality sample per each 10,000 tons per specific gradation submitted for quality testing. The quality samples shall be taken from stockpiled material. Since non-IDOT specified concrete may be included in recycling at central recycling plants, the crushed concrete produced at the central recycling plant is not acceptable for Class A quality use, Class B quality use, or Class C quality hot-mix asphalt mixture use, except as specified herein.

For HMA Surface courses and HMA Binder courses: Quality testing shall include Illinois Test Procedure 96 "Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine", and Illinois Test Procedure 203 "Deleterious Particles in Coarse Aggregate". Standard "Class B" quality limits shall apply but there will be no limit on RAP from the Deleterious Count. Illinois Test Procedure 327 "Resistance to Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus" shall also be performed and a 15.0% limit shall be applied.

For Granular Embankment Special, Granular Subbase, Stabilized Subbase, Aggregate Base, Aggregate Surface and Aggregate Shoulders: Quality testing shall include Illinois Test Procedure 96 "Resistance to Degradation of Small-size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine" with standard "Class D" quality limits applied. Illinois Test Procedure 203 "Deleterious Particles in Coarse Aggregate" shall also be performed but standard "Class C" quality limits shall apply except the Other Deleterious maximum percent limit shall be 7.0%, with no more than 5.0% RAP allowed, nor more than 2.0% other material defined as Other Deleterious. RAP shall not be considered as Other Deleterious when Crushed Concrete is used as Aggregate Wedge Shoulders, Type B.

B. Gradation. Gradation sampling and testing shall comply with the Aggregate Gradation Control System.

C. Stockpiling. Stockpiling, hauling, and loading shall comply with the the Aggregate Gradation Control System. Stockpile pads shall be provided and the haul roads/plant area properly maintained to prevent contamination.

III. Recycled Returned Ready-Mix Concrete

Portland Cement Concrete may be recycled by curing returned concrete either at the Concrete Mix Plant or at a Central Recycling Plant as outlined below:

Returned concrete shall be dumped on a clean stockpile area or concrete pad. A small amount of fines scattered on the pad prior to dumping the returned concrete, will assist in removal of the cured concrete.

No water shall be added to the returned concrete before dumping.

After the concrete truck is empty, it shall then proceed to a different area to "wash out". "Wash out refers to the use of water and agitation to remove the ready-mix residue from the inside the ready-mix truck.

The returned concrete shall be cured for a minimum of 2 weeks to gain strength. Cured concrete is then broken up and placed in piles.

A. Quality. IDOT reserves the right to test this material for quality, as outlined in Section II (A), herein, if contamination is present in the stockpile.

B. Gradation. Gradation sampling and testing shall comply with the Aggregate Gradation Control System. "Wash out" material may be mechanically blended with the returned concrete during aggregate production as long as the final product still meets the required gradation.

C. Stockpiling. Stockpiling, hauling, and loading shall comply with the Aggregate Gradation Control System. Stockpile pads shall be provided and the haul roads/plant area properly maintained to prevent contamination.

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State of Illinois
Department of Transportation
Bureau of Materials and Physical Research
Springfield

POLICY MEMORANDUM

Revised: June 1, 2012	9-08.1
This Policy Memorandum supersedes numbers 9-08.0 dated January 1, 2008	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: CRUSHED SLAG PRODUCER CERTIFICATION AND SELF-TESTING PROGRAM

1.0 INTRODUCTION

The Bureau of Materials and Physical Research has recognized a potential pollution problem in the use of crushed slag in subbase/base course, porous/non-porous granular embankment, backfill, and french drains. Some crushed slags may exhibit the tendency to leach out a greenish-yellow effluent producing an objectionable odor. In order to prevent such an occurrence, this memorandum establishes a certification and self-testing program for crushed slag producers.

2.0 STANDARD SPECIFICATION REFERENCE

2.1 Referenced Articles

- 1003.01
- 1003.04
- 1004.01
- 1004.04
- 1004.05

3.0 CONSTRUCTION USES COVERED

Crushed slag (air-cooled blast furnace) used for the following construction/maintenance uses shall conform to this policy memorandum. The construction/maintenance uses covered are as follows:

1. Subbase (1004.04)
2. Base Course (1004.04)
3. Porous/Non-porous Granular Embankment (1003.04, 1004.05)
4. Porous/Non-porous Backfill (1003.04, 1004.05)
5. French Drains (1003.04, 1004.05)

4.0 PRODUCER SAMPLING AND TESTING PROGRAM

All crushed slag producers supplying material for the uses noted in Section 3.0 of this policy memorandum shall initiate a sampling and testing program as detailed in the current Illinois Department of Transportation Test Procedure 202, "Leachate Determination in Crushed Slag" as detailed in the Department's "Manual of Test Procedures for Materials."

5.0 PRODUCER CERTIFICATION LETTER

All crushed slag producers supplying material for the uses noted in Section 3.0 of this policy memorandum shall submit a certification letter each year to the Illinois Department of Transportation, Bureau of Materials and Physical Research, 126 East Ash Street, Springfield, Illinois 62704-4766. This letter shall certify that the producer will ship only material that has been tested and accepted under Section 4.0 of this policy memorandum.

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POLICY MEMORANDUM

Revised: June 1, 2012	10-08.1
This Policy Memorandum supersedes number 10-08.0 dated January 1, 2008	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: USE OF NON-CERTIFIED AGGREGATE STOCKPILES UNDER THE AGGREGATE GRADATION CONTROL SYSTEM (AGCS)

1.0 SCOPE

1.1 The AGCS requires the aggregate source to control the gradation of its certified aggregate during production. Non-certified aggregate stockpiles are those that were not produced under the requirements of the AGCS.

2.0 PURPOSE

2.1 To establish a procedure to accept specific non-certified aggregate for use under the AGCS.

3.0 ELIGIBILITY

3.1 Only certified aggregate Sources currently running the AGCS are eligible to participate in this program.

4.0 AGGREGATE QUALITY

4.1 Non-certified stockpiles shall have current acceptable quality test data (no more than three [3] years old) before processing. Any stockpile not conforming to this requirement shall be sampled as required by the District and tested for quality at the Bureau of Materials and Physical Research.

5.0 GENERAL PROCEDURE

5.1 The aggregate Source shall submit a letter through the District to the Bureau of Materials and Physical Research (BMPR) requesting to certify a non-certified stockpile for AGCS use using this policy memorandum. The letter shall detail the aggregate code number (Example: 032CM16), stockpile location, and the method to be used to certify the stockpile.

Upon BMPR approval, the District and aggregate Source shall meet to review the method to be used for certification.

5.2 One of the following two methods shall be used to certify non-certified stockpiles for use under the current AGCS.

Method #1:

The designated non-certified stockpile shall be sampled and tested for gradation to establish the critical sieve Master Band prior to shipping the material to a certified project. A minimum of one (1) gradation sample per 500 metric tons for at least 2,500 metric tons of stockpiled aggregate shall be taken and tested during loadout to work not requiring certified aggregate. The average of these results shall be used by the aggregate Source to establish the Master Band on the critical sieve. The aggregate Source may set the specification limits on the other sieves as allowed in Section 6.2 of the current Illinois Department of Transportation (IDOT) policy memorandum, "Aggregate Gradation Control System". After IDOT approval of the Master Band and other sieve limits, the material may be shipped to projects requiring certified aggregate and shall be tested at a minimum rate of one (1) gradation sample for each 1,000 metric tons of loadout.

Method #2

The aggregate Source may submit a plan to the Bureau of Materials and Physical Research proposing a satisfactory method of sampling and testing the entire pile either in-situ or by restockpiling (or any combination thereof). If approved, the aggregate Source shall average all the tests taken to establish a Master Band on the critical sieve. The aggregate Source may set the specification limits on the other sieves as allowed in Section 6.2 of the current AGCS policy memorandum. After IDOT approval of the Master Band and other sieve limits, the material may be shipped to projects requiring certified aggregate. When shipping activity begins, loadout sampling and testing shall be performed in accordance with Section 6.3.3 of the current AGCS policy memorandum.

5.3 All requirements of the AGCS shall apply except those referring to production samples. In addition, all samples shall be washed gradations run in accordance with Illinois Test Procedure 11/Illinios Test Procedure 27. Failing gradation samples shall be handled in accordance with Section 6.5 of the current AGCS policy memorandum, except that references to production samples shall apply to the samples obtained to meet the requirements of this policy memorandum. All test data shall be plotted on control charts as specified in Section 6.4 in the current AGCS memorandum.

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State of Illinois
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POLICY MEMORANDUM

Revised: June 1, 2012	12-08.1
This Policy Memorandum supersedes number 12-08.0 dated January 1, 2008	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: CRUSHED GRAVEL PRODUCER SELF-TESTING PROGRAM

1.0 SCOPE

The crushed gravel aggregate producer is responsible for processing round raw feed gravel into coarse and/or fine crushed gravel aggregate complying with applicable quality and gradation specifications. Consistent application of quality control (QC) of the raw feed to the crusher is required to achieve quality crushed gravel aggregate for construction use.

All coarse and/or fine crushed gravel products for Department / Local Agency use shall be produced according to this policy.

2.0 PURPOSE

The purpose of this policy is to establish a quality control procedure to control raw feed designated for crushing or, as an option, control the crushed particle content in coarse and/or fine crushed gravel products prior to shipment.

3.0 SAMPLING/TESTING PERSONNEL

All sampling and testing shall be conducted by an Aggregate Technician as designated in the IDOT Policy Memorandum "Aggregate Gradation Control System" located in the current IDOT "Manual of Test Procedures for Materials." For the optional procedure listed herein, the Aggregate Technician shall have passed the training course conducted by the Bureau of Materials and Physical Research (BMPR) in the crushed particle test method used.

The overall program shall be administered by a Quality Control (QC) Manager, as designated in the IDOT Policy Memorandum "Aggregate Gradation Control System" located in the current IDOT "Manual of Test Procedures for Materials."

4.0 GENERAL PROCEDURE

All crushed gravel sources shall sample, test, and chart a washed gradation per the frequency noted in Section 6.0 on each raw feed (either belt, bin, shaker deck, or stockpile) being fed to a crusher to produce crushed gravel/crushed gravel sand for Department/Local Agency contracts.

The washed gradation shall include the following in the nested set of sieves:

1. A sieve equal to the smallest size wire cloth in the screen deck over which material is being separated into a raw feed for crushing.

2. A sieve equal to the maximum nominal size of the largest product in the production stream being produced as crushed gravel, if different than #1.

3. A No. 200 sieve.

Appropriate cutter sieves shall be inserted into the nested set of sieves for overload situations and small sieve protection. The washed gradations shall be run according to the test methods noted in Section 6.0.

The gradation result from this procedure shall be the result achieved by subtracting the percent passing the No. 200 sieve (to one decimal place) from the percent passing the maximum nominal size sieve (to one decimal place).

Raw feed which has a gradation result that fails the test limit as per Section 7.0 shall be considered unacceptable. An immediate raw feed resample shall be taken and the sample shall be tested for compliance. The Department may verify the compliance of the product stockpiles prior to further shipment.

If the resample passes, the material may be placed on the approved stockpile. The testing frequency shall be increased to a two per week frequency for two consecutive weeks. The one per week frequency may be resumed if no failures occur during the two-week period.

If the resample fails, the Department shall be contacted and production shall stop until corrective action has been initiated by the source. After production is restarted, an immediate raw feed sample shall be taken and the sample shall be tested for compliance. Any crushed products produced shall be stockpiled separately. Once the sample passes, the inspection procedure noted above shall be followed and material produced may be placed on the approved stockpile.

5.0 OPTIONAL PROCEDURE

As an option to Section 4.0 herein, a crushed gravel source may request, in writing to the BMPR, to sample, test, and chart all crushed aggregate products as to their crushed particle content prior to shipment to any Department / Local Agency contract. If approved in writing by the BMPR, a sample for crushed particle content shall be run and charted on all crushed gravel products according to the frequency and test method detailed in Section 6.0.

Crushed gravel products which fail the appropriate test limit as per Section 7.0 herein shall be considered unacceptable. Production shall be stopped until corrective action has been initiated by the Source. After production is restarted, the inspection procedure detailed in the last three (3) paragraphs of Section 4.0 herein shall be followed.

6.0 TEST METHODS / SAMPLE FREQUENCY

Each crushed gravel source shall test their crushed gravel by the listed test method approved for the Source at the required test frequency. The samples for each raw feed gradation or crushed particle content shall be tested, reported, and charted within 24 hours of sampling. Test calculation sheets shall be retained in a file at the aggregate source for three (3) years.

Procedures	*Test Method**	*Test Frequency (minimum)*
Raw Feed Sieve Analysis	Illinois Test Procedure 11 Illinois Test Procedure 27	1 per week
Crushed Particle Content	Illinois Test Procedure 5821	1 per week

*Current IDOT *Manual of Test Procedures for Materials*

7.0 RAW FEED SIEVE ANALYSIS / CRUSHED PARTICLE CONTENT

The following test limit for the testing procedure run by the Source shall be applied to crushed gravel production tested under this policy memorandum. All crushed gravel products shipped per this policy memorandum shall meet these test limits prior to shipment.

Crushed Gravel Individual Test Limits	
Raw Feed Sieve Analysis	(Percent Passing Nominal Maximum Sieve) - (Percent Passing No. 200 Sieve) $\leq$ 3.0%
Crushed Particle Content (%)	• Category I/II Coarse Aggregate Products ** $\geq$ 85.0% Two-faced or more Crushed Particles and $\geq$ 97.0% One-faced or more Crushed Particles • Category III Products/All Manufactured Sand (Crushed Gravel Sand Only)** $\geq$ 97.0% One-faced or more Crushed Particles

**Aggregate products per Table 1 in the current IDOT Policy Memorandum, "Aggregate Gradation Control System."

8.0 IDOT MONITORING

The Aggregate Inspector shall witness the sampling and splitting of one of the crushed gravel producer's samples a minimum of every 20 production days. The Aggregate Inspector shall obtain one of the two final split portions for IDOT testing. The specific testing run by the producer shall also be conducted by IDOT on its split portion for test results comparison.

Comparison of the sample splits will be considered acceptable if the crushed gravel producer's test result falls within the following limits of the IDOT test result.

Raw Feed Sieve Analysis	2.0%
Crushed Particles Content	2.0%

Any IDOT result not comparing within the appropriate above limits or that fails the test limit noted in Section 7.0 shall be cause for an IDOT investigation. Corrective action may be required by the Department if determined to be a producer problem. Continued lack of comparison or continued failure of the IDOT monitor sample is considered non-compliance with the program and may be cause for removal of the crushed gravel source from this program per Section 9.0 herein.

9.0 ACCEPTANCE / REJECTION

Crushed gravel aggregate sources shall acknowledge in their Approved Aggregate Source Certification letter that all coarse and/or fine crushed gravel products are produced under this policy memorandum and meet all required test limits cited in this policy memorandum prior to shipment for use in any Department/Local Agency project.

Coarse and/or fine crushed gravel products produced from failing raw feed or having an unacceptable crushed particle content shall be isolated and removed from the approved product pile to the satisfaction of the District Materials Engineer or his/her representative.

Shipment of coarse and/or fine crushed gravel products produced from failing raw feed or having an unacceptable crushed particle content (Optional Procedure) may result in the crushed gravel source's removal from the "Approved Aggregate Source List," as per Section 11.0 in the current Department Policy Memorandum, "Aggregate Gradation Control System," located in the current IDOT "Manual of Test Procedures for Materials."

Continued failure of a raw feed or the crushed particle content of a crushed gravel product or non-compliance with the current "Crushed Gravel Producer Self-testing Program" is unacceptable and may result in the crushed gravel production method being rejected by the Department. No crushed gravel products from the Source would be acceptable for shipment for use on Department/Local Agency projects. The general response procedure detailed in Section 11.0 in the Department Policy Memorandum, "Aggregate Gradation Control System," located in the current IDOT "Manual of Test Procedures for Materials," shall be followed.

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POLICY MEMORANDUM

Revised: June 1, 2012	13-08.1
This Policy Memorandum supersedes number 13-08.0 dated January 1, 2008	

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: SLAG PRODUCER SELF-TESTING PROGRAM

1.0 SCOPE

The slag aggregate producer is responsible for processing raw slag into aggregate complying with applicable quality and gradation specifications. Consistent application of quality control (QC) over specific gravity/absorption is required to achieve quality air-cooled blast furnace (ACBF) and steel slag aggregate for use in Portland cement concrete (PCC) and hot-mix asphalt (HMA) mixtures, where allowed.

2.0 PURPOSE

The purpose of this policy is to establish a quality control procedure to control specific gravity/absorption on ACBF and steel slag prior to shipment to Illinois Department of Transportation (IDOT) contracts for use in PCC or HMA mixtures.

3.0 SAMPLING/TESTING PERSONNEL

All sampling and testing shall be conducted by an Aggregate Technician or Mixture Aggregate Technician, as designated in the IDOT "Aggregate Gradation Control System", who has had additional instruction by the Bureau of Materials and Physical Research (BMPR) in the test methods used.

The overall program shall be administered by a Quality Control (QC) Manager, as designated in the IDOT "Aggregate Gradation Control System".

4.0 GENERAL PROCEDURE

All ACBF and steel slag aggregate sources shall run the required tests at the specified frequency listed in this policy memorandum.

These results shall be reported within 24 hours of the completion of the test to the appropriate District Materials Engineer and to all contractors using the slag just tested. The test results shall be retained in a file at the source for 3 years. Charting of test data is recommended.

All slag sources shall submit a stockpile Quality Control Plan to the District Materials Engineer for approval prior to any production. The QC Plan shall detail all procedures the source shall conduct to assure all slag aggregate in IDOT-approved stockpiles conforms to the specific gravity/absorption requirements of this program prior to shipment.

Any slag source running this QC procedure certifies that all slag shipped for use in PCC and HMA mixtures on IDOT contracts and local agency contracts meets the specific gravity/absorption test limits and ranges cited in this policy memorandum prior to shipment.

Non-compliance with the "Slag Producer Self-Testing Program" shall result in the slag source's removal from the current IDOT "Approved Aggregate Source List".

All slag aggregate data (specific gravity absorption, etc.) for any mix design shall be obtained from the appropriate District Materials Engineer.

5.0 TEST METHODS / SAMPLE FREQUENCY

The following slag characteristics shall be tested by the listed test method at the required test frequency.

Slag Characteristic	*Test Method* *	*Test Frequency (minimum)*
Specific Gravity / Absorption		
Fine Aggregate:	Illinois Test Procedure 84	1 per 2,000 tons
Coarse Aggregate:	Illinois Test Procedure 85☞	1 per 2,000 tons

6.0 SPECIFIC GRAVITY/ABSORPTION TEST LIMITS / RANGES

The following specific gravity/absorption test limits and ranges shall be applied to slag tested under this policy memorandum. All slag shipped per this policy memorandum shall meet these test limits and ranges prior to shipment.

Individual Test Limits	
Specific Gravity	± 0.050 from the approved production target** specific gravity per product/production point
Absorption	• Maximum 5.0% per product/production point • ± 1.0 from the approved production target**absorption per product/production point
Moving Target Test Range	
Specific Gravity (the running average§ of the last four specific gravity test results)	± 0.040 from the approved production target** specific gravity per product/production point

* IDOT *Manual of Test Procedures for Materials*

☞ This test method is further modified to require that all test samples be washed, dried, and weighed (for Original Weight) prior to testing using Illinois Test Procedure 11.

** The production targets for both specific gravity and absorption shall be developed by averaging the first four test results at the start of production. If requested by the slag source, historical data for the characteristic may be used to establish the average. All averages shall be approved by the department prior to shipment. A source may request a target change at any time pursuant to departmental approval. Slag aggregate produced after a target change shall be stockpiled separately. Any change in the target may require a new mix design to be run.

§ The running average for specific gravity shall be calculated using the method noted in Section 9.3.1 of IDOT's QC/QA document "Aggregate Producer Control Chart Procedure" in the IDOT *Manual of Test Procedures for Materials*.

7.0 IDOT MONITORING

The Aggregate Inspector shall witness the sampling and splitting of one of the slag producer's samples a minimum of every 20 production days. The Aggregate Inspector shall obtain one of the two final split portions for IDOT testing. All specific gravity/absorption testing run by the slag producer shall also be conducted by IDOT on its split portion for test results comparison.

Comparison of the sample splits will be considered acceptable if the slag producer's test result falls within the following limits of the IDOT test result.

	Fine Aggregate	*Coarse Aggregate*
Specific Gravity	0.066	0.038
Absorption	0.66	0.41

Any specific gravity/absorption result not comparing within the above limits shall be cause for an IDOT investigation. Corrective action by the slag producer may be required at the discretion of IDOT. Continued lack of comparison may be cause for removal of the slag source from this program.

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POLICY MEMORANDUM

Revised: June 1, 2012 14-08.1
This Policy Memorandum supersedes number 14-08.0 dated January 1, 2008

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: INSPECTION OF STONE FOR EROSION PROTECTION, SEDIMENT CONTROL, AND ROCKFILL

1.0 PURPOSE

This memorandum establishes an inspection procedure for the use of stone for Erosion Protection, Sediment Control, and Rockfill.

2.0 STANDARD SPECIFICATION REFERENCE

Referenced Articles

- 1005.01

3.0 STOCKPILING

Stockpiling and handling procedures of material for Department use shall be as noted in QC/QA Procedure, "Stockpiling and Handling of Aggregate," located in the current "Manual of Test Procedures for Materials."

4.0 INSPECTION

The materials will be inspected at the source according to Article 106.04.

5.0 QUALITY SAMPLING AND TESTING PROCEDURE

5.1 *For Gradations RR1 & RR2* - Sodium sulfate soundness testing will be conducted on bedding material (Gradations RR1 and RR2) using the manufactured gradation.

5.2 *For Gradations RR3 thru RR7* - Sodium sulfate soundness testing will be conducted on ledges used for erosion control protection and sediment control. Gradations RR1, RR2, CA01, or CA03 shall be sampled for testing of RR3 thru RR7. If the above sizes are not produced, other sizes approved by the Bureau of Materials and Physical Research may be sampled.

5.3 The Department reserves the right to test all riprap or bedding material in the Department's Rapid Freeze-Thaw for final acceptance.

6.0 GRADATION PROCEDURE

A minimum of one gradation check for each gradation produced shall be performed during initial production each year.

The minimum size of stockpile shall be 1,000 metric tons (1100 tons) or the amount needed for the job, whichever is smaller.

The Producer shall notify the Engineer at least five (5) days in advance of the date when the material will be ready for inspection.

6.1 BEDDING MATERIAL (RR1 & RR2)

A 10,000g (22 lb.) sample shall be obtained and gradation run according to Illinois Test Procedure 27 located in the Manual of Test Procedures for Materials.

6.2 GRADATIONS RR3 THRU RR7.

6.2.1 Gradations will be performed by visual inspection of the stockpile including an inspection for Flat & Elongated pieces. To assist in the visual gradation inspection the producer will be required to maintain a set of keystones on all standard specification gradations produced per Table 1, herein. These keystones shall be located in a close proximity of the represented stockpile. The keystones shall be selected by the Producer and agreed upon by the District. If at any time the keystones become non-representative of the gradation, a new set of keystones shall be established.

Table 1

Gradation	Keystone #1 (lbs)	Keystone #2 (lbs)	Keystone #3 (lbs)
RR3	50 (±5)	10 (±1)	1 (±0.1)
RR4	150 (±15)	40 (±4)	1 (±0.1)
RR5	400 (±40)	90 (±13)	3 (±0.1)
RR6	600 (±60)	170 (±17)	6 (±0.5)
RR7	1000 (±100)	300 (±30)	12 (±1)

If the gradation test results using the procedure as described in 6.2.1 are disputed section 6.2.2 will be conducted prior to section 6.2.3.

6.2.2 DISPUTED GRADATION PROCEDURE (Visual)

If the producer disputes the results of the visual inspection conducted by the District a second visual inspection shall be conducted by the Bureau.

If the Bureau visual gradation is disputed by the producer, a gradation test will be conducted by the District using the dispute gradation procedure described in section 6.2.3 herein. The Bureau reserves the right to be present during the weighed gradation dispute procedure. The weighed dispute gradation procedure will be the final method of acceptance for this material.

6.2.3 DISPUTED GRADTION PROCEDURE (Weighed)

The District will direct all sampling operations, and the Producer shall provide the equipment and personnel necessary to sample and assist in testing in accordance with this procedure.
A grid of the dimensions indicated in the table below shall be marked on a clean surface (e.g., canvas, conveyor belting, concrete pad, etc.), so that a uncontaminated weight of fines and rock spalls may be obtained. Each grid shall be broken down into 5' increments or blocks (e.g., A grid for RR3 will consist of five (5) blocks that are 2' wide by 5' long, aligned in a row, for a total grid length of 25').

Table 2

Gradation	Grid	Sample Size, (blocks to be tested), Minimum
RR3	2' by 25'	2
RR4	3' by 25'	2
RR5	4' by 25'	3
RR6	5' by 30'	3
RR7	5' by 35'	3

Under direction of the District, the producer shall use a front end loader to excavate a representative sample from the working face of the stockpile to be sampled. The front end loader will then spread the sampled material over the grid, by backing and slowly dumping over the length of the grid. The material should be spread to an approximate one (1) rock thickness, in a fairly even distribution over the grid. The minimum sample size for each gradation is indicated Table 2 above, by the number of grid blocks to be tested. The test sample shall consist of all the material contained within the selected blocks, as well as all material on or above the grid lines of the selected blocks.

Gradation RR3 thru RR7 - The material excavated shall be weighed piece-by-piece until all pieces above the minimal specified weight have been weighed and recorded. All fines and rock spalls below the minimum specified weight shall then be gathered and weighed separately. Percentages of each size range for the gradation specified shall be calculated.

David L. Lippert

David L. Lippert, P.E.
Engineer of Materials
and Physical Research

SAB/seh

State of Illinois
Department of Transportation
Bureau of Materials and Physical Research
POLICY MEMORANDUM

Revised: January 1, 2008 27-08.0
This Policy Memorandum supersedes number 06-01 dated January 1, 2006

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS, AGGREGATE PRODUCERS, SUPPLIER YARDS AND TERMINALS

SUBJECT: DESIGNATION OF AGGREGATE INFORMATION ON SHIPPING TICKETS

1.0 SCOPE

1.1 This policy shall apply to all sources that supply certified aggregate for uses identified in the Bureau of Materials and Physical Research Policy Memorandum "Aggregate Gradation Control System" to projects let under the jurisdiction of the Illinois Department of Transportation (IDOT), including local agency projects.

2.0 PURPOSE

2.1 This memorandum establishes a procedure for designating producer information and aggregate properties on shipping tickets.

3.0 PRODUCER/SUPPLIER'S RESPONSIBILITY - GENERAL

3.1 Each Aggregate Producer shall submit to the Bureau of Materials and Physical Research, a completed IDOT "Aggregate Shipping Tickets Information Form for Producers". Supplier Yards and Terminals shall submit a completed IDOT "Aggregate Shipping Tickets Information Form for Suppliers and Terminals". A copy of the appropriate form shall also be submitted to the IDOT District Office that inspects the source. The form shall indicate how each aggregate source shall identify the Producer/Supplier Designation, Product Designation and Freeze-thaw Designation on their shipping ticket. A separate form must be completed for each IDOT Producer/Supplier Number.

If the source makes changes to their Producer/Supplier Designation, a Product Designation, or the Freeze-thaw Designation, the source shall notify the IDOT District Office that inspects the source, by end of business the next working day. The source shall then complete and submit the appropriate "Aggregate Shipping Tickets Information Addendum Form" to the Bureau of Materials and Physical Research within ten (10) working days. A copy of the appropriate "Aggregate Shipping Information Addendum Form" shall also be submitted to the IDOT District Office that inspects the source.

3.2 **Producer/Supplier Designation** - Each aggregate source shall submit on the appropriate "Aggregate Shipping Tickets Information Form", identification for the source. The identification shall meet one of the following methods:

Method 1: The aggregate source shall use the appropriate IDOT Producer/Supplier Number.

Method 2: A unique identification shall be used for the producing source. If a producer has multiple sources, a different identification shall be established for each source. (i.e., a producer has 3 plants; Joe's Plant #1, Joe's Plant #2, and Joe's Plant #3. The identification is defined as JP1, JP2, and JP3.) The source shall indicate on the appropriate "Aggregate Shipping Tickets Information Form", the IDOT Producer/Supplier Number that corresponds to the source identification (i.e., JP1, JP2, and JP3 correspond to IDOT Producer/Supplier Numbers 50000-01, 50000-02, and 50000-03, respectively).

3.3 **Product Designation** – Each aggregate source shall submit on the appropriate "Aggregate Shipping Tickets Information Form", identification for each product sold. The identification shall meet one of the following methods:

Method 1 – The appropriate IDOT Material Code shall be used for each material (i.e., 022CM1101 shall be used for A Quality Superstructure CM11).

Method 2 – A unique product designation, using the appropriate CA/CM, FA/FM or RR identification, shall be defined by the source, to identify each product sold. The source shall indicate on the appropriate "Aggregate Shipping Tickets Information Form", the IDOT Material Code that corresponds to the source's product designation (i.e., the aggregate source uses "CA06 Base" to represent 052CA06). If the source makes two different quality materials for a particular gradation, and each is being stockpiled separately, each would have to have a different product designation (i.e., The source could not use "CA06 Base" to represent both the 042CA06 stockpile and the 052CA06 stockpile). However, if a particular gradation meets the requirements for multiple qualities, the same product designation may be used for both materials (i.e., The aggregate source has a stockpile of CM11 that is sold as 022CM11 for use in Portland cement concrete. The same stockpile is also sold as 032CM11 for use in Hot Mix Asphalt. The product designation for the material is "CM11 Mix".)

3.4 **Freeze-thaw Designation** – For IDOT A Quality coarse aggregate, each source shall indicate on the appropriate "Aggregate Shipping Tickets Information Form", whether the aggregate has IDOT Freeze-thaw approval. The designation shall meet one of the following methods:

Method 1 – The designation "FT" shall be used to identify an IDOT Freeze-thaw approved product. It shall be included with the A Quality Product Designation described in Section 3.3.

Method 2 – A designation shall be defined by the source to identify a Freeze-thaw approved product. The source shall indicate on the appropriate "Aggregate Shipping Tickets Information Form", the Freeze-thaw Designation, along with the A Quality Product Designation described in Section 3.3. Sources that make both Freeze-thaw A Quality coarse aggregate and Non-Freeze-thaw A Quality coarse aggregate shall use separate designations for the different coarse aggregates.

4.0 PRODUCER/SUPPLIER'S RESPONSIBILITY – SHIPPING TICKETS

4.1 Aggregate Producers shall include on their shipping ticket, the Producer/Supplier Designation, the Material Designation, and the Freeze-thaw Designation (if A Quality), as described in Section 3.0.

4.2 Supplier Yards and Terminals shall include on their shipping ticket, their Supplier Designation, the Producer/Supplier Designation of the Certified Source that produced the material, the Material Designation, and the Freeze-thaw Designation (if A Quality), as described in Section 3.0. Supplier Yards and Terminals shall use the same Producer/Supplier Designation, Material Designation and Freeze-thaw Designation as the Certified Source that produced the material.

David L. Lippert

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Engineer of Materials
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SAB/dkt

State of Illinois
Department of Transportation
Bureau of Materials and Physical Research
Springfield

POLICY MEMORANDUM

Effective: January 1, 2013	31-13.0

TO: REGIONAL ENGINEERS AND HIGHWAY BUREAU CHIEFS

SUBJECT: RECLAIMED ASPHALT PAVEMENT (RAP) FOR AGGREGATE APPLICATIONS

1.0 SCOPE

1.1 The RAP aggregate producer is responsible for processing raw feed grindings, asphalt pavement or pavement preservation courses into aggregate that will comply with applicable gradation specifications. Consistent application of quality control (QC) at the crushing/screening plant or jobsite is required to achieve consistent RAP aggregate product for construction use.

1.2 All RAP products for Department/Local Agency aggregate use, whether at the jobsite, mix plant or central recycling facility, shall be tested according to this policy.

2.0 PURPOSE

2.1 The purpose of this policy is to establish a quality control (QC) procedure to manage RAP material designated for use in aggregate applications.

3.0 SAMPLING/TESTING PERSONNEL

3.1 All sampling and testing shall be conducted by either an Aggregate Technician or a Mixture Aggregate Technician as designated in the current BMPR Policy Memorandum "Aggregate Gradation Control System".

3.2 The overall program shall be administered by a Quality Control (QC) Manager, as designated in Section 3.14 in the current BMPR Policy Memorandum "Aggregate Gradation Control System" or the HMA equivalent designated in Section 1030.05 (d)(1) of the Standard Specifications.

3.3 Jobsite stockpiles are for use on the same contract the material originally came from. If the material is used on a different contract, the contractor for that project will have to restart this testing program with the production testing procedure defined in Section 4.1, herein.

4.0 SAMPLING/TESTING PROCEDURE

4.1 Production Testing

4.1.1 All RAP aggregate shall be 100% passing the top sieve of the gradation specified. The material shall be sampled and tested for gradation at a minimum of 1 test every 1,000 tons for the first 5,000 tons during production. After the first 5,000 tons, the material shall be sampled and tested at a minimum of 1 test every 5,000 tons. Sampling shall be according to one of the approved methods listed Illinois Test Procedure 2, in the current IDOT Manual of Test Procedures for Materials.

The required gradation testing sieve shall be the top sieve of the gradation specified.

4.1.2 As part of the gradation testing, a visual of the material to check for uniformity shall also be performed. Material that is one-sized, over-sized, or gap-graded shall be rejected.

4.2 Failing Gradation Samples

4.2.1 Material that does not have 100% passing the top sieve of the specified gradation shall be immediately resampled. The producer shall immediately cease adding new material to their approved pile.

If the resample passes, the material may be placed on the approved stockpile.

If the resample fails, the Department shall be contacted and production shall stop until corrective action has been initiated by the source, through either recrushing or rescreening the material. After production is restarted, an immediate production sample shall be taken and the material stockpiled separately. Once the sample passes, the production testing frequency shall continue and the material can be moved to the approved stockpile.

4.3 Loadout Testing

Loadout samples shall be taken as soon as the pile is shipped/loaded out and then a minimum of 1 test every 5,000 tons thereafter. If a loadout sample fails, an immediate resample shall be taken and loadout of the approved stockpile shall cease until the results of the resample are known.

If the resample passes, loadout of the approved stockpile shall continue.

If the resample fails, the approved stockpile is rejected and the source will need to re-crush or rescreen the material. Production testing frequency shall be followed during this reprocessing.

Jobsite stockpiles shall be visually inspected for over-sized agglomerations (RAP particles that have melded back together), excessive segregation, and any construction debris. If any of these are present, the material shall be rescreened and retested prior to use. If none of the above are present, the jobsite stockpile shall be exempt from loadout sampling.

5.0 IDOT MONITORING

5.1 The Aggregate Inspector or Mixture Aggregate Technician shall witness the sampling of one of the RAP aggregate samples a minimum of 1 every 20,000 tons. The Aggregate Inspector or RE shall obtain a final split of the product for IDOT testing. IDOT will run the gradation over the same sieve size the producer is using. The samples shall be considered in comparison if the IDOT results are the same as the producers.

Any IDOT result not comparing within the limits noted above or fails the limits noted under production testing, shall be cause for an IDOT investigation. Corrective action may be required by the Department if determined to be a producer problem. Continued lack of comparison or continued failure of the IDOT monitor sample shall be considered non-compliance and may be cause for removal of the source from this program per section 6.0 herein.

6.0 ACCEPTANCE/REJECTION

6.1 RAP aggregate sources shall submit a certification letter stating that this material will meet the requirements of this policy and the AGCS prior to shipment for use in any Department/Local Agency project.

RAP aggregate products having unacceptable oversize or gradation shall be isolated and removed for the approved stockpile to the satisfaction of the District Materials Engineer, RE or his/her representative.

Shipment or placement of RAP aggregate having unacceptable properties as defined in Section 4.0 herein shall result in the removal from the Approved Aggregate Source List.

David L. Lippert

David L. Lippert, P.E.
Engineer of Materials
and Physical Research

SAB/jy

Illinois Department of Transportation

Memorandum

To:	All Regional Engineers
From:	Omer M. Osman, P.E.
Subject:	Special Provision for Coarse Aggregate Quality
Date:	April 17, 2015

This special provision was developed by the Bureau of Materials and Physical Research to provide a quality test for oil-stained aggregates and to remove the Los Angeles Abrasion limits for crushed slag.

This special provision should be inserted in contracts using portland cement concrete and hot-mix asphalt.

The districts should include the BDE Check Sheet marked with the applicable special provisions for the July 31, 2015 and subsequent lettings. The Project Development and Implementation Section will include a copy in the contract.

This special provision will be available on the transfer directory April 17, 2015.

80360m

COARSE AGGREGATE QUALITY (BDE)

Effective: July 1, 2015

Revise Article 1004.01(b) of the Standard Specifications to read:

"(b) Quality. The coarse aggregate shall be according to the quality standards listed in the following table.

COARSE AGGREGATE QUALITY				
QUALITY TEST	CLASS			
	A	B	C	D
Na_2SO_4 Soundness 5 Cycle, ITP 104 [1/], % Loss max.	15	15	20	25 [2/]
Los Angeles Abrasion, ITP 96 [11/], % Loss max.	40 [3/]	40 [4/]	40 [5/]	45
Minus No. 200 (75 µm) Sieve Material, ITP 11	1.0 [6/]	---	2.5 [7/]	---
Deleterious Materials [10/]				
Shale, % max.	1.0	2.0	4.0 [8/]	---
Clay Lumps, % max.	0.25	0.5	0.5 [8/]	---
Coal & Lignite, % max.	0.25	---	---	---
Soft & Unsound Fragments, % max.	4.0	6.0	8.0 [8/]	---
Other Deleterious, % max.	4.0 [9/]	2.0	2.0 [8/]	---
Total Deleterious, % max.	5.0	6.0	10.0 [8/]	---
Oil-Stained Aggregate [10/], % max	5.0	---	---	

1/ Does not apply to crushed concrete.

2/ For aggregate surface course and aggregate shoulders, the maximum percent loss shall be 30.

3/ For portland cement concrete, the maximum percent loss shall be 45.

4/ Does not apply to crushed slag or crushed steel slag.

5/ For hot-mix asphalt (HMA) binder mixtures, except when used as surface course, the maximum percent loss shall be 45.

6/ For crushed aggregate, if the material finer than the No. 200 (75 µm) sieve consists of the dust from fracture, essentially free from clay or silt, this percentage may be increased to 2.5.

7/ Does not apply to aggregates for HMA binder mixtures.

8/ Does not apply to Class A seal and cover coats.

9/ Includes deleterious chert. In gravel and crushed gravel aggregate, deleterious chert shall be the lightweight fraction separated in a 2.35 heavy media separation. In crushed stone aggregate, deleterious chert shall be the lightweight fraction separated in a 2.55 heavy media separation. Tests shall be run according to ITP 113.

10/ Test shall be run according to ITP 203.

11/ Does not apply to crushed slag.

All varieties of chert contained in gravel coarse aggregate for portland cement concrete, whether crushed or uncrushed, pure or impure, and irrespective of color, will be classed as chert and shall not be present in the total aggregate in excess of 25 percent by weight (mass).

Aggregates used in Class BS concrete (except when poured on subgrade), Class PS concrete, and Class PC concrete (bridge superstructure products only, excluding the approach slab) shall contain no more than two percent by weight (mass) of deleterious materials. Deleterious materials shall include substances whose disintegration is accompanied by an increase in volume which may cause spalling of the concrete."

80360

Illinois Department of Transportation

Memorandum

To:	Regional Engineers
From:	Omer M. Osman
Subject:	Special Provision for Aggregate Subgrade Improvement
Date:	September 23, 2015

This special provision was developed by the Bureau of Materials and Physical Research to allow the use of gravel in fills over 24 inches in thickness.

The designer should check with the District Geotechnical Engineer to determine the appropriate thickness of the aggregate subgrade material.

When this special provision is used, BDE special provision, "Reclaimed Asphalt Pavement (RAP) and Reclaimed Asphalt Shingles (RAS)" should also be included in the contract.

It should be included in all contracts utilizing aggregate subgrade improvements.

The districts should include the BDE Check Sheet marked with the applicable special provisions for the January 15, 2016 and subsequent lettings. The Project Development and Implementation Section will include a copy in the contract.

This special provision will be available on the transfer directory September 25, 2015.

cc: Omer M. Osman
Aaron A. Weatherholt
John Baranzelli
HST 55734
80274m

AGGREGATE SUBGRADE IMPROVEMENT (BDE)

Effective: April 1, 2012
Revised: January 1, 2016

Add the following Section to the Standard Specifications:

"SECTION 303. AGGREGATE SUBGRADE IMPROVEMENT

303.01 Description. This work shall consist of constructing an aggregate subgrade improvement.

303.02 Materials. Materials shall be according to the following.

Item	Article/Section
(a) Coarse Aggregate	1004.06
(b) Reclaimed Asphalt Pavement (RAP) (Notes 1, 2, and 3)	1031

Note 1. Crushed RAP, from either full depth or single lift removal, may be mechanically blended with aggregate gradations CS 01, CS 02, and RR 01 but shall not exceed 40 percent of the total product. The top size of the RAP shall be less than 4 in. (100 mm) and well graded.

Note 2. RAP having 100 percent passing the 1 1/2 in. (37.5 mm) sieve and being well graded, may be used as capping aggregate in the top 3 in. (75 mm) when aggregate gradations CS 01, CS 02, or RR 01 are used in lower lifts.

Note 3. The RAP used for aggregate subgrade improvement shall be according to the current Bureau of Materials and Physical Research Policy Memorandum, "Reclaimed Asphalt Pavement (RAP) for Aggregate Applications".

303.03 Equipment. The vibratory machine shall be according to Article 1101.01, or as approved by the Engineer.

303.04 Soil Preparation. The stability of the soil shall be according to the Department's Subgrade Stability Manual for the aggregate thickness specified.

303.05 Placing Aggregate. The maximum nominal lift thickness of aggregate gradations CA 02, CA 06, or CA 10 shall be 12 in. (300 mm). The maximum nominal lift thickness of aggregate gradations CS 01, CS 02, and RR 01 shall be 24 in. (600 mm).

303.06 Capping Aggregate. The top surface of the aggregate subgrade shall consist of a minimum 3 in. (75 mm) of aggregate gradations CA 06 or CA 10. When the contract specifies that a granular subbase is to be placed on the aggregate subgrade improvement, the 3 in. (75 mm) of capping aggregate shall be the same gradation and may be placed with the underlying aggregate subgrade improvement material.

303.07 Compaction. All aggregate lifts shall be compacted to the satisfaction of the Engineer. If the moisture content of the material is such that compaction cannot be obtained, sufficient water shall be added so that satisfactory compaction can be obtained.

303.08 Finishing and Maintenance of Aggregate Subgrade Improvement. The aggregate subgrade improvement shall be finished to the lines, grades, and cross sections shown on the plans, or as directed by the Engineer. The aggregate subgrade improvement shall be maintained in a smooth and compacted condition.

303.09 Method of Measurement. This work will be measured for payment according to Article 311.08.

303.10 Basis of Payment. This work will be paid for at the contract unit price per cubic yard (cubic meter) or ton (metric ton) for AGGREGATE SUBGRADE IMPROVEMENT or at the contract unit price per square yard (square meter) for AGGREGATE SUBGRADE IMPROVEMENT, of the thickness specified."

Add the following to Section 1004 of the Standard Specifications:

"**1004.06 Coarse Aggregate for Aggregate Subgrade Improvement.** The aggregate shall be according to Article 1004.01 and the following.

(a) Description. The coarse aggregate shall be crushed gravel, crushed stone, or crushed concrete. In applications where greater than 24 in. (600 mm) of subgrade material is required, gravel may be used below the first 12 in (300 mm) of subgrade.

(b) Quality. The coarse aggregate shall consist of sound durable particles reasonably free of deleterious materials.

(c) Gradation.

(1) The coarse aggregate gradation for total subgrade thickness less than or equal to 12 in. (300 mm) shall be CA 2, CA 6, CA 10, or CS 01.

The coarse aggregate gradation for total subgrade thickness more than 12 in. (300 mm) shall be CS 01, CS 02 or RR 01(see Article 1005.01(c)).

	Coarse Aggregate Subgrade Gradations				
Grad No.	Sieve Size and Percent Passing				
	8"	6"	4"	2"	#4
CS 01	100	97 ± 3	90 ± 10	45 ± 25	20 ± 20
CS 02		100	80 ± 10	25 ± 15	

	Coarse Aggregate Subgrade Gradations (Metric)				
Grad No.	Sieve Size and Percent Passing				
	200 mm	150 mm	100 mm	50 mm	4.75 mm
CS 01	100	97 ± 3	90 ± 10	45 ± 25	20 ± 20
CS 02		100	80 ± 10	25 ± 15	

(2) The 3 in. (75 mm) capping aggregate shall be gradation CA 6 or CA 10."

80274

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CRUSHER AND PORTABLE PLANT ASSOCIATION

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1978

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In the belief that a common understanding of the technical terms applicable to crushers and crushing equipment would benefit the manufacturers, the distributors, the users and operators, and engineering students, the Crusher and Portable Plant Association is publishing this booklet. It represents the combined thinking of representatives of recognized leading United States manufacturers of this equipment. Those contributing to this publication are:

Allis-Chalmers Corporation
Appleton, Wisconsin

Eagle Crusher Company, Inc.
Galion, Ohio

The Frog, Switch & Manufacturing Company
Carlisle, Pa.

Hewitt-Robins Div., Litton Systems, Inc.
Columbia, S.C.

Jeffrey Manufacturing Div., Dresser Industries
Woodruff, S.C.

Pennsylvania Crusher Corporation
Broomall, Pa.

Rexnord, Inc.
Milwaukee, Wisconsin

Telsmith Div., Barber-Greene Company
Milwaukee, Wisconsin

■

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General terms applying to most types of crushers

ACCESS DOOR — Covered opening in frame provided for inspection and access to interior for maintenance.

ATTRITION — Reduction of material by a grinding or rubbing action between materials and/or hard surfaces.

AUTOMATIC LUBRICATION — Either splash or circulating oil or other lubricant, non-manual lubricating system. May have filter, sight glasses and temperature and pressure alarm systems.

BACKLASH — Total clearance between teeth of pinion and gear at pitch line.

BEARING HOUSINGS — Enclosure for main bearings mounted on crusher frame.

BEARING RETAINER — Means of locating a bearing axially.

BEARING SEAL — Device to retain lubricant and exclude foreign matter. Common types are: labyrinth, piston rings, lip seals, cap, slinger rings, shrouds.

BLOCKING — A single piece of material too large to enter the crushing chamber.

BRIDGING — Multiple pieces of material wedged or covering the feed opening of the crusher and preventing entry of additional material.

CHEEK PLATE — Replaceable wearing surface for sides of crushing chamber. Usually of manganese or abrasion-resistant material.

CHOKE FEED — A condition whereby the feed completely fills the crushing chamber.

CIRCULATING OIL SYSTEM — System in which lubricating oil, after passing through the bearings, is returned to a reservoir and recirculated for the purpose of cooling or heating and filtering.

CLOSED-CIRCUIT CRUSHING — System in which the oversize material is separated from the product and returned to the crusher.

CRUSHING CHAMBER — The area of the crusher where crushing takes place.

COUPLING — A device used to direct-connect a crusher to a driving mechanism.

DRIVE — Any device used to transmit rotating force from the power unit to the crusher shaft: V-Belt, Flat Belt, Coupling, etc.

DRIVE GUARD — Safety enclosure for the drive.

EXPANSION BEARING — Free or floating bearing on one end of a shaft to allow for expansion and contraction of the shaft.

FEED OPENING — The inlet opening of the crusher where material enters the crushing chamber.

FINES — Material having particle size smaller than a specified opening.

FINISHED PRODUCT — The resultant material after it has been processed.

FLYWHEEL — A heavy, flat or grooved wheel or sheave used to store and release energy.

FRIABLE — Material that fractures easily.

GRINDABILITY — An index for the resistance of material to size reduction. For coal, see Hardgrove Test; for stone and ore, see Bond and Wang Theory. (Ref: Bureau of Mines, "Dictionary of Mining, Mineral and Related Terms").

GRIZZLY — A heavy duty screening surface consisting of a series of spaced bars, rails, or pipe members; may be stationary, rotating, or vibrating.

GUARD — A protective shield covering exposed moving elements of machinery.

HADFIELD PROCESS MANGANESE — A steel alloy used for abrasion-resistant surfaces containing 11 to 14% manganese. (See ASTM - A 128-64).

INSPECTION DOOR — See "ACCESS DOOR".

LABYRINTH SEAL — See "BEARING SEAL".

LUBRICATION — (Bearings) usually oil or grease. Consult manufacturer for lubricant specifications.

General terms cont'd.

MOBILE CRUSHING UNITS – Moveable crushing units with crawlers, rails, walking beams or pads, rubber, etc. Can be towed or self-propelled. Off-highway application.

MOHS SCALE – The relative hardness of a material as compared to: 1 - Talc; 2 - Gypsum; 3 - Calcite; 4 - Fluorite; 5 - Apatite; 6 - Feldspar; 7 - Quartz; 8 - Topaz; 9 - Corundum; 10 - Diamond.

NOMINAL – Term frequently used in describing product size, and denoting that at least 90% of product is smaller than the size indicated.

OIL RETAINER – A seal to prevent loss of lubricant.

OIL SEAL – See "OIL RETAINER".

OPEN CIRCUIT CRUSHING – One pass through the crusher.

OVERLOAD – When the design capability of a crusher is exceeded.

OVERSIZE – Material that will not pass through a specified opening.

PACKING – Compacted or compressed condition of material in the crushing chamber characterized by a complete or nearly complete absence of voids.

PILLOW BLOCK – A self-contained bearing housing separate from the frame of the crusher.

PLUGGING – Blockage restricting flow of material.

PORTABLE CRUSHING UNITS – Units which can be moved on the highway with minimum disassembly.

PULLEY, FLYWHEEL – Usually the large, heavy, driven pulley designed to transmit energy. Often grooved to take a V-Belt drive.

RATIO OF REDUCTION (REDUCTION RATIO) – Relationship of the top size of the feed to the top size of the crusher product.

REGULATED FEED – Flow of material when controlled.

ROM – Run-of-Mine.

ROQ – Run-of-Quarry.

SCALPING – Removing from crusher feed most of the undersize material.

SEMI-PORTABLE CRUSHING UNITS - SKID OR BASE MOUNTED – Units which are mounted on a structural steel frame having legs or supports to grade.

SHEAR CRUSHING – Reduction of material by a cutting action between two hard surfaces.

SKIDDABLE CRUSHING UNITS – Similar to "SEMI-PORTABLE CRUSHING UNITS", but are capable of being towed or dragged. Off-highway application.

THRUST BEARING – Any plain or anti-friction bearing designed to accept thrust loads.

TOP SIZE – The largest particle size in feed or product.

TRAMP IRON – Any uncrushable metal in the crusher feed.

■

Cage Mills

SINGLE CAGE — A crusher with a horizontal shaft where the material is fed through an opening in the housing into the center of the rotating cage. The cage impacts the material as it passes through the opening between the cage pins, and then impacts on breaker plates or blocks which form the internal crushing surfaces of the housing that surrounds the rotating cage. The material rebounds on to the outside surfaces of the rotating cages and is impacted again to return to the breaker surface. This action continues until the material exits through the bottom discharge opening. See Fig. 1.

MULTI-CAGE — A crusher with two horizontal shafts which counter-rotate and have cages that intermesh single or multiple rows of pins. The material is fed through an opening in the housing into the innermost cage which impacts the material as it passes through the opening between the cage pins. The material is then impacted by the next row of pins traveling in the opposite direction. This action continues until the material passes through all the rows of pins. The material then impacts on liner plates which form the internal crushing members of the housing which surrounds the rotating cages. The material rebounds against the outside of the outer cage and is impacted and returned to the liner plates. This action continues until the material passes through the bottom discharge opening. See Fig. 2.

Cage Mills

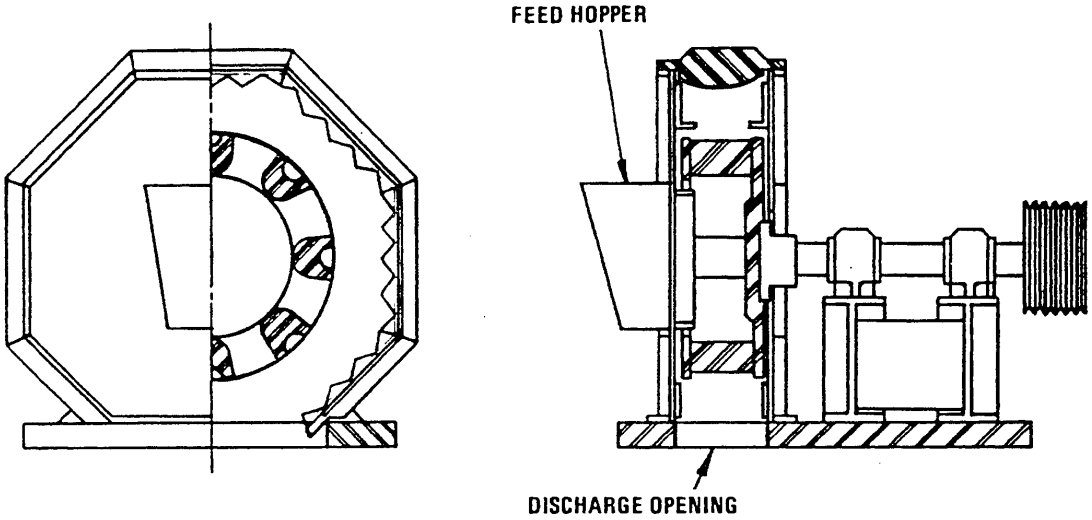


FIG. 1 – SINGLE CAGE MILL.

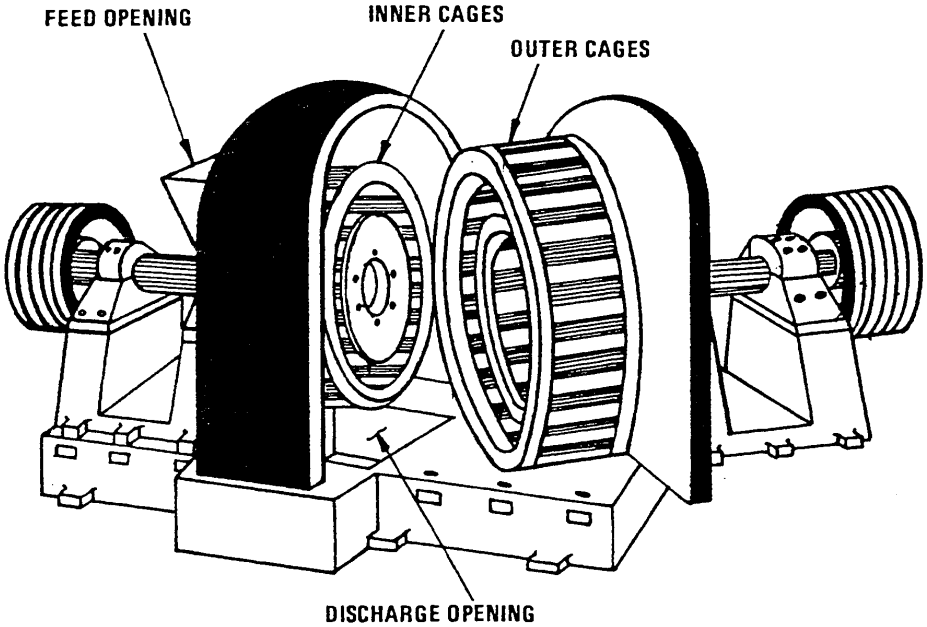


FIG. 2 – MULTIPLE CAGE MILL (4 ROW ILLUSTRATED).

Cage Mills
Terminology

ASSEMBLY DISC – Device attached to horizontal shaft that retains cage.

BALANCE WHEEL – Flywheel-type part on opposite end of shaft from cage used as a flywheel and to counterbalance weight of cage.

BASE – Part of crusher on which the housing and pedestal are assembled.

BREAKER – Plate or block-device against which material is impacted.

CAGE – A disc or ring with protruding pins equally spaced on its flat surface. These pins are attached in circular rows by a ring or disc. Cages may be cast or fabricated.

DRIVE SIDE – Side of housing which shaft assembly enters.

FEED HOPPER – A box-type device used to direct the feed into the cage through the housing.

FEED PLATE – Adjustable plate used to help control feed into crusher.

FEED RING – Device used to keep material being crushed from entering the area between the housing and feed side of cage.

FEED SIDE – Side of housing which feed material enters.

HOUSING LINER – Liner used to protect the housing sides from wear.

INTERNAL IMPACT – Term used to describe the cage action because the feed is to the inside of the crushing member.

PEDESTAL – Part of a crusher on which the shaft assembly is mounted.

PIN – The crushing devices equally spaced on the cage.

PIN SLEEVE – Replaceable hollow pin used on fabricated cages.

SEAL RING – A device to retain material being crushed in the housing where the shaft assembly enters the housing.

Cone Crushers

CONE CRUSHERS — The cone crusher, normally used as a secondary, tertiary, or quaternary crusher, is a relatively high speed gyratory incorporating a flatter head angle. The number of gyrations employed are approximately twice that used in a primary gyratory crusher. See Figs. 3, 4, 5, 6.

■

Cone Crushers

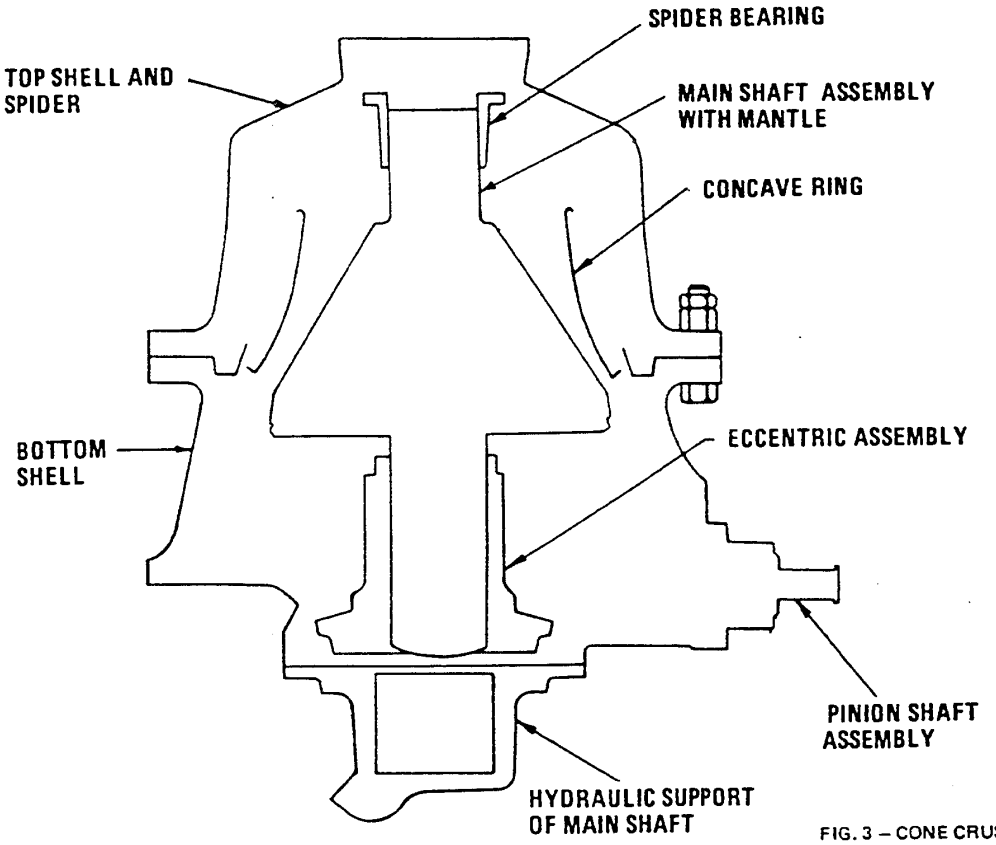


FIG. 3 – CONE CRUSHER.

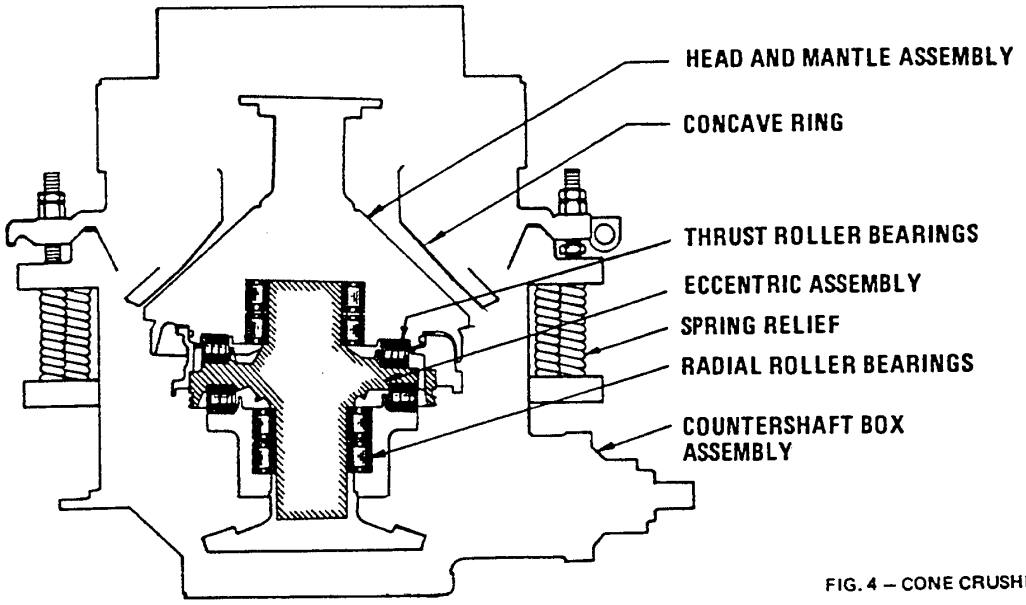


FIG. 4 – CONE CRUSHER.

Cone Crushers

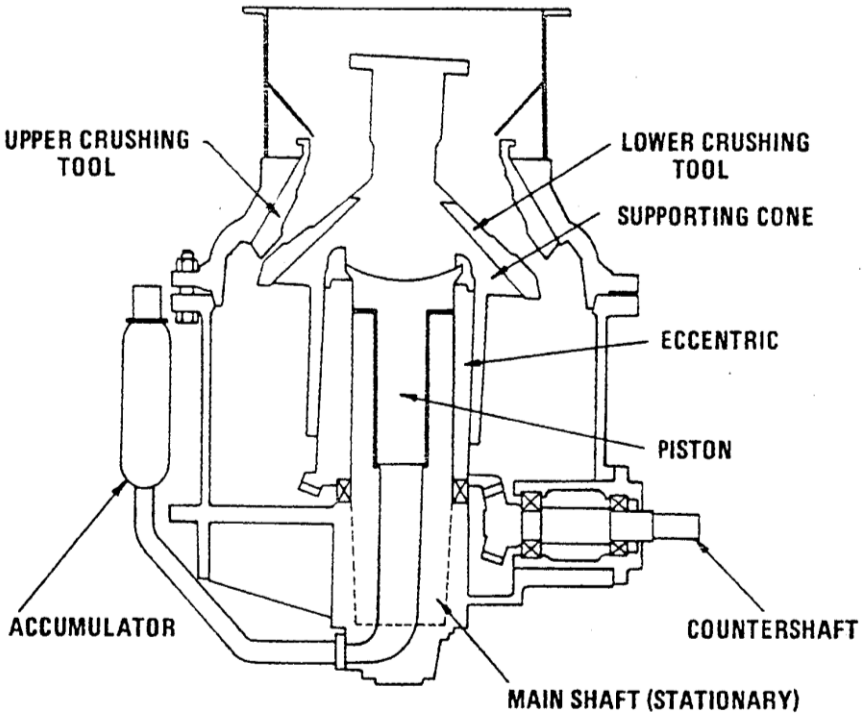


FIG. 5 – CONE CRUSHER.

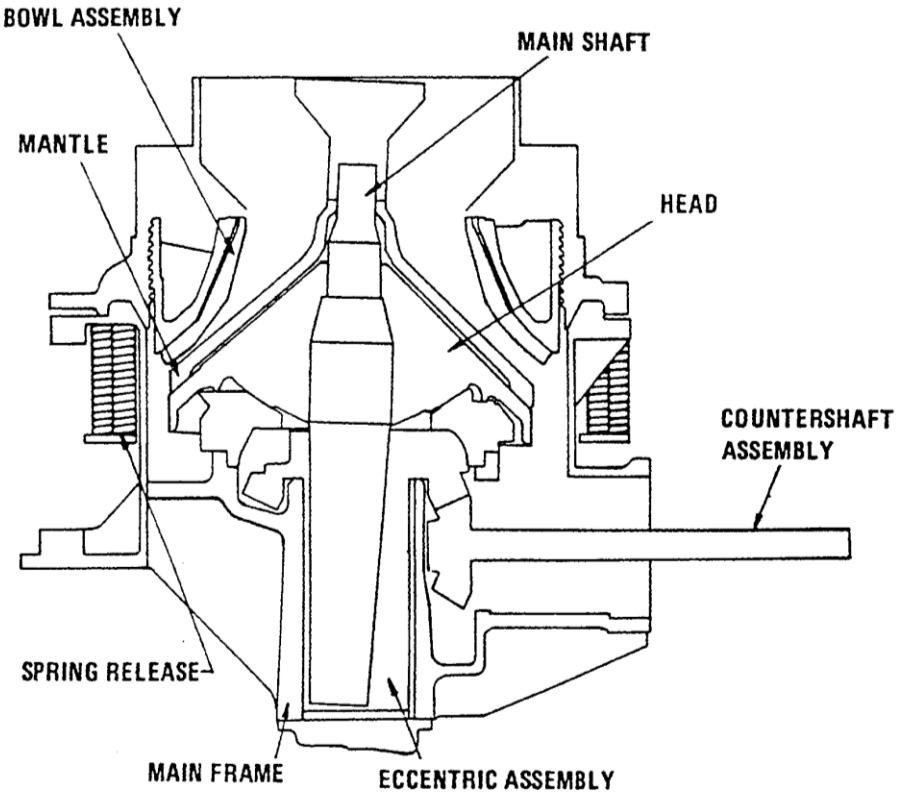


FIG. 6 – CONE CRUSHER.

Cone Crushers
Terminology

ACCUMULATOR — A gas-hydraulic operated unit to provide crushing chamber relief and automatic reset.

ADJUSTMENT CAP — The adjustment cap which fits around the bowl and rests on the adjustment ring. Is used for raising the bowl into the crushing position in the adjustment ring.

ADJUSTMENT RING — See also "UPPER FRAME". The adjustment ring, which seats on a conical machined surface on top of the main frame, and is generally threaded to provide the means of adjusting the bowl assembly.

ADJUSTMENT RING DUST SHELL — A sealing member protecting the lower portion of the bowl and adjustment threads.

ANTI-SPIN DEVICE — Prevents rotation of the mantle and supporting head assembly with the eccentric while allowing free motion in the opposite direction when crushing material.

ARM GUARD — Guards to protect against the erosion of the main frame arms caused by material being discharged from the crushing cavity.

BOTTOM HYDRAULIC CYLINDER COVER — The cover plate below the piston on crushers with hydraulic support main shafts.

BOTTOM PLATE — See "MAIN FRAME CAP".

BOTTOM SHELL — See "MAIN FRAME".

BOTTOM SHELL BUSHING — See "OUTER ECCENTRIC BEARING".

BOWL-CONCAVE SUPPORT — The bowl, which is threaded on its outside diameter, is suspended on heavy duty threads inside the adjustment ring, and is the supporting member for the bowl liner.

BOWL ADJUSTMENT RAMS — Hydraulically adjust the crusher by rotating one threaded member in relation to another.

BOWL LINER — See "CONCAVE RING", "UPPER CRUSHING TOOL".

BOWL LINER "U" BOLT — "U" Bolts rigidly hold the bowl liner to the bowl.

BOWL LOCK — Acts as a safety device to prevent the bowl from turning while crushing.

BUSHING-ECCENTRIC — See "INNER ECCENTRIC BEARINGS".

BUSHINGS-HYDRAULIC CYLINDER, LOWER & UPPER — Bushings, located and keyed in the hydraulic cylinder to prevent wear on the cylinder from movement of the hydraulic piston.

CLAMPING RING — Is used to provide the means of locking the bowl assembly into the crushing position in the adjusting ring.

CLAMPING CYLINDER — The clamping cylinders, located between the clamping ring and the adjustment ring, which provide the clamping force to lock the bowl in place.

CONCAVE RING — Wearing surface, usually manganese steel, located in the stationary section of the crushing chamber. Also referred to as "BOWL LINER" or "UPPER CRUSHING TOOL".

CONE ASSEMBLY — See "HEAD".

CONICAL HOPPER — See "FEED CONE".

COUNTERSHAFT — Located in the countershaft box, has a bevel pinion keyed to it, and drives the gear on the eccentric assembly.

COUNTERSHAFT BOX — The countershaft box provides a housing for the countershaft.

COUNTERSHAFT BOX GUARD — The countershaft box guard provides wear protection to that portion of the countershaft box which is exposed to falling material.

COUNTERWEIGHT — A large counterweight is used to counterbalance the eccentric and head assembly.

DISTANCE SLEEVE — A spacer between the mantle and the mantle nut.

Cone Crushers
Terminology

DUST SEAL – See "HEAD SEALING RING".

DRIVE SHAFT – See "COUNTERSHAFT".

DRIVE SHAFT HOUSING – See "COUNTERSHAFT BOX".

ECCENTRIC – The eccentric has an offset bore to provide the means whereby the head may follow an eccentric path during each cycle or rotation.

FEED CONE – The feed cone directs the falling feed into the crushing members as it comes off the feed plate.

FEED DISC – See "FEED PLATE".

FEEDER FUNNEL – See "FEED CONE".

FEEDER FUNNEL LINER – A replaceable wear liner over the conical section of the feed cone.

FEED HOPPER – Feed hopper is the upper cylinder used to collect the feed and direct the material into the crushing chamber.

FEED PLATE – The feed plate gyrates with the main shaft for the purpose of distributing the feed evenly around the entire crushing chamber.

FEED PLATFORM – The feed platform is a fabricated structure to direct material onto the feed plate.

GEAR – The large bevel gear is keyed to the eccentric and is driven by the pinion on the countershaft.

HEAD (HEAD CENTER) – A casting located between the main shaft and the mantle.

HEAD NUT – A threaded large nut used to tighten the mantle to the head center and mainshaft. See "MAIN SHAFT NUT", "LOCKING NUT".

HEAD SEALING RING – Sealing ring which protects internal components from dust and dirt located under the head.

HOLD DOWN STIRRUP – A clamping device to fasten the feed hopper to the upper frame.

HYDRAULIC CYLINDER-MAIN SHAFT – The cylinder containing the bushings, piston, piston wearing plate and clamp plate on crushers with hydraulic supported main shaft.

HYDRAULIC LOCK/UNLOCK RAMS – System of rams that lock or unlock the adjusting members prior to adjusting the machine.

HYDRAULIC PISTON– MAIN SHAFT – Piston mounted in hydraulic cylinder for raising and lowering mainshaft.

INNER BRONZE SLEEVE – See "INNER ECCENTRIC BUSHING".

INNER COUNTERSHAFT BEARING – The inner countershaft bearing is located adjacent to the pinion.

INNER ECCENTRIC BEARING – An inner eccentric bearing locked into the eccentric bore provides the bearing surface for the main shaft.

INTEGRAL OIL PUMP – Is gear driven from the countershaft and forces oil under pressure into the crusher.

LOCKING NUT – See "HEAD NUT", "MAIN SHAFT NUT".

LOCKING RING – Clamps the concave ring in position against the upper frame.

LOWER CRUSHING TOOL – See "MANTLE".

LOWER FRAME – See "MAIN FRAME".

LOWER RADIAL ROLLER BEARING – Transmits horizontal crushing pressures between the eccentric and the main frame.

LOWER SPRING RING – See "LOWER SPRING SEGMENT".

LOWER SPRING SEGMENT – The lower spring segment is located under the heavy coil springs and provides the means of adjusting the springs to obtain the correct spring force.

LOWER THRUST ROLLER BEARINGS – Transmits vertical crushing loads between the eccentric and the main frame.

Cone Crushers
Terminology

MAIN FRAME (LOWER FRAME) – Transmits the crushing force to the foundation and provides a rigid support for the remaining crushing components.

MAIN FRAME CAP – A plate bolted to the bottom of the frame which gives access to the eccentric assembly.

MAIN FRAME LINER – The main frame liner is welded to the inside of the frame to protect it from wear caused by falling material.

MAIN SHAFT – a.) The tapered shaft which is pressed or shrunk into the head and is driven by the eccentric providing the gyrating motion of the head. b.) The stationary shaft which is pressed into the main frame, and about which the eccentric rotates.

MAIN SHAFT NUT – The main shaft nut holds the torch ring and mantle firmly on the head and may provide support for the feed plate. See "HEAD NUT", "LOCKING NUT".

MAIN SHAFT SLEEVE – a.) The main shaft sleeve is on top of the mantle and is held firmly in place by a main shaft nut threaded directly onto the main shaft. b.) A steel sleeve pressed on the upper journal of the main shaft to protect the main shaft from wear.

MANTLE – A crushing surface, covering the head, is a replaceable casting generally of manganese steel.

OIL CHANNELS, GROOVES, LINES – Passages within the machine for distributing lubricating oil to internal wear surfaces.

OIL COLLAR GEAR – The oil collar gear drives the oil pump gear.

OIL PUMP GEAR – The pump gear is keyed and fitted to the oil pump shaft and is driven by a gear on the countershaft.

OIL RETAINING RING – Prevents loss of lubricants from the system.

OUTER COUNTERSHAFT BEARING – Located at outboard end of the countershaft box

OUTER ECCENTRIC BEARING – The outer eccentric bearing which is locked to the frame, provides the bearing surface for the eccentric assembly.

PINION – The pinion is keyed to the countershaft and drives the gear on the eccentric.

PISTON – Supports the head assembly and transmits vertical crushing force components to the main frame through the hydraulic support system.

PISTON RINGS – See "OIL RETAINING RING".

PUMP GEAR COVER – Located on the main oil pump gear housing and is used to provide access to the oil pump gear when servicing is needed.

PUMP GEAR HOUSING – See "PUMP GEAR COVER".

ROTARY SEAL RING – Provides labyrinth and piston ring seals to prevent dust from entering the crusher.

SOCKET – The socket supports the main shaft assembly and transmits the crushing force to the main frame.

SOCKET LINER – The socket liner is mounted on top of the socket, and provides the bearing surface for the head.

SPIDER CAP – An impact abrasion resistant cover over the upper end of the main shaft and the spider bearing which protects these items from impact and abrasion of the materials entering the crushing chamber.

STEP BEARING – A thrust bearing used to transmit the vertical forces on the main shaft to the supporting hydraulic cylinder.

STEP BEARING PLATES – The step bearin plates, located in the main frame, are thrust bear ings which support the eccentric or main shaft a sembly.

STUD CAP – Renewable cap that prevents wea on the stud nut.

SUPPORT CONE BEARING SEAT – See "STE BEARING".

Cone Crushers
Terminology

SUPPORTING CONE – Driven by the eccentric to impart a gyrating motion to the mantle which it supports.

SUPPORTING CONE BEARING – A convex spherical bronze bearing which supports the supporting cone assembly.

"T" NUT – See "BOWL LINER 'U' BOLT".

TOP SHELL – The upper stationary structure that contains the concave ring and supports the main shaft at the upper end.

TORCH/BURNING RING – A ring located between the locking nut and the mantles to remove extreme force on the locking nut when changing the mantles.

UPPER CRUSHING TOOL – See "CONCAVE RING" and/or "BOWL LINER".

UPPER ECCENTRIC RADIAL ROLLER BEARING – Transmits horizontal crushing pressures between the head and the eccentric.

UPPER FRAME – Supports the concave ring and seats in a conical machined surface and bolts to the main frame.

UPPER THRUST ROLLER BEARING – Transmits vertical crushing loads between the head and the eccentric.

WEAR COLLAR – A conical shaped deflector ring, located under the head assembly, to protect the labyrinth seal area.

Gyratory Crushers

These crushers derive their name from the gyrating action of a heavy mantle or crushing head located within a deep, conical bowl. The crusher is fed at the top. Material is crushed by compression between the mantle and the concaves, and is discharged from the bottom. See Fig. 7.

■

Gyratory Crushers

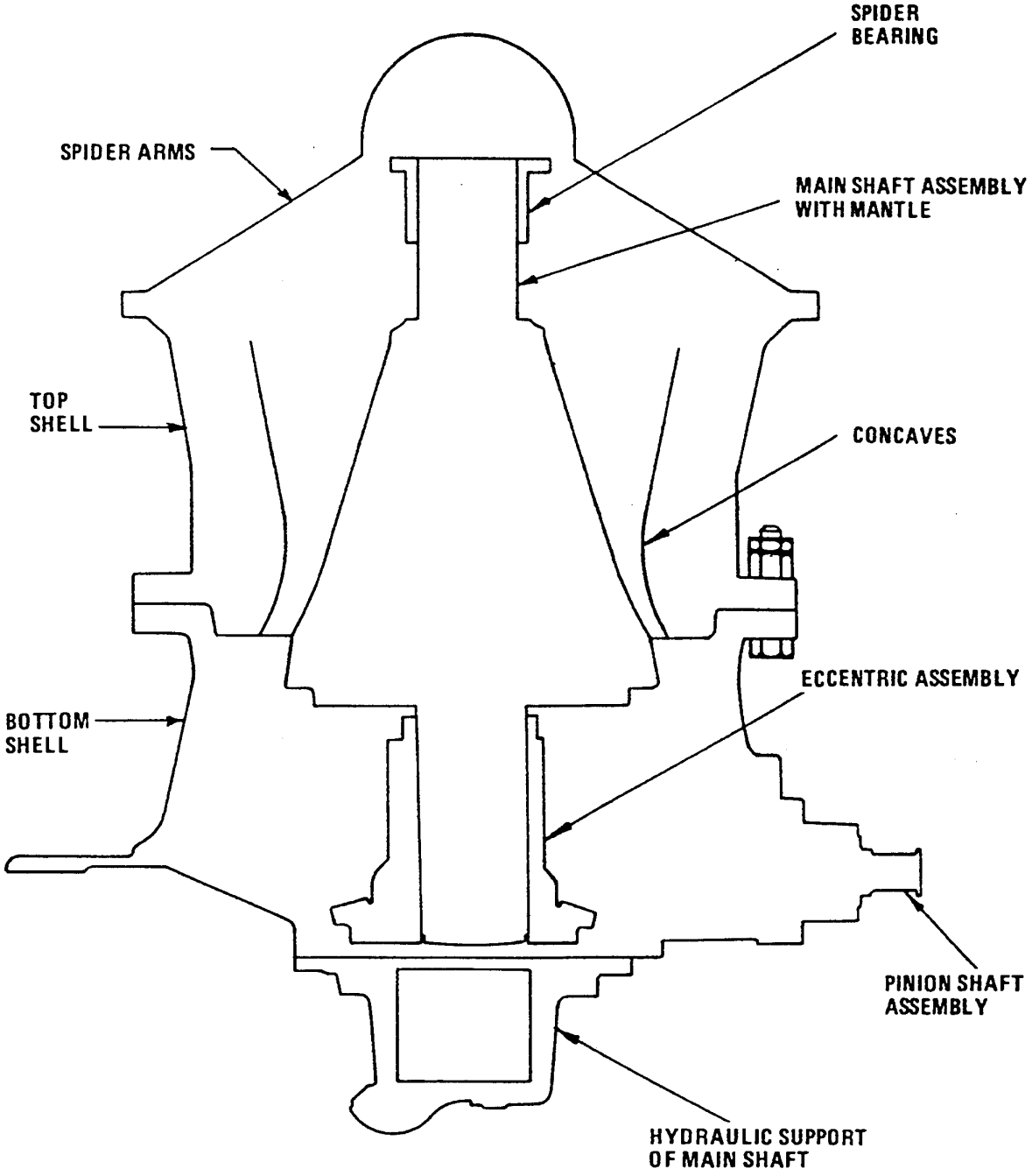


FIG. 7 – GYRATORY CRUSHER.

Gyratory Crushers
Terminology

ARM GUARD — Castings or fabrications which protect the bottom shell arms and countershaft housing from erosion caused by material being discharged from the crushing cavity.

BOTTOM HYDRAULIC CYLINDER COVER — The cover plate below the piston on crushers with hydraulically supported main shafts.

BOTTOM PLATE — The cover plate below the eccentric and gear on spider suspended crushers.

BOTTOM SHELL BUSHING — See "ECCENTRIC BUSHING-OUTER".

CHOKE POINT — That level in the crushing chamber where the capacity of the crusher is limited by the configuration of the crushing surface. See Fig. 8.

CONCAVES — Manganese or abrasion resistant material wearing surface located in the stationary section of the crushing chamber.

COUNTERSHAFT — The shaft that transmits power through the bottom shell from the motor or motor sheave to the pinion.

COUNTERSHAFT BEARINGS — The bearings which allow rotation of the countershaft within the housing.

COUNTERSHAFT HOUSING — The structural component that holds the countershaft bearings. See Fig. 9.

DUST SEAL — The sealing arrangement at the bottom of the crushing chamber designed to prevent dust and dirt from entering the main bearing area.

ECCENTRIC — The cylindrical member converting the circular gear motion to the gyrating motion of the main shaft.

ECCENTRIC BUSHING-INNER — The removable bearing member between the eccentric and the main shaft.

ECCENTRIC BUSHING-OUTER — The removable bearing member between the eccentric and the bottom shell.

Gyratory Crushers

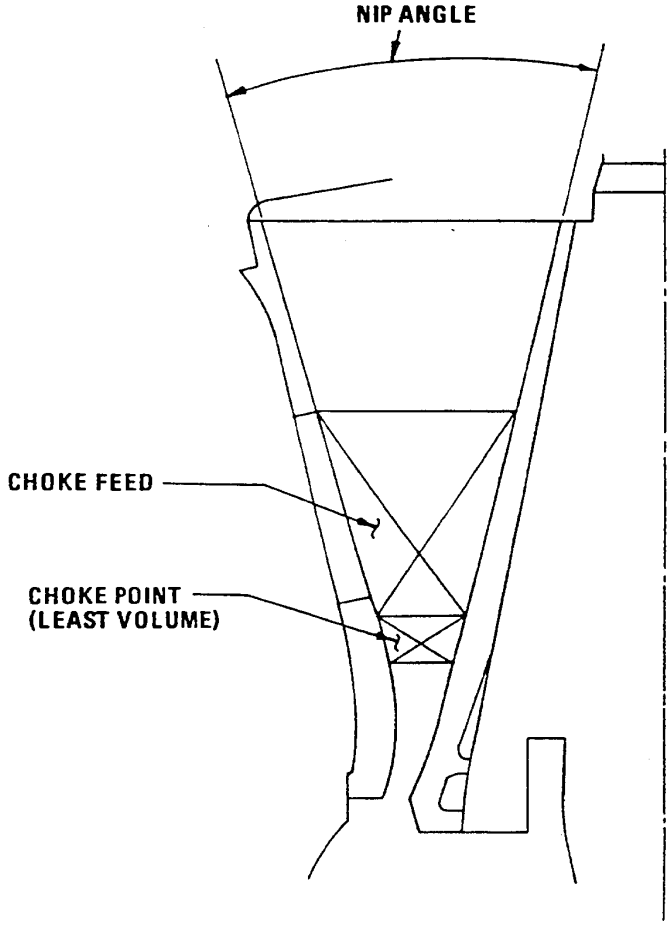


FIG. 8 – NIP ANGLE, CHOKE FEED, CHOKE POINT.

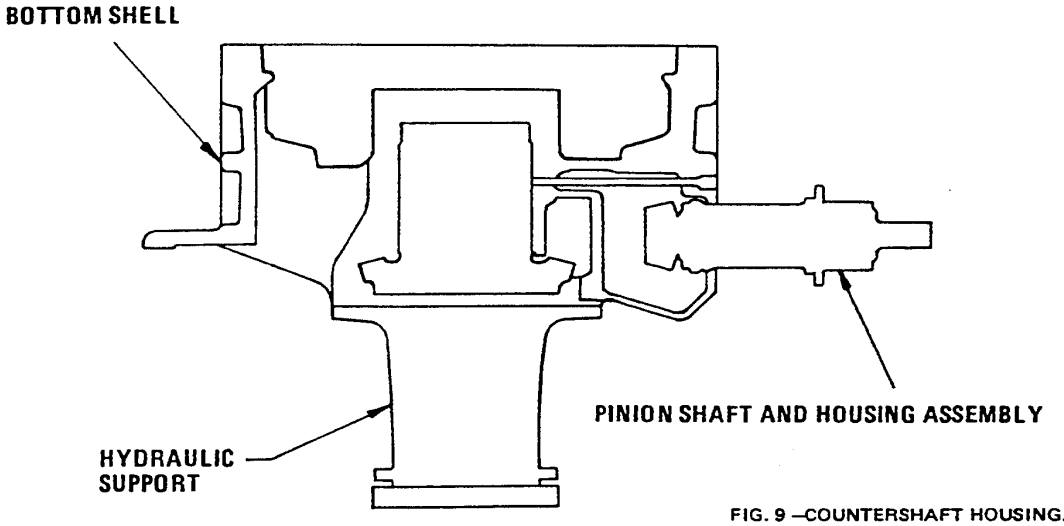


FIG. 9 –COUNTERSHAFT HOUSING.

Gyratory Crushers
Terminology

ECCENTRIC WEARING PLATE OR RING – The bearing support member for the eccentric.

FRAME – See "SHELL".

GEAR AND PINION OR DRIVING GEAR AND DRIVING PINION – The gearing used to transmit power from the countershaft to the eccentric.

HEAD CENTER – A casting located between the main shaft and the mantle.

HEAD NUT – A threaded large nut used to tighten the mantle to the main shaft. See Fig. 10.

HOPPER WEARING PLATES – See also "SPIDER RIM LINERS".

HYDRAULIC SUPPORT – The terms used to describe the hydraulic support of the crusher's main shaft. See Fig. 11.

HYDRAULIC SYSTEM – Term used in conjunction with Lube System on piston supported main shaft.

LUBE SYSTEM – The term used to describe the complete lubrication system for the internal component of gyratory crushers.

MAIN SHAFT – The main gyratory member of a gyratory crusher with appropriate bearing area to transfer the crushing forces to the stationary members.

MANTLE – Manganese steel or abrasion resistant steel casting wearing surface located on the gyrating main shaft portion of the crushing chamber.

NIP ANGLE – The included angle between the mantle and the concave. See Fig. 8.

NUT, SUSPENSION-ADJUSTING – A large nut used to support and adjust the position of the main shaft on spider suspended crushers. See Fig. 10.

PINIONSHAFT BEARINGS – See "COUNTERSHAFT BEARINGS".

PINIONSHAFT – See "COUNTERSHAFT".

PINIONSHAFT HOUSINGS – See "COUNTERSHAFT HOUSING".

PISTON – The moveable supporting member for the main shaft in the hydraulic support cylinder.

PISTON BUSHING – The removable bearing member between the hydraulic support piston and the hydraulic cylinder.

Gyratory Crushers

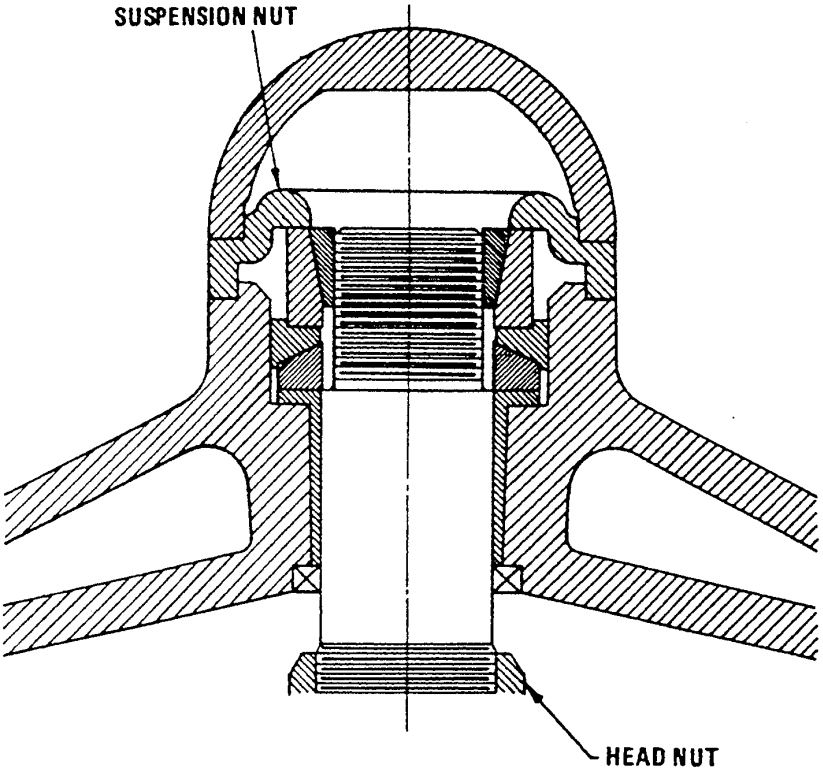


FIG. 10 – NUT, SUSPENSION AND HEAD NUT.

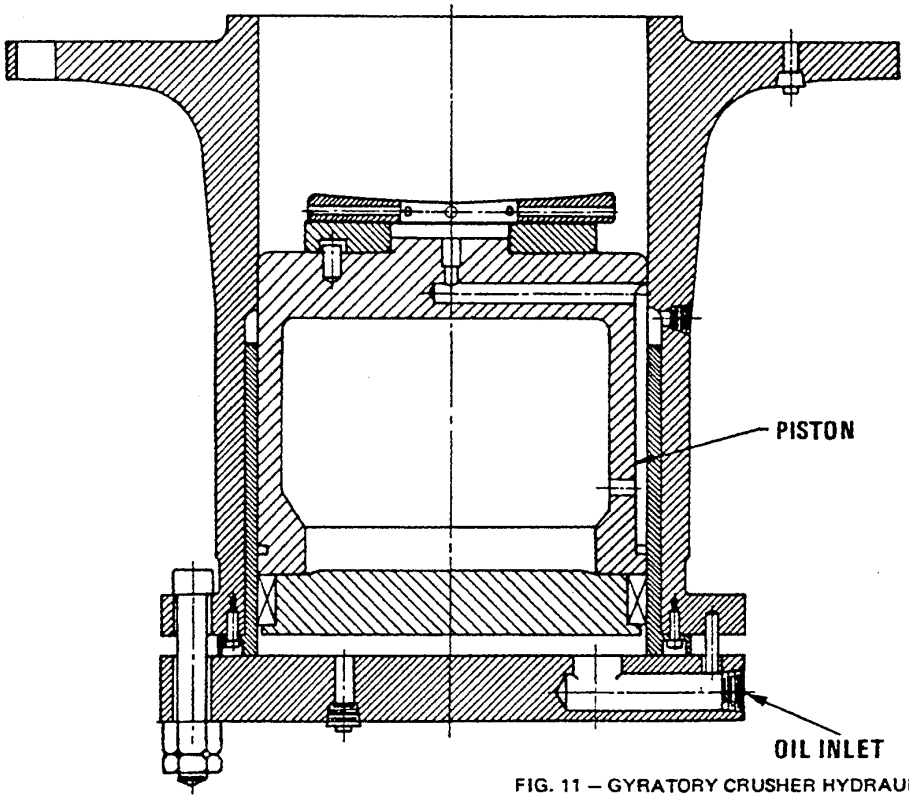


FIG. 11 – GYRATORY CRUSHER HYDRAULIC SUPPORT.

Gyratory Crushers
Terminology

POSITION INDICATOR – A device which indicates the position of the mantle in relation to a mantle to concave zero point.

SHELL – The main stationary structural member of a crusher composed of two or more sections depending upon the size of the crusher, and designated as:

TOP SHELL – Uppermost Section

MIDDLE SHELL – Center Section

BOTTOM SHELL – Bottom Section; see sketch under "COUNTERSHAFT HOUSING".

SPIDER – A casting with radiating arms installed across the top of a gyratory crusher which fixes the position of the upper end of the main shaft.

SPIDER ARM SHIELDS – Abrasion resistant covers to protect the spider from wear.

SPIDER BUSHING – The upper pilot bearing member mounted in the spider.

SPIDER CAP – An impact abrasion resistant cover over the upper end of the main shaft and the spider bearing which protects these items from the impact and abrasion of the material entering the crushing chamber.

SPIDER RIM LINERS-(HOPPER WEARING PLATES) – An abrasion resistant cover over the circumferential portion of the spider to protect it from wear.

STEP BEARING – A thrust bearing used to transmit the vertical forces on the main shaft to the supporting hydraulic cylinder.

SUPPORT WEAR RINGS – See "STEP BEARING".

SUSPENSION NUT – See "NUT".

SUSPENSION BEARING – See "SPIDER BUSHING".

■

Impactors and Hammermills

IMPACTOR — A crusher with rotor, without screen bars or grates, crushing primarily by impact. See Figs. 12, 13, 14.

HAMMERMILL — A crusher equipped with a rotor to which are attached hammers, normally free-swinging, and frequently equipped with grates. Crushing is achieved by impact, shear, and attrition. See Figs. 15, 16, 17.

■

Impactors and Hammermills

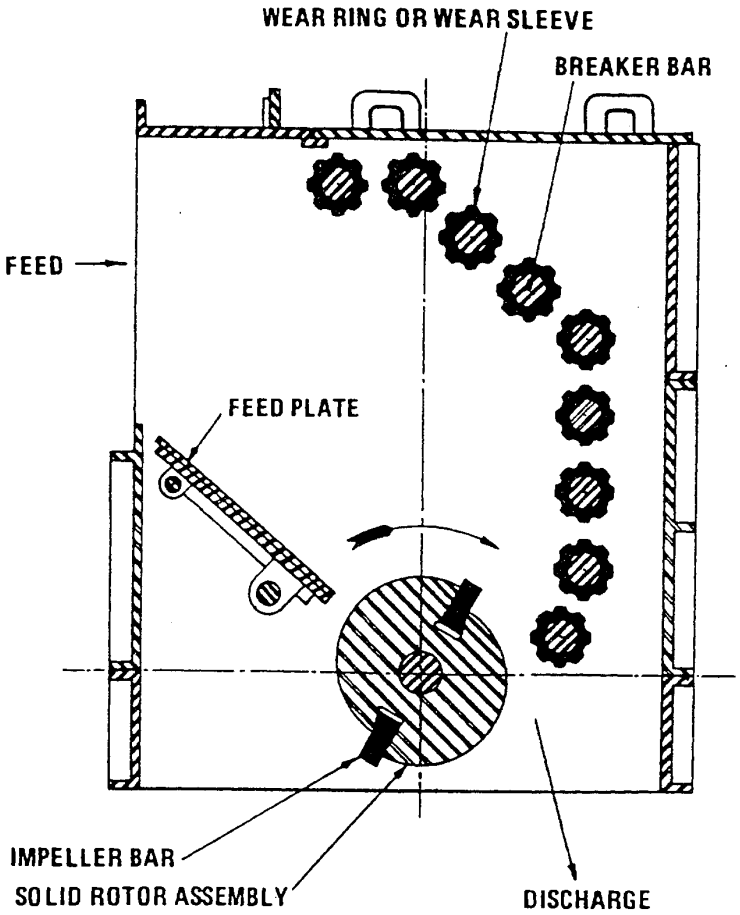


FIG. 12 – SINGLE ROTOR IMPACTOR.

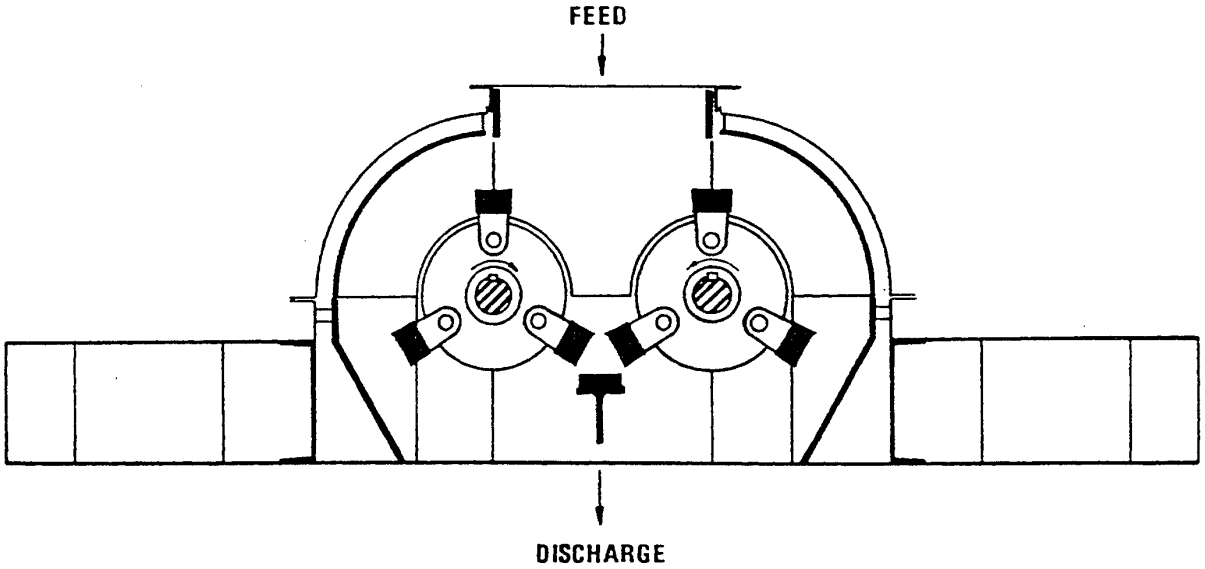


FIG. 13 – DOUBLE (TWIN)-ROTOR IMPACTOR.

Impactors and Hammermills

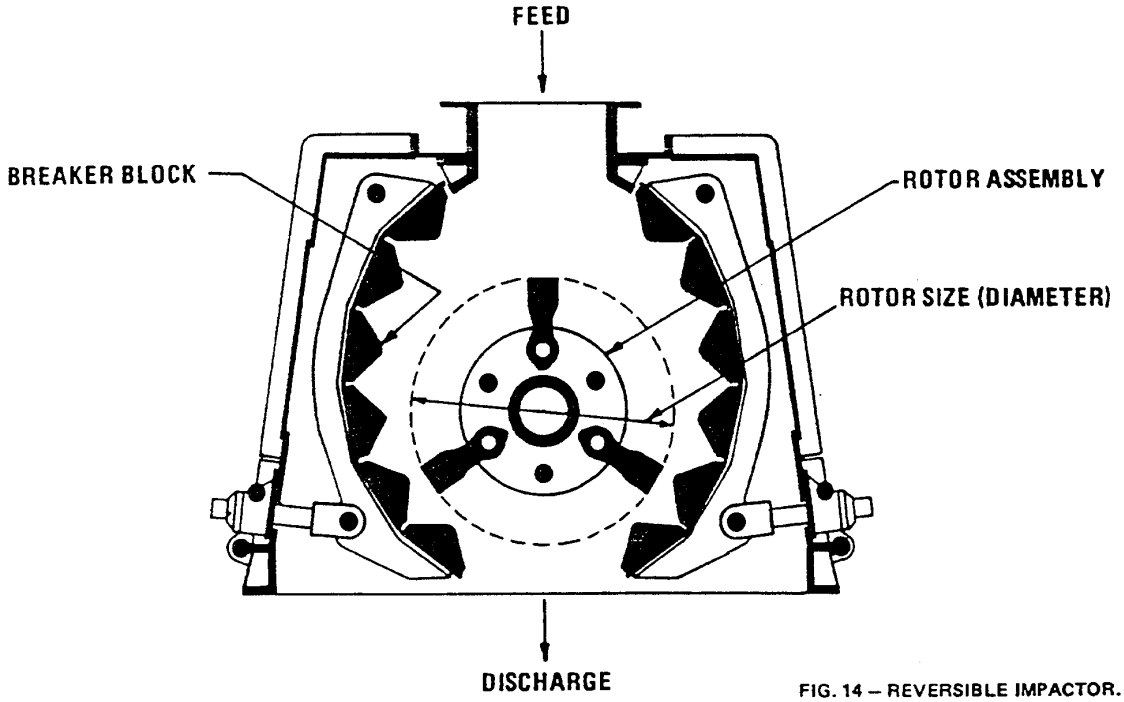


FIG. 14 – REVERSIBLE IMPACTOR.

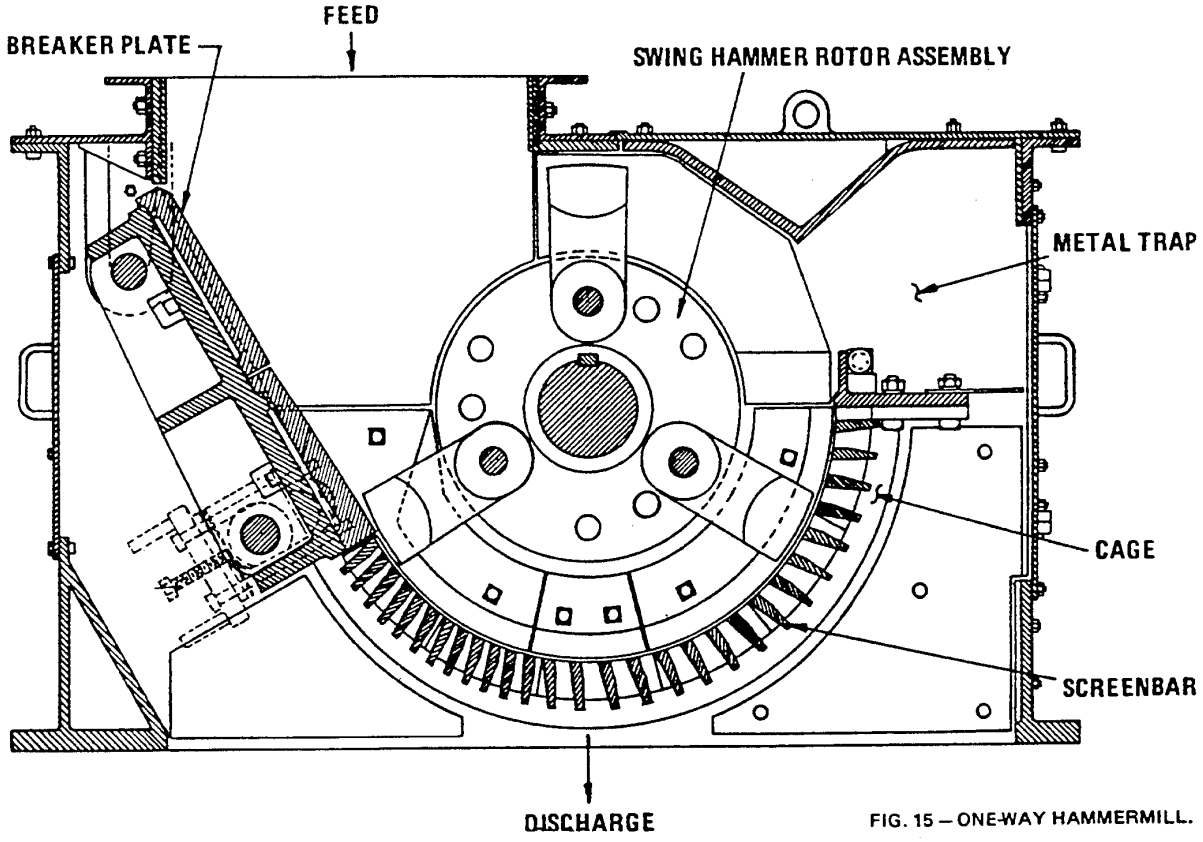


FIG. 15 – ONE-WAY HAMMERMILL.

Impactors and Hammermills

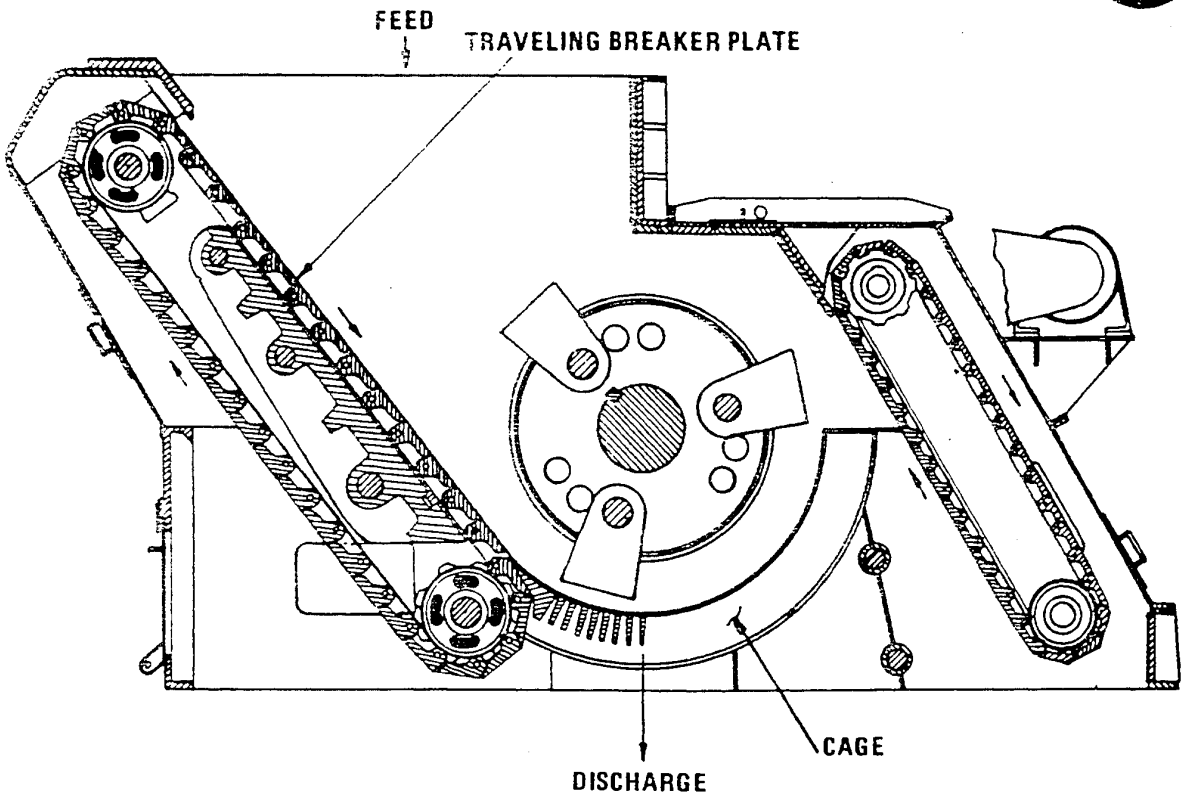


FIG. 16 – NON-CLOG HAMMERMILL.

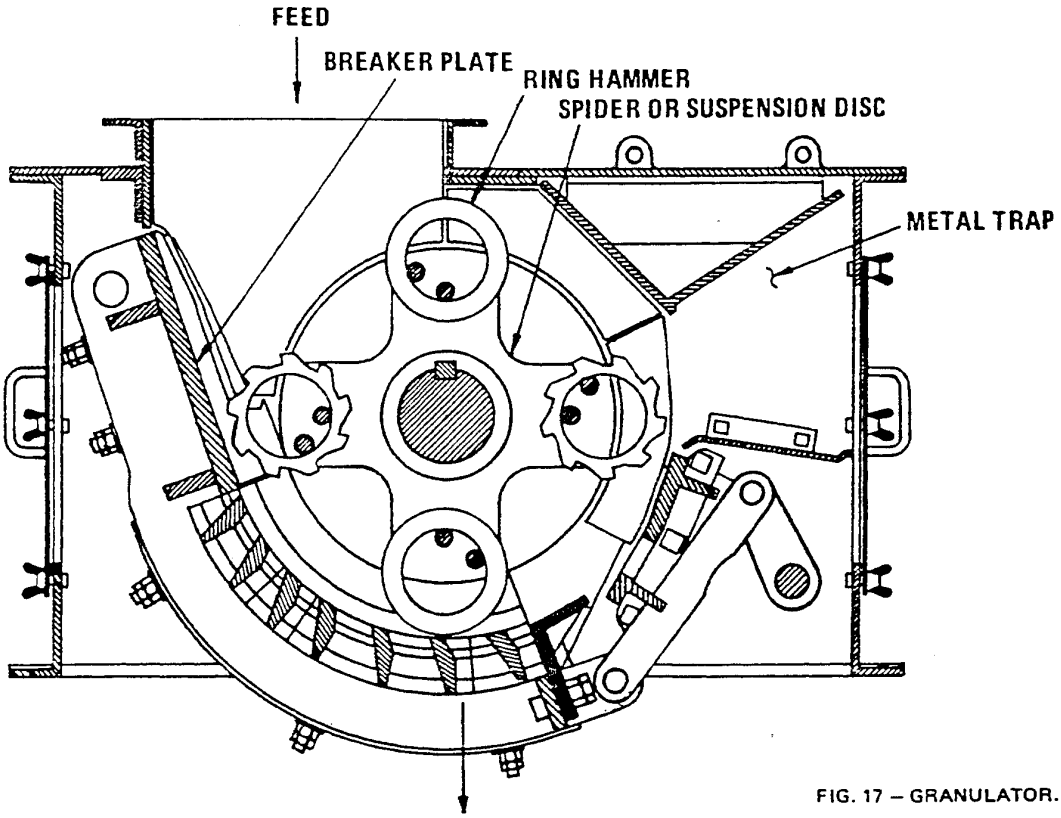


FIG. 17 – GRANULATOR.

Impactors and Hammermills

Terminology

BEATER – See "HAMMER" and/or "IMPELLER BAR".

BLOW BAR – See "IMPELLER BAR".

BREAKER BAR – Bar separate from the rotor for crushing and sizing of material. Such bar may be fixed or adjustable.

BREAKER BAR SLEEVE – See "WEAR SLEEVE".

BREAKER BED PLATE – Support for traveling breaker plate links.

BREAKER BLOCK – See "LINER".

BREAKER PLATE – Member against which material is crushed. This member may be fixed or adjustable. See Fig. 17.

CAGE – Assembly, fixed or adjustable, generally consisting of a frame holding screen bars, grate bars, grate sections, screen sections, or screen (perforated) plates. See Fig. 15.

CAGE MILL – See section of this Glossary giving definitions of cage mills and terms peculiarly applicable thereto.

CAGE SHAFT – Member attached to crusher frame for supporting cage assembly.

CENTER DISCS – See "SUSPENSION DISCS".

CHAIN CURTAIN – Strands of chain covering the feed opening of a crusher to prevent flyback or ricochet of material.

COLLARS – See "SPACING COLLARS".

CRUSHING CHAMBER – Space inside the machine provided for stone expansion following crushing of material.

DISCS – See "SUSPENSION DISCS".

DOUBLE (TWIN) ROTOR IMPACTOR – See "IMPACTOR" at beginning of Section.

DOWNRUNNING – See "HAMMERMILL".

DROP HEIGHT – Vertical free fall distance from the feed mechanism to the top of the hammer circle.

DUST GATE – Dust suppression device in top of hammermill.

END DISCS – Two steel discs, one on each end of the rotor, made with flanges to protect the ends of the hammer pins and the side frames.

END FRAME – Frame section parallel to the rotor shaft.

FEED PLATE – Sloped member, fixed or adjustable, used to transfer material to be crushed from feed opening to the rotor. See Fig. 12.

FEED PLATE-HYDRAULIC – Hydraulically actuated plate to assist in eliminating bridging of material across the rotor.

GRANULATOR – See Fig. 17.

GRATE – A sub-assembly of screen bars or perforated plates.

GRATE BAR – See "SCREEN BAR".

GRID – Breaker plate with multiple openings.

HAMMER – Crushing element attached to rotor, usually free-swinging.

HAMMER ARRANGEMENT – The configuration (spacing) of the hammers in the rotor assembly.

HAMMER BALANCE – 1. See "ROTOR BALANCE". 2. Weight of each hammer must equal the weight of the opposing hammer or hammers. 3. Arrangement of hammers in the rotor assembly so that weight distribution is achieved to minimize crusher vibration.

HAMMER-BULLHEAD – See "HAMMER T-HEAD".

HAMMER CIRCLE – Diameter of circle scribed by hammer tip with hammer extended.

HAMMER DISCS – See "SUSPENSION DISCS".

HAMMER PINS – Solid cylindrical rod or shaft which supports hammers in the rotor assembly.

Impactors and Hammermills

Terminology

HAMMER-RIGID – See "IMPELLER BAR" or "HAMMER".

HAMMER RING – Ring-shaped member, either smooth or toothed on external surface, supported by hammer pins. The ring hammer is free to rotate through the material while crushing by impact and compression.

HAMMER SHANK – Section of hammer that supports the head.

HAMMER-SLUGGER – Bar-type hammer with multiple shanks.

HAMMER T-HEAD – Hammer with head wider than shank.

HAMMERMILL-DOWNRUNNING – A hammermill where the material feeds into the downward rotation of the rotor.

HAMMERMILL GRANULATOR – A hammermill equipped with rings rather than hammers to achieve crushing action.

HAMMERMILL-PULVERIZER – A fine grind hammermill usually producing a product below 10 mesh.

HAMMERMILL-SHREDDER – An adaptation of the hammermill equipped with fixed or free-swinging hammers to reduce material mainly by shearing and attrition, and partially by impact.

IMPACT – Striking of one moving object against another moving or fixed object.

IMPACT BAR – See "BREAKER BAR".

IMPACTOR-DOUBLE (TWIN) ROTOR – A crusher equipped with two rotors with rigid or free-swinging hammers; rotors may turn in the same or opposite directions - normally used for either primary or secondary crushing; reduction is accomplished by impact. See Fig. 13.

IMPACTOR-REVERSIBLE – A crusher with a rotor that can be operated either clockwise or counter-clockwise. See Fig. 14.

IMPACTOR-SINGLE ROTOR – A crusher equipped with one rotor with impeller bars or free-swinging hammers used for either primary or secondary crushing; reduction is accomplished by impact. See Fig. 12.

IMPELLER – See "ROTOR".

IMPELLER BAR – Bar rigidly attached to and extending the full width of the rotor, and used as the crushing element in impactors. See Fig. 12.

LINER – Abrasion-resistant replaceable plate or shape protecting interior of frame from wear.

LINK – Traveling breaker plate element.

LINK PIN – Pin connecting links of traveling breaker plate.

LOWER FRAME – The lower section of the crusher housing, generally below the center line of the rotor.

METAL TRAP – Compartment within a crusher to collect uncrushable objects. See Figs. 15, 17.

NON-CLOG – Crusher with traveling breaker plate(s) for sticky materials. See Fig. 16.

PRIMARY CRUSHER – The first crusher used in a crushing system.

PULVERIZER – See "HAMMERMILL".

PULVERIZER-RING – See "HAMMERMILL-GRANULATOR".

REVERSIBLE CRUSHER – See "IMPACTOR-REVERSIBLE".

ROTOR – A rotating assembly with crushing element within an impactor or hammermill which imparts the force required to reduce the material fed to the crusher. (See General Drawings-Impactor and Hammermill.)

ROTOR BALANCE – Proper distribution of weight in rotor to minimize vibration due to operation.

ROTOR SIZE – Tip diameter by the width.

ROTOR WEIGHT – Weight of total rotor assembly less the bearings.

Impactors and Hammermills
Terminology

SCALLOPING – Uneven wear pattern on parts.

SCREEN BAR – Welded or cast bars arranged to control product size. Also known as "GRATE BAR". See Fig. 15.

SCREEN PLATE – A perforated plate, flat or curved.

SCREEN SECTION – See "GRATE".

SCRUBBER BAR – See "BREAKER BAR".

SET-OUT HOLES – Series of holes in discs to allow moving the hammer pins further from the rotor shaft, thereby compensating for hammer wear.

SHAFT SEALS – A device for sealing the opening between the shaft and the side frame.

SHIM – Plate, wedge, or bar used to fill gaps, achieve alignment or adjustment in various assemblies in machinery.

SHREDDER – See "HAMMERMILL-SHREDDER".

SIDE FRAME – Frame section perpendicular to the rotor shaft.

SINGLE ROTOR IMPACTOR – See "IMPACTOR-SINGLE ROTOR".

SPACING BLOCKS (LUGS) – Intermittent blocks welded or cast to the screen bars to give proper spacing between the bars for product sizing.

SPACING COLLARS – Short sleeves mounted on the rotor shaft to space the discs properly in an impactor or hammermill.

SPACING RINGS – Small rings used in conjunction with certain hammers to space the hammers between the discs properly.

SPIDERS – Elongated discs.

SPIDER ROTOR – A rotor equipped with spiders. See Fig. 17.

STOP PIN – Steel pins similar to hammer pins in a motor which prevent the hammers from wedging between the discs or impacting the spacing collars during flyback.

STRIPPER BAR – See "BREAKER BAR".

SUSPENSION BAR – See "HAMMER PINS".

SUSPENSION DISCS – Circular plate members that are fitted snugly on the rotor shaft and support the hammer pins.

TIE BAR – Strengthening member.

TIP SPEED – Speed of hammer tip expressed in feet per minute.

TRAMP IRON POCKET – See "METAL TRAP".

TRAVELING BREAKER PLATE – Traveling chain of links in a non-clog crusher. See Fig. 16.

TWIN-ROTOR IMPACTOR – See "IMPACTOR".

UPPER FRAME – That section of the frame assembly extending from the center line of the rotor upwards, containing the crushing chamber and the feed opening.

UPRUNNING – See "HAMMERMILL".

WEAR RING – Short cylindrical ring (doughnut) mounted on a breaker bar for protection of the bar from wear. See Fig. 12.

WEAR SLEEVE – Cylindrical cover for breaker bar protection. See Fig. 12.

WINDAGE – The air flow generated by the motion of a crusher during operation.

■

Jaw Crushers

JAW CRUSHERS – A jaw crusher consists of a main frame with a stationary crushing surface and a swing jaw with a moving crushing surface. The inclined swing jaw moves to compress material against the stationary crushing surface. See Figs. 18, 19.

Twin jaw crushers have two swinging (movable) jaws synchronized by chain or gear drive, no stationary jaws.

■

Jaw Crushers

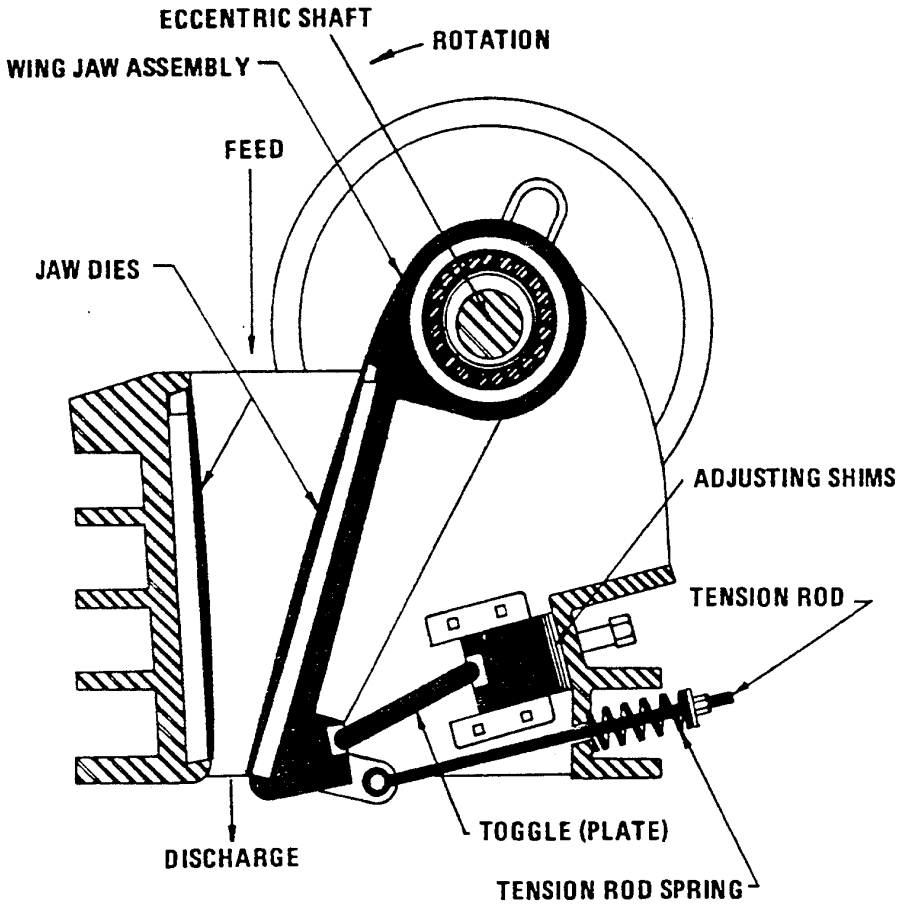


FIG. 18 – OVER HEAD ECCENTRIC JAW CRUSHER.

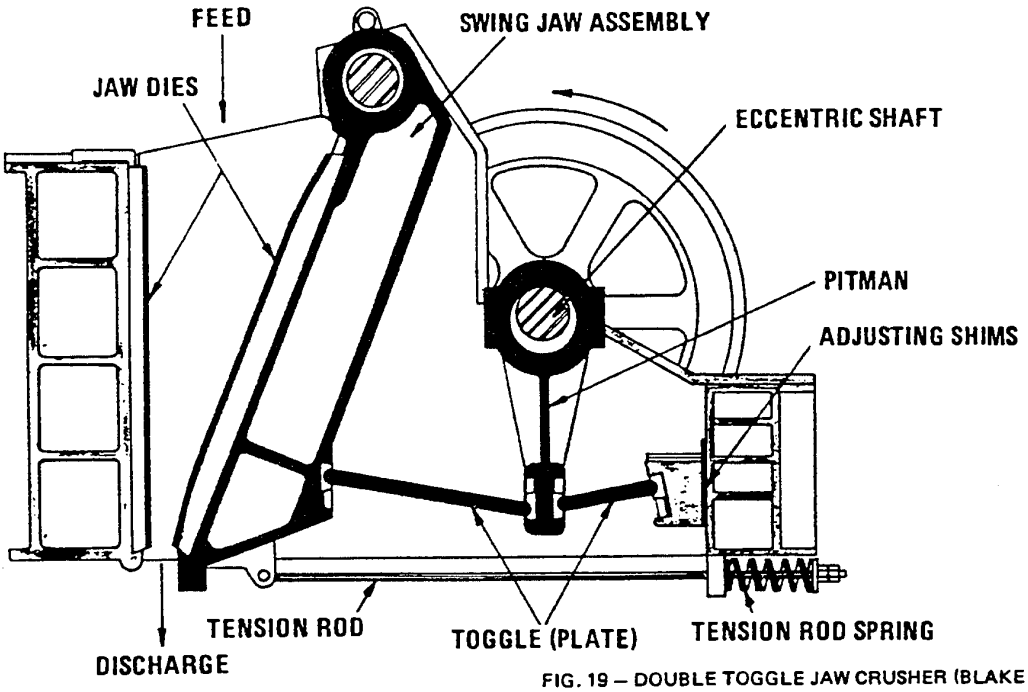
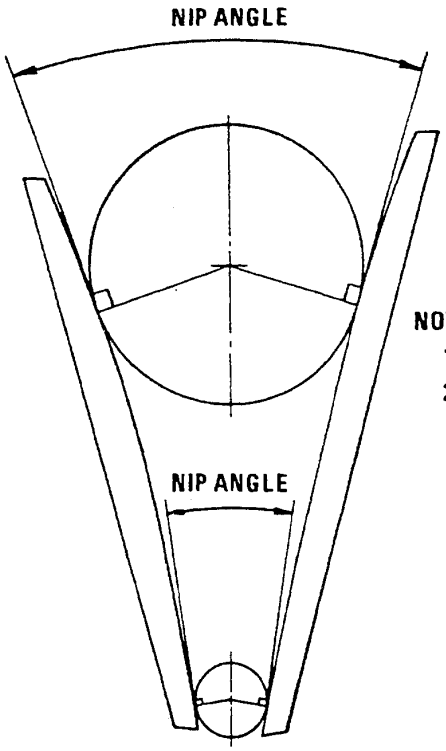


FIG. 19 – DOUBLE TOGGLE JAW CRUSHER (BLAKE TYPE).

Jaw Crushers



NOTE:

1. NIP ANGLE VARIES WITH CURVED JAW DIES
2. MAXIMUM NIP ANGLE OCCURS AT MINIMUM DISCHARGE SETTING

FIG. 20 – ANGLE OF NIP.

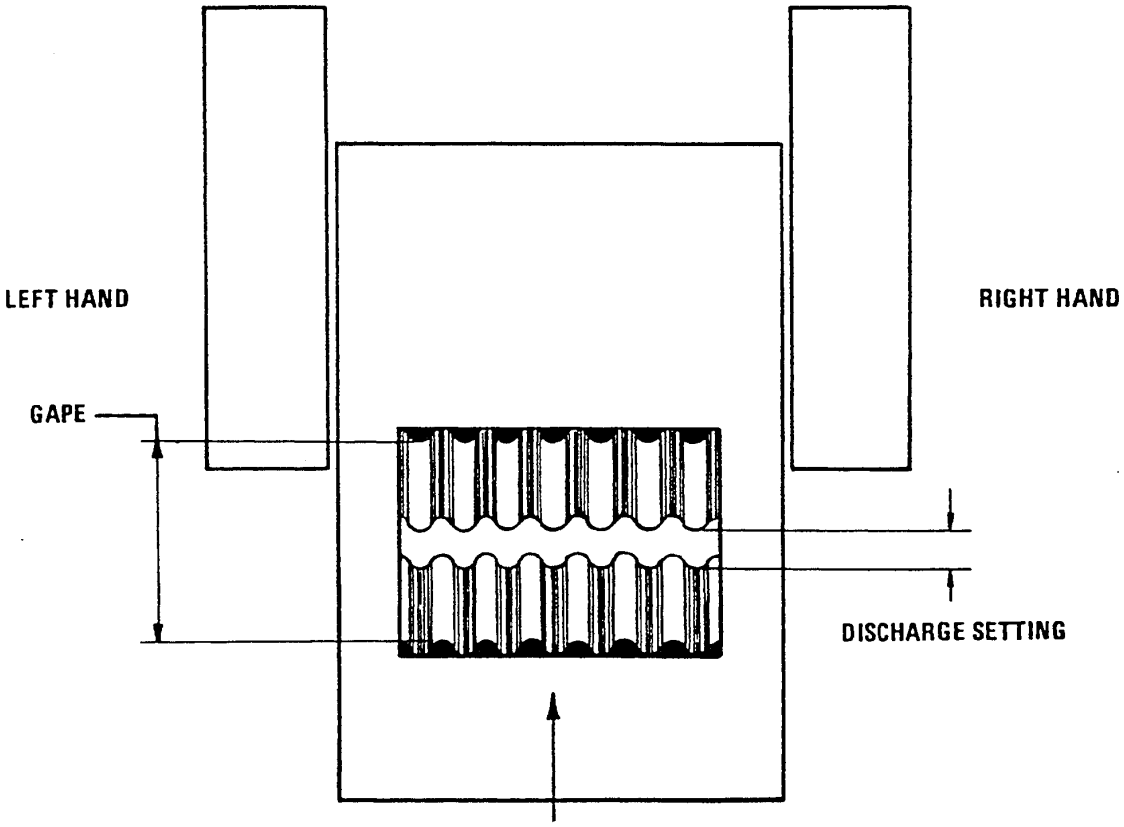


FIG. 21 – JAW CRUSHER - HAND OF DRIVE.

Jaw Crushers
Terminology

ANGLE OF NIP – Acute angle formed by stationary and swing jaw. See Fig. 20.

BEARINGS-JAW – A crusher component which allows rotation of the shaft on which it is mounted. Basic types are roller and sleeve (plain).

BEARING CAP – A type of bearing seal. Also the top portion of a split bearing housing.

BLAKE-TYPE JAW CRUSHER – Has two shafts and two toggles. The swinging jaw is pivoted at the top and actuated at the bottom.

CLOSED SIDE SETTING – Distance between jaw dies measured at their bottom with the jaw in the closed position. Measurement of distance is taken from peak of corrugation to valley of opposing corrugation on jaw die surfaces.

COUNTERWEIGHT – Weights placed on flywheels to balance the crusher.

CRUSHING CHAMBER-JAW – The area confined by the stationary and swinging jaw dies and the cheek plates in which crushing takes place.

DISCHARGE OPENING-JAW – The area between the jaw dies and the cheek plates at the bottom of the crushing chamber.

DOUBLE TOGGLE JAW CRUSHER – Has two shafts and two toggles. The swinging jaw is pivoted at the top and actuated at the bottom.

ECCENTRIC SHAFT – Shaft machined with a portion of the axis off-center to impart a crushing motion to the swinging jaw.

FEED OPENING – The inlet opening of the crusher confined by the jaw dies and the cheek plates.

GAPE – The distance between the jaw dies at the top, i.e., the gape of a 3042 jaw crusher is 30". See Fig. 21.

HAND OF DRIVE – Right or left on which drive is located. See Fig. 21.

HYDRAULIC ADJUSTING MECHANISM – Hydraulic pump which locates the swing jaw to assist in the addition or removal of shims when changing discharge settings.

JAW DIES (JAW PLATES) – Renewable crushing surfaces with different types of configurations on the surface. See also "SWING JAW ASSEMBLY".

JAW DIE WEDGES – Bolted wedges used to tighten and secure jaw dies.

LEFT HAND – See "HAND OF DRIVE".

MAIN FRAME – Major casting or weldment that supports the crushing members.

MOTOR BASE – Slide base to maintain proper V-belt tension.

MOVABLE JAW ASSEMBLY – See "SWING JAW ASSEMBLY".

OPEN SIDE SETTING – Distance between jaw dies measured at their bottom with the jaw in the open position. Measurement of distance is taken from peak of corrugation to valley of opposing corrugation on jaw die surfaces.

OVERHEAD ECCENTRIC-(SINGLE TOGGLE JAW CRUSHER) – Eccentric shaft and bearing mechanism located at the top of the swinging jaw assembly to impart crushing motion to the machine.

PITMAN – The eccentric mechanism in a Double Toggle or Blake-type jaw crusher, having two toggles and two shafts. Often referred to as the swing jaw mechanism in the overhead eccentric type jaw crusher.

RIGHT HAND – See "HAND OF DRIVE".

ROD TENSION – See "TENSION ROD".

ROLLER BEARING – Common types used in jaw crushers are spherical, taper, and cylindrical roller bearings.

ROTATION – Direction. See Fig. 18.

SAFETY RELEASE – A mechanism which prevents damage to the crusher from uncrushable objects.

Jaw Crushers
Terminology

SHIM-ADJUSTING – Steel spacer plates to locate and hold swinging jaw in the desired discharge position.

SINGLE TOGGLE JAW CRUSHER – See "OVERHEAD ECCENTRIC".

SIZE – Gape by width, i.e., 30 x 42.

SLIPPAGE – Action that occurs when the angle of the nip is too great, thus retarding acceptable flow rate of the material to be crushed.

SPEED – RPM of the eccentric shaft of the crusher flywheel.

STATIONARY JAW DIES – See "JAW DIES".

STROKE – Amount of movement of the swing jaw which is controlled by the amount of eccentricity of the eccentric shaft and the toggle system.

SWING JAW ASSEMBLY – Consists of jaw dies, shaft and bearings.

SWINGING (MOVABLE) JAW DIES – Manganese crushing surface mounted on the swing jaw. See "JAW DIES".

TENSION ROD SPRING ASSEMBLY – Designed to maintain a tight contact between the swinging jaw, toggle plate and main frame. See Figs. 18, 19.

TOGGLE OR TOGGLE PLATE – A spacing member located between frame and Pitman and/or swing jaw which may also act as a protective member.

TOGGLE BLOCK – Either holds or is the stationary toggle seat.

TOGGLE SEAT – A bearing surface, usually a replaceable insert, designed to take the wear due to toggle movement.

WEDGES – See "JAW DIE WEDGES".

■

Double and Triple Roll Crushers

DOUBLE ROLL CRUSHER — A crusher having two rolls mounted in the same plane, revolving towards each other. Material is crushed between them. See Fig. 22.

TRIPLE ROLL CRUSHER — A crusher using three rolls, allowing two crushing chambers, thus increasing the machine's ratio of reduction. See Fig. 23.

■

Double and Triple Roll Crushers

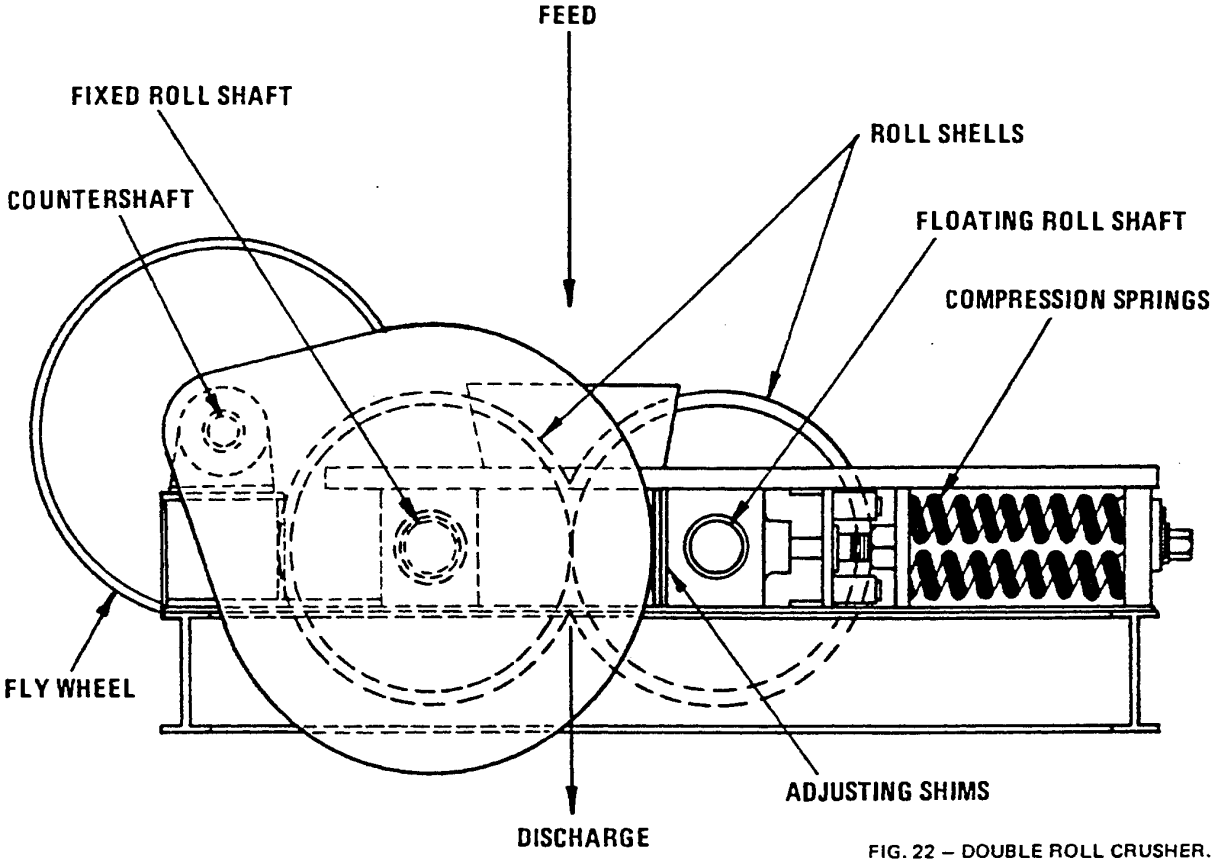


FIG. 22 – DOUBLE ROLL CRUSHER.

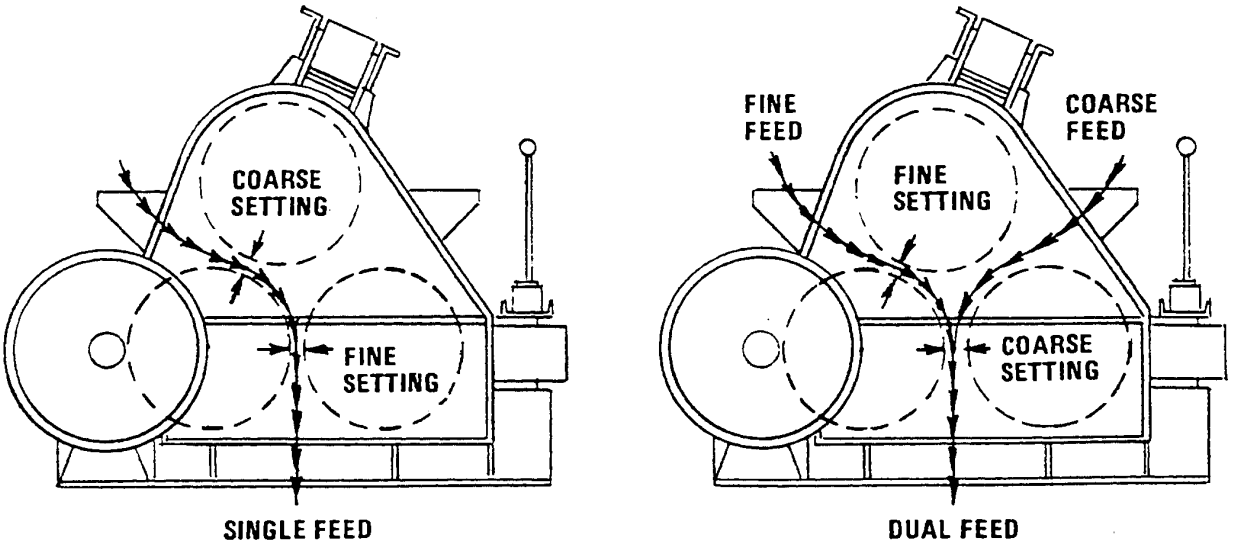


FIG. 23 – TRIPLE ROLL CRUSHER.

Double and Triple Roll Crushers

Terminology

ADJUSTING SHIMS – Fabricated steel plates used to maintain or change discharge setting between the rolls. See Fig. 22.

BEARING BLOCKS – Stationary and movable. See "MOVABLE AND FIXED BEARING BLOCKS".

BULL GEAR – Mounted on the drive roll shaft and is driven by pinion gear on countershaft. Also called "DRIVEN GEAR" or "SPUR GEAR".

CHAIN DRIVE – Roller chain and sprockets used to synchronize the rolls and impart power and motion to them from the countershaft.

COUNTERSHAFT – Shaft that transmits power from the flywheel-pulley to the power train for the stationary roll assembly. See Fig. 22.

DISCHARGE SETTING – Area defined by the space between the rolls at their closest point.

DRIVE GEAR – The pinion gear mounted on countershaft that drives the driven gear that is mounted on the stationary or drive roll shaft.

DRIVEN GEAR – See "DRIVE GEAR" or "BULL GEAR".

FEED HOPPER – Fabricated box located above the feed opening with or without feed control members.

FIXED ROLL SHAFT – Non-adjustable roll shaft assembly. See Fig. 22.

FLOATING ROLL SHAFT – Adjustable roll shaft assembly. See Fig. 22.

FRAME – Main support members.

GEAR CASE – Oil tight housing for pinion and bull gear.

GUIDE BAR – Wearing bar on which the guide plates work.

GUIDE PLATE – Small steel plates that keep the floating roll assembly in position on the frame (guide bars) throughout fore and aft movement due to adjustment or spring action.

HAND OF DRIVE – Determined when facing the crusher from the spring end.

HYDRAULIC ADJUSTMENT – Hand activated hydraulic pump which locates the moveable or floating roll to assist in the addition or removal of adjusting shims when changing discharge setting.

MOVABLE AND FIXED BEARING BLOCKS – Housing containing bearing and seals for movable and fixed roll shafts.

OIL FLINGER – Ring or flange on shaft used to insure lubrication or enhance sealing.

OIL LUBRICATION – System of lubricating crusher bearings - usually a splash oiling system.

OIL SLINGER – See "OIL FLINGER".

PINION, SPUR – Small gear on countershaft or back gear shaft, usually a driving gear. A lubricating gear.

PISTON RING – A metal seal to retain lubricant or protect the bearing from entrance of foreign material.

RIM – Wheel or part on which the pneumatic tire is mounted.

RIM SAFETY (TIRE) – Means of retaining a pneumatic tire on its rim.

RING, TAPER – Wedge-shaped part used to mount and lock roll shell to roll drum. Also called "roll shell wedge".

ROLL DRUM – Part that supports the roll shell to the roll shaft.

ROLL SHAFT – One of the two or three main shafts that carry a crushing roll.

ROLL SHELL – The removable wearing surface on a crusher roll, usually manganese steel.

RUBBER OR PNEUMATIC TIRE DRIVE – Tires mounted on fixed and movable roll shafts to keep movable roll speed synchronized with fixed roll.

SPACER BLOCK – Steel box located between the

Double and Triple Roll Crushers
Terminology

jib and the main frame to maintain a fixed dimension.

SPRING – Compression springs allow the floating roll to move when an uncrushable object enters between the two roll shells. It is a relief mechanism. See Fig. 22.

SPRING PLATE – Part used to provide a seat for the compression springs.

SPRING RETAINING ROD – Rod that guides the springs and provides means of compressing the springs.

SPUR GEAR – See "DRIVEN GEAR" and "BULL GEAR".

STAR GEARS – Deep tooth-type gears used to transmit the power and synchronize the stationary roll assembly to the floating roll assembly and allow for adjustment. Also called "finger gears".

STAR GEAR HOUSING – An oil and dust tight cover, protecting the star gears from entrance of foreign material. It also retains the lubricating oil for the star gears.

TAPER SEGMENT – Split or segmented taper ring. Also called "roll shell wedge segment".

TIRE GUARD – Safety guard around the pneumatic tires that synchronize the rolls.

TIRE HUB – The wheel upon which the pneumatic tires are mounted.

V-BELT DRIVE – Consists of a grooved pulley on the motor or power unit, a set of matched V-Belts, and the grooved flywheel/pulley on the crusher countershaft.

WEARING PLATE (FRAME) – Lower cheek plate which protects lower structural members from abrasion.

■

Single Roll Crushers

The single roll crusher consists of a revolving toothed roll and stationary breaker plate supported within a heavy steel frame. Crushing is performed by shearing and compressing material between the roll surface and breaker plate. See Fig. 24.

Single Roll Crushers

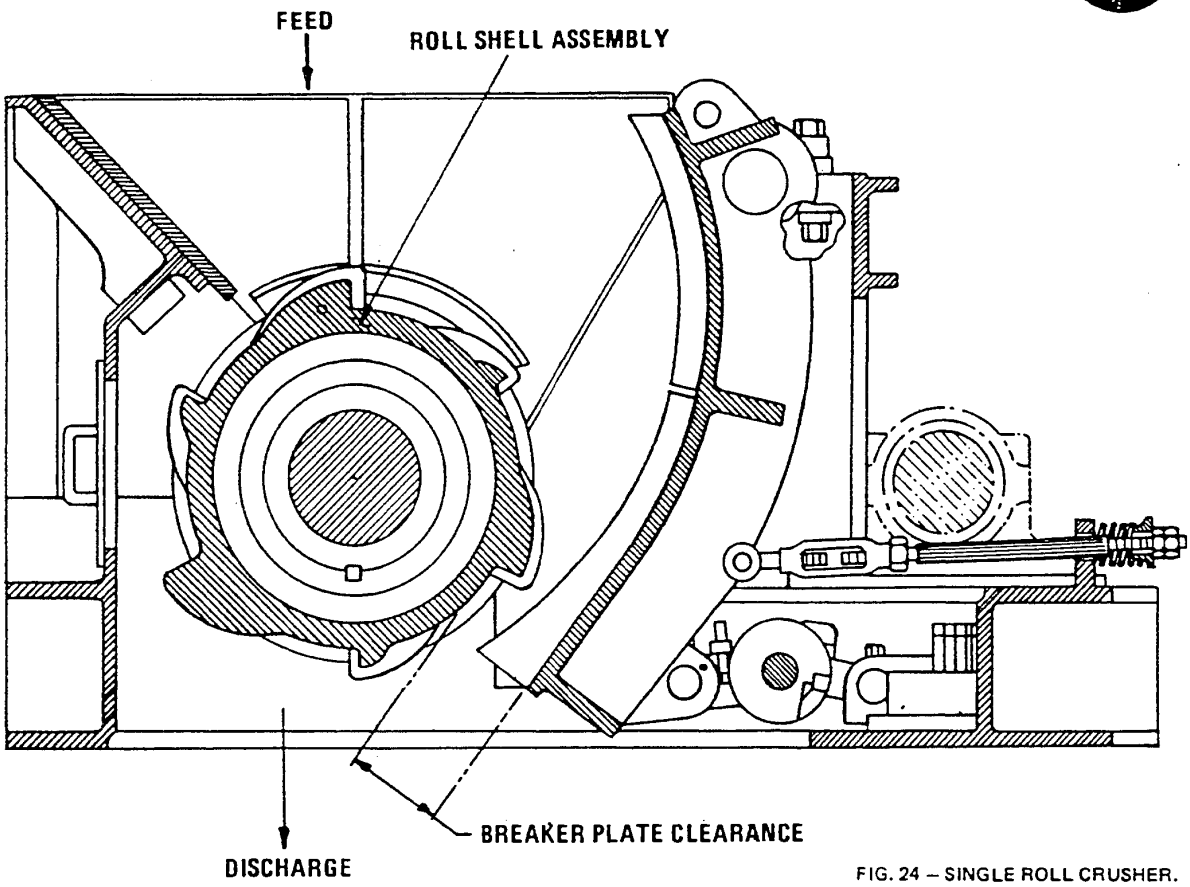


FIG. 24 – SINGLE ROLL CRUSHER.

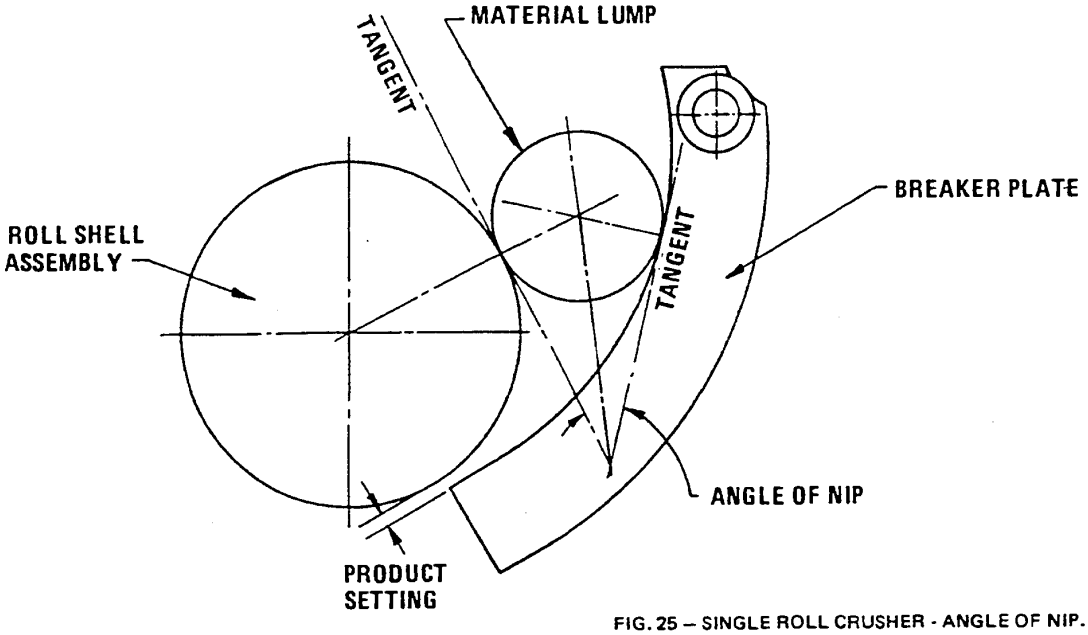


FIG. 25 – SINGLE ROLL CRUSHER - ANGLE OF NIP.

Single Roll Crushers

Terminology

ANGLE OF NIP — The angle formed by lines tangent to the roll face and breaker plate at those points where the particle to be crushed is in contact. See Fig. 25.

BREAKER PLATE CLEARANCE — Space between bottom of wear tip and roll shell matrix. See Fig. 24.

BULL GEAR — Large gear on roll shell.

BUSHING — Bronze sleeve bearing in which roll shaft and countershaft operate.

CHOKE FEED — Completely filled crushing chamber.

COUNTERSHAFT — Shaft upon which drive pulley and pinion are mounted.

DRUM — See "ROLL SHELL".

FROZEN COAL CRACKER — Single roll crusher specifically designed to break frozen masses of coal.

HOLDBACK ROD — Device that keeps breaker plate in position.

MATRIX — Roll shell cylinder surface from which the teeth protrude.

PINION — Small gear on countershaft engaging roll shaft gear.

ROLL SHAFT — Shaft on which roll is mounted.

ROLL SHELL ASSEMBLY — Roll shell and shaft. See Fig. 25.

ROLL SHELL SEGMENT — Sections of roll shell when shell is not a single piece (usually in quarters).

SEGMENTS — Replaceable plates mounted on the roll shell.

SLUGGER TEETH — The large teeth on a single roll face which first strike material with impact.

TEETH — Protrusions on roll shell.

TENSIONING RODS — Long rods which hold the breaker plate in place and equipped with cushioning springs to protect against severe shock.

TOGGLE RELEASE MECHANISM — Spring-loaded device that automatically allows breaker plate to release and pass an uncrushable piece of material.

V-SHAPED MAW — The area formed by the breaker plate and the moving crusher roll.

WEAR PLATE — Renewable liners on breaker plate that form one side of the nip angle.

WEAR SHOE — Replaceable section at lower edge of crushing face of breaker plate, designed to assist in product sizing.

WEAR TIP — Replaceable section synonymous with "WEAR SHOE".

■

Test Definitions

BULK DENSITY OF SOLIDS — Weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature. Refer to ASTM E12-61T-61 for procedure.

BURBANK ABRASION — A standard method of comparing the relative abrasiveness of rocks, minerals and ores. The testing device serves only to compare one material with another under identical conditions of processing, and does not measure abrasion in absolute terms. Procedure is outlined in Pennsylvania Crusher Corporation Burbank Test Procedure.

COMPRESSIVE STRENGTH — Method of determining a material's resistance to compressive failure. Resistance is measured in pounds per square inch. Refer to ASTM C170-50 for procedure.

DEVAL — Test to determine resistance to wear of aggregate, sometimes referred to as a measure of hardness. The lower the percent of loss, the harder the rock. Refer to ASTM D2-33 for procedure.

FINENESS MODULUS — An empirical factor obtained by adding the total percentages of a sample retained on each of a specified series of sieves and dividing the total by 100. Refer to ASTM C-125 for procedure.

GRINDABILITY INDEX (HARDGROVE) — The grindability of a coal is expressed as an index showing the relative hardness (or ease of pulverizing) of that coal compared with a standard coal chosen as 100 (unity) grindability. Refer to ASTM D409-37T for procedure.

LOS ANGELES RATTLER ABRASION TEST — Test to determine resistance to wear of aggregate, sometimes referred to as a measure of hardness. The lower the percent of loss, the harder the rock. Refer to ASTM C-535-65 (large) and ASTM C-131-69 (small) for procedure.

SOUNDNESS TEST — Test to determine resistance of material to freezing and thawing disintegration. Tested by direct methods or by a simulated soundness test using sodium sulfate or magnesium sulfate crystallization as the disrupting agent. Refer to ASTM C88-73 for procedure.

SPECIFIC GRAVITY — Ratio of unit weight of matter to that of water. Refer to ASTM C127059 and 128-59 for procedure.

TOUGHNESS — Impact test to determine energy required to cause fracture. The height of the fall, in centimeters of a 2KG hammer is called toughness. See ASTM C-131-39 for procedure.

WORK INDEX — The purpose of this test is to measure the foot-pounds per inch of thickness required to crush material of a standard size. From this value a work index is calculated. By applying the work index, specific gravity, feed analysis, and a certain constant, an approximation of crusher horse power may be determined. The test was originated by Fred Bond of Allis-Chalmers Corporation. Refer to A-C Test No. 07R9235B for procedure. Will also be able to be found in new AIME Minerals Processing Handbook when published.

■

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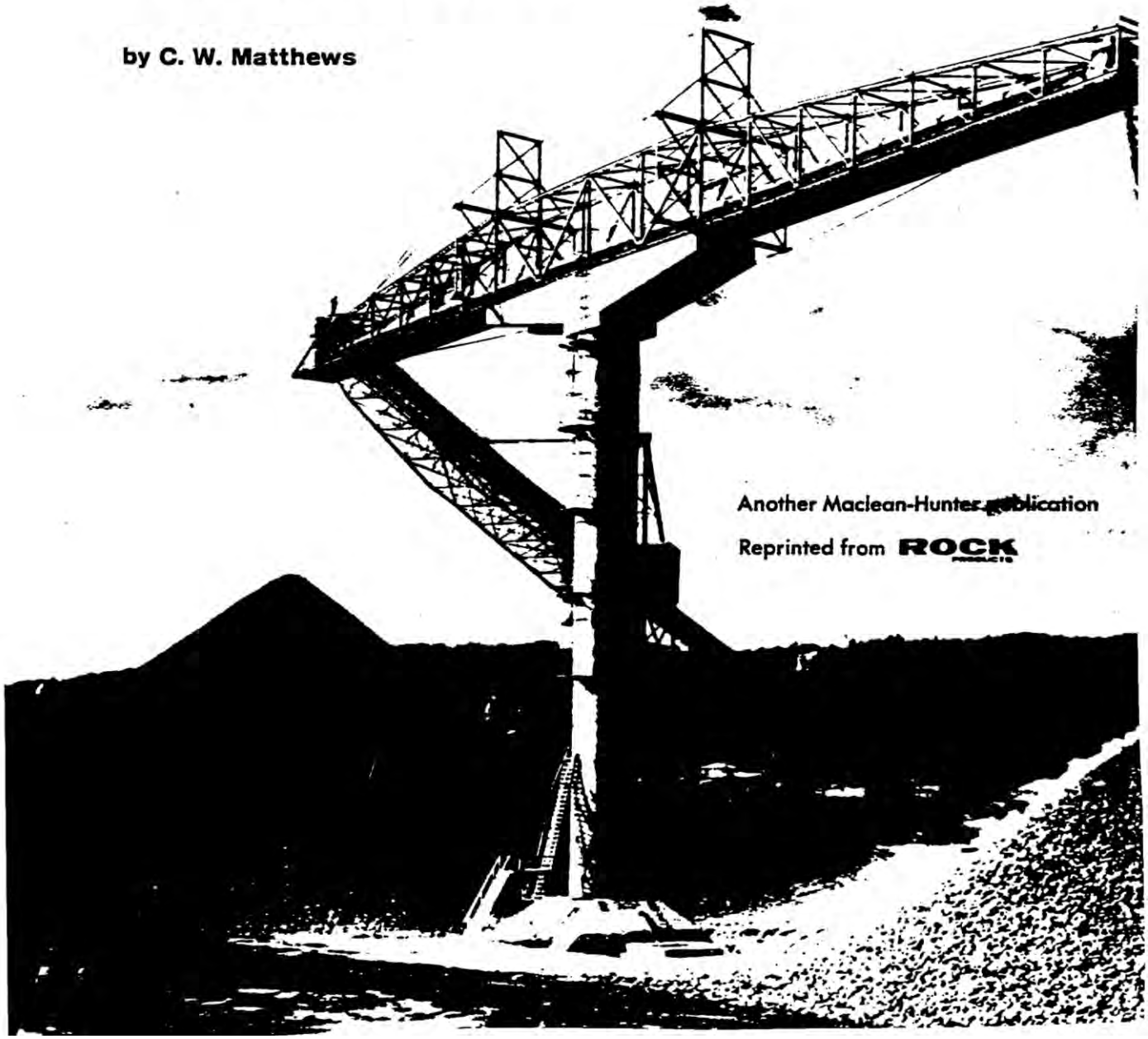
STOCKPILING OF MATERIALS

- **A comprehensive series on this vital, often misunderstood operation. A practical step-by-step guide to the storage of materials**

by C. W. Matthews



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Stockpiling of materials

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STOCKPILING OF MATERIALS, Part 1

How to choose the right type of stockpiling

- **Many factors determine what type of stockpiling is best for your operation: What is the hardness, particle strength, flowability and abrasiveness of your material? Do you need indoor or outdoor storage? What other environmental conditions should you consider?**

by C. W. Matthews*

Almost every plant processing a bulk material faces the need to provide for the storage of large quantities of this material. If storage cannot be handled quickly and efficiently, the result may be confusion and loss of time and production—all, ultimately, reflected in higher operating costs.

In some operations, this storing (or stockpiling) can be done very effectively with bins or tanks. However, in most rock products operations the materials are too coarse, or too wet, or the volume of flow too great for such containers of fixed capacity to be adequate and economical.

Then the stockpile becomes the only reasonable solution to the problem. Sometimes just spreading the material on good old Mother Earth provides a happy answer. Usually, however, this cannot be done haphazardly except in an emergency. If this is to be the regular mode of handling material, then the placing and reclaiming equipment must be carefully studied to obtain a handling system that is economical to build and reasonable in cost to maintain and operate.

Each handling operation consumes time and energy—both of which carry a fairly high price tag these days, and give promise of becoming even more costly in the days to come. In this series of articles, we shall attempt to develop a rational basis for the design of a stockpiling system, including the type of stockpile, the selection of placing and reclaiming equipment, and many other factors. We shall not restrict our attention to any one industry, but shall attempt to cover as many as time and space will permit. Perhaps in this way, a successful solution to bulk material handling in one industry may, with modification, be applied in another industry.

Purposes of stockpiling

The term stockpiling as used in this article refers specifically to the storage of bulk materials in piles of various types on the ground, or in bins that are not elevated. Let us review the purposes served by stockpiles:

1. To provide an adequate reserve of raw materials for a process plant, and to make possible a rate of production different from the source of supply;

2. To provide an adequate reserve of fuel for operation of a power plant.

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Author's note: A special word of thanks is extended to C. M. Schloss Jr., of Link-Belt Co. and Frank Bernard of Barber-Greene for their interest, encouragement, and helpful suggestions on the preparation of this article.

as insurance against shipping delays, weather, strikes, etc.;

3. To provide a sufficient storage capacity at different points in a process, in order to damp out surges of material.

4. To provide a sufficient storage capacity for the finished product, so that market demands can be satisfied promptly and economically;

5. To permit the blending of various grades, sizes, or types of material.

In addition to these major purposes, there are many special applications, such as temporary stockpiles for dewatering a product, "cooling" tanks for lowering the temperature of aggregate used in mass pours, etc.

It is interesting to note that the use of mobile storage units appears to be on the increase, particularly for handling materials that may not be exposed to the weather without loss of value.

Cement is delivered in portable units to the contractor jobsite batching plant. As the containers are emptied, they are replaced by full ones. Large users with docking facilities receive cement by the barge-load in a similar manner.

Drilling mud is warehoused in portable tank units, close to scene of intermittent operation for which permanent facilities cannot be justified.

The first step in the rational design of a stockpile should be the proper classification and the careful description of the physical and chemical properties of the material. Attention must also be given to the environmental factors to which the stockpiled material will be exposed.

To provide an orderly approach to the problem, Table I—design data form—has been prepared. Note that it covers the properties and factors mentioned, but that the properties are viewed from the standpoint of how they influence the choice of equipment, and how their response to the environment may or may not require the protection of a permanent building. Since it is extremely difficult to provide exact quantitative values to many of these properties, a qualitative rating scale has been established.

Note your rating for a given item by making a check in the box that you consider most descriptive of the material that you plan to stockpile.

Some of these items will seem to have little value in designing a stockpiling system, and it is probably true that in many cases of stockpile design, not all of these properties and factors need be considered at depth. In many cases, the designer simply follows the prevailing practice of the given industry, without too much thought as to the basic reasons that underly the practice. Since the practice has grown out of actual experience in handling the material, it required consideration at one time or another, of all these properties and the factors of environment as well. Perhaps, in understanding these properties a little better we can do a better job with the materials and avoid having to learn the "hard way" of unhappy experiences.

Let us review briefly the various items detailed on this data form and try to develop an understanding of the various properties and their significance in the design of the total stockpiling system.

Properties influencing the choice of equipment

1. Hardness—The hardness of a material will usually provide a good indication of the rate of abrasive wear that will be encountered in chutes,

Please turn page

Table I—Data required for stockpile design

Project: _____ Prepared by: _____
Location: _____ Date: _____
Name of material: _____: Chemical formula: _____
Purpose of stockpile: _____
Location in flowsheet: _____
Flow rate ( ): Placing: _____; Reclaiming: _____; Storage: _____

Properties influencing choice of equipment:

1. Hardness: ___ Mohs scale.
   Very hard ( ); Moderate ( ); Soft ( )
2. Range of sizes: Very coarse ( ); Wide range ( ); Very fine ( )
3. Particle strength: Strong ( ); Medium ( ); Weak, friable ( )
4. Degradation of material:
   Undesirable ( ); Not a factor ( ); Desirable ( )
5. Flowability: Angle repose: ___°
   High ( ); Moderate ( ); None or low ( )
   Angle drawoff ___°
6. Abrasiveness: High ( ); Moderate ( ); None or low ( )
   Particle shape: sharp, angular ( )
   smooth, rounded ( )
7. Tendency to pack: High ( ); Moderate ( ); None or low ( )
8. Material temperature: Hot ( ); Moderate ( ); Cool or low ( )
9. Contaminable: Highly ( ); Moderately ( ); None or low ( )
10. Corrosiveness: High ( ); Moderate ( ); None or low ( )
11. Combustibility: High ( ); Moderate ( ); None or low ( )
12. Toxic fumes and dust:
    Harmful amount ( ); Moderate ( ); None or low ( )
13. Floodability Highly fluid ( ); Moderate ( ); None or low ( )

Properties influencing choice of outdoor vs indoor storage:

a. Bulk density: ___ pcf:
   Light, fluffy ( ); Intermediate ( ); Heavy, dense ( )
b. Specific gravity: ___ Low ( ); Intermediate ( ); High ( )
c. Porosity of particles High ( ); Medium ( ); None or low ( )
d. Moisture content: ___% by wt.
   Critical ( ); Little control ( ); None req'd ( )
e. Soluble in water: Highly ( ); Moderately ( ); None or low ( )
f. Hygroscopicity: High ( ); Moderate ( ); None or low ( )
g. Cementing tendency: High ( ); Moderate ( ); None or low ( )
h. Contaminable: Highly ( ); Moderately ( ); None or little ( )

Environmental factors:

A. Rain and snow: Heavy ( ); Moderate ( ); Little, none ( )
B. Humidity: High ( ); Moderate ( ); Low ( )
C. Wind:
   Frequent & high velocity ( ); Moderate ( ); Seldom, & low ( )
D. Dust: High dust area ( ); Moderate ( ); Low ( )
E. Temperature: Extreme High ( ); Moderate ( ); Extreme Low ( )
   Ambient: ___°F max; ___°F min.
F. Feed to stockpile is received from: _____
G. Reclaimed material is delivered to: _____

Recommendations:

I. Place stockpile outdoors ( ); indoors ( ); provide protection ( )
II. Placing material: USE _____
III. Reclaiming material: USE _____
IV. Time in storage: _____

STOCKPILING OF MATERIALS

continued . . .

gates, and other items of equipment. This can be a factor in the case of equipment such as wheeled scrapers and loaders that are required to operate on the surface of the piled material. There is no good way to correlate hardness with wear rates, but the use of the Mohs scale of hardness does permit a description of the relative hardness.

2. Range of sizes—This property will provide an indication of the degree of segregation that may be encountered in building the stockpile. A wide range of particle sizes will usually require greater handling care in order to control the amount of segregation that occurs. If segregation cannot be prevented, then corrective measures must be introduced into the reclaiming step. It is good practice to obtain a sieve analysis of the material as well as any specification that must be met by the material after reclaiming. It should be noted that the size and percentage of lumps often determine the size of equipment and feed openings, regardless of the capacity requirements.

In his Handbook of Mineral Dressing, Taggert suggests that if size segregation must be avoided, material going into the stockpile should not have a size ratio greater than 2:1.

3. Particle strength—The degree of strength possessed by the particle can be a key factor in the selection of the handling methods. Material that is highly resistant to crushing will permit a wider choice of equipment. Material that is readily broken down into smaller pieces will require greater handling care and the size of the stockpile may be severely restricted if excessive breakdown of particles must be avoided. Also, careful attention must be given to the number and height of all transfer points. The use of equipment that operates on the surface of the pile should be carefully studied and may not be advisable in some cases.

4. Flowability—The ease with

Table II—Equipment recommendations related to properties of stockpiled materials

Properties of material to be stockpiled		Placing			Reclaiming			
Property	Degree	Conveyors—Over stockpile	Buckets—Over stockpile	Surface Equipment On stockpile	Conveyors—Under stockpile	Buckets—Over stockpile	Surface equipment On stockpile	Notes
Hardness	Very hard	OK	OK *	OK *	OK *	OK *	OK *	*Check wear rate
	Moderately	OK	OK	OK	OK	OK	OK	
1	Soft	OK	OK	NG+	OK	OK	NG+	+Check 3, 4, 7
Range of sizes	Very coarse	OK *	OK	OK	OK	OK	OK *	*Check maximum size
	Wide range	OK+	OK	OK	OK+	OK	OK+	+Check segregation
2	Very fine	OK	OK	OK *	OK	OK	OK *	*Check tire size
Particle strength	Strong	OK	OK	OK	OK	OK	OK	
	Medium	OK	OK	OK	OK	OK	OK	
3	Weak- Friable	OK	OK	NG+	OK	OK	NG+	+Check 4, 7
Degradation of material	Undesirable	OK	OK	NG	OK	OK	NG	
	Not a factor	OK	OK	OK	OK	OK	OK	
4	Desirable?	OK	OK	OK	OK	OK	OK	
Flowability	High	OK	OK	NG *	OK	OK	NG *	*Check tire size—flotation track
	Moderate	OK	OK	OK	OK	OK	OK	Consider special method
5	None, or low	NG ?	OK	OK	NG ?	OK	OK	?/Check angle repose
Abrasiveness	High	OK	OK+	OK+	OK+	OK+	OK+	+Check wear rate
	Moderate	OK	OK	OK	OK	OK	OK	Consider AR plate
6	None, or low	OK	OK	OK	OK	OK	OK	
Tendency to pack	High	OK	OK	NG *	OK *	OK	NG *	*Check 3, 4; Rip, scarify
	Moderate	OK	OK	OK ?	OK ?	OK	OK ?	?Check 3, 4, 5
7	None, or low	OK	OK	OK	OK	OK	OK	
Material temperature	Hot: +200° F.	OK+	OK	OK+	OK+	OK	OK+	+Use Hi Temp Rubber,
	Mod: 200 to 70	OK	OK	OK	OK	OK	OK	(and check expansion)
8	Cool: −70° F.	OK	OK	OK	OK	OK	OK	
Contaminable	Highly	OK	OK	NG	OK	OK	NG	
	Moderately	OK	OK	NG *	OK	OK	NG *	*Check limits
9	None, or little	OK	OK	OK	OK	OK	OK	
Corrosiveness	High	OK *	OK *	OK *	OK *	OK *	OK *	*Check coatings, etc.
	Moderate	OK	OK	OK	OK+	OK+	OK	+Check coatings, etc.
10	None, or low	OK	OK	OK	OK	OK	OK	
Combustible	Highly	?	?	?	?	?	?	?No data available
	Moderate	OK	OK	OK *	OK	OK	OK	*Provides compactn
11	Little or none	OK	OK	OK	OK	OK	OK	
Toxic fumes & dust	Harmful amnts	OK	OK	NG+	OK	OK	NG+	+Check safety rqmts
	Moderate	OK	OK	OK	OK	OK	OK	
12	None	OK	OK	OK	OK	OK	OK	
Floodability	Highly fluid	?	?	?	?	?	?	
	Moderate	OK	OK	OK	OK	OK	OK	
13	None or low	OK	OK	OK	OK	OK	OK	

which the material flows will greatly influence the choice of reclaim system to be employed. It should be noted that, in tunnel reclaiming, the available or "live" storage of the stockpile is a function of the angle of draw-off. This angle may be very different than the angle of repose assumed by the material as it comes to rest in the pile. The angle of repose also affects the total storage that a given stockpile can contain as well as the ground area that will be required.

Because of their importance, the value assigned to the angle of repose and the angle of draw-off should be verified by testing of the material. The angle of slide (the minimum angle at which the material will slide on a steel plate) should also be determined and the slopes of all chutes and hoppers set 2 to 5 deg steeper than these values.

In cases where two sloping plates intersect, be sure to keep the valley angle above the minimum angle of slide. This will require that the two plates be sloped even more steeply.

All free-flowing materials and many other materials may be reclaimed rather easily and economically, at all capacities, by means of gates. However, subsequent conveying systems usually necessitate the use of feeders for the regulation of flow.

For non free-flowing materials, consider the use of equipment that exerts a positive digging or displacing force of the particles to dislodge them and move them to the recovery point.

When the angle of draw-off is steep and equipment such as shovels and loaders are being used, the height of the pile should be limited as a safety precaution against "slides".

5. Abrasiveness—This property is really a composite of several different features of the material. It includes the strength, hardness, and shape of the particle. Obviously, sharp angular edges are far more abrasive than smooth rounded ones. The rate of abrasive wear will vary directly with the pressure and velocity of the particle across a surface. For this reason, it is desirable to hold the slopes of chutes and hoppers as close as possible to the angle of slide of the material. Slopes steeper than this will move more material, but the structure will experience much greater wear. The use of dead beds of the material at points of impact will help to reduce this wear, but may introduce another problem in the case of wet, sticky materials that show a tendency to build up into an immobile mass. In these cases, the use of A-R steel, A-R (abrasion-resistant) liners, alloy steels or coatings may be desirable.

The most common stockpiles are these single conical piles; however, the expense of building where covered storage is required usually makes this type impractical

6. Tendency to pack—Some loose materials have a tendency to pack and become more dense, which can create a problem for the reclaim system. Such materials usually require a feeder that has a strongly positive action. In extreme cases, a digging action such as a shovel or bucket-wheel excavator provides may be required. With such materials, it is preferable that the equipment not roll or crawl on the surface of the material.

7. Material temperature—The temperature of the material being stockpiled will greatly affect the choice of the placing equipment. High temperature materials may require special rubber belting or the use of steel belts. Surface equipment should be chosen with care, and the hazards to equipment and operator carefully considered. In such cases, less efficient but more rugged equipment may prove more satisfactory and more economical in the long run. Conveyors such as screw, oscillating or drag type should be considered.

8. Contaminability—The danger of contamination may be easily overlooked in storing rock products. Yet, wind-borne dust and debris can seriously dilute the market value of a product, result in the mis-evaluation of an ore, or carry organic materials into an aggregate.

9. Corrosiveness—The corrosive properties of a material should be carefully evaluated before selecting equipment. Often corrosion can be readily controlled by the use of protective coatings, but when abrasion is also present, the effectiveness of these coatings is greatly reduced. Each passage of abrasive material over a surface tends to expose a new area of metal to the corrosive elements. The combination of corrosion and abrasion needs investigation if the cost of maintenance for equipment and structures is to be kept at a reasonable level.

10. Combustibility—The problem of stockpiled materials burning is usually not a great concern, except in the case of fuels such as coal. With these materials, special methods of placing and protecting the stockpile must be observed. Spontaneous combustion may occur in coal stockpiles unless they are properly layered and compacted. This matter will be discussed at greater length under methods of protecting materials in stockpiles.

11. Toxic Fumes and Dust—When there is a great amount of toxic fumes and dust from the material, it is best to select placing and reclaiming equipment that can be remotely operated. Equipment that brings the operator close to the stockpile should be avoided, if possible.

12. Floodability—Very floodable materials may not be suited to stockpile storage and will require special attention to the choice of placing and reclaiming equipment.

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STOCKPILING OF MATERIALS

continued . . .

By way of summarizing this discussion, a compact form of data for the selection of equipment is included in Table II. Note that it regards placing and reclaiming equipment as belonging to two separate and distinct operations. Note, also, that these classes of equipment are subdivided into three categories:

Placing: 1. Conveyors—Over stockpile, including belt conveyors, shuttle belts, trippers, etc., as well as screw and drag conveyors.

2. Buckets—over stockpile, including dragscrapers, draglines, clamshells, cranes, etc. Bottomless drag conveyors are included in this group.

3. Surface equipment—On stockpile including loaders, dozers, wheeled scrapers, etc.

Reclaiming: 1. Conveyors—under stockpile, including belt conveyors, feeders of various types, etc.

2. Buckets—over stockpile, including dragscrapers, draglines, clamshells, cranes, bucket-wheel excavators, shovels, etc.

3. Surface equipment—On stockpile, including loaders, dozers, wheeled scrapers, etc.

By entering this tabulation at the left with the various properties of the material and reading across to the vertical column that applies, one can read out the recommendation for that class of equipment. In many cases, just one negative evaluation (N. G.=Not Good) is enough to discourage the use of that equipment. For example, if degradation is undesirable, equipment that moves on the material is N. G., and consideration should go to the other two classes.

Properties influencing choice of outdoor vs indoor storage

Let us return again to Table I and consider the items listed in the lower portion.

1. Bulk density—The bulking property of a material would appear to be affected by rain, snow, and wind. A material that is low in bulk density and is very light and fluffy will be moved readily by the wind and may become a nuisance to neighboring properties, as well as a loss of potential income for the owner. In such a case, a protective building would seem desirable. Where the looseness or lightness of the material is not too critical, some temporary form of cover may suffice.

2. Specific gravity—The specific gravity of the individual particles as well as their size will determine the extent to which wind will transport the material. Low density particles will be more susceptible to this hazard than will particles of high density. When the fineness of the particles gets below 100 mesh it is somewhat doubtful that a high gravity will prevent it from being blown away. For low and intermediate gravities, then, it appears best to move the stockpile indoors, if particle size is small.

Table III—Recommendations for indoor/outdoor storage, related to material properties, environmental factors

Material-Property		Environmental Factors														
		Rain and snow			Humidity			Wind			Dust			Temperature		
Property	Degree	Heavy	Moderate	Little, none	High	Moderate	Low	Frequent and high velocity	Moderate	Infrequent and low velocity	High dust area	Moderate dust area	Low dust area	Dry, arid area high temperatures	Moderate	Extremely low temperatures
Bulk density a	Light, fluffy	IN	IN	IN	—	—	—	IN	IN	IN	—	—	—	—	—	—
	Intermediate	OUT	OUT	OUT	—	—	—	IN	OUT	OUT	—	—	—	—	—	—
	Heavy, dense	OUT	OUT	OUT	—	—	—	IN	OUT	OUT	—	—	—	—	—	—
Specific gravity b	Low	—	—	—	—	—	—	IN	IN	OUT	—	—	—	—	—	—
	Intermediate	—	—	—	—	—	—	IN	IN	OUT	—	—	—	—	—	—
	High	—	—	—	—	—	—	OUT	OUT	OUT	—	—	—	—	—	—
Porosity c	High	IN	IN	OUT	—	—	—	—	—	—	—	—	—	—	—	—
	Medium	IN	IN	OUT	—	—	—	—	—	—	—	—	—	—	—	—
	Low, or none	OUT	OUT	OUT	—	—	—	—	—	—	—	—	—	—	—	—
Moisture content d	Requires control	IN	IN	IN	IN	IN	IN	IN	IN	OUT	IN	IN	OUT	IN	IN	IN
	Little control	IN	IN	OUT	IN	IN	OUT	IN	OUT	OUT	IN	OUT	OUT	IN	OUT	IN
	None	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
Soluble in water e	Highly	IN	IN	IN	IN	IN	OUT	—	—	—	—	—	—	—	—	—
	Moderately	IN	IN	IN	IN	OUT	OUT	—	—	—	—	—	—	—	—	—
	None	OUT	OUT	OUT	OUT	OUT	OUT	—	—	—	—	—	—	—	—	—
Hygroscopity f	High	IN	IN	IN	IN	IN	IN	—	—	—	—	—	—	—	—	—
	Moderate	IN	IN	OUT	IN	IN	OUT	—	—	—	—	—	—	—	—	—
	None	IN	OUT	OUT	IN	OUT	OUT	—	—	—	—	—	—	—	—	—
Cementing tendency g	High	IN	IN	IN	IN	IN	IN	—	—	—	—	—	—	—	—	—
	Moderate	IN	IN	OUT	IN	IN	OUT	—	—	—	—	—	—	—	—	—
	None	OUT	OUT	OUT	OUT	OUT	OUT	—	—	—	—	—	—	—	—	—
Contaminable h	Highly	—	—	—	—	—	—	—	—	—	IN	IN	IN	—	—	—
	Moderately	—	—	—	—	—	—	—	—	—	IN	IN	OUT	—	—	—
	None or little	—	—	—	—	—	—	—	—	—	OUT	OUT	OUT	—	—	—

3. Porosity—Porous particles will pick up and retain moisture. In cold climates, this may result in the particle freezing and being degraded. The freezing of surface moisture may bind the particles together in a solid mass, which may make reclaiming difficult, if not impossible. In such cases, indoor storage may be necessary.

4. Moisture content—Whenever the control of the moisture content of the material is a consideration, the stockpile should be protected from the wetting effect of rain and snow, or the drying effects of a hot sun, high ambient air temperatures, and wind. In areas subject to blowing dust, protection should be provided to avoid the "drying" effect of the dust fines.

5. Soluble in water—When materials that are soluble in water must be stockpiled, it is obviously desirable to place them under cover. When the amount of rainfall is slight, temporary cover may be adequate. The effect of humid conditions on such material should be studied.

6. Cementing tendency—This property is closely related to moisture absorption tendencies and solubility and should require a similar amount of protection. This cementing tendency can also effect the choice of reclaim equipment. See also "Tendency to Pack."

7. Contaminable—The degree to which a material can be diluted or spoiled by dust along with its subsequent loss of market value is a good economic measure of the value that can be placed on a protective building. This same property will affect the choice of equipment. See Item 9, under the preceding discussion.

Environmental factors

In the design of a stockpiling system, there must be a matching of the physical and chemical properties of the material with the various factors of environment, such as rain, snow, humidity, wind, dust and temperature. We have discussed the various material properties, let us turn our attention to the environment and its influence.

1. Rain and snow—The amount of rain and snow can be the determining factor in establishing the need for a permanent cover over a stockpile. Highly soluble materials definitely require a building. Absorbent materials need protection from moist air and rainfall. In light rainfall areas, this material could be protected by temporary covers. Very fine material that shows a tendency to cementing or that must be maintained within narrow limits of moisture content should be protected from rain and snow.

Rail-mounted stacker is building a windrow, while the dozer is working on a ramped stockpile. Both windrows and ramped stockpiles are suitable for large quantities of material

2. Humidity—Since the amount of moisture in the atmosphere is usually a direct function of the amount of rainfall in that area, the statements above would apply here, too. Sometimes, however, humidity can present additional problems, especially inside enclosed spaces, that are seemingly safe from the harmful effects of rain and snow. Some materials may show a greater tendency to "cake" or cement together in a mass that requires reclaim equipment with a positive digging action. Such materials are often corrosive in the presence of small amounts of moisture, and corrosion control must be considered.

3. Wind—In areas that are exposed to high winds, the possible loss of fines from an outdoor stockpile should be carefully evaluated. The nuisance value may be sufficiently high to warrant the consideration of some form of cover. The danger of dilution by dust is another factor. The drying effect of the wind should not be overlooked, if moisture content must be maintained at an optimal level.

4. Dust—If a stockpile of contaminable material must be built in a dusty area, it is desirable that it be placed within a sheltering structure. Otherwise a severe dust problem may be met by some temporary form of protection such as sprays or chemical binders, or canvas covers.

5. Temperature conditions—Low temperatures may produce frost or freezing which may damage the particles or make reclamation extremely difficult. It may be necessary to "shoot" or "rip" frozen crusts of material and make provisions for crushing the frozen lumps. High temperatures, on the other hand, may have a harmful drying effect, and some form of protection should be provided to prevent this. These environmental factors and the material properties that appear to be most closely related to them are tabulated in Table III: "Recommendations for Indoor or Outdoor Storage."

There are, however, many other factors that should be considered in designing the stockpile system. Among these:

Site Conditions—The ground surface on which the stockpile is placed should be firm, solid, and well-drained. Preferably, the site should be raised, not subject to flooding, and have a good slope away from the area of the stockpile. If the area is not well-drained, provide drainage ditches along the toe of the stockpile slopes for the full length of the storage site. If tunnels or culverts are used to reclaim from under the pile, they should be "daylighted"—that is, sloped to drain to an open surface—or else provided with a sump and drainage pump. Before the stockpile is laid down, the area should be cleared of all refuse.

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STOCKPILING OF MATERIALS

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debris, vegetation, and other organic matter.

Equipment—The equipment that delivers the material to the stockpile area can be a deciding factor in the selection of the type of stockpile and the forms of protection employed.

Time in Storage—The time that material is retained in storage should be carefully considered. Factors such as wind or erosion losses, freezing, packing, cementing, leaching or chemical deterioration are all influenced by the element of time.

Determining the size of the stockpile

When the type of placing and reclaiming equipment has been selected and the need for a protecting building established or eliminated, the designer must proceed with the final sizing of the stockpile.

If he is lucky, and the plant site has a large land area available, his task is relatively easy, and the problem is one involving geometry alone. If space is limited, however, and the stockpile of generous dimensions, he can have a real headache. In some few cases, off-site storage may provide a solution, but in most cases, the cost of transportation and re-handling are prohibitive and the scheme must be abandoned.

In some cases the land area may be adequate, but the limitations of height may restrict the capacity of the stockpile to a minimum. The height of the pile is often limited by the placing and reclaiming equipment, soil conditions, proximity to a railroad, dock, or stream, the characteristics of the material, and the need to insure a safe operation. Often, the only solution to this problem is in providing additional take-offs which will increase the available tonnage, or an altering of the delivery system to permit the building of additional piles. In some cases, it may be necessary to consider the use of mobile equipment so that the dead storage can be totally reclaimed.

The volume or tonnage of the stockpile should be based on the flow rate through the plant, and the desired period of retention, as well as the period of plant operation that must be satisfied. In all such cases, the amount of live storage in the pile should be calculated carefully.

When sizing product stockpiles, the plant production rate and the probable demands of the market should be determined as accurately as possible and a reasonable safety factor included in the size that is finally established. Blending piles are another special case.

Here, the size must be based on the balance that can be maintained between the various sources of supply and the anticipated rate of demand for plant feed. For blending stockpiles, the reclaim equipment must be designed to keep the degree of segregation at a minimum.

Classifying stockpiles

In the layout of a stockpiling system, there are many different arrangements available to the designer, and many different combinations of equipment from which to choose. Each system must be custom made to suit the characteristics of the material, the factors of environment and tonnage and space requirements.

Out of the almost infinite variety that results, a pattern can be detected, in part. If we consider the shape of the various stockpiles, we can develop a classification system that defines and describes seven different classes or types of stockpiles.

For the purpose of this series, then, we shall employ the following types:

1. Conical stockpiles
2. Windrows - parallel
3. Windrows - radial
4. Ramped stockpiles
5. Cribbed stockpiles
6. Bins - on ground
7. Mobile bins

Each of these types of stockpiles can be built—and material reclaimed—by many different types of equipment. In an effort to develop a relationship between stockpile types and the various items of equipment, (Table IV) was prepared. In subsequent articles, we shall provide further descriptions of the arrangements that these various types of stockpiles have produced and give details of the equipment used.

Table IV—Types of stockpiles and usual material handling method

Type of Stockpile	Methods of protection	Methods of placing material in stockpile	Methods of reclaiming matl from stockpile
Conical piles	Buildings Plastic covers Chemical binders	Conveyors	Conveyors Loaders & dozers Clamshells & draglines Shovels Dragscrapers
Windrows—parallel	Buildings Plastic covers Chemical binders	Conveyors Dragscraper	Conveyors Loaders & dozers Clamshells & draglines Shovels. Bucket wheel excavt Dragscrapers. Rotary reclaimers
Windrows—radial	Plastic covers Chemical binders	Conveyors Dragscrapers	Conveyors Loaders & dozers Clamshells & draglines Shovels. Bucket wheels Dragscrapers. Rotary reclaimers
Ramped stockpiles	Compaction Chemical binders Seeding	Trucks Scrapers. Tractor-drawn Dozers	Loaders & dozers Clamshells & draglines Shovels Dragscrapers
Cribbed piles	Buildings	Conveyors Trucks Loaders & dozers	Conveyors Loaders & dozers Clamshells & draglines Shovels
Bins—on ground	Buildings Self-enclosed	Conveyors	Conveyors Cranes, with clamshells
Bins, mobile R.R. Cars Barges	Self-enclosed	Conveyors Clamshells Loaders	Conveyors (track hoppers) Unloaders, bucket Clamshells Pneumatic conveyors

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Single stationary conveyors (from left to right): (A) no auxiliary—conical pile; (B) with slinger—conical pile; (C) with pivoted boom—radial windrow; (D) with reversible belt—two conical piles; (E) with shuttle belt—windrow

STOCKPILING OF MATERIALS, Part 2

Building stockpiles— the techniques & equipment

- **Conveyors, buckets and surface equipment are the major methods. Variations and combinations, each with its own advantages and disadvantages, result in versatility and a tailor-made system**

For the sake of convenience in discussing the various types of equipment, an arbitrary classification according to placing or reclaiming function will be made. This will permit a simpler and more logical presentation of the various types and combinations of equipment.

In describing the various methods used for placing materials in stockpiles, three major categories will be established:

1. Conveyor equipment that operates above the stockpile and discharges material on the stockpile. Included in this category are belt conveyors, screw conveyors, and the various types of stackers.

2. Bucket equipment that operates over the stockpile and deposits or moves material over the top surfaces of the stockpile. Equipment reaches over stockpiled material, but is not supported on material. Included in this category are dragscrapers, draglines, clamshells, bridge cranes, drag conveyors.

3. Surface equipment that operates on the stockpile and deposits or moves material over the top surfaces of the stockpile. The equipment is supported on the stockpiled material. Included in this category are loaders, dozers, wheeled scrapers (carryalls).

In actual practice, it is often necessary or desirable to employ several different combinations of equipment. Some of the more common groupings are presented in the following table, with a guide to their application.

Conveyors—above stockpiles

By far the most common method of placing materials in stockpiles is with the use of belt conveyors. Where conveyors are not used to directly place materials in stockpiles, they are often used to supply the equipment that is building the stockpile.

Let us look at several of the most commonly used arrangements of conveyors and conveyors with auxiliary units. Detailed descriptions of the various items of equipment will be given in a later section.

1. Single stationary conveyor: The single stationary conveyor is very satisfactory for delivering material to a stockpile of moderate size. This arrangement can only build a stockpile of conical shape and fixed height. If any sizable amount of storage is required, it must be gained by raising the height of the discharge pulley. To accomplish this gain in elevation requires a single long belt (or series of belts) due to limiting angles of incline on the belt. This, in turn, necessitates heavier and stronger structural elements and more massive foundations. The height of conical stockpiles seems to be limited to a practical maximum of 100 ft. Tables in the engineering section of the series will provide the means for quickly obtaining the volume and surface area of a given cone.

The discharge chute is usually cantilevered beyond the support bent so that the stockpile will not completely bury the structure. This arrangement also permits the use of auxiliary equipment as will be described later.

2. Single stationary conveyor—with slinger: When the conditions of the installation limit the designer to a single conveyor of a restricted height, a gain in storage volume can be obtained by the introduction of various

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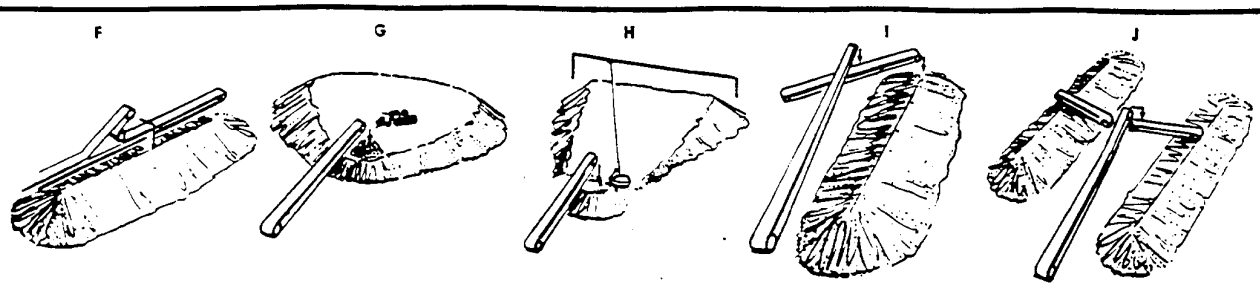


Conveyors (from left to right): (F) single stationary conveyor, with tripper—windrow; (G) single stationary conveyor, with loader, dozer, carry-all; (H) single stationary conveyor, with dragscraper—conical or windrow; (I) stacker, with single wing conveyor—windrow; (J) stacker, with double wing conveyor—two windrows

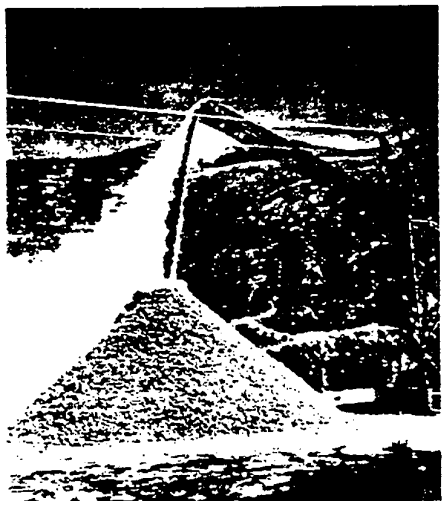
STOCKPILING OF MATERIALS

continued . . .

auxiliary units. The simplest addition that can be made is the attachment of a slinger or thrower to the discharge chute of the conveyor. This unit, which is essentially a short high-speed belt, can increase storage volume as much as ten times. The slinger is effective, however, only when segregation of sizes and densities is not a problem. In windy areas, or where fines content is relatively high and material is very dry and dusting, use of slinger may be undesirable.

3. Single stationary conveyor—with pivoted boom: Another method of increasing the storage volume attainable with a stationary conveyor is to add a horizontal belt supported on a boom truss and arranged to pivot on the centerline of the conveyor discharge. The boom conveyor can discharge its material along an arc of about 270 deg and can build a radial stockpile of considerable volume. The structure required to support a long boom can become rather elaborate, which imposes some limitations on this method.

The stationary conveyor is best for moderate-size stockpiles; if more material is required, the discharge pulley can be raised
(Courtesy, Oregon Portland Cement Co.)



4. Single stationary conveyor—with reversible belt: If only one type of material is being stockpiled, the addition of a short reversible belt under the discharge of the stationary conveyor, will permit the doubling of the storage volume.

If more than one type of material is to be stockpiled, then the length of the reversing cross-belt should be sufficient to form two free-standing cones —with no overlapping of the material in the cones.

5. Single stationary conveyor—with shuttle belt: Another arrangement can be obtained by placing the reversing belt just described on a wheeled frame, so that it may be moved back and forth on an elevated track. In this way, the two cones would expand into a long windrow or tent-shaped pile. The tonnage or volume gained by this method will vary directly with the length of the shuttle belt installed. Shuttles may be built in all belt widths and their length is limited only by drive and takeup requirements.

Shuttle belts are often used to handle lumpy, sticky, or highly abrasive materials that would be objectionable in tripper chutes. They occupy less head room than trippers and their weight is more uniformly distributed along the supporting structure; these belts have been up to 500 ft long.

6. Single stationary conveyor—with tripper: If the stationary conveyor can be extended along an elevated horizontal line, a traveling tripper may be installed. The tripper can be arranged to traverse almost the entire length of the level belt section and to discharge its material into a long tent-shaped windrow. If desired, short wing conveyors can be mounted under the tripper discharge and a wider windrow obtained. In windy areas, the long section of belt rising up to the discharge pulley should be sheltered from the wind.

This arrangement is an extremely effective one, and is widely used with many variations. Operator's platforms may be located on one side or both; trippers may be driven by conveying belt, powered by electric motors, or moved by a cable system.

7. Single stationary conveyor—with loader, dozer or carry-all: In cases where the material is to be placed in the stockpile by surface equipment (equipment that actually travels on the stockpiled material), the conveyor serves as an auxiliary unit. Its function is simply to place material within reach of the mobile equipment. The size and shape of the stockpile then become functions of the range and maneuverability of the surface units.

This arrangement is limited only by the properties of the material being stockpiled. If, for example, degradation of the material is undesirable, or the compaction produced by the equipment causes packing, equipment that reaches over the stockpile may be required. See Section I for a further discussion of material properties as they influence the choice of equipment.

8. Single stationary conveyor—with dragscraper: When material properties prevent the use of equipment that operates on the surface of the stockpile, a unit such as the dragscraper should be considered. This flexible unit can be arranged to move material over a considerable area. If sufficient space is available, such a combination can provide an economical solution to the problem of ma-

terial handling. Usually, the conveyor is used to deposit the incoming material in a small "cushion" pile in front of the headpost of the dragscraper machine. The cable-operated bucket then moves the material over the storage area and places it in conical piles or windrows, either parallel or radial.

9. Stacker—single wing conveyor: The stacker usually consists of a cantilevered boom mounted on a wheeled carriage and arranged to travel along a straight or curved path. Units are also available with crawler tread mountings.

Stackers can be designed to produce tent-shaped windrows along a straight line several hundred feet long, or along the arc of a circle up to about 270 deg in central angle. Most generally, stackers receive the material that they handle from a conveyor-tripper unit.

The single-wing stacker has a boom located on one side of its tower structure, usually fixed at right angles to the stacker's line of travel, but sometimes hinged on a horizontal axis so that the height of discharge can be adjusted. This permits the distance that material must fall into the pile to be maintained at a minimum, thus reducing the amount of degradation that occurs and lessening the amount of dusting and wind segregation that can occur.

10. Stacker—double wing conveyor: The double-wing stacker is similar to the single-wing unit, except that it can discharge to either side of its line of travel. In some cases, this is accomplished by means of a single reversible belt conveyor, in other, two separate conveyors are employed. The latter arrangement has the advantage of using two independently hinged booms so that two stockpiles of maximum height can be built on storage area.

11. Stacker, radial—no auxiliary units: The radial stacker is usually a single, inclined conveyor with a pivot at the tail end, on the centerline of the loading point. The conveyor structure is supported near the midpoint of its length by a tower or bent which is mounted on a wheeled carriage. This wheeled support is arranged to travel along a curved path and can describe an arc up to 270 deg in central angle. Units are available with rubber tires, flanged wheels, or crawler tracks. In most cases, the carriage is self-propelled.

12. Stacker, radial—with slinger or thrower: When additional storage is required in a radial stacker installation, the slinger or thrower provides an economical solution. Unit suffices when segregation, degradations, and dusting are not considerations.

13. Stacker—radial boom side conveyor: An interesting variation of the single-wing stacker described above, is one in which the boom is arranged to pivot about a vertical axis for 90 deg of arc (more or less), at the same time that the stacker moves along its main line of travel. A flat-topped windrow of greater storage volume can then be built. This arrangement also permits the addition of a reclaiming device such as a bucket wheel at the end of the boom.

14. Stacker—traveling radial boom: By modifying the unit just described so that the boom can pivot through 180 deg of arc (90 deg on either side of the line of travel) a stockpile of enormous volume can be produced rather economically. When this unit is wheel-mounted, the track is usually withdrawn as the stockpile grows. When mounted on crawler tread, this unit allows maximum movement.

15. Bridge conveyor: In many cases, process or blending requirements call for material to be placed in a stockpile in shallow, uniform layers. The bridge conveyor mounted on a trussed

Clamshells, working over the stockpile, have the advantages of a long reach, dumping height and dumping accuracy, and can build highes piles than a dragline or shovel

structure and arranged to travel the length of the stockpile, while a tripper travels the width of the pile, can readily meet this requirement.

In many cases, the bridge is equipped with a trolley mounted on the top of the trusses and equipped with a clamshell to reclaim material from the stockpile. The clamshell drops its load into a hopper located above the bridge conveyor. By reversing the direction of belt travel, material can be moved over the same units that delivered it to storage.

In other cases, a dragscraper or track cable machine is used for reclaiming material from stockpiles.

Buckets—over stockpiles

When the properties of the material being stored do not permit the use of equipment that travels on the stockpile, or when the rate of material flow is relatively low, careful consid-

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Conveyors (from left to right): (K) radial stacker, no auxiliary—radial windrow; (L) radial stacker, with slinger or thrower—radial windrow; (M) stacker, with radial boom—windrow; (N) stacker, with traveling radial boom—windrow; (O) bridge conveyor, with tripper—windrow

For greater storage capacity, a dozer working on conveyor discharge can build a ramped stockpile. Ramp should be kept to a reasonable grade: about 20 percent
(Courtesy, International Harvester Co.)

STOCKPILING OF MATERIALS

continued . . .

eration should be given to units of equipment that reach over the stockpile. Units of this type include dragscrapers, dragline, clamshells, bridge cranes, and drag conveyors.

1. Dragscrapers: The use of dragscrapers for handling materials into (and out of) storage is well established. Usually, this machine is suitable for moving relatively small volumes of material over rather large areas. The dragscraper consists of a cable-operated bottomless scraper bucket controlled by a drum hoist, powered by an electric motor or an internal-combustion engine. The bucket rides on a flow of the material which it is moving. When pulled forward the bucket loads, when pulled backwards, it empties, anywhere in the storage area within the radius of its operating cables. This equipment can give excellent service under many conditions: where material is wet, damp, abrasive, or of high temperature.

2. Draglines: These units, either wheel or crawler-mounted, are usually employed for excavating materials at ground level or below. The stockpiles built by this machine are usually short-term storage or surge piles. The height of the pile will obviously be limited by the length of the boom. When placing material into conical piles or windrows, the maximum height of pile will be approximately 50 percent of the boom length. This limitation results from the angle of repose of the material and necessary clearance allowances for the unit and its rigging.

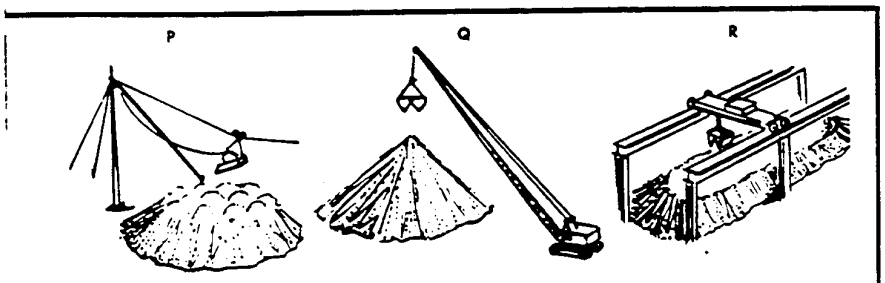
3. Clamshells: Clamshells are effective in placing materials into stockpiles because of their reach, dumping height, and dumping accuracy. The clamshell can pick up material that is above or below the level of the machine itself and place the material at a higher level than is possible with a dragline or shovel.

4. Bridge cranes: Bridge cranes with clamshell buckets are sometimes used for placing materials into stockpiles. Usually their use is restricted to storing bulk materials within buildings or partially enclosed structures.

The crane runway structure can be readily incorporated into the structural frame of a building, making the bridge crane a reasonable choice for the indoor handling of bulk materials.

5. Drag conveyors: The units considered here are of the bottomless variety, in which the surface of the stockpile provides the bed on which the incoming material is moved. Drag conveyors with bottom plates are suitable for many of the applications described for belt conveyors. The drag conveyor is suitable for handling materials that are damp, sticky, wet, or have a high temperature.

6. Shovels: The shovel is primarily a digging apparatus and is not designed for stockpiling. This application is only incidental to its digging function. Usually its limited boom length and dipper stick do not allow for the development of any considerable volume of storage.



Buckets over stockpile (from l. to r.): (P) dragscraper—conical pile or windrow; (Q) dragline, clamshell or shovel—conical pile or windrow; (R) bridge crane—windrow

Surface equipment—on stockpiles

1. Loaders, dozers: The use of these units is usually restricted to the building of ramped stockpiles, in which the material is spread over the ground. Succeeding loads are placed on top of previously placed materials, and gradually a depth of material is accumulated. Gradually, a sloped surface or ramp is developed from which the machine can dump the material on the existing slopes. It is desirable to keep the ramp at a reasonable grade—say 20 percent—so that the speed of the units will not be reduced too greatly. Rubbertired machines will produce a more compact stockpile than crawler type machines, because of the greater unit pressure that their wheels exert.

2. Wheeled scrapers (carry-alls): Where large volumes of stockpiles are being built that occupy very large areas, the use of the wheeled scraper should be investigated. This unit will operate over a large radius and will provide the required compaction for materials such as coal. In addition, the unit will serve for reclamation of the material as desired.

3. Trucks: Trucks are often used for placing materials directly onto stockpiles. Usually this application is limited to cases where small lots of material are being delivered from several sources, and the size of the stockpile is small. Stockpiles built by this method are usually reclaimed by surface equipment such as loaders and dozers.

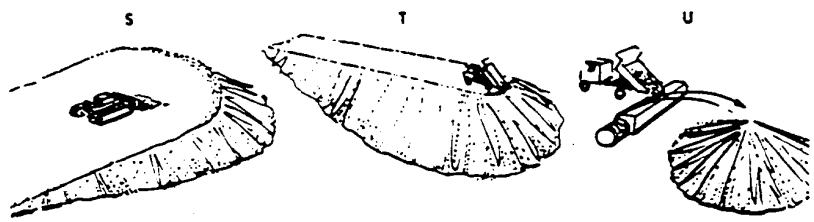
4. Trucks—with Truck Dump Piler: In cases where trucks cannot be operated on the stockpiled material, or where increased storage volume is desired, a new device is available that seems to offer possibilities. The portable Truck Dump Piler for bulk materials, recently developed by Stephens-Adamson Mfg. Co., locates directly under a dump truck at ground level and is easily towed from place to place. It will fill any storage area

outside or inside, throwing bulk granular material in a steady, compact stream for distances up to 65 ft; and will pile material to a height of up to 40 ft. The angle of discharge of the unit may be anywhere from horizontal to vertical. The unique centrifugal thrower action of the machine does not require material fall, but operates with material fed through a side inlet from the hopper.

The standard unit will unload a 5-ton truck of 75 pcf material in one minute. Smaller units will discharge 90 tph into 20-ft high stockpiles. The use of this unit must be limited however, to materials that are not harmed by segregation, degradation, or where wind and dusting are not problems.

In the preceding discussion, we have attempted to illustrate a few of the major units of equipment and the various combinations that are often employed in stockpiling.

In a further effort to define the usefulness of these various units, Table V has been assembled.



Surface equipment on stockpile (from l. to r.): (S) loaders, dozers—ramped storage; (T) trucks—ramped storage; (U) truck, truck dump piler—conical pile or windrow

The column headed Equivalent Pile—CY, attempts to provide a rough comparison of the stockpiling potential of nearly equivalent units of equipment. The following conditions seemed to obtain a common denominator for the majority of "conveyor" applications:

The equivalent stockpile is 30 ft high, with angle of repose at 37 deg, stacker booms are 100 ft long, windrows are approx. 300 ft long to approximate the length of arc of a radial windrow built on a 100-ft radius.

The column headed Placing Rate—CYH attempts to provide the approximate limits that usually apply to standard units of equipment. These values cannot be exact because of the many variables that must be considered. They should, however, provide a rough basis for comparison, and be of value in eliminating a method on the basis of capacity requirements.

Table V—Methods of placing materials in stockpiles

		Primary equipment	Auxiliary equipment	Types of stockpiles	Equivalent pile—cy	Placing rate—cyh
A. Conveyors—above stockpile	1	Conveyor	None	Conical Pile	1,850	150- 4,450
	2	Conveyor	Slinger	Conical Pile	9,260	80 to 330
	3	Conveyor	Pivoted Boom	Radial Windrow	15,925	150 to 750
	4	Conveyor	Reversible Belt	2— Conical Piles	3,700	150 to 750
	5	Conveyor	Shuttle Belt	Windrow	6,300	150- 1,500
	6	Conveyor	Tripper	Windrow	15,200	150- 1,500
	7	Conveyor	Loader, Dozer, Wheeled scraper	Ramped Stockpile		150- 2,200
	8	Conveyor	Dragscraper	Conical Pile or Windrow		150 to 750
	9	Stacker—	Single wing	Windrow	15,200	150 to 750
	10	Stacker—	Double wing	Windrow	30,400	150- 1,500
	11	Stacker—radial	None	Windrow— radial	15,925	150 to 750
	12	Stacker—radial	Slinger	Windrow— radial	80,000	80 to 330
	13	Stacker	Radial boom	Windrow	33,700	150 to 600
	14	Stacker—radial	Traveling radial	Windrow	158,000	150 to 600
	15	Bridge conveyor	Tripper	Windrow		
B. Buckets—over stockpile	1	Dragscraper	None	Conical Pile or Windrow	15,200	10 to 1,000
	2	Dragline	None	Conical Pile or Windrow		70 to 350
	3	Clamshell	None	Conical Pile or Windrow		60 to 300
	4	Bridge Crane	None	Windrow		
	5	Drag Conveyor	None	Conical Pile	1,850	
	6	Shovel	None	Conical Pile		90 to 510
C. Surface equipment—on stockpile	1	Loaders, Dozers	None	Ramped Storage		
	2	Wheeled Scrapers	None	Ramped Storage		
	3	Trucks	None	Ramped Storage		
	4	Trucks	Truck Dump Piler	Conical Pile or Radial windrow		70 to 300

Note: To convert cubic yards per hour to tons per hour—multiply value in cu. yds. by 1.35 (For material weighing 100 p.c.f.)

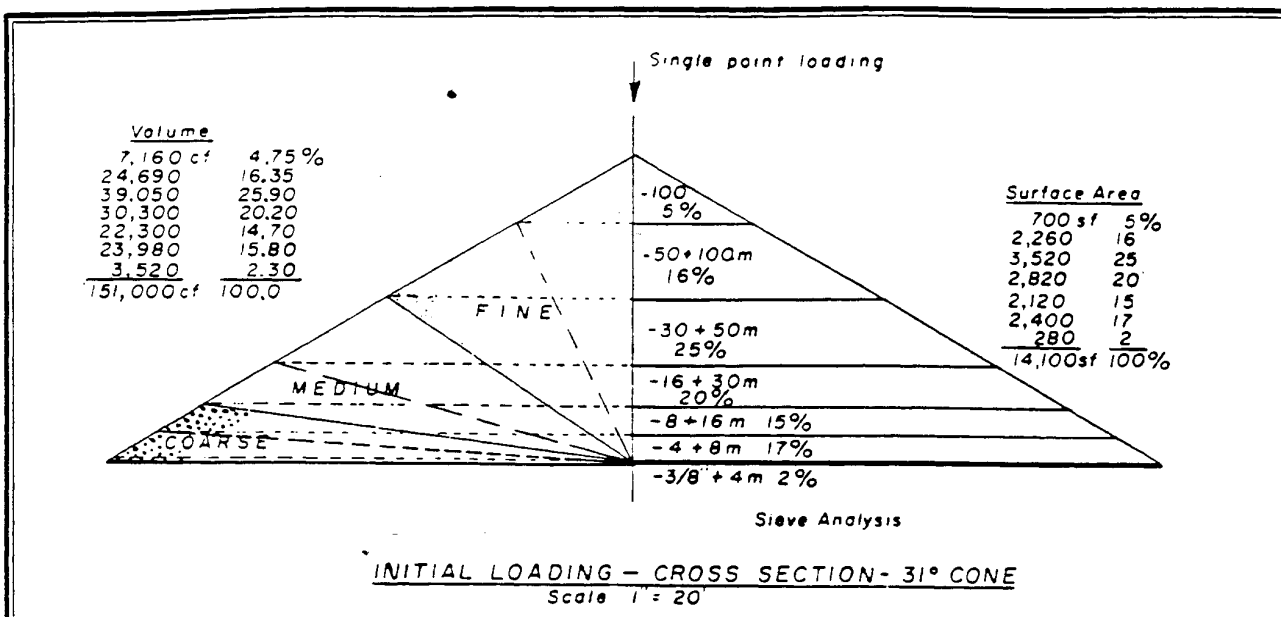


Fig. 1—Theoretical pattern of particle segregation, by sizes

STOCKPILING OF MATERIALS, Part 3

Segregation, degradation, dusting: How to solve these problems

- **Big differences in particle size and density mean big stockpiling problems. Author tells how to offset the force of gravity on your stockpile and end material breakdown and dusting of fines**

Whenever bulk materials are placed in stockpiles, many problems can be anticipated, regardless of the materials being handled or local conditions that prevail. In the earlier discussion of material properties and their relation to the equipment that is used, we covered many of these problems briefly. Let us now consider them at some length and describe in detail some of the corrective and preventive measures available to the plant designer and operator.

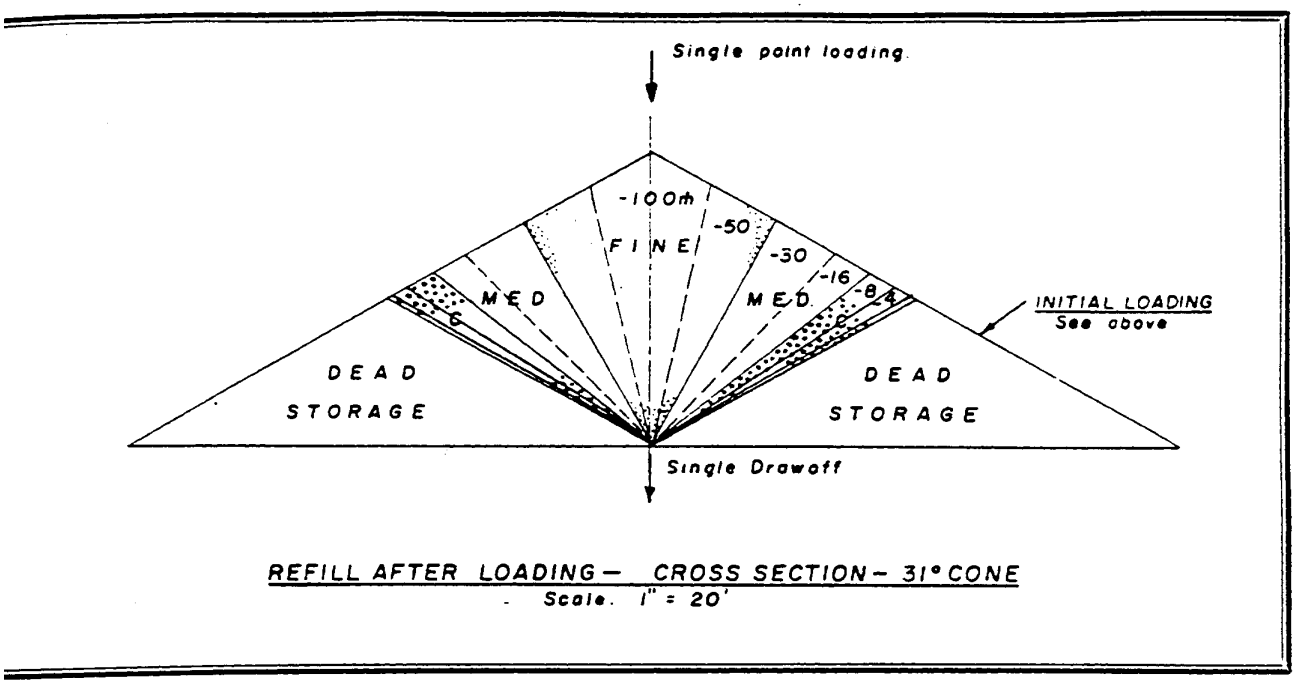
1. Segregation of material by size or density: We have segregation to contend with whenever we handle materials that cover a wide range of particle sizes or differ greatly in density. This segregation can occur as a result of the action of wind, water, gravity, or the use of equipment such as slingers.

Wind blowing across a stream of falling material may produce a classification of fine from coarse particles, or light from heavy densities. The fines (or light particles) will be carried horizontally for some distance, while the coarse (or heavy particles) continue their vertical travel into the pile. Depending on the size and specific gravity, this windblown material may end its travel at the far edge of the pile (as shown in Fig. 1), or may be blown into the next county.

To counter this action of the wind, rock ladders, telescoping chutes, or lowering wells are effective. Perforated pipe may be used effectively with the finer sizes of material. The use of hinged boom conveyors that lower the discharge pulley close to the top of the pile minimizes free fall distance of material and reduces dusting.

The segregation caused by gravity is, by far, the most common and the greatest source of difficulty to the stockpilers. Anyone who has carefully examined a stockpile is aware that the coarse material usually ends up at the lower end or edges of the pile, while the fine material occupies the upper central portions.

Fig. 1 illustrates how this segregation separates the material. Note in the upper portion how material falling on the tip of the cone tends to roll down the sloping surface. The finer particles, having little mass, tend to



stop almost in the place where they first land. The coarser particles, on the other hand, tend to travel farther down the slope, since their greater weight and relatively larger size permits a rolling motion to develop. When material is drawn from this pile, it will have a widely-varying size distribution, and re-blending of these sizes to meet specification grades can be troublesome and costly.

It may be of interest to note that this "theoretical" model was constructed by distributing the various sizes in the pile on the basis of their sieve analysis. Each size fraction was spread over the surface of the pile on an area equal to its fraction of the whole. For example, the material assumed contained 5 percent minus 100 mesh particles. Therefore, it was assumed that the minus 100 mesh material would occupy the upper 5 percent of the cone's surface. The remaining sizes were distributed over the cone's surface on this same basis. After the total amount was thus distributed, the volumes occupied by each size group were calculated. It was surprising to note the correlation between the size distribution, the area, and the volume distributions.

One obvious way to avoid this segregation would be to build the pile or windrow in shallow layers, using equipment that is capable of covering the entire area. For example, when placing material with a clamshell, the large pile may be built up by the accumulation of many small heaps of material. This suggestion is illustrated in Fig. 2.

Since it is not always feasible to prevent segregation, there is a need to consider some corrective measures that may be taken. Assuming a conical pile with a single center draw-point, a theoretical model was prepared to show the probable distribution of sizes in the live-storage portion of the cone.

Note in the lower portion of Fig. 2 how the zones of material are arranged. If this pile were "drawn-down" it would appear that a sequential tapping of the various sizes would occur. When first flowing, there would be primarily fines, later followed by the medium sizes, and finally the coarse particles.

To verify these assumptions, a small test model was constructed and the actual material placed and reclaimed in the various ways that were being considered for the stockpile handling system. While the actual distribution does not exactly match the assumed, it does show an encouraging degree of similarity—enough to suggest that this method of developing a theoretical model can provide some guidelines for the designer.

As a result of these studies, two possible systems for correcting segregation were developed. These are illustrated in Fig. 3.

The top view illustrates a method using four conical piles, each having a single, centrally-located draw-off point. Note that by filling these cones and drawing them off in a definite sequence, the various size zones are tapped in approximately the desired proportions. The key to this idea lies in never tapping a pile until it is completely filled, and never filling a pile until it has been completely drawn-off. If this simple rule is violated, the result will be total confusion of sizes in the pile, and a loss of the re-blending process. One difficulty of this plan was the arrangement of the placing equipment in the existing plant. For a new plant, a shuttle conveyor, tripper or screw conveyor would have worked very well.

The lower view illustrates the use of multiple draw-points in a single cone. Note the theoretical distribution of particle sizes in the cone, and the way in which the various size fractions can be tapped and blended. By regulating the rate of discharge from the various draw-points, a good re-blending of sizes can be obtained.

Again, this last concept was tested in the small-scale model, and a rea-

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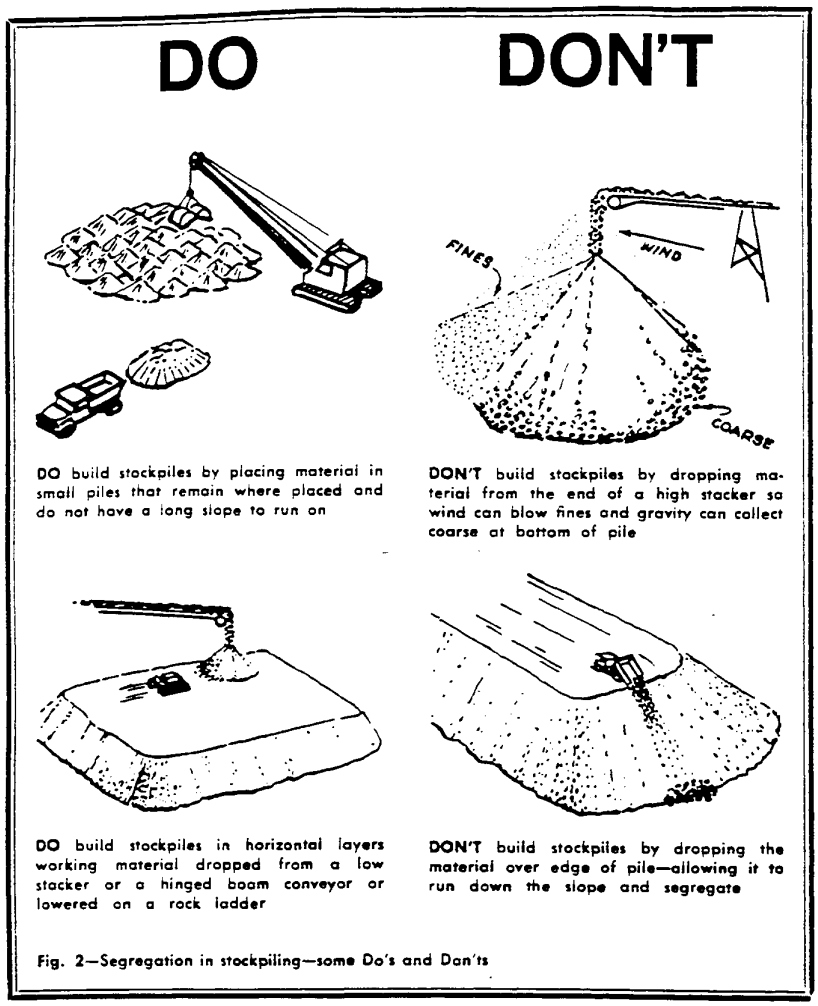


Fig. 2—Segregation in stockpiling—some Do's and Don'ts

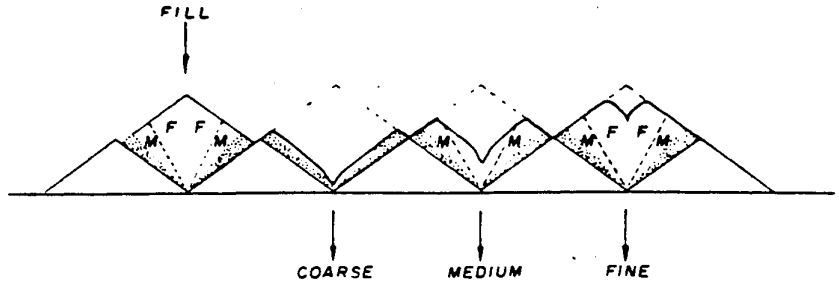
STOCKPILING OF MATERIALS

continued. . .

sonably good confirmation obtained for the theoretical model. Note how the coarse sizes are to be found in the outermost pockets, while the fine sizes have remained in the central zone. It is of interest to mention that a reclaim system was later built under a stockpile of this material, and that operating experience to date has further verified the assumptions and test results.

2. Degradation of material: Wherever there is bulk handling of materials with attendant falling, sliding, or abrading of particles on each other, there will be some breaking down of the coarser into fines. The increase of fines may be detrimental because it disrupts the size distribution of the product, making it less desirable, or even unusable. Sometimes the production of excessive fines may make the material more susceptible to "dusting" or windage losses. These problems may result in some economic losses, but more often their greatest threat may be as a hazard to health or the creation of a community nuisance.

Degradation as a result of impact after falling may be lessened by using devices such as rock ladders. Here the free fall distance is broken up into relatively short drops. The material



MULTI - CONE ARRANGEMENT

NOTE PILES ARE TO BE DRAWN DOWN IN SEQUENCE, SO THAT A DIFFERENT SIZE FRACTION IS BEING TAPPED IN EACH PILE. FILLING IS BEGUN WHEN "LIVE" PORTION IS EMPTIED

Fig. 3—Methods of correcting for particle size segregation

falls on a dead bed of its own type of material, then slides on the sloping surface only to drop over the edge of the ladder "rung" and land on the next lower ledge. Each time, the direction of travel is reversed, so that the material starts each subsequent fall with little or no momentum available from the preceding drop. In this way, the velocity is restricted as well as the fall distance.

Degradation, as a result of equipment weight compacting the material excessively, can be avoided or lessened by the proper choice of equipment. If degradation must be avoided entirely, the use of equipment that moves on the surface of the stockpile should be avoided, and preference given to units that are suspended over or above the material. In some cases, the proper choice of surface units may alleviate the problem. Crawler treads or flotation tires may provide a relatively simple yet effective solution.

3. Dusting of material and windage losses: The presence of excessive fines, whether a result of the process or the method of placing, can be a nuisance. Dusting can be reduced by reducing the distance through which the material must fall. This lessens the time of its exposure to the action of the wind and reduces the impact with which it hits the pile. The use of rock ladders has been described previously. Another approach is through the use of a hinged boom which will bring the discharge pulley close to the top surface of the material. As the height of the stockpile increases, the boom is raised enough to maintain the desired clearance.

Another device is the telescoping chute, which reaches in the extended position through the distance between ground and discharge point. As the pile of material grows, the chute is gradually retracted. The material is thus completely sheltered from the effects of all normal wind action.

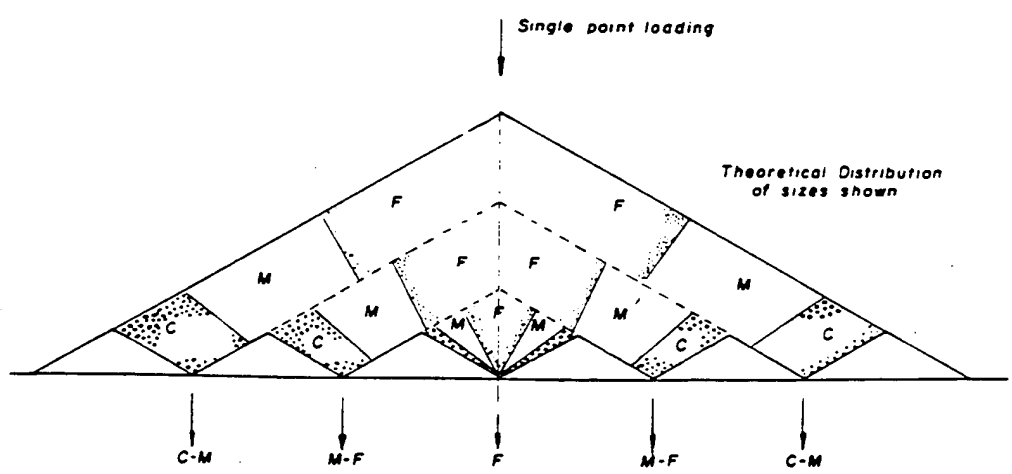
The use of "lowering wells" can also provide an effective means of wind protection. These wells are constructed of circular pipe sections arranged on a vertical centerline that coincides with that of the discharge chute. At intervals along this vertical pipe column, there are square or rectangular openings provided through which the material may flow if the pipe has been filled to the level of that particular opening.

For handling fine materials, one operator has found that a perforated steel pipe will function as a lowering well.

The use of other "mechanical" devices such as covers or protective buildings will be covered in detail in another section. These do not prevent the production of dust during the handling of the material, but they do work to reduce the effect of wind on material that is already placed in the pile.

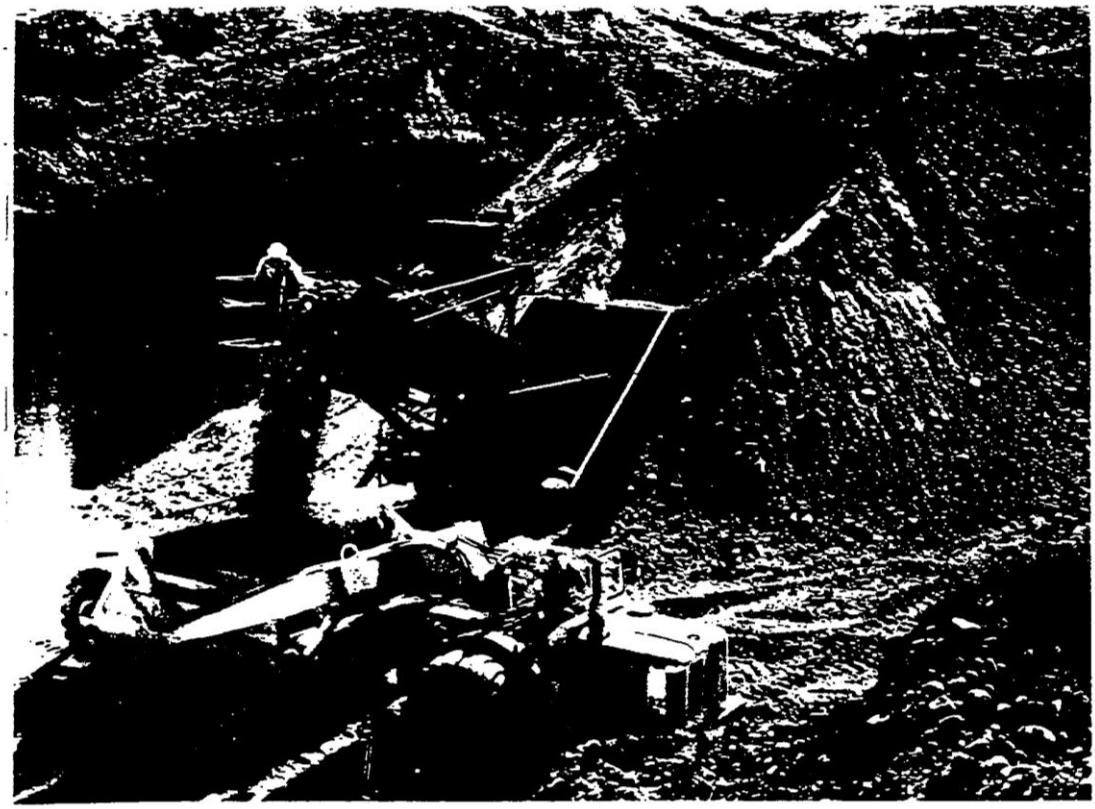
The use of chemicals to combat dust follows two different avenues of approach. In one case, the use of water in the form of fine sprays to settle the dust is simply made more effective by the addition of wetting agents, which reduce the surface tension of the water. This method provides temporary relief. Another approach calls for spraying material after it has been placed in the stockpile. In this case a chemical works to bind the fine particles to adjacent particles, thus forming a porous crust on the surface of the pile which is very resistant to wind action. Both of these chemical aids to stockpiling will be described in detail at a later time.

4. Contamination and erosion of materials in stockpiles: Naturally, the most effective method of protecting a stockpile from contamination and erosion is to place it within a permanent weathertight enclosure. Where this is not possible, the use of temporary covers or pavings may be considered. The contamination spoken of here may be dust or windblown debris, or rain falling on dried material. In each case, the problem does not result from handling methods, but is one of properly adapting to the environment. In a subsequent section, this method of control will be more fully discussed.



MULTIPLE DRAW-OFF ARRANGEMENT

NOTE DRAW-OFFS TAP DIFFERENT SIZE FRACTIONS OF PILE BY PROPER PROPORTIONING OF DRAW-OFF FLOW RATES, BLEND OF PRODUCT CAN BE CONTROLLED.



Portable conveyor under hopper feeds bowl-type scraper. Generally, gates should be used to cut off material flow, while a feeder should be used to regulate or meter the flow (Courtesy, Barber-Greene Co.)

STOCKPILING OF MATERIALS, Part 4

How to reclaim successfully

- **A wide variety of equipment and techniques can be adapted to meet any requirements. But be prepared for common reclaiming problems: bridging, packing, rat-holing, plugging and flooding**

In describing the various methods used for reclaiming materials from stockpiles, three major categories will be established:

1. Conveyor equipment that operates under the stockpile and withdraws material from below the pile. Included in this category are gates, feeders and conveyors.
2. Bucket equipment that operates over the stockpile, withdraws material from the top surfaces of the pile and is not supported on it. Included in this category are dragscrapers, draglines, clamshells, shovels, bridge cranes, rotary reclaimers, bucket-wheel excavators, and drag conveyors.
3. Surface equipment that operates on the stockpile, is supported by it, and withdraws material from the top surfaces of the pile. Included in this category, are loaders, dozers, and wheeled scrapers (carry-alls).

In actual practice it is often necessary or desirable to employ different combinations of these various types of equipment. The more commonly used groupings of equipment are presented in the following table.

Description of various methods

1. Conveyors under stockpiles—When reclaiming materials from stockpiles, the use of conveyors operating through tunnels under the stockpiles is a fairly well-established practice. The availability of economical prefabricated tunnel sections and feeders that are compact and efficient have probably helped to encourage this method.

The tunnel generally runs below grade for the length of the stockpile, and then slopes upward to a discharge point above the ground level. At intervals along the length of the tunnel, openings are cut in the roof to permit the material in the stockpile to flow into the tunnel and onto the belt conveyor. Usually, the material is funneled through a hopper and the rate of flow is controlled by means of gates, chutes (the by-guess and by-golly method) or feeders.

The arrangement of the tunnel structure and related equipment will be determined largely by the type and size of the stockpile. Details of the various tunnel sections, types of gates, chutes, and feeders will be given in a later section.

In the case of free-flowing materials, a feeder may not be required. A gate in the chute between the draw-point hopper and the transporting conveyor is necessary to shut off the flow of material. Generally, gates should be used to cut off a flow of material, while a feeder should be used to regulate or meter the flow.

The gate may be a radial gate, a clamshell gate, or a slide gate. These gates provide a fairly positive shut-off, and can be used safely with materials that tend to "flood" or flow with highly fluid characteristics.

With material that is free-flowing and that does not flood, it is possible to employ an adjustable chute—one that can be raised or lowered to vary the angle or slope and so start and stop the flow of material. Shut-off of flow is accomplished by raising the chute so that the toe of the material falls within the length of the chute.

Where any degree of control of flow volumes is desired, or the materials are not free-flowing but tend to be sluggish in their movement, then a feeder is definitely indicated.

A detailed discussion of feeders and criteria for feeder selection will be presented in a later section.

2. Equipment that operates over the stockpile—

● Dragscrapers: The use of the dragscraper for placing material has been described. Usually, all that is required to adapt this machine to reclaim operations is the addition of a sloped loading ramp to elevate material.

● Draglines: The dragline may be used successfully for reclaiming materials from stockpiles by providing a loading hopper into which the bucket may be emptied. Trucks or cars may be loaded by opening the flow control gate under the hopper. Small draglines may empty their buckets directly into the transport equipment.

● Clamshells: The clamshell is especially suited to stockpile reclaiming since it operates in a vertical digging range. Its dumping accuracy is well suited to directly loading material into trucks or railroad cars or elevated hoppers.

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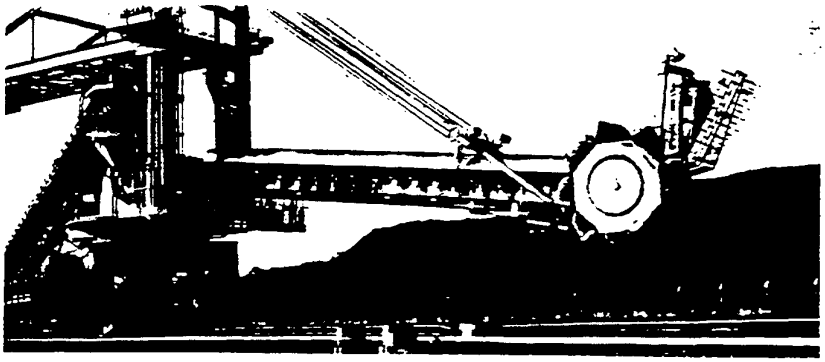
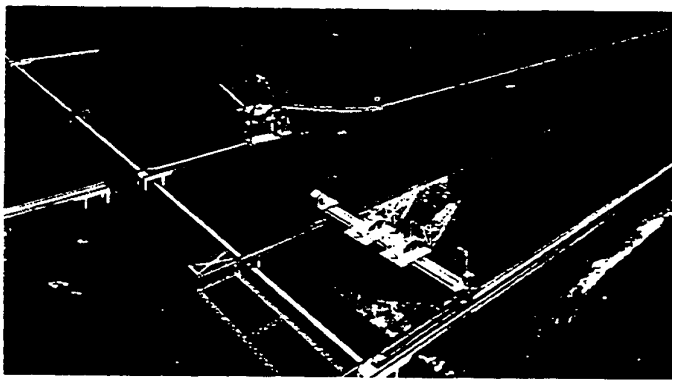


Above: 8-bucket wheel, mounted at end of 86-ft long boom, is used for reclaiming by this bucket wheel machine. Operator's cab is suspended above for maximum visibility. (Dravo Corp.)



Rotary reclaimer at work on large windrow is particularly good when a combination of blending and reclaiming is needed (Courtesy, Hewitt-Robins, Inc.)

Table VI—Methods of reclaiming materials from stockpiles

		Primary equipment	Auxiliary equipment	Materials delivered to	Reclaim rate (approximate) cu yd/hour	Reclaim rate (approximate) tons/hour*
Conveyors—under stockpile	1	Feeder	Conveyor	Process or transport	1.0 to 2.600	1.5 to 3.500
	2	Feeder-Conveyor (combined unit)	Conveyor	Process or transport	30 to 900	40 to 1.200
	3	Gates or chutes (manual control)	Conveyor	Process or transport		
Buckets—over stockpile	1	Dragscraper	Conveyor	Process or transport	10 to 1.000	15 to 1.400
	2	Dragline	Conveyor	Process or transport	70 to 350	95 to 475
	3	Clamshell	Conveyor	Process or transport	50 to 300	70 to 400
	4	Shovel	Conveyor	Process or transport	90 to 510	120 to 700
	5	Bridge crane	Conveyor	Process or transport		
	6	Rotary reclaimer	Conveyor	Process or transport	220 to 13.000	300 to 17.500
	7	Bucket wheel excavator	Conveyor	Process or transport	250 to 13.000	340 to 17.500
	8	Drag conveyor	Conveyor	Process or transport	7.5 to 35	10 to 50
	9	Bucket unloader	Conveyor	Process or transport	750 to 3.000	1.000 to 4.000
Surface equipment—on stockpile	1	Loader	Conveyor	Process or transport		
	2	Dozer	Conveyor	Process or transport		
	3	Wheeled scraper	Conveyor	Process or transport		

*Based on material weighing 100 p.c.f.

STOCKPILING OF MATERIALS

continued . . .

● Shovels: The power shovel is well suited to reclaiming material from stockpiles, especially where a strong digging action is required. The material can be readily placed in hoppers, trucks or railroad cars.

● Bridge cranes: Bridge cranes with clamshell buckets may also be used for reclaiming materials.

● Rotary reclaimers: The rotary reclaimer has been applied successfully to reclaiming materials from both parallel and radial windrows. The value of this unit lies in its ability to minimize the segregation that often accompanies reclaiming operations through the use of a unique harrow arrangement. Pickup of materials is accomplished by the rotating buckets, which discharge onto a belt conveyor. The adaptability of this unit is demonstrated by its application inside of a dome-shaped building as well as on long straight windrows.

● Bucket wheel excavators: The bucket wheel has been used for excavating, but only of late has it been applied to reclaiming of material from stockpiles. An interesting application is seen in the stacker-bucket wheel machine. This unit can reclaim at rates up to 700 tph although present plant requirements permit it to loaf along at 250 tph. The stacking capacity of this unit is 1,500 tph.

● Drag conveyors: The drag conveyor has been used successfully for material reclaiming. In the Messiter system, a harrow rakes material off the face of the pile, while a drag conveyor moves the material laterally from the toe of the pile and delivers it to a belt conveyor parallel to the centerline of the stockpile.

In the "Dodge System", drag conveyors with adjustable bottoms are used to place materials in stockpiles. In the reclaim arrangement, without the bottom plates, drags are used to rake material from the toe of the slopes and into a hopper which loads a belt conveyor. Another system uses the drag to rake material down the slope of the windrow and into a hopper which loads a belt conveyor running parallel to the pile.

● Bucket unloaders: The bucket unloader might be described as a bucket elevator that has lost its casing. This unit is principally used for unloading materials from barges, rectangular bins, or other containers. It is extremely well-suited to working in close quarters and can be arranged to perform its operations automatically.

3. Surface equipment operating on stockpiles—

● Loaders: The flexibility and speed of operation of the modern loader has made it an extremely efficient unit for reclaiming materials from stockpiles, and for use in clean-up work around stockpile areas. The loader may be used to load out trucks or railroad cars directly, or by placing the material in a discharge hopper.

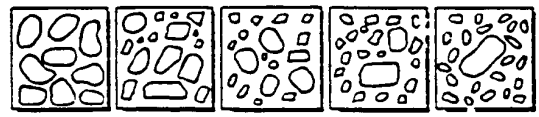
● Dozers: In some applications it is unnecessary to pick up and carry the material. When this is the case, the dozer may be used successfully to push material into a "trap" (depressed hopper) which loads a conveyor that is inclined sufficiently to load trucks or other transport units.

● Wheeled scrapers: The use of the wheeled scrapers is limited to very large stockpiles. The average sized plant cannot justify the cost of such units as these. They are successfully employed around large coal-burning power plants, where large tonnages must be handled quickly and cheaply.

In the preceding discussion we have attempted to illustrate a few of the major units of equipment and the various combinations that are often employed in the reclaiming of materials from stockpiles.

In a further effort to define the usefulness and areas of application of these various units, Table VI has been assembled.

The rate of reclaiming indicated is based on the use of standard units of equipment. Naturally, these values cannot be highly exact, however, they should provide a rough basis for comparison, and be of value in eliminating a method on the basis of approximate capacity requirements.



ORE TYPE →					
THROAT OPENING FACTOR	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	$1\frac{1}{2}$
PCT LARGER SIZE PIECES	95–100	60–80	40–60	20–30	5–10
OTHER CONDITIONS	SCREENED	MINE RUN	MINE RUN		

Chart I—Throat opening selection—To determine throat opening (1) select picture that matches type of material to be handled, and (2) read-out throat opening factor. Multiply the factor by largest dimension of the biggest piece of material. This will provide the minimum throat opening to prevent bridging

Problems encountered in reclaiming materials

1. Bridging, or arching over drawpoint opening—In some materials, the particles will pack together and form an arch over the drawpoint, which will support the material above and prevent its movement toward outlet.

One simple aid in overcoming this condition is to provide small round openings in the sides of the chutes or hoppers through which a long rod may be inserted and used to dislodge material from the arch and cause its collapse.

This problem can often be reduced by making the opening as large as possible and giving the side plates of the hopper a fairly steep slope. A slope of 60 deg with the horizontal will usually provide a surface on which material does not "hang-up." In the case of plates that meet at right angles to form a valley, be sure that the valley angle is well above the angle of slide of the material.

Vibrators, aerators, or mechanical rotating impellers are sometimes used to break down arches. However, it is best to check your material before applying these devices, for some materials just pack more under vibration, while aeration may cause fluidization and other problems. Some of these devices may not be suitable for use under stockpiles that are exposed to the weather, where rain and snow can affect the moisture content.

2. Rat-holing, glory-holing, or stove-piping over drawpoint openings —In some extreme cases the material exhibits a tendency to flow only through a central shaft, just above the drawpoint opening. When this occurs, there is little that can be done to promote flow. Pokeholes can provide some relief, but usually they are rather inadequate in coping with this problem.

Scrapers, drag conveyors, or screw conveyors are frequently used on materials with this tendency to convey material along the top of the pile to the hole. This problem can be somewhat offset by providing a large number of closely spaced openings under the stockpile.

If the tendency of the material to glory-hole is very pronounced and the measures mentioned above are of little or no avail, then serious consideration should be given to a different system of reclaiming—preferably the use of buckets or surface equipment.

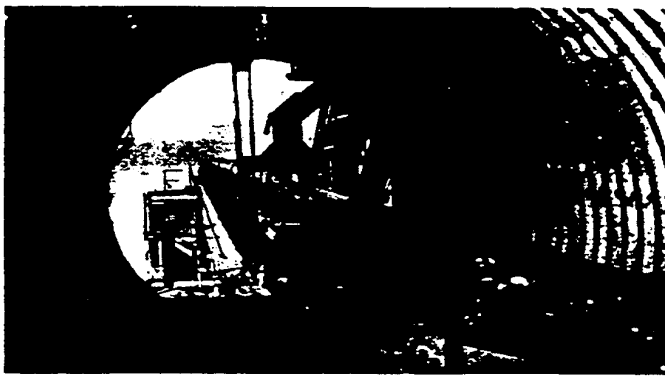
Several patented devices currently available claim to overcome the problem of rat-holing by a realignment of the forces that act upon the material. A detailed description of such units will be given in the section on equipment under the topic of hoppers. In particular, refer to the Bin-Dicator Hyperbolic Outlet (BHO), Vibra-Screw Bin Activator, and the Easy-Flo Bin Outlet.

3. Packing of materials in stockpile—This problem may be the result of many different factors. It may result from an adverse moisture content which prevents the material from flowing; freezing of the material; a cementing action between the particles; or pressure from vehicles or the weight of the material above.

In extreme cases it may be necessary to blast or rip the material in order to remove it from the stockpile. In some cases, it becomes necessary to crush the material in order to regain the particle size that is required.

When material exhibits an undesired tendency to pack, it is probably wisest not to place wheeled or crawler equipment on the stockpile, but to rely on overhead equipment for placing and on equipment with a strong digging action for reclaiming. Dragscrapers, loaders or shovels working at the edges of the pile may be satisfactory. When reclaiming this kind of material with loaders and shovels, the operator should be on the lookout for the formation of "cliffs" which may suddenly collapse and damage the equipment or harm the operator.

Above: Bridge crane with clamshell bucket works over outdoor storage pile. Dumping accuracy of clamshell makes it well suited to direct loading into trucks, railroad cars or elevated hoppers



A typical conveyor installation is this steel reclaim tunnel. Availability of economical, pre-fabricated tunnel sections has stimulated this method (Courtesy, Barber-Greene Company)

4. Plugging of drawpoint openings —Plugging of drawpoint openings as a result of the interlocking of coarse particles can be corrected by proper sizing of the opening dimensions.

As a general rule, the least dimension of the opening should be 2½ to 3 times the maximum dimension of the largest particle of material being handled.

The throat opening selection chart (Chart I) was developed for bins, but should apply to stockpile drawpoints equally as well.

In some cases, when handling sluggishly flowing material, the problem can be alleviated by improving the rate of flow through the opening. This can be accomplished by setting the slopes of the chutes and hoppers at an angle of inclination that is greater than the minimum angle of slide for the material. Allowances should be made for the effects of factors such as: rusting and roughening of the metal surfaces, both of which tend to cause the bulk material to stick and "hand-up."

The use of alloy steels or various coatings and linings should be considered for extreme conditions. The use of a low-friction lining such as Teflon may put increased capacity through a troublesome hopper. The section on abrasion will discuss some of these materials in greater detail.

5. Flooding—Flooding is the term applied to the unstable, fluid-like flow of a dry, solid material. The characteristic rush of material results from the entrainment of air in the material, as it flows through an empty or partially empty hopper; or as the result of the collapse of an arch or bridge of material in a hopper.

Care must be exercised in designing gates for the regulation and control of the flow of such materials. The selection of feeders should always be done in consultation with the equipment manufacturer.

6. Abrasion and corrosion—The abrasive and corrosive properties of a stockpiled material will have little effect on the flow characteristics of the material, but they do exert a great influence on the materials of construction that are used in the equipment.

In reclaiming materials from stockpiles, or in transferring material from one unit of equipment to another, it is customary to use hoppers and chutes fabricated from steel plate. Ordinary mild steel will usually serve this

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STOCKPILING OF MATERIALS

continued . . .

purpose very well when the hardness of the bulk material is 4 or less on the Mohs scale. Mild abrasion will be encountered when the Mohs hardness is between 5 and 7, and severe abrasion is likely for hardnesses in the range from 8 to 10.

Unfortunately, hardness alone is not a valid guide to the amount of abrasive wear that is likely to be encountered. Factors such as particle shape and weight, the angularity of the particle, sharpness of edges, rate of flow, velocity of particle, and the amount of impact—all influence rate of abrasion that is likely to be experienced.

If abrasion is encountered, it can be dealt with most readily by installing abrasion-resistant liners at the points of excessive wear. Some operators try to anticipate these before the operation is started. Others prefer to install unlined hoppers and chutes and run for a brief period; then shut down and install liners at the points that exhibit the greatest abrasion. In either case, the course of further abrasion is directed against the expendable liner and the costlier conveying structure is given an extended operating life.

These liners are available in many different materials and varying thicknesses, and can be installed by welding or bolting in place.

Sometimes wear points can be protected by building a small box or shelf to trap and retain some of the bulk material. The "dead bed" that is formed will protect the chute material by directing the abrasive force of the material being handled against itself. The disadvantage of this idea is the fact that the material will tend to pack and build up in the chute for some distance. Flow through the restricted area thus formed is usually less than is required and complete stoppage and plugging may result. If the bulk material has a moisture content in excess of 3 to 5 percent this is an arrangement that is best avoided. Remember, too, that the liner provides a better sliding surface than does the deadbed.

The corrosive properties of stockpiled material can be rather difficult to deal with, and therefore, it is desirable that these properties be carefully studied and their effects on equipment and structures investigated.

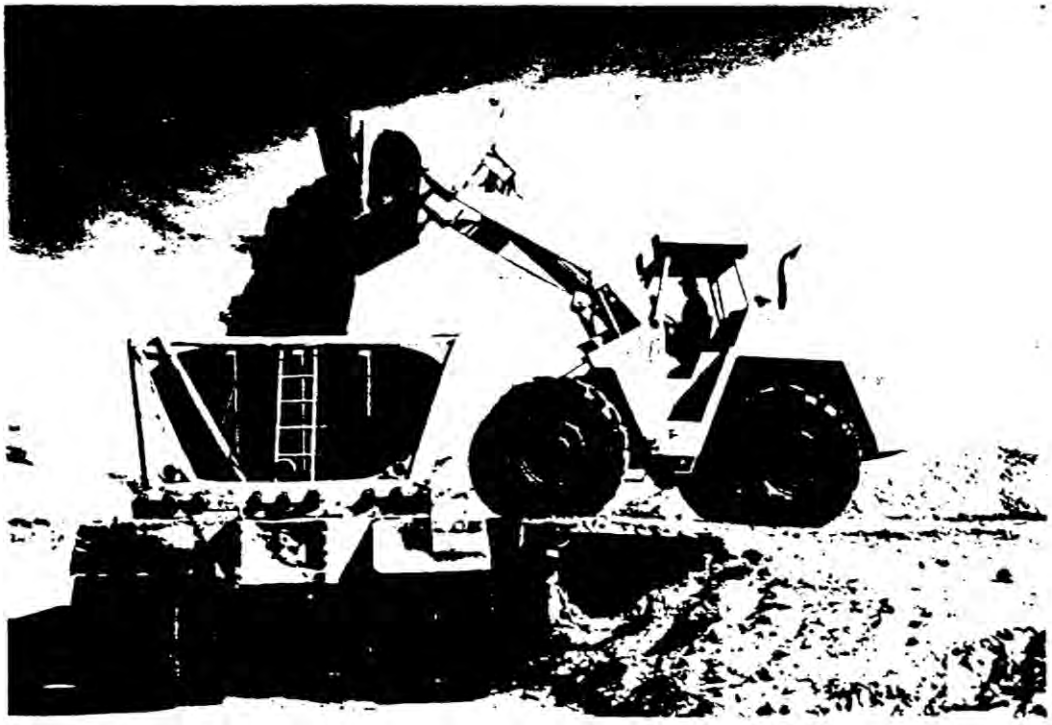
A material may cause no trouble in the dry state, but when moistened by rain or snow, this same material may become a real problem. In many cases, the material of construction may form a passive protecting film which halts the progress of the corrosion. If the bulk material handled is fine, light and non-abrasive, there is no need for great concern. However, if the particles being handled are heavy, coarse, with sharp edges, and exert an abrasive action on the structure, the protective film may be quickly abraded away. Removal of this film exposes a fresh surface to the corrosive process, and loss of metal proceeds at an accelerated rate.

If corrosion alone is the problem, some form of protective coating will probably prove adequate. Galvanizing, cadmium plating, cladding with stainless steel, coating with one of the epoxies or phenolic resins may be employed.

The key to the successful application lies in the proper surface preparation. Here the recommendations of the manufacturer should be carefully followed. With plastic coatings, consideration should be given to the use of multiple coats. The use of different colors for the layers will provide a visual indicator of the rate at which the coating is being removed, and warning of failure given before the bare material is exposed.

For severe conditions of corrosion, the use of special alloys is desirable. These should always be field tested.

When abrasion and corrosion are encountered together, no single solution probably will be available. A description of various systems and combinations will be given in another part.



After front-end loader reclaiming, this tractor shovel loads directly into truck. Loader may also be used to place material in a discharge hopper (Courtesy, Clark Equipment Company)

STOCKPILING OF MATERIALS, Part 5

Indoor storage: Modern design & materials make custom-cover possible

- **Where maximum protection is desired, today's indoor storage facilities are low-cost, highly efficient and designed to meet any requirements**

Certain guidelines for protection of stockpiled material already have been presented. All of these were intended primarily to emphasize the manner in which material properties and environmental factors must be carefully studied and appropriately matched to determine the best location for a stockpile of a given material.

The buildings used for the storage of bulk materials vary widely as to shape, arrangement and materials of construction that are employed. In general, the configuration of the building is determined by the type of stockpile and the equipment that is used for placing and reclaiming the material. The materials of construction are determined by the properties of the stockpiled material and certain economic considerations. The preferences of the individual designer and his desire for uniqueness and attention to esthetics also play a large part in the design of the building's frame and structural details.

The various shapes of buildings which have been constructed may be set forth in three general categories: (1) conical, including domes and semi-domes; (2) tent-shaped, including arches, and (3) box-shaped, rectangular or flat-roofed buildings. Table VII relates these shapes to stockpile types, construction materials and equipment.

The materials in common use today are steel, wood, aluminum and concrete. In most cases the choice appears to be determined by the corrosive characteristics of the stockpiled material. The use of protective coatings may permit the use of materials that are not corrosion resistant but have desired properties of stiffness and strength. The cost of periodic maintenance should be studied carefully.

In selecting the type of concrete to be specified, consideration should be given to the corrosive properties of the stockpiled materials and their affect on the concrete. It may be desirable to consider the use of plastic coatings as a precautionary measure. When in doubt, test the affect of the raw material to be handled on structural components that are being considered.

Typical buildings used to protect conical stockpiles

Kalium Chemicals Ltd.: Five beehive storage domes will each stockpile 37,500 tons of potash. Diameter of

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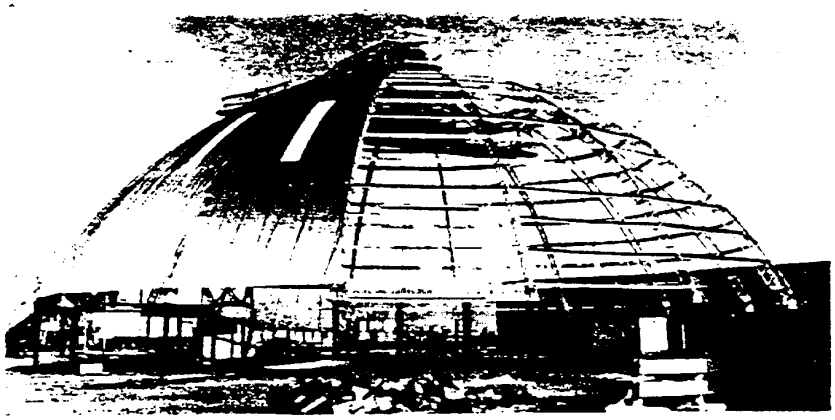
Kaiser Cement & Gypsum Co.'s 16-sided gypsum storage dome at Antioch, Calif., designed by Kaiser Engineers, holds up to 35,000 tons of raw material



Above: National Gypsum Co.'s Fink dome, built by General Conveyor, Inc., measures 175 ft in diam, 80 ft high, has 25,000 sq ft of floor space, and will hold 40,000 tons

Tent-type storage buildings are becoming increasingly popular because of their efficiency and low cost. This was one built at the Cave-in-Rock, Mo., quarry of Missouri Portland Cement Co.'s Joppa plant

STOCKPILING OF MATERIALS

continued . . .

each dome is 190 ft, while overall roof height equals that of an eight-story building. Floor area is 27,000 sq ft.

The structural frame consists of Glulam beams and purlins, with plywood roof sheathing topped by two layers of fiberglass roofing impregnated in asphalt.

Material is delivered into the building by an overhead belt conveyor system. Reclaim of material is by conveyor (with a capacity of 500 tph) to the loadout tower for bulk loading in covered hopper cars and for bagging.

International Minerals & Chemical Corporation—Esterhazy: Semi-dome buildings are 200 ft in diam and rise to a height of 78 ft above floor level. A concrete wall retains the surrounding fill and provides a concrete tension ring to carry the compressive load imposed by the roof structure.

Laminated wood beams and wood purlins support the corrugated metal roof cover. Material is delivered to the building by a 30-in. belt conveyor.

Material is reclaimed from the stockpile through seven drawpoints which feed a 30-in. reclaim belt conveyor. The 35,000 tons of potash can be reclaimed by gravity, with final cleanup by a front-end loader.

Aluminum dome—bauxite storage: An aluminum dome 300 ft in diameter rises 100 ft above its concrete foundation wall. The structure consists of 656 triangular aluminum sheets supported by aluminum tubular struts fastened by stainless steel bolts. The shell is entirely self-supporting with no beams or columns. 65,000 tons of dried bauxite (minus 1½ in. in size) are stored within the building in a semi-circular (radial) windrow.

The material is discharged into the storage area at the rate of 350 tph by a 70-ft long stacker conveyor. The storage pile attains a maximum height of 60 ft.

The stacker, which has a total dead weight of 200,000 lb, is suspended from the dome by 34 cables (⅞-in. diam). Eight additional cables are used to stabilize the stacker and adjust for movement caused by deflections of the dome due to temperature changes.

Material is reclaimed by means of a dual-wheel (33-ft diam) Hewitt-Robins bucket reclaimer, which pivots around the centerline of the dome and scoops up bauxite ore at the rate of 2,000 long tph. As the wheels rotate, they advance into the pile and at the same time traverse the face.

Aluminum dome—raw sugar storage: One aluminum-domed warehouse has a storage capacity of 30,000 tons of raw sugar. The base diameter is 238 ft and the total overall height above the floor is 96 ft. A reinforced concrete wall, 6 ft high, surrounds the base. Eight parabolic steel trusses support the purlins and exterior sheathing of hammered, embossed aluminum. Plastic windows provide natural light within the building.

Material is delivered by an inclined belt conveyor to the stacking shuttle conveyor. This shuttle is 58 ft on centers and moves back and forth on rails 105 ft long. The entire shuttle bridge is suspended from a circular track 70 ft in diam. The bridge can rotate 360 deg in five minutes at 44 fpm and the shuttle belt can travel forward or backward at 45 fpm.

Material is reclaimed by a front-end loader with 3,000-lb carrying capacity, which places the raw sugar in a 9,000-lb hopper located over the foot of an 18-in. belt conveyor.

Iron ore rain hood: In some cases there is no need for a total weatherproof enclosure. The conical metal cover is an example of a simple rainhood which keeps moisture out of an already sticky material which is rather difficult to reclaim.

The cover is 110 ft high and shelters a 100,000-ton stockpile (45,000-ton live storage) which attains a height of 100 ft. The iron ore has a bulk density of 250 lb/cu ft.

Material is delivered to the stockpile by a single stationary conveyor which discharges on the vertical centerline of the hood cone. It is reclaimed by four feeders in a 200-ft tunnel under the storage area.

Plastic rigid domes: An interesting development in the use of plastics for buildings is a new process recently announced by the Dow Chemical Co., Midland, Mich. The two domes are 80 ft in diam and are covering trickling filters at the municipal facility in Midland. Another 80-ft dome has been used as the roof structure for a convention hall-theater in Traverse City, Michigan.

These structures are built entirely of foam plastic boards, with an impervious covering to shed the weather. Construction is relatively simple. Note in Fig. 4 how by means of a pair of booms and a specially designed ma-

chine. Styrofoam boards are shaped and fastened together to develop a dome by generating a continuous spiral: also how the roof structure appears to be made of one endless board. In one test structure, a pair of workers completed the erection of a 45-ft dome in one working day!

Since Styrofoam offers insulating properties as well as dimensional stability, it may be especially useful in covering process equipment such as thickeners and stockpiles of material that require protection from the weather. Costs for these structures will vary with the size and shape of the dome. For approximate "ball park" estimates, a unit cost of $2.50 per sq ft can be used. This figure provides for the cost of the plastic and the actual generation of the dome itself, but does not include the finished covering of the dome or the dome foundation structure. Domes have been covered with various substances, including latex paint and a cementitious cover.

Arch-type storage building: One

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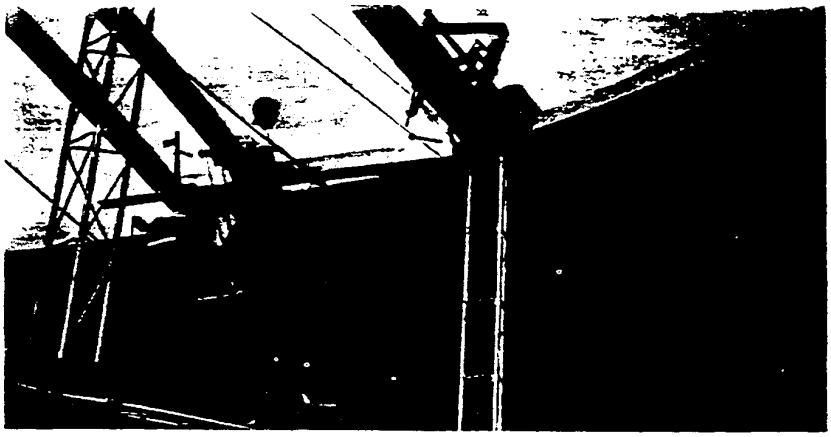

Fig. 4 (above)—Styrofoam boards shaped and fastened together form a dome which appears to be made of one endless board

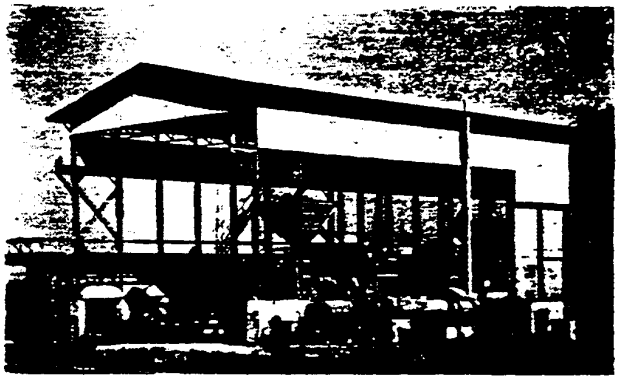

Fig. 5—Truck crane places iron ore and sand in storage hopper of steel-framed storage building to alter shale and limestone composition

Table VII—Types of buildings used to protect stockpiles from weather

Types of buildings	Materials of construction	Types of stockpiles	Placing equipment commonly used	Reclaiming equipment commonly used
Cones or domes	Frame: Steel, Wood, Aluminum, Plastic Cover: Steel, Wood, Aluminum, Plastic, Protected metal	Conical piles Radial windrows	Conveyors— belt, screw, shuttle, trippers, slingers, pneumatic	Feeders Conveyors Rotary reclaimers Loaders
A-frames or arches	Frame: Steel, Wood Cover: Steel, Wood, Aluminum, Plastic, Protected metal	Windrow (parallel)	Conveyors— belt, screw, shuttle, trippers, slingers Dragscrapers	Feeders Conveyors— belt, screw, drag Dragscrapers Loaders Rotary reclaimers
Box or rectangular frames	Frame: Steel, Concrete Cover: Steel, Wood, Aluminum, Plastic, Protected metal, Concrete	Windrows (parallel) Bins on ground-craneways	Conveyors— belt, screw, shuttle, trippers, slingers Dragscrapers Crane, bridge-w/clamshell bucket	Feeders Conveyors— belt, screw, drag Dragscrapers Loaders Rotary reclaimers Crane, bridge-w/clamshell bucket

STOCKPILING OF MATERIALS

continued . . .

type of arched storage building used to store ammonium sulphate is 136 ft wide x 300 ft long and rises 57.5 ft at centerline. Floor area is 40.800 sq ft; roof area is 54.964 sq ft.

Structure consists of 16 Glulam arches at 20 ft on centers, with sawn purlins and end wall framing, 2-in. tongue and groove decking, and transite walls including doors. All lumber was treated with Wolman salts and all connecting hardware is of Type 304 stainless steel.

Material is placed in storage by means of conveyor supported overhead from building arches. It is reclaimed by a front-end loader, which deposits material onto a belt conveyor that is loaded along far side of building.

Tent-shaped storage building: A tent-shaped bauxite storage building 190 ft wide x 600 ft long rises 91 ft high and has a total storage capacity of 160,000 tons.

Material is distributed to the storage pile within the building by means of an overhead 48-in. belt conveyor 588 ft long, equipped with a traveling belt tripper.

Material is reclaimed from under the stockpile through a reclaim tunnel on a belt conveyor 24 in. wide x 600 ft long which discharges onto a 24-in. inclined belt conveyor and then to the mill bins.

Arch-type building for potash storage: Two large arch-type buildings might be used. The larger of the two is 150x500 ft and has a capacity of 70,000 tons of material. The smaller building is 100x600 ft and has a total capacity of 50,000 tons.

The foundations, floors, and exterior walls are of reinforced concrete. The frame is of structural steel covered with corrugated galbestos siding. Interior compartments are formed by bulkheads of concrete and steel.

Material is placed in storage by stationary and shuttle-type conveyor belts, chutes, and drag conveyor. It is reclaimed by means of a slusher (dragscraper) and front-end loaders which deliver the material to a floor hopper. Material is then conveyed by bucket elevators, screw conveyors, belt conveyors, and gravity chutes to the loading point. Loading is accomplished with chutes, slingers, and various units of bagging equipment.

Products stored in these buildings include: muriate of potash (standard, coarse, granular); sulphate of potash-magnesia (standard, coarse, granular); potassium sulphate (standard, coarse, granular); potassium chloride (refined).

The following characteristics are significant to the design of the indoor storage system: density, 70 to 100 lb/ cu ft; particle size, from 90 percent plus 14 mesh to 95 percent plus 65 mesh; free flowing material, with an average angle of repose of 33 deg; exposure of this material, direct rain or snow is unacceptable; humidity, in this area normally very low and a minor problem, although it can cause some caking; above average winds and local dust and sand, minimum building openings are desirable; and corrosion, minimal for existing humidity levels.

Steel-framed storage building: Material from the transport belt conveyor system is transferred to a 24-in. wide distributing conveyor with belt-propelled traveling tripper which discharges into designated areas within the building. It is reclaimed from within the building by an overhead crane. In Fig. 5 a truck crane is placing iron ore and sand in the storage hopper to correct deficiencies in composition of the shale and limestone.

Whenever the moisture content of the shale is sufficient to impair the efficiency of the ball mill (during the winter and in rainy seasons), the wet shale is placed by overhead crane in the storage bin and fed into the small dryer in the foreground. The dried shale is then returned to storage by an oscillating conveyor and centrifugal discharge bucket elevator. The dry shale is separated in storage, ready for processing.

An integral part of any storage building design must be the method by which material is reclaimed. At present, the most commonly employed means appear to be: (1) feeders and conveyors in reclaim tunnels under the stockpile (Fig. 6); (2) front-end loaders loading material into trucks or onto conveyors (Fig. 7); (3) dragscrapers loading material onto conveyors (Fig. 8); and (4) rotary reclaimers loading conveyors (Fig. 9).

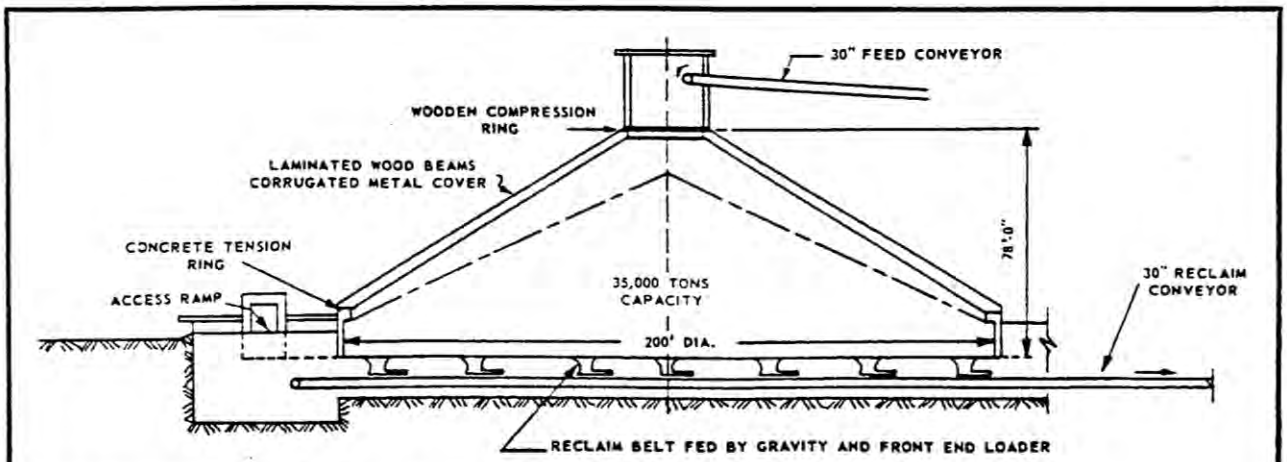

Fig. 6—Conveyor reclaim system in 35,000-ton storage building (Courtesy, International Minerals & Chemical Corp. (Canada), Ltd.)

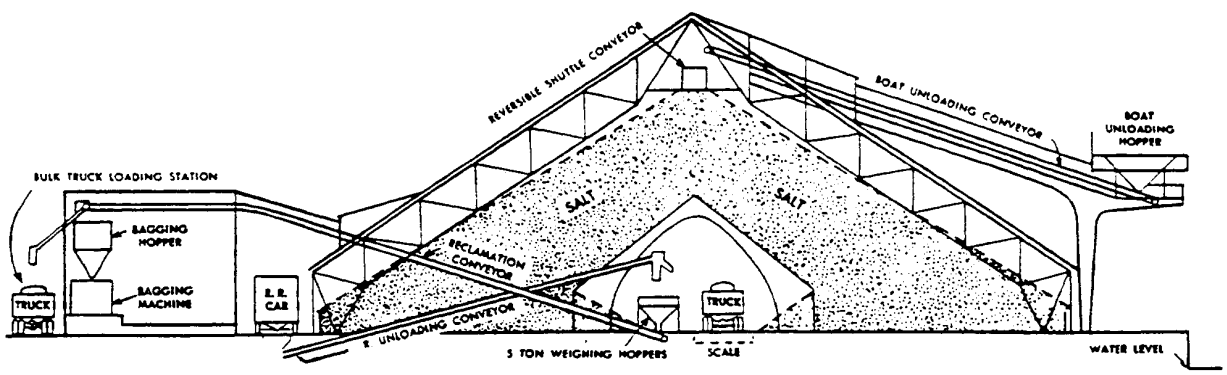

Fig. 7—Front-end reclaiming in salt storage system (Courtesy, Hewitt-Robins, Inc.)

Structural details

For further information on glued laminated wood structures, contact: Unit Structures, Koppers Co. Inc., Forest Products Div., Peshtigo, Wisc., Weyerhaeuser Co., Wood Products Div., Tacoma, Washington 98401; Timber Structures, Inc., N. W. Yeon Avenue at N. W. 29th Ave., Portland, Ore. (P. O. Box 3782)

A brand new use has been found for the laminated wood bowstring truss. Normally designed for rectangular buildings, the bowstring is used in a perfectly circular dome structure for a bulk calcium chloride storage building.

The building has a clear span of 180 ft in diam. Material is delivered into the building by a roof-top conveyor and allowed to form a natural pile, round in plan, and with a 45-deg. angle of repose. The lower retaining walls are of concrete and stand 16 ft above grade.

The roof system consists of 26 bowstring trusses, braced and tied together in 13 pairs. The trusses each have a length of 120 ft along the bottom chord and 125 ft 8 in. along the top chord. The trusses connect at an apex hub so that their arcs form a dome.

The roof structure is designed for a live load of 30 psf and a dead load of 7 psf. Design is adequate for winds up to 75 mph.

Cost of the structure is $80,000, including engineering, materials and erection. The roof area is 45,000 sq ft and the floor area is 25,000 sq ft. It is felt that this system using bowstring trusses is economical for spans from 120 to 250 ft.

The roof covering consists of ¾-in.

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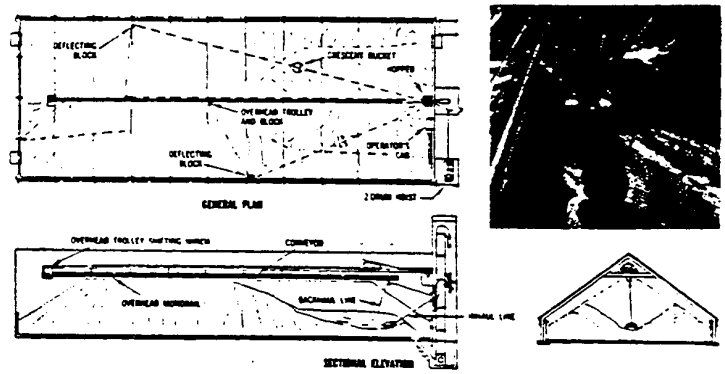


Fig. 8—Dragscraper reclaiming using an elevated monorail trolley system for straight-line recovery (Courtesy, Sauerman Bros., Inc.)

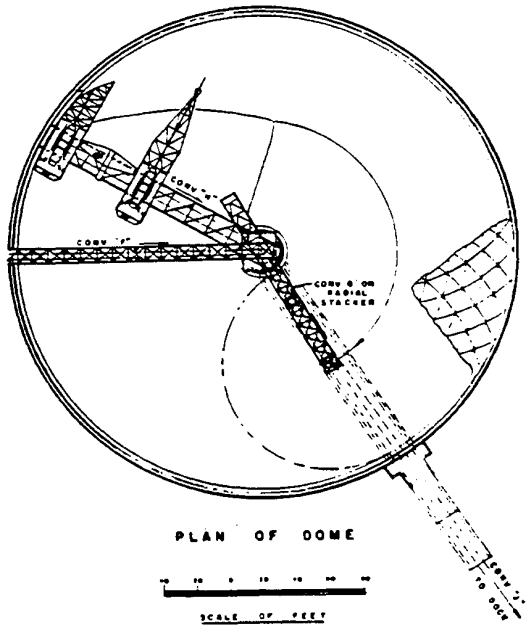


Fig. 9—Rotary reclaiming wheel loading onto conveyors (Courtesy, Hewitt-Robins, Inc.)

STOCKPILING OF MATERIALS

continued . . .

thick Balsam Wool wood fiber insulation with a reflective bottom surface applied over the joists. A sheet of plywood (½-in. thick) was applied over the Balsam Wool. A neoprene-Hypalon roofing is applied directly to the plywood.

Three bulk storage warehouses, each 142 ft wide x 240 ft long, are used for the storage of sugar beet pulp.

Each of the 70-ft high buildings used 318,000 board ft of laminated wood in the main structural members, and 120,000 board ft for the roof purlins. The A-frames were decked with plywood, then covered with galvanized steel sheets.

Cost of all the wood, doors, ventilators, siding, interior wood paneling, catwalks, exterior ladders, and supports for a conveyor system came to $2.70/sq ft erected in place on the owner's foundation.

Laminated wood was specified for economy, fire resistance, and noncorroding properties.

Fig. 10 shows details of the structural frame of a 97,250-sq ft building used for storage of 80,000 tons of potash.

The glued laminated timber arches support the roof and eliminate all interior posts, enabling equipment to operate without interference.

The heavy timber structural framing is reported to have cost $1.04/sq ft erected in place—and a savings of $60,000 over the cost of steel framing is claimed. Since the timber is inert to chemical action, no protective painting or maintenance is required.

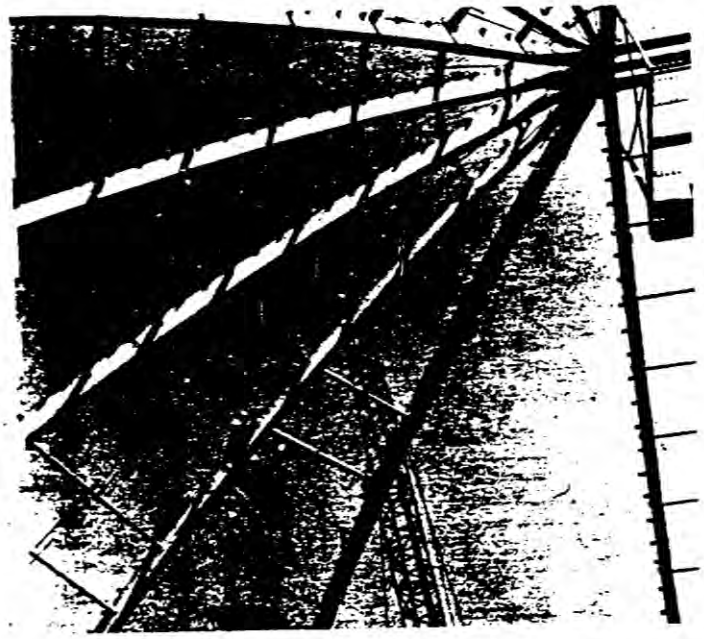


Fig. 10—Glued laminated timber arches support the roof of this 97,500-sq ft building used to store 80,000 tons of potash, and enable mechanical equipment to operate with a minimum of interference (Timber Structures, Inc.)

Fig. 11 (below)—A continuous border of planks and old tires used as weights will help to keep a temporary storage cover in place

Temporary covers

In cases where the stockpiled material must be retained in storage for a relatively short period of time, the cost of permanent construction cannot be justified. In such cases, the use of plastic, canvas, or other film coverings may provide an adequate solution to the problem.

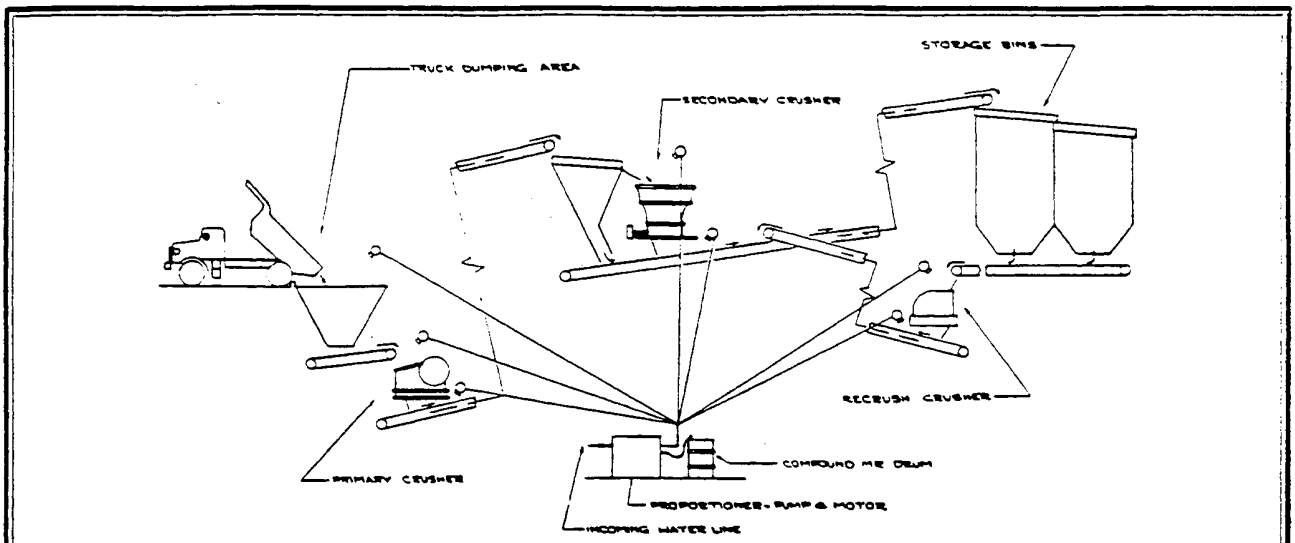
Covers of nylon-reinforced plastic are available in many different sizes, running as large as 200x200 ft. The size of sheet furnished generally is limited only by the handling capabilities of the purchaser.

Holding the cover down presents some problems. It should be tied at the bottom of the pile in such a manner that stress concentrations do not occur. Weights should also be placed along the top and sides of the pile so that lifting action of the wind does not cause the cover to be abraded by the stockpiled material below.

Fig. 11 shows how the edges of the cover have been fastened to a continuous plank border, and the manner in which old tires have been employed as weights to restrain the cover. In some applications, sacks filled with the stockpiled material are used as weights; breaking and spillage of the sacks does not result in a contamination of the stockpile.

Various weights and grades of plastic covers are available. For stockpile covers of any great area, three or four-ply material is probably best. Covers of this material weigh from 38 to 62 lb. per sq ft. The cost of the cover material ranges from 6½ to 12½¢ per sq ft of surface area.

Plastic stockpile covers are available from: Griffolyn Co., Inc., P.O. Box 33248, Houston, Texas, 77048; Canton Containers, Inc., P.O. Box 871, Canton, Ohio.



Typical application of a Chem-Jet dust collection system in rock crushing operations (Courtesy, Johnson-March Corp.)

STOCKPILING OF MATERIALS, Part 6

Chemical binders: One solution to dust suppression

- **Chemical binders, pavings and sealants not only cut down dust, they effectively protect stockpiles from wind and moisture**

There are two basic approaches to the elimination of dust in handling and storing material that contains very fine particles.

The most commonly used is a dust control system that works for the suppression of dust through the receiving, crushing, conveying, and stockpiling operations. The other employs a chemical spray that binds together the uppermost particles and forms a protecting crust on the surface of the stockpile. A modification utilizes a paving material to form an impervious coating on the surface of the pile.

Dust suppression system: In this system, dust is controlled by spraying dust-producing points in the process flow with a chemical solution which causes the dust to agglomerate. In this method, the dust is not removed from the flow of material but continues on without loss.

These spray systems contain four elements which are varied to suit the unique requirements of each specific dust control problem: (1) the chemical compound—a surface active agent; (2) proportioning equipment—to mix the agent with water in the required proportions; (3) distribution system—to deliver the solution to the points of application, and (4) actuating controls—to automatically control application of the chemical solution to the flow of material.

This system of dust suppression is an outgrowth of the use of plain water. When untreated water is used, however, approximately 5 to 8 percent of moisture (by weight) has to be applied to suppress the dust adequately. When the material is later put through a heating or drying process, the heat required to drive off this moisture is an added expense. When shipping follows, transportation costs are increased by the addition of this useless water.

The chemical system of dust suppression employs a surface active agent such as Compound MR to reduce the water's surface tension sufficiently so that fines will be wetted with the least amount of treated water. When one part of Compound MR is mixed with 1,000 parts of raw water, the moisture addition to the process flow is less than one-half of one percent.

Proper proportioning of agent and water is important for rapid wetting, and speed of wetting is essential to effective dust suppression. The wetting rate varies with the material being processed, the surface active agent used, and the dilution ratio in water. Proper proportions should be determined by laboratory tests on a sample of the material. The indicated ratio

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STOCKPILING OF MATERIALS

continued . . .

is then adjusted for such factors as: ratio of fines to coarse particles, characteristics of the rock, moisture content, etc.

In applying treated solution to a stream of rapidly moving material, it is usually necessary to establish several points of application. Once the entire stream of material has been dust-proofed, the material can be conveyed through several transfer points without requiring further treatment.

Spray actuation and control are important, especially when the flow of material is intermittent. Sensing controls are used to actuate the individual spray headers only when there is rock on the conveyor.

Since there are so many variables involved, complete cost figures are not available. Costs (material and labor) generally run between ⅓¢ and ½¢ per ton of sprayed material. Naturally less spray is required during seasons of precipitation.

The treatment described will protect materials in a stockpile from windage loss until the added moisture has been removed by heat and wind. Then some more permanent form of surface treatment must be applied. If the material is to be in storage for a short time and weather conditions are favorable, additional treatment may not be required.

Chemical binders: The second approach to the problem of dust control calls for the application of a chemical spray to the surfaces of the stockpile. The chemical coats the topmost particles with a thin film, causing them to adhere to one another. The surface crust that forms is tough, durable, and highly resistant to the action of wind and rain. Moisture can still penetrate this surface and pass through the void spaces between the particles.

As long as the surface crust remains intact, the stockpile is adequately protected from windage loss, the dust nuisance is eliminated, and the entire stockpile is protected against erosion and guttering by heavy rainfall.

After the film has dried it is insoluble. Its toughness and flexibility enable it to resist considerable strain and movement due to alternate freezing and thawing. By adding a coloring agent to the binder, treated areas can be readily identified. This device permits the application crew to detect areas that may not have been coated properly. It also provides an indicator that warns of the removal of coated material and the exposure of untreated materials. Two chemicals available for this application are Compound SP and Coherex.

Compound SP (Johnson-March Corp.) is a synthetic organic polymer in a water base. It will coat all types of materials regardless of composition or particle size. The film is inert, unreactive, and non-toxic and does not affect burning qualities. Further processing of raw materials at elevated temperatures will result in an ashless combustion residue, since the compound is organic in composition.

Compound SP is used as received, without dilution. It can be applied by any type of spraying equipment. The normal rate of application for all grades is 1 gal. per 100 sq ft of surface area. On the average, effective protection is provided for a year or more, depending upon the materials covered and the prevailing climatic conditions.

Several grades of Compound SP have been developed to meet the many variable conditions, such as differences in types of raw materials, particle size, surface wettability, and climatic conditions. Selection of the proper grade should be made after consultation with the manufacturer.

Golden Bear Coherex is a stable emulsion which consists of semi-liquid petroleum resins and a wetting solution. The resins are film-forming and dust-binding, while the wetting solution serves as the carrying and penetrating agent, keeps the resins dispersed in finely divided particles, and makes the dust-binder readily miscible with water in any proportions.

The dust-binder consists of natural petroleum resins, wetting agents, sequestering agents, and water. The petroleum resins, which constitute about 60 percent of the concentrate, are nonvolatile under atmospheric conditions and have a high affinity for soil. The wetting agent increases the spreading power of the diluted emulsion and increases the penetration of the resinous particles into the soil. The sequestering agent makes the preparation stable against hard water and thus permits dilution of the emulsion with almost all types of water.

This non-flammable mixture can be applied by hand sprayers, orchard sprayers, or spreader trucks, depending on the extent of the area to be covered. Best results are obtained by spraying under pressures of about 40 to 60 lb. The usual dilution rate is one part of Coherex to four parts water. The rate of application required varies with the material being sprayed. For sandy materials, 1.5 to 2.0 gal. of fluid per sq yd will obtain a 2-in. depth of penetration. Thirty gallons of Coherex will produce 150 gal. of solution.

At this rate of application, the approximate cost of Coherex will run from 9¢ per sq yd (in bulk volumes) to 28¢ per sq yd (in 55 gal. drums). These costs will vary with transportation charges. Labor should be added for a total cost.

Fig. 12 illustrates the two methods of controlling dust by means of chemicals: dust suppression system and chemical binders.

The main elements of the suppression system are shown as well as the direct application of chemicals to the stockpile itself.

Pavings: One method of paving employs a mixture of woodpulp and asphalt in a slurry which is sprayed over the exposed surface of the pile. A special gun atop a truck sprays the stockpile—first with a paper-base fiber and then with a coating of asphalt-bentonite, which sets in a few hours. This

Table VIII—Particle exposure to wind action

Particle diameter in mm	Mesh sizes	Wind susceptibility
0.0 to 0.42	0 to 40m.	Highly erodible
0.42 to 0.84	40 to 20m.	Difficultly erodible
0.84 to 6.40	20m. to ¼ in.	Usually non-erodible
6.40 and over	¼ in. up	Non-erodible

Adapted from Golden Bear Oil Co., "Manual on Control of Dust and Wind-Erosion with Golden Bear Coherex," page 5.

¾-in. coating is designed for at least six months of protection.

A two-man crew can cover two 15-ton piles per day. Cost is roughly estimated to be about half that of conventional covers. This covering is said to do an excellent job of preventing wind erosion and provides waterproofing; however, each raw material requires individual analysis to determine which waterproofing agent will be compatible with it.

For further information, contact Sprayturf Ltd., Rural Route #1, Delaware, Ont., for details of their "Spraytarp" method.

Sealants: Another method of sealing stockpiles of coal against the penetration of air and moisture is described by the Bituminous Coal Institute in Section D-3 of their BCI Fuel Engineering Data Book, pp. 2-3.

"In this method, the top and sides of the stockpile are covered with an airtight seal of asphalt or road tar. This seal may be applied with spraying equipment similar to that used by highway departments. The top of a large storage pile can be capped by the use of a hose and hand nozzle. Small piles can be capped by hand spraying only.

A covering or cap, ⅛ in. thick and requiring about 1 gal. of asphalt per 10 sq ft of area, has been found satisfactory. The sides exposed to prevailing winds should be treated somewhat more heavily for greater assurance against access of air.

A preference has been shown for the AE-4 grade of asphalt emulsion because of its quick water-separation and superior coating properties.

It should be emphasized that the foregoing sealing method is optional and usually not required if proper attention has been paid to the layer method of building and compacting the stockpile."

Wind susceptibility of soils. When placing bulk materials in outdoor stockpiles, the question arises as to what minimum size of particles can be safely exposed to wind action. As a guide, Table VIII, based on the work of W. S. Chepil, is offered.

The minimum velocity required to start soil movement (threshold velocity) varies with grain sizes. It is interesting to note that the threshold velocity attains a minimum value at grain sizes 0.10 to 0.15 mm (140 mesh) of 8 to 9 mph at 6 in. above the ground surface. The range of threshold velocity for all grain sizes is from 13 to 30 mph at a height of 1 ft above the surface.

One chemical binder, Coherex, being applied here, consists of semi-liquid, film-forming, dust-binding resins, carried in a wetting solution (Courtesy, Golden Bear Oil Co.)

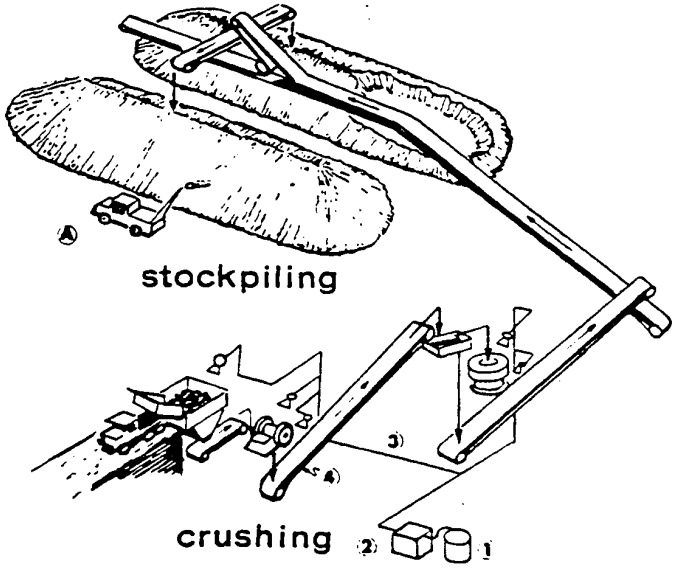

Fig. 12—Two methods of controlling dust by means of chemicals: Chem-Jet dust suppression system—Wet down particles at dust-producing points; key: (1) chemical compound, (2) proportioning equipment, (3) distribution system, (4) actuating controls. Chemical binder system—Bind particles together to form protective crush; key: (A) Compound SP, or Coherex (Courtesy, Johnson-March Corp.)

Use of material properties

In many cases it may be possible to adequately protect stockpiles simply by giving due consideration to the properties of the material.

An example of this concept may be seen in the following quotations taken from section D-3 of The Bituminous Coal Institute Fuel Engineering Data.

"Plants having reserve piles larger than 500 tons should always build a

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STOCKPILING OF MATERIALS

continued . . .

compacted coal pile. Compaction seals out air and minimizes spontaneous heating. It also reduces heating-value loss to one per cent or less." If the material that you are stockpiling is harmed by exposure to the air and its stay in storage will be long enough for appreciable damage to occur, then perhaps compaction of the material may be employed as a protective measure.

"Dumping coal on the pile segregates it, creates flues and promotes heating and fires. The pile should be built in successive layers 1 to 2 ft thick. Each layer should be thoroughly compacted by repeatedly running a bulldozer or weighted roller over the coal."

The flues or channels created by haphazard stacking of materials may also permit the intrusion of rain and ground water into the interior of a stockpile with somewhat less damaging, but none the less harmful, effects on some minerals and chemicals. The stockpile should be constructed so that it sheds water. This can be accomplished rather easily by employing the following procedure:

"Dress the pile by sloping the tops of successive (coal) layers and compacting the pile toward the sides. The sides of the pile must be compacted and dressed. This prevents rain, melting snow and ice from penetrating the pile. Pile slopes should not be too steep; an angle of 30 deg to the horizontal is a good slope to maintain. Steep side slopes can cause segregation and erosion from wind and rain.

"Crown the top of the pile slightly or allow for slope in one direction. Saucer-shaped tops create a problem of standing water, wetting the coal so that it clogs chutes and conveyors.

"It is recommended that, insofar as possible, only one type of coal be placed in the stockpile. For large compacted reserve storage piles, the coal should be a slack or nut and slack size not exceeding 2 in. top size. Size breakdown should be such as to fill all the voids in the coal as it is compacted. Large size or double-screened coal should never be compacted."

The problem of erosion in stockpiles can be met by providing a top layer of coarse material on the slopes. For example, BCI suggests, "a 6-in. layer of fine coal (¼-in. x 0) be placed over the top and slopes of the shaped stockpile. As an anchor, place over this a 4-in. layer of larger size material (at least 2 in. x 0). The combination will materially prevent wind and rain erosion." Unfortunately, because much of this material must be placed by hand, the cost of the stockpiling operation is increased.

Figs. 13 and 14 highlight some of the recommendations made above. While most of these ideas have pertained directly to the handling of coal, it is not too difficult to visualize these same principles being applied to all long-term stockpiles that can be affected adversely by prolonged exposure to the weather.

Fig. 13—Haphazard stacking of material, showing air circulation (Courtesy, Bituminous Coal Institute)

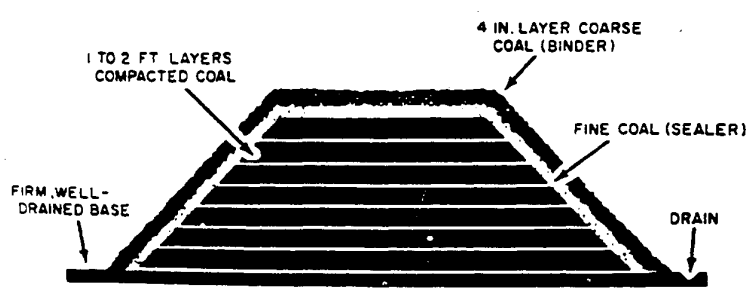

Fig. 14—Cross-section of a compacted stockpile (Courtesy, Bituminous Coal Institute)

STOCKPILING OF MATERIALS, Part 7

The fine art of feeder selection

- **In choosing among the 12 principal types of feeders, consider that every feeder is designed for a specific purpose depending on the characteristics of the material to be handled**

Conveyors and related equipment are the principal tools of the majority of stockpile systems. More specific and detailed information on these units of equipment, mentioned in the preceding sections on design and operation of stockpiling systems, will appear in this and subsequent articles. Feeders will be discussed in this section on conveyors. Future articles on material handling equipment will deal with belt and other types of conveyors, slingers and throwers, trippers and stackers, followed by bucket-type units, mobile equipment and auxiliary structures for stockpiling operations.

Feeders are used to regulate the flow of solids from storage units such as bins, hoppers, silos and stockpiles. The feeder, regardless of type, can be depended on to maintain the required flow of material at a steady uniform rate. Providing, of course, that the feeder has been correctly selected and properly installed.

There are many different types of feeders available today, and the selection of a feeder for any application is still in the nature of an art, rather than a science. The selecting of a feeder should begin with a careful consideration of the material to be handled. The physical and chemical properties of the material should be investigated and any unusual characteristics noted.

Each type of feeder has been designed to handle material having certain specific characteristics under fairly well-defined loading conditions. Particular attention should be paid to the following characteristics—(1) size of particles and distribution of sizes; (2) flowability of the material; (3) abrasive quality of the material; (4) moisture content of the material; (5) special conditions of temperature, corrosiveness, etc., and (6) desired rate of flow (tph) and bulk density of material.

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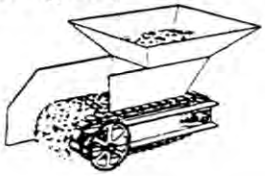
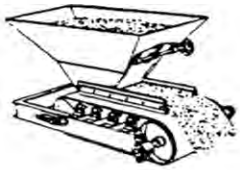
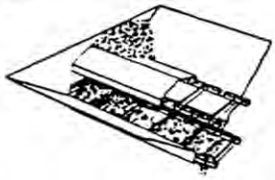
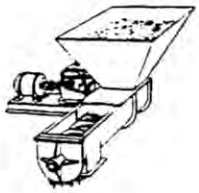
Right: Portable heavy-duty apron feeder—Hydro Electric Power Commission of Ontario (Courtesy, Smith Engineering Works)

Table IX—Feeder capacity range and effect of material characteristics

Type of feeder	Capacity range—tons per hour	Material characteristics: Size: Fine Granular	Size: Large lumps	Flowability: Very free	Flowability: Free	Flowability: Sluggish	Abrasiveness: Non-abrasive	Abrasiveness: Mildly abrasive	Abrasiveness: Very abrasive	Path of travel (I) Horizontal	(II) Inclined	(III) Combined
Apron (pan)	57 to 688		×	×	×	×	×	×	×	×	×	×
Belt (with rolls)	40 to 1200	×	×		×	×		×	×	×	×	×
Flight	36 to 182	×	×	×	×	×	×	×	×		×	×
Screw	10 to 187	×	×		×	×	×	×	×		×	×
Reciprocating	82 to 450	×	×	×		×	×	×	×	×	×	
Vibratory—electrical	25 to 1,000	×	×	×	×	×	×	×	×	×	×	
Vibrating—mechanical	35 to 1,550	×	×		×	×		×	×	×	×	
Table, rotary stationary plow	12 to 57	×	×		×	×	×	×	×	×	×	
Plow, rotary stationary table	300 to 3500	×	×			×	×	×	×	×	×	
Rotary (vane)	1.5 to 117	×	×		×	×		×	×		×	

Adapted from Link-Belt Catalog 1000

TYPE OF FEEDER	GENERAL INFORMATION
Apron (pan) 	The apron feeder is made up of over-lapping metal flights fastened to endless steel chains which pass around a head and tail sprocket. The flights or pans are available in high-carbon steel, manganese steel, nickel-chrome-moly, etc. Apron feeders are self-cleaning and can be started under full load. Pan speeds usually run from 10 to 30 fpm. Headroom requirements are low. Rate of feed regulated by varying speed of travel or changing area of feed opening to apron
Belt 	The belt feeder consists of an endless belt, usually rubber covered, which passes around a head and tail pulley. Intermediate support is provided by flat idler rolls, or a flat steel slide plate. Headroom requirements are low. Belt speeds of 10 to 50 fpm are recommended, depending on characteristics of material. Capacity of feeder can be varied by changing gate opening and belt speed. Belt feeders are self-cleaning, but a belt scraper is used to eliminate carry-back of fine material
Flight 	Flight feeders usually consist of a flat pan (trough) over which material is moved by a series of bar flights. The flights extend the full width of the feeder and are supported at each end on endless steel chains. Material is moved along pan by pushing action of flights. Abrasion-resistant steels are used for pans and flights. Flow is regulated by varying depth of material on pan, changing speed of flights. Flight feeders are self-cleaning and are positive in action. Not recommended where accurate proportioning is required
Screw 	The screw feeder consists of a spiral of metal flighting mounted on a steel shaft which is supported within a U-shaped trough. The screw is rotated by drive consisting of chain or V-belts, a reducer and an electric motor. Flighting is available in regular or short pitch, and diameters are uniform or tapering. Diameter increases in the direction of material travel. For discharging materials that pack or bridge under pressure, multiple-screw feeders are often installed in flat-bottomed bins
Reciprocating	This feeder consists of a flat plate that is moved back and forth in a reciprocating motion. Rate of material flow is controlled by varying throw of eccentric, speed of driver, discharge opening in feed hopper. The cost of this feeder is low in relation to its capacity. Installation costs also low, due to simplicity of unit. Feeders are not self-cleaning. For abrasive applications, plate can be lined with AR wearing surface. A grizzly can be installed on discharge end to place fines on belt

CAPACITY DATA

Apron width (inches)	Max. particle size (in.) 50 pcf material unsized	50 pcf material sized	100-125 material unsized	100-125 material sized	Capacity: Cu ft per hr with skirt height of 12"	18"	24"	Tons per hr. with skirt height of 12"	18"	24"
18	6	3	6	3	1140			57		
24	8	4	6	3	1620	2400		81	120	
30	8	4	6	3	2100	3100	4090	105	155	204
36	8	4	6	3	2570	3800	5020	128	190	251
42	8	4	6	3	3040	4500	5950	152	225	296
48	8	4	6	3	3520	5200	6880	176	260	344

Note: Capacity based on handling material weighing 100 lb per cu ft, feeder speed of 20 fpm, skirt plates loaded to 75% of theoretical max. cross section. Capacity directly proportional to feeder speed and weight of material. Max. speed of 40 fpm (Adapted from Link-Belt Catalog 1000)

MATERIALS HANDLED

Well-suited to handle heavy, coarse, lumpy, hot, or abrasive material. This includes sand, stone, gravel, cement clinker and slag. Often used where impact loads are severe. Not normally used for very fine or corrosive material

Belt Width (inches)	Max. lump size (inches) non-abrasive	abrasive	Capacity of belt: At speed of 200 fpm cu ft per hr	tons per hr	At max. recommended speed of 60 fpm cu ft per hr	tons per hr
18	4	4	800	40	2400	120
24	5	5	1200	60	3600	180
30	6	6	2200	110	6600	330
36	6	8	3720	186	11,160	558
42	6	10	5680	284	12,040	852
48	6	12	8000	400	24,000	1200

Note: Capacity based on handling material weighing 100 lb per cu ft and with skirt plates loaded to 75% of theoretical max. cross section. Max. recommended angle of incline—10°. Max. recommended speed—60 fpm for abrasive materials, and 100 fpm for non-abrasive materials. Max. recommended weight of material—100 lb per cu ft (Adapted from Link-Belt Catalog 1000)

Any bulk solid that can be handled on a belt conveyor can probably be handled on belt feeder. Good for fine material, or fines mixed with lumps of moderate size. Sticky or hot materials, or large pieces with sharp edges may be a problem to handle

Flight width (inches)	Max. lump size (inches)	Capacity at 20 fpm cu ft per hr	tons per hr	Capacity at 50 fpm cu ft per hr	tons per hr
18	3	728	36.4	1820	90.0
24	3	968	48.4	2420	121.0
36	3	1460	73.0	3650	182.5

Note: Capacity based on handling material weighing 100 lb per cu ft. Max. recommended weight of material—100 lb per cu ft. Max. recommended speed—50 fpm (Adapted from Link-Belt Catalog 1000)

Flight feeders are generally used for light-weight, relatively non-abrasive materials, such as coal and wood chips. They are not recommended for materials with large lumps or consisting entirely of fines

Screw diam (inches)	Max. lump size (inches)	Speed (rpm) max. recommended	Capacity at max. recommended speed cu ft per hr	tons per hr
Regular pitch				
6	⅛	70	315	15.75
9	⅛	70	1120	56.00
12	⅛	60	2250	112.50
14	⅛	50	3100	155.00
16	⅛	40	3740	187.00
Short pitch				
6	¾	70	210	10.50
9	1½	70	749	37.50
12	2	60	1500	75.00
14	2½	50	2100	105.00
16	3	40	2440	122.00

Note: Capacity based on handling material weighing 100 lb per cu ft, and 90% of theoretical capacity. Max. lump size applies where unsized material consisting of coarse and fines where 25% of volume does not exceed max. lump size and average size of balance does not exceed one-half of the max. lump size. When lumps exceed 25% of volume or material contains hard unbreakable lumps, consult equipment manufacturer. Material characteristics strongly affect screw feeder performance—verify any selection with the equipment manufacturer (Adapted from Link-Belt Catalog 1000)

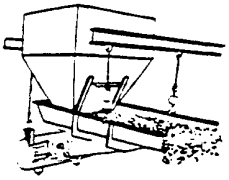
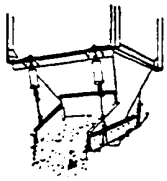
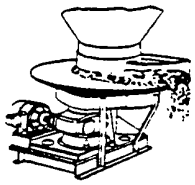
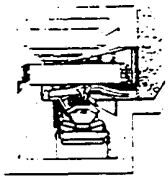
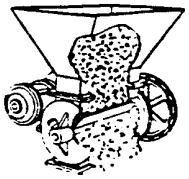
Uniform diameter screws are used for fine, free-flowing materials. Tapering diameters will handle material containing fair percentage of lumps. For very free-flowing material use longer shrouds, extra short-pitch screws to reduce flushing along screw

Feeder width (inches)	Max. lump size (inches)	Stroke (inches	Capacity: Cu ft per hr	tons per hr
18" x 90" long	6	5	1634	82
	6	6	1961	98
	6	8	2616	132
24" x 96" long	10	5	2735	136
	10	6	3270	164
	10	8	4365	218
30" x 102" long	12	5	3859	192
	12	6	4630	232
	12	8	6175	308
36" x 114" long	15	5	5624	282
	15	6	6748	338
	15	8	8999	450

Note: Capacity based on handling material weighing 100 lb per cu ft. Capacity based on crank speed of 50 rpm; recommended crank shaft speed—10 to 60 rpm. Capacity based on skirt plates loaded to 75% of theoretical max. cross section, and directly proportional to weight of material. Max. size lumps not to exceed

Handles almost any bulk material, but best suited for material that is damp or contains large lumps. Not recommended for handling highly abrasive materials. This feeder less limited by size of material than some other types

Table X Types of feeders

TYPE OF FEEDER	GENERAL INFORMATION
Vibratory, electric 	Material on feeder pan is moved by being thrown upward and forward by the vibration of the pan or trough which is mounted on springs. Actuating mechanisms use magnets and electromagnets, operated by single-phase ac; or use vibrators driven by pulsating dc which is produced by a rectifier. Headroom required is minimal, and discharge can be located very close to the belt or unit being fed. Feeders may be installed horizontal or up to 10 deg. Feeders are self-cleaning and may be fitted with grizzly extensions
Vibrating, mechanical 	Material on feeder pan is moved by being thrown upward and forward by the vibration of the pan or trough which is mounted on springs. Actuating mechanism for inducing vibrations are mechanical devices such as eccentric shafts. Entire unit is usually mounted on coil springs. Headroom required is minimal, and discharge can be located very close to the belt or unit being fed. Feeders may be installed horizontal or up to 10 deg. off horizontal. Feeders are self-cleaning, and may be fitted with grizzly extensions
Rotary table—stationary plow 	This unit consists basically of a disc or plate (usually horizontal) from which material is scraped off by a plow at a regulated volumetric rate. Generally, table feeders are located directly under a hopper opening. Material on plate attains its natural angle of repose. As the table rotates, the stationary plow scrapes material over the edge. Capacity may be varied by use of variable-speed drives, or changing height or angle of plow
Rotary plow—stationary table 	This feeder consists of a rotating plow which moves back and forth along a stationary table or shelf. The plow is usually mounted on a self-propelled, track-mounted carriage located over a belt conveyor. As the plow rotates, it moves between predetermined points, and moves material off the shelf or shelves. Capacity may be varied by changing rate of travel along shelf, or changing height and angle of plow
Rotary vane 	The rotary vane feeder consists of a number of pockets formed by a series of vanes mounted on a shaft. The vane type has a positive discharge action. Feeders are generally connected to overhead storage bins or collecting hoppers. The rate at which material is discharged is determined by speed of feeder rotation. This speed may be controlled by one of the several types of variable-speed drives. A rotor with adjustable tips is available for use when wear of vanes must be compensated for

CAPACITY DATA

Feeder size pan width x pan length	Capacity Cu ft per hr	Capacity tons per hr	Link-Belt Model No.
10" x 36"	500	25	F-22 DT
18" x 42"	1,000	50	F-33 DT
24" x 48"	2,000	100	F-44 DT
36" x 60"	4,000	200	F-45 DT
48" x 60"	10,000	500	F-55 DT
48" x 60"	10,000	500	F-66 DT
60" x 72"	20,000	1,000	F-86 DT

Note: Capacity based on handling material weighing 100 lb per cu ft, and with troughs sloping 6 degrees downgrade (Adapted from Link-Belt Catalog 1000)

MATERIALS HANDLED

Practically every type of bulk material can be handled by vibrating feeders, in an almost infinite size range. These feeders are not recommended for sticky materials. The electrical type is used where more precise control of feed rate is required

Feeder size (inches) width x length	Capacity—tph 0° downslope	5°	10°
Synchromatic			
36 x 60, 96, 120	310	380	450
48 x 72, 96, 120, 144	510	600	760
60 x 72, 96	700	800	950
Geared counterweight			
48 x 96, 120, 144	560	650	850
60 x 72, 96, 120, 144	700	800	1,000
72 x 96, 120, 144	940	1,200	1,550

Note: Capacity based on handling sand weighing 90 lb per cu ft, with 3% moisture (Adapted from Link-Belt Book 2969)

Practically every type of bulk material can be handled by vibrating feeders, in an almost infinite size range. These feeders are not recommended for sticky materials. Often used for general applications such as feeding a crusher, where precise control over feeding rate is not required

Nominal table diam (inches)	Table speed rpm	Capacity cu ft per hr min.	Capacity cu ft per hr max.	Capacity tons per hr min.	Capacity tons per hr max.
48	6.3	235	515	11.8	26.0
60	5.4	290	630	14.5	31.5
72	5.4	380	825	19.0	41.3
84	6.0	525	1140	26.3	57.0

Note: Capacity based on handling material weighing 100 lb per cu ft. Capacity is directly proportional to weight of material (Adapted from Link-Belt Catalog 1000)

This feeder is used for handling sticky or lumpy materials as well as comparatively fine materials. It is not recommended for regulating the flow of materials that tend to flood

Each of these units is custom-built to meet the requirements of a specific job. As a result, no table of definite capacities for a fixed number of sizes can be provided. This type of feeder has been furnished with capacities ranging from 300 to 3,500 tph

This feeder is suggested for reclaiming ore, sinter, limestone, and most materials that will not flush thru the opening and off the shelf. It is said to be particularly advantageous for handling material that tends to pack or arch

Feeder size (inches)	Capacity 5 rpm	10 rpm	15 rpm	20 rpm	25 rpm	30 rpm	units
6"	1.50	3.00	4.50	6.00	7.50	9.00	TPH
	0.50	1.00	1.50	2.00	2.50	3.00	CFM
8"	3.00	6.00	9.00	12.00	15.00	18.00	TPH
	1.00	2.00	3.00	4.00	5.00	6.00	CFM
10"	5.25	10.50	15.75	21.00	26.25	31.50	TPH
	1.75	3.50	5.25	7.00	8.75	10.50	CFM
12"	10.80	21.60	32.40	43.20	54.00	64.80	TPH
	3.60	7.20	10.80	14.40	18.00	21.60	CFM
14" x 20"	19.50	39.00	58.50	78.00	97.50	117.00	TPH
	6.50	13.00	19.50	26.00	32.50	39.00	CFM

Note: Capacities are based on use of "H" Series heavy duty feeder. Capacity based on handling material weighing 100 lb per cu ft (Adapted from Prater Pulverizer Co. Bulletin P-64)

Used for volumetric feeding of wide range of dry pulverized or granule material, especially those which tend to arch, such as lime and cement. Except for special types, vane feeder should not be used on wet, sticky material, since it relies on gravity to make it self-cleaning

Please turn page

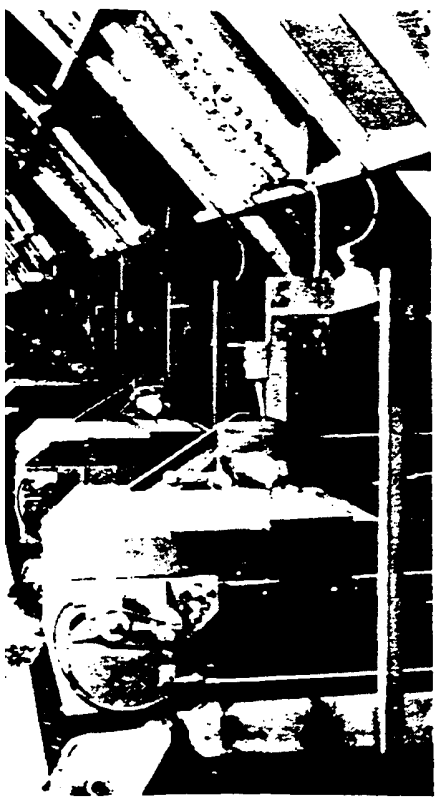
STOCKPILING OF MATERIALS

continued . . .

In the following pages, we shall attempt to provide data that may be helpful to the operator who needs a feeder for his plant. These tables are for guidance around the obvious pitfalls, and are probably better indicators of what feeders should *not* be used in a given case, rather than exact recommendations as to what can be used.

Table XI provides a recommendation for the twelve principal types of feeders as applied to various stockpiled materials. It will be obvious that many qualifying conditions have been omitted from this table. As a consequence, there is a need to correct the obtained results.

Table IX shows a range of capacity for each feeder and indicates the effect of various material characteristics. The recommendations of this table may be used to correct or modify results obtained from Table XI.



The Waytrol feeder consists of three principal parts: the feeder, the weigh belt and the control unit
(Courtesy, The Jeffrey Manufacturing Co.)

Table X is a summary of the average capacities that may be expected from the principal types of feeders under carefully stated conditions of loading and operating speed. Table X also has general information on the unit and the types of material with which it is generally used. It should be realized that each material is different because of unique conditions of size, shape, moisture content, etc. Therefore, it is well to test each material before any final choice of a feeder is made.

Table XI—Feeder recommendations for stockpiled materials

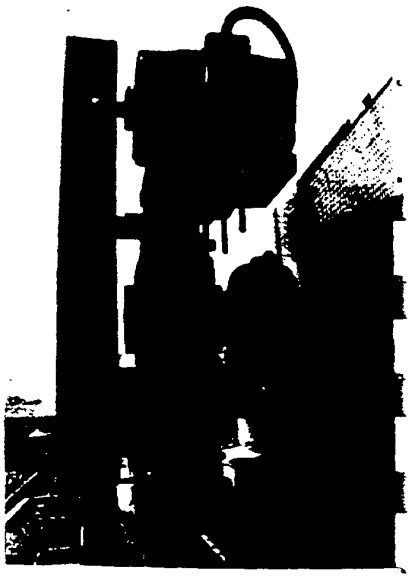
Stockpiled materials	Feeder recommendations: Apron (pan) feeder	Belt feeder—w/rolls	Belt feeder—w/slide plate	Flight feeders	Screw conveyor—uniform diameter	Screw conveyor—tapering diameter	Reciprocating plate feeder	Vibrating—electrical	Vibrating—mechanical	Table, rotary, w/stationary plow	Plow, rotary, w/stationary table	Rotary feeder—open type w/vanes
Asbestos ore or rock	NR	X	P	F	F	F	X	X	X	X	NR	NR
Asphalt, crushed, ½" or under	NR	X	X	X	X	X	X	X	X	F	NR	NR
Bentonite, crude	X	X	F	O	NR	NR	X	X	X	F	NR	NR
Bentonite, 100-mesh, or under	NR	O	O	X	O	O	O	O	O	NR	NR	X
Cement, portland	NR	P	F	X	X	X	NR	NR	NR	NR	NR	X
Cement, clinker	X	X	NR	X	NR	NR	X	F	F	NR	NR	NR
Chrome ore	X	X	NR	O	O	O	O	O	O	O	X	NR
Clay, calcined	NR	NR	P	F	F	F	F*	F*	F*	P	NR	X
Clay, fine, dry	NR	P	F	X	X	X	F	F	F	X	X	X
Clay, lumpy, loose	X	X	P	NR	NR	NR	X	X	X	X	X	NR
Coal, anthracite	X	X	P	O	O	O	X	X	X	X	X	NR
Coal, bituminous, mined, -50m	NR	F	X	O	O	O	O	O	O	O	NR	X
Coal, bituminous, run of mine	X	X	P	NR	NR	NR	P	F	F	F	X	NR
Coal, bituminous, sized	X	X	X	P	NR	NR	X	X	X	F	X	NR
Coal, bituminous, slack, -½"	X	X	X	P	NR	NR	X	X	X	F	NR	NR
Coal, bituminous, not cleaned	X	X	F	P	NR	NR	X	X	X	NR	X	NR
Dolomite, lumpy	X	X	F	F	NR	NR	X	X	X	NR	NR	NR
Feldspar, ground, ⅛" or under	NR	F	F	X	X	X	F	O	O	NR	NR	NR
Feldspar, powdered	NR	F	F	F	X	X	O	O	O	NR	NR	NR
Fluorspar	F	X	F	O	NR	NR	X	X	X	F	NR	NR
Granite, broken	X	X	F	NR	NR	NR	X	F	F	X	X	NR
Gravel, screened	F	X	F	O	O	O	F*	F*	F*	F	NR	NR
Gypsum, calcined, -½"	NR	X	P	O	NR	NR	X	X	X	NR	NR	NR
Gypsum, calcined, powdered	NR	X	X	X	X	X	NR	P	P	NR	NR	X
Gypsum, raw, -1" or under	X	X	F	F	NR	NR	X	X	X	O	NR	NR
Kaolin clay, 3" or under	X	X	F	O	NR	NR	F	O	O	O	O	NR
Kaolin talc, 100-mesh or under	NR	X	F	X	X	X	X	X	X	NR	NR	X
Lignite, air-dried	O	X	NR	O	O	O	O	O	O	X	X	NR
Lignite, raw	O	O	O	O	O	O	O	O	O	O	O	NR
Lime, ground, ⅛" or under	O	O	O	O	O	O	O	O	O	O	O	O
Lime, hydrated, -⅛"	O	O	O	O	O	O	O	O	O	O	O	O
Lime, pebble	P	F	X	X	X	X	X	O	O	NR	NR	NR
Limestone, agricultural, -⅛"	P	X	X	X	X	X	X	X	X	F	P	X
Limestone, crushed	X	X	X	F	NR	NR	X	X	X	X	P	NR
Limestone dust	O	O	O	O	O	O	O	O	O	O	O	O
Manganese ore	X	F	P	NR	NR	NR	X	X	X	NR	NR	NR
Marble, crushed, ½" or under	X	X	F	P	F	NR	X	X	X	P	P	NR
Phosphate sand	P	X	P	P	P	P	F	F	F	F	P	NR
Pumice, ⅛" or under	P	X	P	P	F*	F*	F*	F*	F*	F*	P	NR
Sand, bank, damp	P	X	P	P	F	P	X	X	X	P	P	NR
Sand, bank, dry	P	X	P	P	F	F	X	X	X	P	P	NR
Sand, foundry, prepared	P	X	P	P	P	P	X	X	X	X	P	NR
Sand, foundry, shakeout	X	X	P	NR	NR	NR	X	X	X	P	P	NR
Sand, silica, dry	P	X	P	P	P	P	X	X	X	P	P	NR
Shale, crushed	F	X	F	F	F	F	X	X	X	P	P	X
Slag, furnace, granular	F	X	P	P	P	P	X	X	X	P	P	X
Slag, furnace, lumpy	F	X	P	P	NR	NR	X	X	X	P	P	NR
Slate, crushed, ½" or under	F	X	F	F	F	F	X	X	X	P	P	X
Slate, ground, ⅛" or under	F	X	F	F	F	F	X	X	X	P	P	X
Traprock, crushed	X	X	F	P	P	P	F	F	F	P	P	NR
Vermiculite, expanded	O	O	O	O	O	O	O	O	O	O	O	O
Vermiculite ore	X	X	X	NR	NR	NR	X	X	X	NR	X	NR

Key: X—excellent application, F—fair application, P—poor application, NR—not recommended, O—consult manufacturer, *consider A. R. liners

STOCKPILING OF MATERIALS, Part 8

Belt conveyor design— a study in versatility

- **Belt conveyors provide high capacity for low power and deliver uniform volumes of almost any material at any speed. They are low in initial cost and maintenance, yet simple, quiet, reliable and adaptable to many applications**



Good pulley design features guarded, amply sized lagged pulleys. Installation uses Torque-Arm reducer, one of many types available

The belt conveyor is an indispensable tool in the field of materials handling. These endless rivers of rubber are the flexible, versatile sinews of modern industry. Without them, the wheels of industry would grind slowly to a halt.

We will outline the factors to be considered in conveyor system design and offer some practical suggestions for increasing the efficiency and life of this vital system. The principles described apply to all sizes and types of belt conveyors, but need additional qualification to apply to systems other than smaller, simpler installations.

A conveyor consists of a fabric belt, usually rubber covered, that passes around two cylindrical pulleys located at either end.

The top surface of the belt is used to transport materials. And in most bulk-handling applications, it is given a trough-like shape by various arrangements of rolls, or idler stands. The trough shape increases the volumetric carrying capacity of the belt and also reduces the amount of sag that occurs between idlers.

The belt conveyor may be arranged to operate in the horizontal plane, or at various angles. The maximum allowable angle will be determined by the type of material being carried and the angle at which it begins to roll or slip along the surface of the belt due to the force of gravity. Most materials cannot be conveyed on angles steeper than 20 deg.

The loading hopper receives the material and is used to funnel it onto the belt surface. Usually, the downstream end and sides of the hopper are fitted with plates to hold the material on the belt and confine and guide it until it can stabilize its place on the belt.

The inner faces of the vertical plates are usually covered with strips of rubber which project below the bottom edge of the plate and nearly touch the conveyor belt. These skirts reduce the damage caused by rocks or lumps that may be wedged between the skirt-boards and the belt.

The skirt-boards should extend along the belt until the loaded material comes to rest on the belt.

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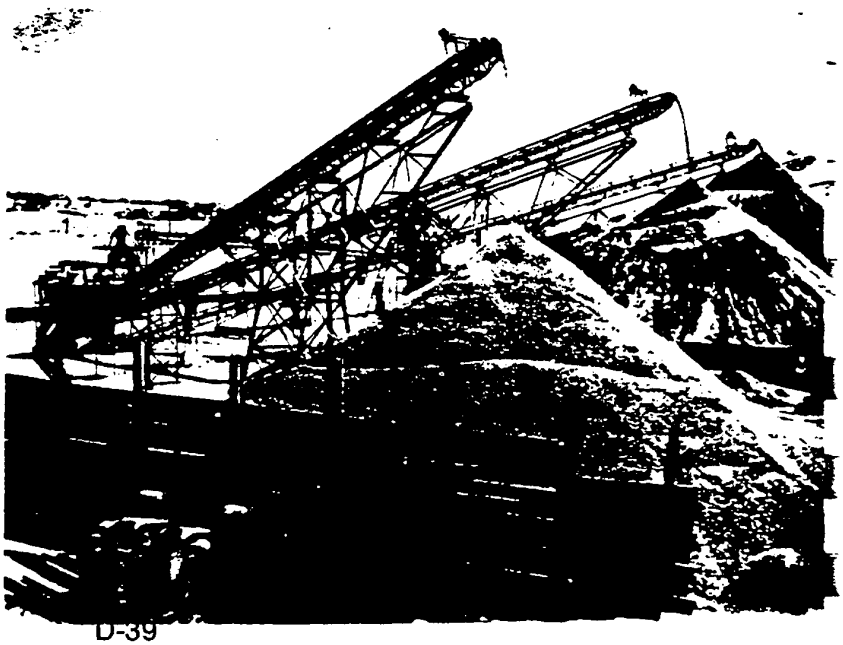
Above: Two types of conveyor supports

Below: Typical stockpiling and reclaiming arrangement for medium-sized crushed stone plant



STOCKPILING OF MATERIALS

continued . . .

Usually, a board length of three to four times the belt width is adequate. To prevent wedging between belt and skirt-board, the bottom of the skirt-board should have an increasing clearance in the direction of belt travel. A taper of ¼ in./ft is standard, while ½ in./ft is recommended where extremely coarse material is carried.

In handling large lumps of material, the loading section may be equipped with impact type troughing idlers which cushion the impact of the material falling on the belt.

The pulleys are usually stationary, although the last pulley may be arranged with a screw take-up which is used to take up the stretch in the belt and maintain the slack-side tension at a satisfactory level to prevent slippage at the drive pulley. The screw take-up manually adjusted, is used on belts up to 50 ft on centers.

The supporting structure for all of the conveyor machinery can be trussed sections, simple channels or wooden beams. The choice depends on the distance between vertical points of support. For conveyors that are out-of-doors and run for considerable distances, steel trusses are generally recommended. However, in some recent installations, prestressed concrete channels have been used successfully.

When selecting the depth of truss section, give consideration to the deeper sections. Their greater load-carrying ability may permit longer spans and fewer supporting bents or towers, and so prove more economical than shallow sections that require more frequent supports.

The top chord of the truss or the upper flange of the channel is usually covered with a light gauge steel sheet to catch material that may fall off the troughed section on to the return belt below. Dribbles of material can soon foul up the pulleys and cause damage to the underside of the belt itself. The deck plate (in the order of 24 gauge steel) also provides a stiffening action for the supporting angles or channels.

The troughing idler stands are set on top of the deck and bolted into the structural support members. The spacing of these idlers is determined by the belt tension and the weight of the belt plus material. The idler-to-idler span is selected so that belt sag will be limited to two percent of the span. On small conveyors, a single uniform spacing is generally used; while on large conveyors, the spacing may be varied with the tension in the belt.

There are a great many different types of idlers, built for different classes of service. Table XII offers some indication of the various idlers available.

Troughing idlers which are so mounted that they tend to pivot about a center vertical axis and guide the belt back onto its normal pathway are called training or guide idlers.

Some companies install the regular troughing idlers with a slight tilt (1 or 2 deg) in the direction of belt travel, to supplement the guiding effect of the training idler. The troughed training idlers are usually located 50 ft from the head pulley and tail pulley and at 50-ft centers all along the belt. Return training idlers are on the same centers.

Where the material being conveyed must be protected from the effects of wind and rain, a partial covering can be made of corrugated metal sheets rolled into an arch. Usually, if a full covering is used, removable panels are installed along the walkway side of the conveyor to permit inspection and servicing of the belt and idlers. Of course, the entire conveyor and walkway may be enclosed in a gallery if all-weather operation is necessary.

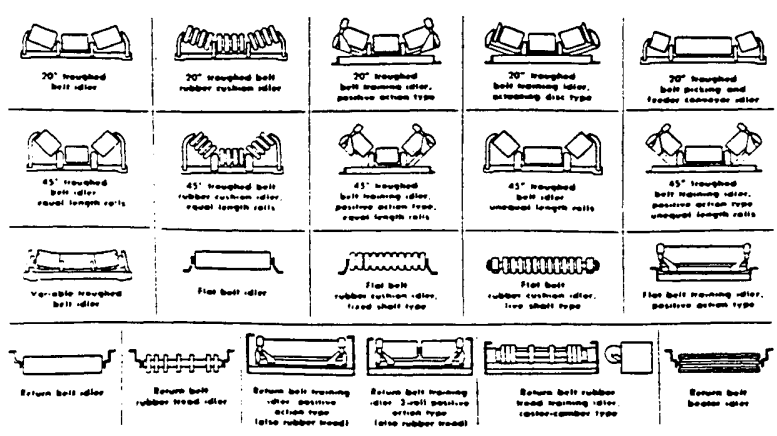
The conveyor belt usually consists of several plies of fabric covered with and separated by rubber to resist the effects of abrasion and mildew. The fabric may be cotton duck, dacron, rayon, or nylon fibers, or a combination of these materials. The top side of the belt usually has a heavier cover to resist cutting, gouging and abrasion; and to prolong the wear life. The bottom side of the belt has a thin coating of rubber ($\frac{1}{32}$ or $\frac{1}{16}$ in.) to provide a protective seal and increase the friction between the belt and the drive pulley.

The drive for belt conveyors is generally located at the head or elevated end of the conveyor. The drive may be arranged above the belt, below the belt, or off to one side. The type of drive reduction that is provided will influence this arrangement, too.

In most cases, the driver will be an electric motor. Other prime movers may be required by local conditions. If electrical power is not available, it may be desirable to provide generating capacity so that the conveyors may be powered by electric motors. This arrangement will permit remote control operation and provide a more flexible installation.

The drive reduction may be accomplished in many different ways. Standard speed motors, gear reducers, V-belts or chain drives may be employed. The shaft-mounted reducer with a torque arm and V-belts provides a compact, economical, and efficient means of reducing motor

Table XII—23 of the more common types of conveyor idlers (Courtesy, Link-Belt Co.)



speed as much as 15 hp. These reducers are usually provided with internal back stops which prevent the backward and downhill movement of the belt in the event of a power failure.

In some cases, gearmotors with sprockets and roller-chains are used to drive the conveyor. This design is generally most economical in the 15 to 100-hp range. Over 100 hp, direct-connected parallel-shaft reducers provide the finest drives when coupled to the shafts with forged steel gear couplings.

The head terminal consists of the head pulley, shafting, pillow blocks, and supporting structure.

Generally, the smaller belt conveyors are driven at the head end. As the belt approaches the head pulley, tension reaches a maximum value. When the belt passes around the pulley, additional stresses are placed on the conveyor belt. Stress is most critical for thick belts that must wrap around small-diam. pulleys.

It is fairly good sense, therefore, to use larger pulleys in preference to smaller ones. The expenditure of a few extra dollars for the larger pulley may easily save hundreds of dollars in extended belt life.

The use of self-aligning ball-bearing pillow blocks is fairly universal today. Babbitted bearings are still used in many places, but they require better lubrication and more attention than the anti-friction types.

While at the head terminal, a few comments on tramp iron protection seem appropriate. Three practical methods are available today. They are: (a) magnetic pulleys; (b) suspended magnets; and (c) metal detectors.

Magnetic pulleys have been available for quite some time but, recently, Indiana General Corp. invented a barium ferrite ceramic magnet called Indox, which obviates the faults of the old electromagnets and the old Alnico magnets.

Suspended magnets may be permanent or electro. Generally, for the large industrial application, the electro type is required. Although the magnet may be applied over the belt anywhere, best results are obtained when it is suspended in the chute over the head pulley. In this way, the ferromagnetic materials can move through a loose bed of material before high falling velocities are attained.

Please turn page

Belt conveyor design form

Job #_____; Conveyor #_____; E #_____; Calculated by _____; Date_____

Note: Numbers in left margin are page numbers in *Goodyear Handbook of Belting*, 1953 Edition, and *Belt Conveyors*, by Hetzel & Albright, Third Edition, 1941.

GENERAL DATA:

G64 Material: _____; Unit weight: _____ pcf

Lump size: _____; Size distribution: _____

Capacity: _____tph ave.; _____tph max.

Moisture content_____; Material temperature_____

ARRANGEMENT DATA:

G177 Incline: Max. angle_____deg_____; (Bevel -_____in. 12)

H213 Act. angle_____deg_____; (Bevel -_____in. 12)

Horizontal projection: _____ft_____in. Note: where H exceeds 25 ft. check G31

Vertical lift (H): _____ft_____in.

Slope length (L): _____ft_____in.

Drive preference: _____

BELT CAPACITY:

G62 For sized, unsized, lumps_____in. size, use minimum belt of_____in.

H216

G63 Max. speed for_____in. belt handling this material is_____fpm

G53 For_____pcf material @_____tph use_____in. belt @_____fpm

H197 % Loading: _____act/_____max = _____% (try for 65%)

POWER REQUIREMENTS:

Assuming anti-friction type idlers:

G36 Empty_____in. belt_____ft long req._____hp x _____fpm / 100 = _____hp

H139

G36 Horizontal movement of_____tph over distance of_____ft = _____hp

H140

G38 Elevate material: _____tph for lift of _____ft = _____hp

H142

G71 Trippers: _____tph for_____trippers = _____hp

H143

Total hp required at head shaft: _____hp

TENSIONS:

Effective tension: $T_e = \frac{\text{Total hp} \times 33{,}000}{\text{S (in fpm)}}$ = _____ x 33,000 = _____#

G123 "K" = _____for_____deg angle of wrap._____pulley, and

H146

G143 _____type of take-up.

Tight-side tension: $T_1 = T_e\ (1+K)$ =_____(1.) = _____#

Slack-side tension: $T_2 = T_e\ (K)$ =_____(0.) = _____#

BELT: Ply and duck:

G111 Using_____oz duck: _____in. belt_____ply @_____#/pi. Tb=_____#

H169

Using_____oz duck: _____in. belt_____ply @_____#/pi. Tb=_____#

G113 Min plies for_____in. belt handling_____=_____ply_____oz duck

H168

Max plies for_____in. belt handling_____=_____ply_____oz duck

Use: _____in._____ply_____oz duck belt; Tb =_____#

BELT: Carcass and cover:

Time cycle: $TC = \frac{2\ L}{S}$ = 2(_____) =_____minutes

where L is distance cc.; S is speed, in fpm, of belt.

G130 Belt stress rating: Act/allow. = _____/ _____= _____%

H169

G130 Pulley rating: _____% of stress: act/allow. =_____/ _____=_____%

H170

G117 Grade of friction coat: _____#

H172

G121 Cover thickness: Carrying side :_____psi x_____in. thick

H174

G122 Pulley side :_____psi x_____in. thick

IDLERS:

G162 Troughing:_____pcf matl on_____in. belt requires_____in. spacing

H118

Return: _____in. spacing

PULLEY:

G130 Head:_____in. diam x_____in. face; bare, lagged, straight crowned.

Tail:_____in. diam x_____in. face.

Snub:_____in. diam x_____in. face; Bend:_____in. x_____in. face.

rpm head pulley = S/π Diam (ft) =_____/π_____=_____rpm

SHAFTING: (From Dodge load tables for pulleys and shafts)

R = T_1 + T_2 =_____+_____=_____#

V = K x T_e =_____x_____=_____#

K taken as _____for_____in. ctr brg to edge of rim.

Head:_____in. shaft with Hub No._____for_____in. x_____in. pulley

Tail:_____in. shaft with Hub No._____for_____in. x_____in. pulley

Snub:_____in. shaft with Hub No._____for_____in. x_____in. pulley

Bend:_____in. shaft with Hub No._____for_____in. x_____in. pulley

MOTOR SIZE:

Total hp from power requirements: _____hp

G72 hp loss in drive selected: _____hp

Required hp: sum of above: _____hp

G133 Use:_____hp squirrel cage motor, design B, C, _____ph_____cy_____v

_____rpm, open, DP, SP, TENV, TEFC, frame_____

Shaft diam:_____; Key:_____

BRAKE SIZE:

hp to elevate material _____hp

hp to run empty _____hp

hp to move horizontally _____hp

Sum: Last two items. _____hp-_____hp

Total hp to be taken up by brake =_____hp

Torque at head pulley = hp x 33,000 S =_____ x 33,000 _____=_____ ft-lbs

TAKEUP:

Screw-type:_____% ctr distance (_____ft) = _____in. travel.

G143

Automatic:_____% ctr distance (_____ft) = _____in. travel.

Slack-side tension, T_2 = _____#

G323 Wt of belt =_____# ft x_____ft rise _____#

Difference _____#

Wt of gravity takeup = 2 times difference =_____#

On installation, locate takeup at_____% or _____ft from bend P

DRIVE:

Type of drive:_____

Head pulley rpm_____; head pulley_____:_____

Reducer in rpm_____; reducer in_____:_____

Speed ratio _____

Motor out rpm_____; motor out_____:_____

Speed ratio _____

STOCKPILING OF MATERIALS

continued . . .

Metal detectors are more than tramp iron protection. Indiana General, for example, can supply a high intensity detector capable of locating a .02-in. diam sphere in a box of cereal on a conveyor belt. These units are scaled up for power plant, rock, and other conveyor belt applications.

The discharge chute collects the material as it falls from the head pulley and funnels it on its way to another conveyor, storage unit, or process vessel. These chutes are generally fabricated from steel plate (⅛ to ⅜-in. thick) and hung from the head terminal support structure.

In cases where the belt velocity is high and the material abrasive, the inner surfaces of the chute are lined with abrasion-resistant materials.

Rubber belting, sheet rubber, ceramic blocks, and A-R steels can be used to effectively reduce the abrasive wear on the chute proper. Usually, the lighter plate is used for chute construction when liners are to be installed. When magnets are used, the utmost care must be exercised. Either non-magnetic materials such as class 300 stainless should be used, or the chutes kept well away from the magnet to prevent the induction of a magnetic field in the chute which might attract iron.

When handling wet, sticky materials, it is desirable to wipe the fines off the carrying surface of the belt. This cleaning should normally be done just after the belt passes over the head pulley. Rotating bristles or rubber-vaned brushes driven at high speed usually do a good job of cleaning dry materials from the belt. Unfortunately, they wear rapidly and require considerable maintenance.

The only cleaning necessary on the pulley side of the belt is the removal of material which may fall on the return run and be carried between the belt and tail pulley. Plows set immediately in front of the tail pulley usually are adequate for this purpose. However, sometimes, "slat" or "wing" pulleys are required.

The use of a gravity take-up is recommended for belts over 50 ft on centers. They are usually located at the point of lowest tension in the belt, which is just behind the head pulley.

The counterweight provided plus the weight of the take-up assembly, will equal two times the slack-side tension of the belt. The counterweight box can be fabricated from steel plate and arranged to receive scrap steel plate, punchings, or concrete, in the required amount.

If the counterweight is located out-of-doors, be sure to provide drain holes in the bottom of hollow counterweight boxes. When the proper amount of counterweight is applied, the slackside tension is maintained at a constant value and stretch in the belt is removed automatically.

The gravity take-up should be installed with sufficient height so that it can adjust freely to the belt loading. Take-up pulley travel can vary from 2 to 5 percent of the belt center distance, and is a function of belt strength, fabric, and conveyor tensions. Other automatic take-up systems have been used successfully in which air or hydraulic cylinders, or springs have replaced the counterweights. When the automatic take-up is used, a fixed tail terminal should be used.

The return idlers are straight, cylindrical rolls. They may be rubber-covered, and are available in 4 in. diam (minimum), but for most industrial applications, 5 or 6-in. diam are frequently used. The return idlers are usually suspended from brackets fastened to the bottom of the troughing idler supports. To avoid excessive sag in the flat return belt, these rolls are usually spaced at a maximum of

Table XIII—Weight of material

Material	Lb. per cu. ft.	Angle of repose	Abrasiveness*
Asbestos ore or rock	81		VA
Asbestos shread	20-25		MA
Ashes, fly	40-45	42-deg.	VA
Cement, Portland	94		MA
Cement, clinker	75-95	30-40-deg.	VA
Clay, dry, fines	100-120	35-deg.	VA
Clay, dry, lumpy	60-75	35-deg.	VA
Dolomite, lumpy	90-100		MA
Earth, excavated, dry	70-80	35-deg.	NA
Earth, wet, containing clay	100-110	45-deg.	MA
Granite, 1½ to 2-in. lumps	85-90		VA
Granite, ½-in. screening	80-90		VA
Granite, broken	95-100		VA
Gravel	90-100	40-deg.	MA
Gypsum, ½ to 3-in. lumps	70-80	30-deg.	NA
Gypsum dust	60-70	42-deg.	NA
Lime, ground, ⅛-in. and under	60	43-deg.	NA
Lime, hydrated, ⅛-in. & under	40	40-deg.	NA
Lime, hydrated, pulverized	32-40	42-deg.	NA
Lime, pebble	53-56	30-deg.	NA
Limestone, agricultural, —⅛-in.	68		MA
Limestone, crushed	85-90	35-deg.	MA
Limestone, dust	80-85		MA
Marble, crushed, ½-in. & under	90-95		MA
Pumice, ⅛-in. & under	40-45		VA
Quartz, 1½ to 3-in. lumps	85-95		VA
Quartz, ½-in. screening	80-90		VA
Rock, soft, excavated with shovel	100-110		MA
Sand, silica, dry	125		VA
Sand, bank, damp	110-130	45-deg.	VA
Sand, bank, dry	90-110	35-deg.	VA
Sandstone, broken	85-90		VA
Shale, broken	90-100		MA
Shale, crushed	85-90	39-deg.	MA
Slag, blast furnace, granular, dry	60-65	25-deg.	VA
Slag, blast furnace, granular, wet	90-100	45-deg.	VA
Slate, 1½ to 3-in. lumps	85-95		MA
Slate, crushed, ½-in. & under	80-90	28-deg.	MA
Trap rock, 2-3 in. lumps	100-110		VA
Trap rock, ½-in. screenings	90-100		VA
Vermiculite, expanded	16		NA
Vermiculite, ore	80		MA

*NA—non-abrasive; MA—mildly abrasive; VA—very abrasive

Table XIV—Max. angle of incline

Material carried	Maximum angle (degrees)
Coal, sized	16
Earth	20
Gravel, sized, washed	12
Gravel, sized, unwashed	15
Gravel, unsized	18
Gravel, bank run	20
Sand, dry	16
Sand, moist	20
Stone, sized, lumps over 4-in.	15
Stone, sized, lumps under 4-in.	16
Stone, unsized, lumps over 4-in.	16
Stone, unsized, lumps under 4-in.	18
Stone, fines ⅜-in. and under	20

10 ft. Since the carrying side of the belt rides on these idlers, there is a tendency for them to collect large amounts of sticky fines. The effectiveness of the belt wipers or cleaners can be gauged by the amount of material that collects beneath the return idlers.

When return idlers are hung from the bottom flange of a channel support, it is often a good idea to provide a spreader between the channels to keep the lower flanges from twisting outward, and dropping the return out of its bracket. A pipe and rod combination can be used effectively for this situation. The pipe is cut to the desired length between channels. The rod passes through the pipe, emerges from the sides of the two channels, and the nuts are tightened down.

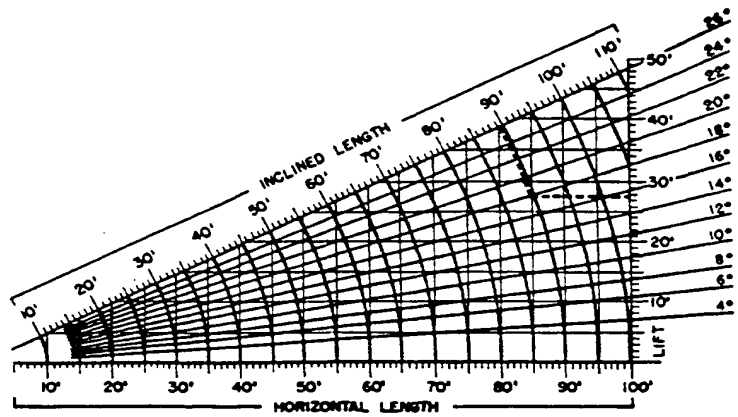


Fig. 15—Table for estimating conveyor slope. To find inclined length and/or degree of slope for conveyors, the horizontal distance and vertical lift must be known. The example, indicated by dotted lines, shows that a conveyor with a horizontal distance of 85 ft and a lift of 27½ ft would have an inclined length of 89½ ft and a slope of 18 deg (Courtesy, Hewitt-Robins)

Training idlers are often desirable on the return side of the belt. For best results, return training idlers should be located on the same centers as those on the carrying run of belt (see Table XII.)

The bent, or cross-braced A-frame, is the most commonly used support. This structure is usually made of steel, either angles, channels, wide-flanged beams, or pipe. It can also be constructed of timber or concrete, if desired. When a bent is located close to a stockpile, it should be of heavy, rugged construction to withstand the action of the material and equipment that may be used around the pile. Cantilevered truss sections are generally most satisfactory for stockpile use.

All machinery requires periodic inspection and maintenance. When this machinery is elevated and extends over some distance, a good access walkway is vitally important. A well-supported walkway with proper handrails and a non-slip decking will encourage workers to make their rounds regularly. Expanded steel grating makes a good deck, provided the heavier sections are used. The lighter sections have too much spring and give one an uncomfortable feeling of being airborne.

When an inclined section of belt conveyor is turned into the horizontal plane, a bend pulley can facilitate the change in direction. If a smoother transition is desired, several troughing idlers may be located close together at different elevations along the desired belt path. This arrangement has the advantage of introducing less "untroughing" of the belt.

When trusses of different depths are connected together, a short transition section will simplify the process and provide a better appearance.

For exploring some of the facets of belt conveyor design, we have prepared a simple design form as an outline and a place to record determinations as they are made. We have successfully employed this form for many years, in the design of the smaller, relatively short belt conveyor.

As with all materials-handling equipment, a description of the material to be handled is the first consideration. Weights of the various bulk materials may be approximated if the actual field-weight of the material is not known. A short table of material weights is given in Table XIII.

Information on the arrangement of the individual conveyor should include a sketch of the closure that is required. Data should be obtained on the equipment unit to which the material is to be delivered. The maximum practical angle at which a belt conveyor will carry a given material is determined by such characteristics as uniformity, shape of lumps, moisture content, angle of repose, and flowability.

Factors that govern the behavior of materials on an inclined conveyor are belt speed, degree of loading, and method of loading. Table XIV provides conservative maximum angles at which belt conveyors will carry materials safely, even at high speeds, when loaded intermittently. Most conveyor experts recommend inclines somewhat less than these maximums (about 5 deg), particularly when handling materials that contain large lumps. Fig. 15 presents in graphic form, the relationship between horizontal distance, rise, conveyor length, and angle of incline.

Determining the capacity of a belt conveyor is a critical step in the design procedure. It is a common mistake for the inexperienced designer to base his design on the average rate of material flow rather than on the peak loads. In practice, most conveyor systems are forced to carry a widely fluctuating load, which in extreme cases, may be two or three times the hourly average. If an excessive peak tonnage is encountered, the designer should give consideration to adding surge bins and feeders to average out the heavy overloads.

A convenient chart, from which the capacity of a given belt may be readout for a series of different belt speeds, is provided in Table XV. Note, at the extreme right of this table, the maximum lump size that is recommended for each belt width. Very often, on conveyors handling coarse material, the size of the belt will be determined by particle or lump size, rather than tonnage requirements.

Belt speed is an important factor

Please turn page

STOCKPILING OF MATERIALS

continued . . .

when handling dusty and fragile materials. With dusty materials, 300 fpm must be considered the maximum speed. Generally, fragile materials and very abrasive materials will be carried at even slower speeds. A high percentage of large lumps will also limit the practical speed. This danger is much greater in a narrower belt, and therefore, it is customary to relate belt speed with belt width. Table XVI gives maximum recommended belt speeds for several classes of material.

The use of a narrow belt is unwise for several reasons—its inability to carry large lumps, its failure to trough properly, its lack of sufficient strength to withstand the tensile stresses in the belt.

Percent of loading, as obtained from the ratio of actual capacity to maximum capacity, should be something less than 100 percent. Most manufacturers recommend 65 percent for normal loading conditions. For unusually good conditions, a maximum of 80 percent may be used. To safely apply this higher value, lump size should not exceed one-half of the indicated maximum, belt slopes should be at least 5 deg less than the maximum, and feeders should be used to insure a uniform rate of feed.

The head or drive shaft of a belt conveyor requires horsepower to: (1) move the empty belt and overcome the friction of the idlers and other components; (2) move the load horizontally; (3) lift the load vertically; (4) to drive trippers or other accessories, and (5) to accelerate the loaded belt.

Since it is normally assumed that a motor can deliver 50 percent in excess of its normal torque for the time required to accelerate the loaded belt, item (5) is usually ignored for horizontal or inclined conveyor types.

Note, that this summation of horsepowers, gives the total hp required at the drive shaft. Before selecting a motor, choose a drive and then allow for the losses in that drive. As a rule, an additional 10 percent will usually cover these losses.

The calculation of tensions in the belting is rather easy for the small conveyor, once the hp at the head shaft and the belt speed have been determined. To find the tight-side (carrying side) and the slack-side (return side) tensions in a conveyor with the drive at the head end, requires the determination of a value for "K". This factor "K" accounts for the angle of wrap of the belt around the head pulley, the friction characteristics of the pulley (bare or lagged) and the type of take-up (screw-type or counterweighted). Various values of "K" are given in the Table XVII.

In selecting the conveyor belt to be used, first investigate the requirements of ply and fabric weight, then cover thicknesses. The first step in specifying a belt is determining carcass design. The proper carcass must satisfy the following five considerations:

1. Operating tensions—the belt must have strength adequate to withstand the maximum pull applied to it.
2. Minimum plies for proper loading support—carcass must contain enough plies to support the load between idlers without spillage and prevent creasing at idler roll junctions.
3. Maximum plies for proper troughing—the belt must be flexible enough to maintain good contact with all idler rolls, particularly the horizontal idler roll. Insufficient flexibility encourages poor tracking, resulting in spillage and edge damage. This is particularly important when selecting a belt for 35 or 45 deg idlers.
4. Proper choice of carcass fabric—there are many improved materials available in this area.

Table XV—Conveyor speed, size and capacity chart

Belt Width	Wt. per cu. ft. of Mat'l	Capacity in tons per hour — Belt speed in fpm. 100	150	200	250	300	350	400	450	500	550	600	650	Max. size uniform size	Lump in. with 90% fines	Normal speed fpm.	Cu. yd. per hr. at 100 rpm.
18	50	27	40	54	67	81	94	108	122	135				3	5	250	19.8
	75	40	60	80	100	121	140	160	180	200							
	100	54	81	108	135	162	189	216	243	270							
	125	67	100	134	167	200	234	268	301	335							
	150	81	121	162	201	243	284	324	365	406							
20	50	33	49	66	82	99	115	132	148	165	182			3½	6	300	49.7
	75	50	75	100	125	150	175	200	225	250	175						
	100	67	100	134	167	200	234	258	292	326	360	394					
	125	84	126	168	210	252	294	336	378	420	462	504					
	150	100	150	200	250	300	350	400	450	500	550	600					
24	50	49	73	98	122	147	171	196	220	245	275	300		4½	8	300	71.5
	75	74	111	148	185	222	250	296	332	370	407	444					
	100	99	148	198	248	298	346	396	445	495	544	593					
	125	125	188	250	314	375	438	500	562	625	687	748					
	150	149	222	298	373	447	521	596	670	745	819	894					
30	50	80	120	160	200	240	280	320	360	400	440	480	520	6	11	350	118
	75	120	180	240	300	360	420	480	540	600	660	720	780				
	100	160	240	320	400	480	560	640	720	800	880	960	1040				
	125	200	300	400	500	600	700	800	900	1000	1100	1200	1300				
	150	240	360	480	600	720	840	960	1080	1200	1320	1440	1560				
36	50	116	174	232	290	348	406	464	522	580	638	696	760	8	15	400	173.7
	75	174	261	348	435	522	610	696	783	870	956	1044	1131				
	100	233	350	466	582	700	815	932	1050	1165	1281	1398	1515				
	125	294	441	588	735	882	1028	1176	1324	1470	1617	1769	1911				
	150	348	522	696	870	1044	1218	1392	1565	1740	1912	1088	2262				
42	50	164	246	328	410	492	574	656	738	820	902	984	1070	10	18	400	245
	75	245	368	490	612	735	857	980	1102	1225	1348	1470	1593				
	100	328	492	656	820	984	1148	1312	1475	1640	1804	1968	2132				
	125	405	608	810	1012	1215	1418	1620	1822	2025	2225	2430	2632				
	150	492	738	984	1230	1476	1722	1968	2208	2460	2704	2952	3198				
48	50	220	330	440	550	660	770	880	990	1100	1210	1320	1430	12	21	400	328
	75	330	495	660	825	990	1155	1320	1485	1650	1815	1980	2144				
	100	440	660	880	1100	1320	1540	1760	1980	2200	2420	2640	2860				
	125	550	825	1100	1375	1650	1925	2200	2475	2750	3025	3300	3575				
	150	660	990	1320	1650	1980	2310	2640	2970	3300	3630	3960	4290				
	Maximum belt speed, fpm. Abrasive Mat'l.								Average Mat'l.				Free Flow				

5. Economics—belt cost should be carefully evaluated. Under most conditions, it is safe to use the least expensive construction that satisfies the first four design requirements given above. However, this definitely may not be the most economic selection if the conveyor is carrying high temperature or abrasive material, or if belt is used on a short feeder.

List all the carcasses which meet the tension requirements. Be sure, in checking this list, that the figures apply to the type of splice that will be used.

The next step must be the determination of the minimum number of plies required to resist impact and to smoothly transport the load. The principal factors are: (1) the amount of free fall, velocity, and direction of the material at the loading point; (2) type and spacing of idlers at the loading point; (3) weight and maximum lump size of material; (4) lump shape—impact from round material is about 50 percent that of jagged lumps; (5) sizing of material—lumps mixed with fines do less damage than uniformly sized feed; (6) frequency with which the same portion of the belt comes under the loading point—the time cycle factor, and (7) use of a grizzly to bed fines on the belt before the coarse material is loaded.

Troughability is another consideration. The type of fabric will determine the number of plies that will trough properly. For example, more plies of nylon cord construction can be used than some heavy cotton duck, and yet the nylon will provide greater troughability. The width of the belt also exerts an influence on troughability. A 60-in. wide belt with 10 plies of 48-oz duck will trough satisfactorily, while a 24-in. belt may be restricted to three plies.

Careful evaluation of these factors should reduce carcass construction to only two or three choices. At this point, it is good to make a comparison of costs and to make the final decision on the basis of economics.

Carcass fabrics have undergone the greatest improvements in recent years. The introduction of three synthetic fabrics (rayon, nylon, and dacron) have brought the principal changes. These fabrics appear to be slowly replacing cotton in most belt applications. All three synthetic fibers currently in use are stronger than cotton. Nylon is strongest, with dacron and rayon following in that order.

Table XVI—Max. recommended belt speeds

Belt width in inches	Belt speed in feet per minute			
	Lump stone	Gravel	Crushed stone and ore	Sand
18	300	350	400	400
24	350	400	450	450
30	400	450	500	500
36	450	500	550	550
42	500	550	550	600
48	550	600	550	600

Table XVII—Values of drive factor K for single drives

Arc of contact degrees	Screw takeup*		Counterweighted takeup	
	Bare pulley	Lagged pulley	Bare pulley	Lagged pulley
1	2	3	4	5
150	1.20	1.00	.84	.67
180	.97	.80	.64	.50
210	.80	.66	.50	.38
240	.68	.56	.40	.30
270	.58	.49	.32	.24

Column 4 is based on friction coefficient (f) = .30
Column 5 is based on friction coefficient (f) = .35
*Column 2 is higher than Column 4 by an amount sufficient to show 20% higher T_1 with screw takeup. Likewise Column 3 is higher than Column 5 to indicate a 20% higher T_1. This is done to provide a reserve for intermittent and inaccurate tension control that goes with screw takeup and not because any actual difference in friction between belt and pulley appears when a screw takeup is used. T_1 as previously defined, is tight side tension

Five principal combinations of fibers have been used by U. S. belting manufacturers:

1. Rayon/Nylon—Rayon in warp/nylon as filler. Two types of rayon are used—stable fibers and continuous filaments.

2. Rayon—All-rayon constructions are available in strengths as high as 150 lb per ply inch. Rayon belts are more than 30 percent thinner than cotton belts of equal strength.

3. Cotton/Nylon—These are made with cotton warp and nylon filler. They have good resistance to impact and have excellent fastener holding characteristics.

4. Cotton/Rayon—Similar to cotton/nylon fabrics in that rayon is used as filler. Strengths are more than 75 lb per ply inch.

5. Dacron—All-dacron construction is new, but seemingly very successful. A new, improved dacron-type fibre soon to be available may make this fabric even more popular. This material is particularly resistant to wet mildew and does not stretch the way some other synthetics do.

In selecting a cover, consider the wear on the rubber is a result of the severity and frequency of the cutting and abrasive action.

Although $\frac{1}{32}$-in. bottom covers are standard, a $\frac{1}{16}$-in. or heavier bottom cover will give better service on a vulcanized splice, present more resistance to oil and be less likely to be damaged by a buildup of material on idlers and pulleys.

Two other factors to be considered in selecting covers are—rubber quality and special cover design. Most manufacturers provide cover material in three qualities.

In general, the following recommendations apply to these three grades:

Grade 1-Suitable for rugged applications, in which large lumps of hard, jagged, highly-abrasive materials are handled.

Grade 2—Heavy-duty service. This is usually the best choice for most applications.

Grade 3—Not recommended in the rock-products industry, except for small-sized, non-abrasive materials. Unfortunately, many operators choose this grade because of its low first cost.

Belt life can be increased by the use of special designs. The step-pad and step-ply designs, which place additional rubber in the center of the belt without increasing the overall thickness, are good examples.

Other specialized belt designs are available for specific application in the rock products industry. Most common of these are the ribbed belt, the cleated belt, and the flanged belt. The ribbed and cleated belts are used to carry material up unusually steep inclines. The flanged belts greatly increase the carrying capacity of a belt by allowing heavier loading and faster belt speeds. Generally, these three types of special belts are applied to existing installations in an effort to overcome operating problems.

STOCKPILING OF MATERIALS, Part 9

How to select and use slingers, trippers, stackers to the best advantage

- **These discharge units come in a variety of mountings for your material handling needs. Movable trippers are more efficient than a series of fixed trippers, unless dusting is a serious problem**

Slingers or throwers are auxiliary units generally used to spread the discharge of a belt conveyor over a wide area. Essentially, these units are short, high-speed belt conveyors in which the carrying surface is held in a concave curve by large hold-down discs at each side of the belt.

A vertical spout funnels the incoming material onto the curved section of belt between the discs. In traveling this curved path, the material is held against the belt by centrifugal force, and quickly attains the high speed of the belt. As the belt passes around the front pulley, the material continues outward along its trajectory.

The trajectory of the material can be controlled by raising or lowering the front pulley, while the direction is controlled by swiveling the entire unit about the centerline of the spout.

The units are available in a variety of mountings, and may be suspended, bracketed, or wheel supported. The arrangement most commonly used for stockpiling is the suspended, swivel-mounted unit.

Practically any loose, dry, free-flowing bulk material can be handled in granular form or in lumps up to 2 in. Capacities of standard units range from 2,200 cu ft/hr to 18,550 cu ft/hr. These units can "throw" material as far as 90 ft and pile it to a height of 35 ft above the discharge pulley of the slinger. When properly mounted, the unit can rotate 360 deg.

Commonly furnished with electric motor drives, the units are also available with gasoline engine drives.

The tripper provides the most practical means for removing large quantities of abrasive materials from fast-moving belts at intermediate points along the length of the conveyor. It gives a relatively complete discharge without scraping the material against the surface of the belt.

The tripper consists essentially of an intermediate discharge pulley, a bend pulley, and a discharge chute or chutes. The discharge pulley is elevated sufficiently to permit the chute to clear the section of the belt that continues on to the head pulley.

The relative positions of these components is shown in Fig. 16. Note that additional troughing idlers may also be required to support the belt as it rises to the intermediate discharge point.

Trippers may be stationary or movable. To provide mobility, the components described above are usually mounted on a wheeled carriage and supported on a pair of rails which parallel the centerline of the conveyor.

Several different chute arrangements are possible (see Table XX). The simplest is the side discharge chute which directs material to one side or the other of belt conveyor.

Another arrangement permits the material to be directed to either side or, by centering the flop-gate, delivered to both chutes. A third arrangement provides a bypass back onto the

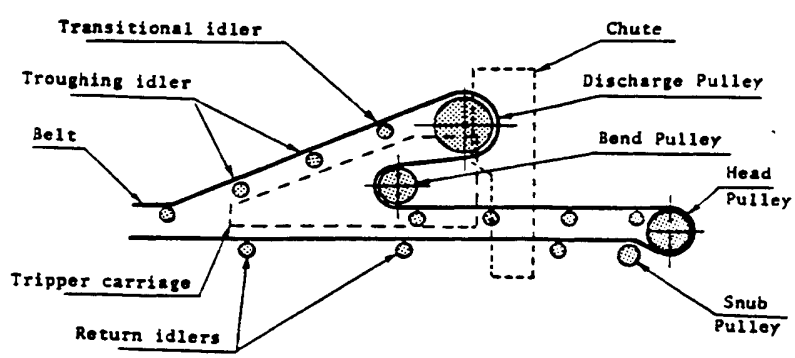


Fig. 16—Typical arrangement of tripper components (Courtesy, Barber-Greene Co.)

main conveyor. This last arrangement is used most often with stationary conveyors since it permits the use of a series of fixed trippers.

The movable tripper may be powered in several different ways. The main conveying belt may provide the motive force, or the tripper frame may be pulled back and forth by an auxiliary cable which is wound on a small power-winch, or the tripper carriage may be propelled by its own drive motor.

The movable tripper may be arranged to discharge continuously as it moves along the conveyor. When it reaches the end of its travel in one direction, it may be reversed automatically and returned to the other end. The tripper may also be stopped at one point and allowed to remain there as long as is required. Locks or brakes prevent the tripper from creeping under belt friction.

The movable tripper is more efficient than a series of fixed trippers. Raising the belt over a series of discharge pulleys not only consumes more power, but places more stress and abrasion on the belt itself. The fixed trippers are justified when dusting is a serious problem. Obviously, a fixed tripper can be sealed more effectively than a moving tripper. However, there are several efficient zipper-like seals available.

In selecting a tripper, consideration should be given to the following:

1. The type of drive required (see Table XIX).

2. The belt tension rating of the tripper should be equal to or greater than the maximum tension in the conveyor belt at the tripper.

3. The pulley diameter should be equal to or greater than the recommended minimum diameter as determined by the rated belt tension of the trippers.

4. The discharge chute should be chosen to provide maximum flexibility in directing the material to alternate paths of flow.

5. The discharge chute should have a slope steep enough to assure the flow of material through it. The following slope angles have been found to be satisfactory:

(a) Free-flowing materials, such as grains and beans ..... 30-50 deg

(b) Free-flowing materials, such as clean gravel, clean sized coal ..... 35-40 deg

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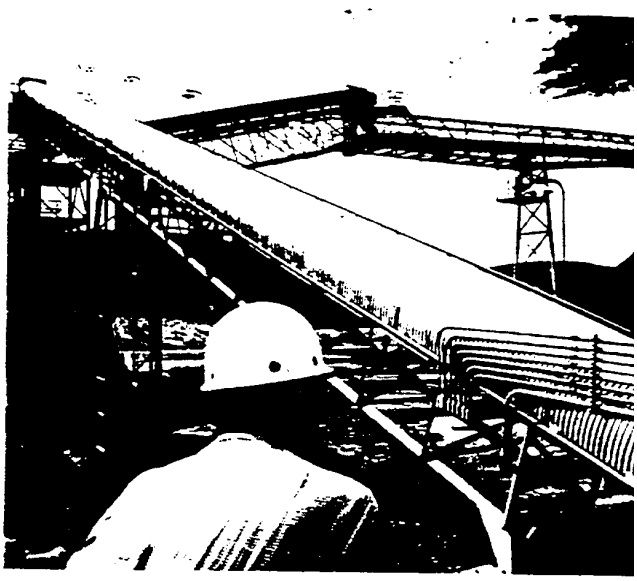
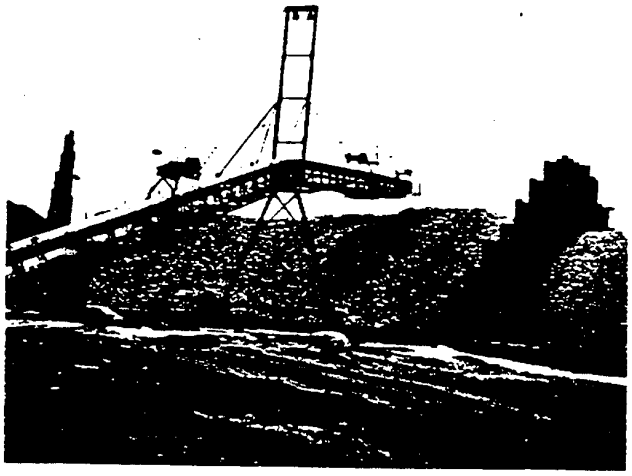
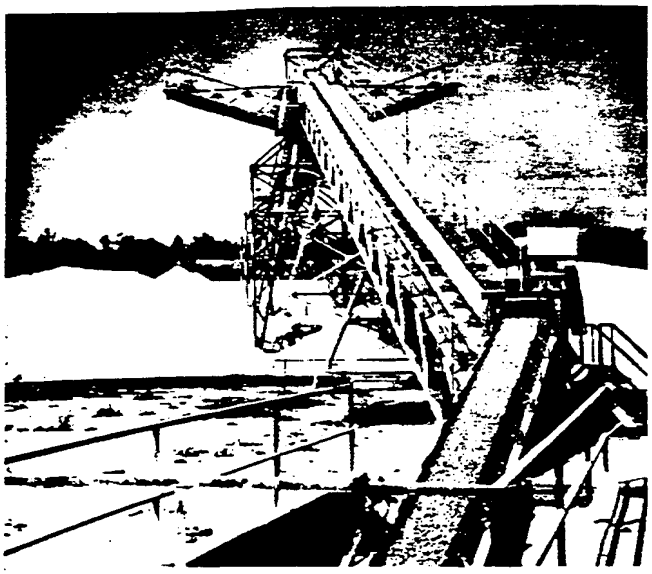


This is a simple structural arrangement designed to keep the bent structure out of the stockpiled material. Note stockpile at far right end of the cantilevered conveyor, and discharge chute at left end which will permit the building of a second conical pile (Courtesy, Alpha Portland Cement Co.)

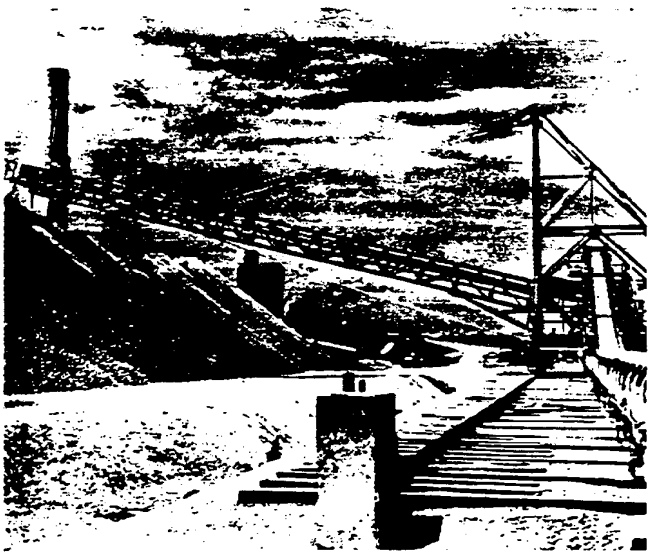


A radial stocker of conventional style; note hinged boom which keeps fall of material at a minimum and reduces breakage and segregation of material. Note, also, the partitions used to separate different grades of material (Courtesy, Barber-Greene Co.)

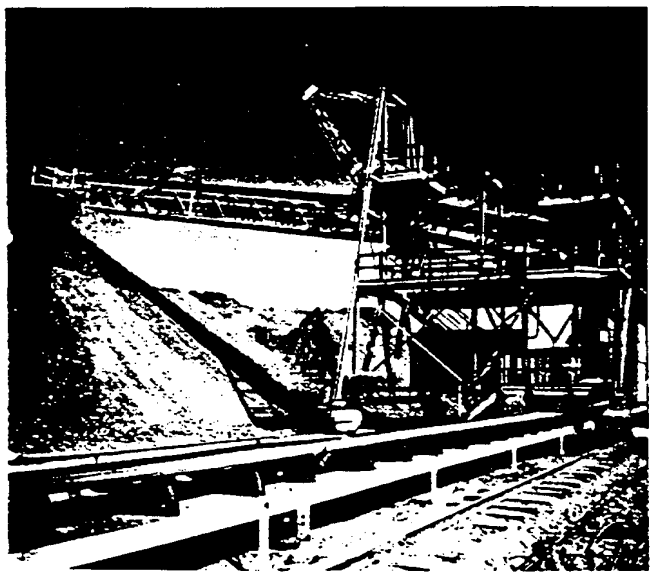
Stationary stacker-conveyor supported on a concrete structure is both sturdy and pleasing to the eye. Note that structure is buried in the stockpiled material without harmful effects. Notice, also, gravity takeup in the intermediate tower with a precast concrete bridge to provide access (Courtesy, Ideal Cement Co.)



A belt conveyor emerges from a tunnel which runs under two ground level feed points. Stone is lifted to an elevated trestle where a traveling tripper with side-wing stackers discharges it to any desired point over the storage area (Courtesy, Stephens-Adamson Mfg. Co.)



Side-wing stacker with adjustable-height boom; note track-and-tie arrangement on which stacker tower travels. Note, also, the small clearance between top of stockpile and conveyor discharge. Probe for sensing location of material can be seen projecting below boom (Courtesy, Barber-Greene Co.)



Single side-wing stacker with short boom conveyor is adjustable to suit height of stockpile. Note small amount of fines being moved by wind (Courtesy, Link-Belt Co.)

STOCKPILING OF MATERIALS

continued . . .

(c) Moderately free-flowing materials, such as low-moisture sand, crushed stone, coal, ores . . 40-50 deg

(d) Sluggish materials, similar to moist earth, wet coal, ores having fines and clay . . . . . 50-60 deg

If the material is so sluggish that a steeper slope is required, then a short cross-belt (reversible, if necessary) is often used instead of a chute.

6. Chute material of construction should be suitable for the materials being handled. The following materials are available and frequently used: ¼-in. mild steel, ⅜-in. mild steel, ¼-in. A.R., ¼-in. Corten, ¼-in. S.S. Type 304.

Special trippers are available for high-speed belts, high-tension belts, and high tripper travel speeds.

One note of caution—watch the radius of the vertical curve at the tripper. On large trippers, or where belts have high tensions, provisions are made to add idlers to prevent the belt from dumping sideways due to too long an unsupported span being produced as the belt lifts off the belt conveyor idlers. In larger sizes, the tripper is used to deliver material to boom conveyors mounted on traveling stacker towers.

For information on the smaller traveling and stationary trippers, contact any manufacturer of belt conveyor components. For data on the larger units, see the section on stackers which follows.

The stacker, as the name implies is used for stacking materials in piles. Stackers may be stationary or movable inclined conveyors. Stationary conveyors, however, are rather limited as to the size of stockpile that they can build.

Generally, if any appreciable volume of storage is to be obtained with a fixed conveyor, it must be fairly long to elevate the material to a considerable height. This arrangement has been used successfully to build stockpiles up to 100 ft in height. Such arrangements are often necessitated by the limitations of space.

Before designing such a unit, however, it is well to check on soil conditions and the type of stocking and reclaim structures that will be re-

quired. These structures can be very expensive when loadings are severe. Also, considerable horsepower will be expended in elevating the material to such great heights.

In the design of the supporting structure, it is desirable that the discharge point be cantilevered out over the pole as much as possible. This arrangement will keep the bent out of the stockpile and reduce the possibility of wear, hidden corrosion, or surface equipment damaging the mainstay of the conveyor.

Where ample space is available, it is more economical to place the material in low stockpiles distributed over a greater area. To do this with conveyors requires that some easy means be available for moving the conveyor equipment.

A simple form of movable conveyor mounting is found in the radial stacker. In this unit, the tail (lower) end of the conveyor structure is mounted on a fixed pivot point located directly below the centerline of the loading chute. In this way, the entire conveyor may be rotated about this point without affecting the conditions of loading. The head (upper) end of the conveyor is cantilevered out over the stockpile of material that it places.

The conveyor structure may be supported on a wheeled bent located midway along the truss structure. These units are available in standard sizes from 18 to 36 in. in belt width, and up to 150 ft in length. Larger units are available as special design items.

In another arrangement, the tail loading point is mounted atop an elevated tower, and the head end of the conveyor is supported by cable guys.

Either of these arrangements will place material in a curved, kidney-shaped stockpile lying along an arc from 180 to 270 deg. Again, the volume available from such a layout is relatively limited unless it is raised fairly high, or some auxiliary unit of equipment used, such as a dozer or a slinger.

A rather simple means of obtaining increased storage employs a traveling tripper installed on a length of horizontal conveyor elevated 25 or 30 ft above grade. An inclined belt delivers material to the tripper belt and the tripper discharges the material into a long, parallel windrow. The length of the pile will be established by the length of tripper travel that is provided. This travel may be fairly short or may be several hundred feet in length.

Trippers of standard manufacture generally travel about 40 to 50 fpm, but specially-engineered units may traverse 100 fpm.

If the discharge from the tripper is directed onto a short horizontal belt placed at right angles to the path of the main conveyor, two parallel stockpiles may be built. There are, however, several limitations in such a layout. Consequently, this same result is often accomplished by placing the main conveyor a few feet above the ground level and mounting the cross-belt or belts on a movable support tower.

The cross-belts are often hinged so that the free-fall height of the material is minimized, thus reducing dusting, breakage and segregation.

These various units employ high towers and long booms in order to build stockpiles of any appreciable height. In one unusual installation, the designer specified a relatively small stacker, but compensated for this by setting the unit atop a large fill of waste rock. This stable, maintenance-free base lifted the discharge point high enough to permit the placing of a fairly large stockpile on either side of the stacker.

These various arrangements of a traveling tower with cantilevered boom conveyors can build stockpiles

Please turn page

Table XVIII—Slinger capacities—standard machines (Courtesy, Link-Belt Co.)

Belt width	Cubic feet/hour		Cubic yards/hour		Tons per hour*	
(inches)	From	To	From	To	From	To
10	2.200	3.600	80	133	110	180
14	3.460	8.550	128	317	173	427
20	8.370	13.100	310	485	417	655
28	12.000	18.550	444	687	600	930

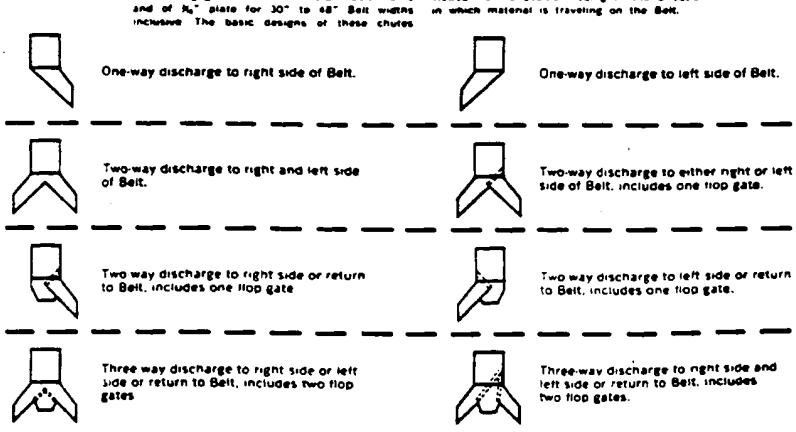
*Assumes material having bulk density of 100 pcf

Table XIX—Tripper drive characteristics (Adapted from Link-Belt Catalog 1000)

Tripper drive	Tripper travel speed	Mode of control	Special comments
Motor-propelled	30 fpm. normal; up to 100 fpm on special design	Automatic or manual	Used where tripper is frequently moved or reversed
Cable-propelled	33 fpm	Automatic or manual	Used where electrical conductors are undesirable
Belt-propelled	1/10th of the speed of the conveyor	Manual	Used where tripper movements are not frequent

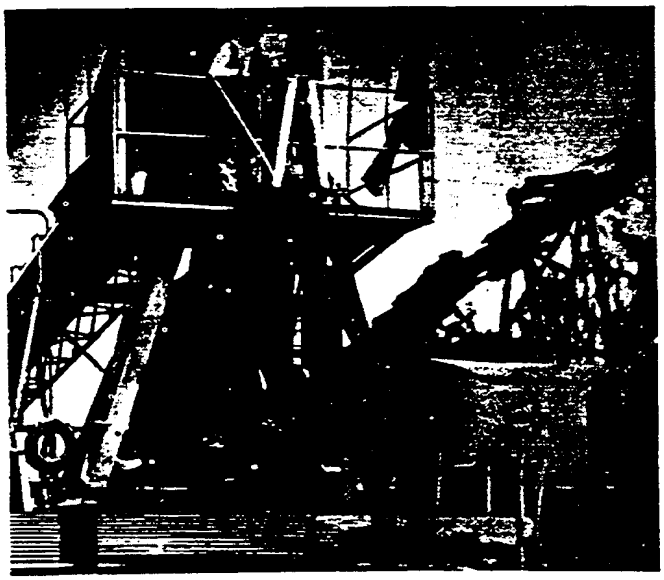
Table XX—Trippers—standard discharge chutes (Courtesy, Hewitt-Robins)

Standard structural steel chutes are constructed of No. 10 gage sheets for 18" to 24" Belt widths and of ¼" plate for 30" to 48" Belt widths inclusive. The basic designs of these chutes are shown by figures 1 to 8. These figures are viewed from a position facing in the direction in which material is traveling on the Belt.

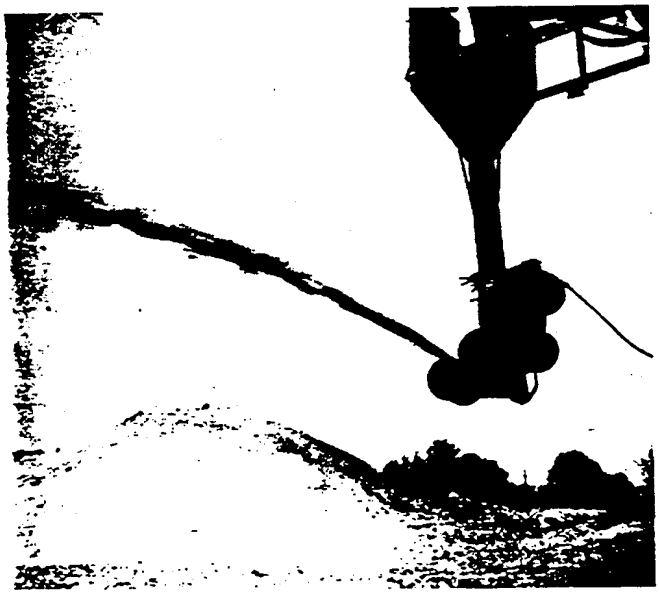


When it is necessary to deflect the material downward from a side discharge chute, a Turndown Chute section, for all of the designs shown above, can be furnished. When Chutes are handling abrasive material, liner plates made of alloy cast iron or abrasive resisting steel can be furnished. When Chutes are handling material which tends to pack or stick, liner plates made of stainless steel can be furnished.

This Trimount stacker is the first of its kind and operates at the Pea Ridge Plant of Meramec Mining Co. (Courtesy, Rex Chainbelt, Inc.)



A Jetslinger in the bow of a vessel hurls sand up to 90 ft into roadbed being constructed along a Louisiana bayou. An operator uses a wheel to rotate the slinger and direct sand over the 120-ft wide roadbed (Courtesy, Link-Belt Co.)



Slingers are available in a variety of mountings, the most common of which is this swivel-mounted type (Courtesy, Stephens-Adamson Co.)

STOCKPILING OF MATERIALS

continued . . .

having a considerable storage volume. This straight-line layout is also well-suited to the use of tunnel conveyors for reclaiming.

In reviewing the installations shown to this point, it is evident that a considerable volume of storage space lying along the stacker rails between the two parallel stockpiles, is lost.

By giving the boom conveyor a pivot mounting and placing it on the center line of the delivery conveyor, an arc of 180 deg (90 deg on either side of the track) can be covered. This system usually requires, however, that the track be removed as the stacker retreats from the growing stockpile, or that the stacker tower be mounted on a wheeled or crawler-track carriage.

In some cases, the boom is only arranged to pivot to one side about a vertical axis, permitting the building of a wider parallel windrow. More importantly, it makes feasible the use of the boom conveyor for reclaiming, by the addition of a bucket-wheel excavator at the end of the boom.

The larger stackers are massive units of machinery and require careful engineering, fabrication, and erection. The use of electric drivers makes possible the remote or automatic control of these units.

Since track-mounted stackers are supported on rails which are often placed on poorly-compacted soil, some settlement can be anticipated. One manufacturer has attempted to correct for this possible uneveness of the rails by mounting the support tower on a three-wheeled carriage frame.

Stackers are manufactured with boom lengths ranging from 25 to 250 ft. Recently, longer-boomed models have been introduced. The tower's speed of travel varies, but a speed of 50 fpm is often used.

The choice of a stacker will be influenced by many factors, of which the following are the more important: (1) size of storage area available; (2) volume of material to be placed in storage; (3) required time-rate of placing material; (4) permanence of the installation; (5) time that material will remain in storage, and (6) reclaiming method that must be used.

When a belt conveyor won't do

- **There are many ways of conveying bulk solids which can supplant or supplement belt conveyors. These other units are especially useful for hot, sticky or abrasive materials**

While the belt conveyor is the workhorse of the materials-handling industry, it should be remembered that there are other equally useful means of transporting bulk solids.

Very often, special characteristics of the material being handled require the use of these other units. For example, high temperature materials (300F and above) may be satisfactorily handled by an apron conveyor, whereas a belt conveyor would be plagued with problems.

Also, these other types can be used to supplement belt conveyors.

Apron conveyors usually consist of a series of metal plates with sideboards attached to two strands of chains so as to provide a continuous conveying surface. An overlap along the sides of adjacent plates or pans provides a relatively leak-proof jointing. Material is placed on the conveyor through a chute or constricting hopper and discharged over the head pulley.

Apron conveyors can be used to move a variety of bulk materials such as ores, stone, sand, gravel, coal, cullet, foundry and industrial refuse, garbage, and many similar materials. When properly designed, these conveyors can also handle steel scrap, castings and steel strip.

These conveyors can be arranged to handle materials along horizontal, inclined, or combined horizontal and inclined paths. The maximum angle of inclination is about 20-25 deg. However, by proper choice of pan shape, inclines to 45 deg may be negotiated successfully. Speeds up to 100 fpm may be used for apron conveyors. When used as picking table conveyors, speeds should not exceed 75 fpm.

Where large capacities are required, or the handling of large lump sizes is necessary, open-top carriers are usually recommended. These conveyors use heavy steel buckets supported on two strands of roller chain. The

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Screw conveyor system used in dust collection and recycling at Ash Grove Lime & Portland Cement Co., Chanute, Kansas

Table XXI—Conveyor comparison chart

Conveyor	Arrangement*	Length Available	Capacities**
Belt conveyor	H, I, both	1,000 ft plus	to 5,000 tph
Apron conveyor	H, I, both	100 ft	to 1,300 tph
Bulk-flo conveyor	H, I, both	100 ft	to 140 tph
Drag conveyor	H, I	100 ft	to 50 tph
Flight conveyor	H, I, both	100 ft	to 580 tph
Oscillating conveyor	H	120 ft	to 350 tph
Screw conveyor	H, I, both	300 ft	to 500 tph
Pneumatic conveyor	H, I, both		to 200 tph
Skip hoist	V, I	200 ft	to 470 tph
Sidekar-carrier	H		
Gravity discharge conveyor-elevators	H, V, both	500 ft	to 500 tph
Peck carrier	H, V, both	500 ft	to 500 tph

* Arrangement is H: Horizontal; V: Vertical; I: Inclined

** Capacities: based on 100 pcf material. To convert to cubic feet per hour, multiply tons per hour by 20

STOCKPILING OF MATERIALS

continued . . .

buckets are available in a wide variety of shapes and in several different thicknesses of material. Such conveyors are well-suited to handling very abrasive or hot materials. By using perforated pans or buckets, these conveyors can be applied to quench tank service.

Bulk-Flo conveyors usually consist of a combination elevator and conveyor which can travel along a horizontal, vertical, or inclined path. The conveying medium consists of an endless chain with flights attached at spaced intervals, and contained within a close-fitting casing. Material to be conveyed flows in through feed openings and fills the spaces between flights. As the chain is moved, the flights move the material through the casing. At suitably located openings, the material is discharged from the casing.

Bulk-Flo conveyors can be used to move a variety of granular, crushed, ground, or pulverized materials. Flake graphite, lignite, mica, soda ash, pebble lime; sulphur, crushed; and vermiculite are examples of materials that have been handled successfully in these conveyors.

Casings are available in a large number of different metals ranging from hot-rolled mild steel, plain or galvanized; low alloy steels; stainless steel; aluminum or monel metal.

The drag conveyor consists of a single strand of wide chain which pushes the material along the bottom of the trough. Trough may have vertical or flared sides and be of steel, hard iron, or concrete.

The conveyors can be used to move ashes, coal, sawdust, pulp wood, and hot or cold cement clinkers. Conveyors made of plain links are used without flights or other attachment and make an economical installation where capacity requirements are average and space saving is important.

Flight conveyors have a series of spaced scrapers or flights drawn along the length of a stationary trough by one or two endless power-driven chains. Material is fed into the trough or at a series of loading points near one end, and then discharged at the other end or through a series of discharge openings in the bottom of the trough. Openings are generally controlled by means of slide gates.

Flight conveyors are used to move granular, lumpy, very free-flowing, non-abrasive, or mildly corrosive materials along horizontal or inclined paths, or a combination of horizontal and inclined. The maximum angle of inclination is about 40 deg. The maximum length of conveyor recommended is about 100 ft. A maximum speed of 100 fpm should not be exceeded.

Flights are usually made from malleable iron or steel plate, and may be arranged to slide directly on the trough bottom, or by using a pair of steel bars for support, may be arranged to have a limited clearance off the bottom. To eliminate the wear that results from the sliding of the flight support shoe along the continuous support bars, the larger flight conveyors are usually provided with roller-suspending flights.

By suspending the flights from a centrally-located bracket, the conveyor can be arranged so that it will convey materials on both runs.

Oscillating conveyors usually consist of a steel conveying trough mounted on a series of steel springs or vibrating reeds in such a manner that the trough is given an upward and forward oscillating motion. This motion moves the material toward the point of discharge with a powerful, surge-proof, conveying action.

Oscillating conveyors can convey successfully most granular, free-flowing materials, as well as hot, abrasive, fine (100 mesh), dusty, lumpy, stringy, and difficult-to-handle materials. Since the conveyor trough is fabricated from

Table XXII—Material characteristics table

Material	Maximum particle size	Average weight per cu. ft.	Percent loading	hp. factor	Component group	Abrasiveness	Note
Asbestos, ore	—½"	81	15	1.2	C-4	HA	2
Asbestos, shred	Fibers	20-40	30B	1.0	B-4	MA	2,34
Borax	—½"	60	30B	1.0	B-4	MA	
Borax	—⅓"	50-60	30B	0.7	B-4	MA	
Cement, clinker	+½"	75-80	15	1.8	D-4	HA	
Cement, portland	—100M	75-85	30B	1.4	B-4	MA	1
Chalk, crushed	+½"	85-90	30B	1.9	B-4	MA	4
Chalk, ground	—100M	70-75	30B	1.4	B-4	MA	1,4
Dolomite	+½"	80-100	30B	2.0	B-4	MA	
Fly ash, dry	—100M	35-45	15	3.5	C-4	HA	1
Granite, broken	+½"	95-100	15	2.5	D-4	HA	
Gypsum, calcined	—½"	55-60	30B	1.2	B-4	MA	
Gypsum, calcined	—100M	60-80	30B	0.8	B-4	MA	
Gypsum, raw	—1"	90-100	30B	1.6	B-4	MA	
Lime, hydrated	—⅛"	40	30A	0.8	A-2	NA	1,4,5
Lime, hydrated	—200M	32-40	30A	0.6	A-2	NA	1,4,5
Lime, unslaked	—⅓"	60	30A	0.6	A-2	NA	4
Lime, pebble, unslaked	+½"	53-56	30A	2.0	B-1	NA	
Limestone, crushed	+½"	85-90	30B	1.6	B-4	MA	
Limestone, dust	—100M	56	30A	0.6	A-2	NA	1
Marble, crushed	—½"	80-95	15	2.0	C-4	HA	
Mica, ground	—⅛"	13-15	30B	0.7	B-4	MA	
Mica, pulverized	—100M	13-30	30B	0.9	B-4	MA	1
Mica, flakes	—⅛"	17-22	30B	1.0	B-4	MA	3,5
Oyster shells, ground	—½"	53	30B	0.9	B-4	MA	
Oyster shells, whole	+½"	80	30B	2.0	B-4	MA	5
Pumice	—¼"	40-45	15	1.6	C-4	HA	4
Quartz	—⅛"	85	15	1.8	C-4	HA	
Sand, damp, bank	—⅛"	110-130	15	2.8	C-4	HA	
Sand, dry, bank	—⅛"	90-110	15	1.7	C-4	HA	
Sand, dry, silica	—⅛"	90-100	15	2.0	C-4	HA	
Shale, crushed	—½"	85-90	30B	1.0	B-4	MA	
Slag, furnace	—½"	60-65	15	1.2	C-4	HA	
Slag, furnace	+½"	55-60	15	2.4	D-4	HA	
Talc	—100M	40-60	30B	0.8	B-4	MA	1,4
Talc	—½"	80-90	30B	0.9	B-4	MA	
Vermiculite, expanded	—½"	16	30B	0.5	B-4	MA	3
Vermiculite ore	—½"	80	30B	0.8	B-4	MA	

HA—highly abrasive; MA—mildly abrasive; NA—nominally abrasive
Explanation of notes: 1. Fluidizes easily; 2. Emits toxic fumes or dust; 3. Exceptionally light or fluffy; 4. Tends to pack under pressure; 5. Fibrous material which tends to mat

metal, it is possible to use it for conveying materials having temperatures up to 250F. Where dusting or contamination are a problem, the trough may be fitted with a dust-tight cover.

These conveyors are used to convey material along a horizontal path only, and are effective in lengths to 100 ft. Generally, these units can be installed without difficulty on concrete foundations or on structures under 10 ft high. Installations on the upper floors of buildings, over bins, etc., should be carefully engineered to minimize transmitting vibrations to the structure. Consult the manufacturer on such critical applications.

Units are available in a wide variety of sizes and several different duty classes: Light—capacities from 5 to 23 tph; medium—capacities from 10 to 80 tph; heavy duty—capacities from 40 to 120 tph, and extra heavy duty—capacities to 350 tph.

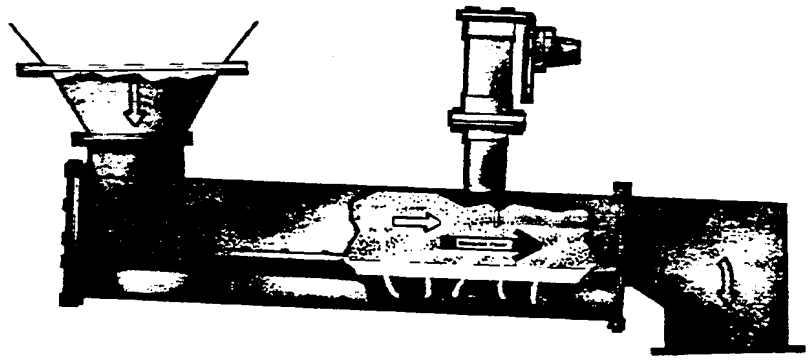
By means of many available modifications, oscillating conveyors may be adapted to many special uses:

1. Decks may be fitted with screens or grizzlies for sizing or scalping.
2. Troughs may be partitioned for conveying simultaneously several different materials.
3. Tubular troughs are available for gas-tight installation or pressurized installations.
4. Troughs may be hooded for cooling or drying applications.
5. Special troughs are available for handling high temperature materials, and abrasive or corrosive materials.

Table XXIII—Data on typical air activated gravity conveyors

Air trough sizes A	B	C	D	Weight trough steel	Capacity* cubic feet per hour
6"	2"	4"	1¼"	14 ga	600
8"	3"	6"	1¼"	14 ga	1,000
10"	3"	6"	1¼"	14 ga	2,000
12"	3"	8"	1¼"	12 ga	3,400
14"	3"	10"	1¼"	12 ga	4,800
16"	3"	10"	1¼"	12 ga	7,800

* These rates are for air troughs conveying regular portland cement from an aerated source 30 ft over a 6-deg slope with 5 scfm of air available per sq ft of aeration medium



KVS Air-Float conveyor—material to be moved rests on porous ceramic plate which is inclined 6-10 deg below the horizontal. A small amount of air diffusing through the pores of the plastic fluidizes the solid particles. Fluidized mass flows down the slight incline by gravity (Courtesy, Kennedy Van Saun Corp.)

Screw conveyors have a helical screw rotating in a stationary trough. Material is fed into the trough at one end (or several intermediate points), and is moved along its length by the rotation of the screw. Bearing hangers support the screw at intervals. Material is usually discharged by means of slide gates located at intervals along the bottom.

Screw conveyors can be used to move a wide variety of materials satisfactorily, but give careful attention to the physical, chemical, and handling characteristics such as contamination, corrosiveness, degradability, fluffiness, flowability, etc. Some typical materials handled in screw conveyors are given in Table XXII.

Screw conveyors can be arranged to move materials along a horizontal, inclined, or vertical path. The maximum length of screw conveyor is determined by the torque capacity of the power-transmitting components. This length will be greatly influenced by the characteristics of the material being handled. Generally, a maximum length somewhere between 100 and 300 ft seems to prevail as a practical limit. Where one long conveyor is not feasible, a series of conveyors in tandem may provide a satisfactory solution. Conveyor screws or regular pitch may be used for incline of 20 deg or less. Above 20 deg, the use of short pitch conveyor screws operating in a tubular or shrouded trough is required.

Occasionally, the characteristics of the material being handled require the use of non-conventional equipment, such as: Extremely hot materials—use cast screws and troughs or high-temperature alloys.

Sticky or viscous materials—ribbon flight screws may be desirable, or special coatings may be applied to the screws and trough to aid the flow of the material.

Extremely abrasive materials—use troughs of abrasion resistant metals or hard-surface the flights.

Corrosive materials—use screws and troughs of stainless steel, monel metal, nickel, aluminum, or other alloys.

Applications that require a mixing or aerating action—use ribbon flights or cut flights, or combine one of these with paddles.

Applications that require heating or cooling—use jacketed troughs through which a heating or cooling media may be circulated.

Applications that must be decontaminated—use screws and troughs of special construction which will eliminate the accumulation of material and facilitate cleaning.

Air activated gravity conveyors usually consist of a two-compartment conveying trough. The lower compartment is separated from the upper one by a special porous material. Air enters the lower compartment, permeates the porous material, and is entrained in the material being conveyed in the upper compartment. This action reduces inter-particle friction and accelerates flow.

Conveyor is installed at an angle slightly higher than the fluidized angle of repose The slope required varies according to the material conveyed.

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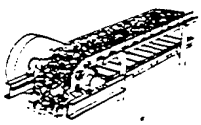
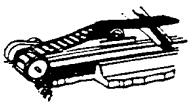
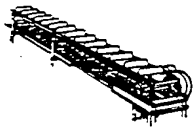
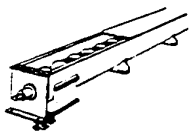
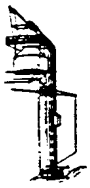
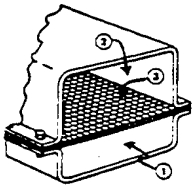
Table XXIV—Types of conveyors

Type	General information	Capacity data	Materials handled
Apron 	The apron convevor consists of a series of jointed, overlapping or interlocking metal plates (pans) on which the material is carried. The pans are mounted on two strands of chain which pass around head and foot wheels and are supported on tracking Pans are available in many types, from flat plates to round-bottom buckets Apron convevor can operate on horizontal or inclined path	Apron / TPH* / Max. speed / Lump-in. 18" / 3.4 / 100 fpm / 6-4 24" / 4.5 / 95 / 8-5 30" / 5.6 / 85 / 12-6 36" / 6.8 / 80 / 14-7 42" / 7.8 / 70 / 16-8 48" / 9.0 / 65 / 19-10 54" / 10.0 / 60 / 21-11 60" / 11.2 / 60 / 24-12 *TPH given for 100 pcf mat'l at speed of 1 fpm Lump size: Unsized—Sized	Widely used for handling ores, stone, sand, gravel, coal, cullet, foundry and industrial refuse, garbage and similar materials. Degradation during transport is minimized with this unit. Suitable for handling hot materials
Bulk-Flo	Material is conveved by these conveyor-elevators in a continuous column by cross flights attached at intervals to an endless chain, which operates inside a close-fitted casing Casings are available in mild steel, plain or galvanized finish, low-alloy steel, stainless steel, aluminum or monel metal	Bulk-Flo Model / Tons* Hour / Max. lump size 35 / 25 / ¾" 57 / 50 / 1¼" 610 / 80 / 2" 712 / 110 / 2½" 913 / 140 / 2½" *Capacity is based on 100 pcf material and maximum conveyor speed of 80 fpm	Suitable for crushed, granular, ground or pulverized materials. Alloy chain flights and casing can be furnished for handling abrasive and corrosive materials
Drag 	Material is conveyed by being dragged in troughs of mild steel, white iron or concrete by single strands of wide drag chains For abrasive material, use white iron. For mildly abrasive, use concrete, and for non-abrasive, use mild steel Note: Capacity table assumes 100 pcf material drawn at maximum speed recommended for the material being drawn	Trough / Abrasive / Mild / Non-abr. 10½" / 4.4 / 12 / 50 16" / 6.5 / 18 / 56 19¾" / 8.0 / 23 / 46 20" / 12.0 / 33 / 50 Max. speed recommended/trough Abrasive—white iron—5-7 fpm Mild abr—concrete—10-20 fpm Non-abr.—steel tgh—30-80 fpm	Satisfactory for handling sawdust, wood chips, coal and abrasive materials such as ashes, hot or cold cement clinkers
Flight 	Scraper plates or flights carried by one or two strands of chain push material along in troughs which may be horizontal, inclined or a combination of both. Discharge may be over the end or through gates at intermediate points Note: Capacities are based on 100 pcf material at 100 fpm speed, 75% of cross-section filled and 30° maximum angle of inclination	Flight / TPH / Lump (max.) 10 x 4 / 46 / 3" 12 x 5 / 68 / 3½" 15 x 6 / 104 / 3½" 18 x 6 / 128 / 5" 16 x 8 / 160 / 8" 20 x 10 / 260 / 10" 24 x 10 / 300 / 12" 30 x 12 / 540 / 14" 36 x 12 / 580 / 16"	This is particularly suitable for handling granular, lumpy, very free-flowing, non-abrasive or mildly corrosive material
Oscillating	Moves material in a uniform, continuous flow by an upward and forward oscillating motion of a continuous metal trough, mounted on surge-proof legs Available for light, medium and heavy-duty service. Oscillating convevors can also be used for scalping, cooling, heating and drying Capacities in table are based on 100 pcf material	Trough / TPH / Duty/Unit 8" / 5 - 10 / Light 12" / 10 - 15 / Light 18" / 15 - 23 / Light 10" / 10 - 50 / Medium 20" / 10 - 80 / Medium 24" / 40 - 50 / Heavy Duty 30" / 50 - 75 / Heavy Duty 36" / 75 - 90 / Heavy Duty 42" / 90 -105 / Heavy Duty 48" / 105 -120 / Heavy Duty	Well suited for handling all granular, free-flowing, hot, abrasive, fine, dusty, lumpy, stringy materials. Good for difficult-to-handle materials, or where contamination or corrosion is a problem.
Screw 	The screw convevor consists of a stationary trough within which a helical flight (screw) rotates. Material is moved along the bottom of the trough by the rotation of the screw. The screw may be operated on the level or at an incline. Material can be discharged through the end or bottom of trough. Can also serve as cooler or dryer unit.	Screw / 15% / 30% / 45% / Lump 6" / 2 / 9 / 18 / ¾ 9" / 7 / 28 / 60 / 1½" 12" / 17 / 60 / 135 / 2 14" / 24 / 90 / 200 / 2½" 16" / 35 / 125 / 280 / 3 18" / 45 / 170 / 380 / 3 20" / 62 / 217 / 500 / 3½ Capacity based on 100pcf material and max. recommended speed. % is % of fill in trough section	Adapted to handling a wide range of bulk materials. Particle size, abrasiveness and flowability are important factors in the selection of a screw conveyor, and should be carefully checked
Skip hoists 	Material is elevated in a bucket which operates in vertical guides and is raised and lowered by a hoist-operated cable. Operation of the bucket may be manually controlled or fully automatic Bucket speeds range from 100 to 450 fpm. Buckets may be arranged for single-bucket operation or balanced operation using two buckets. Balanced units will deliver twice the tonnage of single buckets	Bucket size / Tons/hour* 20 cf / 26 30 / 38 40 / 52 60 / 78 80 / 102 100 / 128 120 / 154 *Capacities given are for the single-bucket type at 100 fpm for 100 ft lift, and include a time allowance to load, travel, dump	Adapted for high lifts of batches of bulk materials. Will handle all materials except those which are very fine, light, fluffy, contaminable, highly corrosive or have harmful, dusty or explosive properties
Pneumatic (gravity type) 	Material is aerated by the dispersion of air throughout its mass. This action reduces inter-particle friction and accelerates flow. The material is made to flow by installing the convevor at an angle slightly steeper than the fluidized angle of repose. A slope of 4 to 10 degrees is sufficient for most installations Kev: (1) air chamber, (2) material chamber, (3) aeration medium	Air trough / Capacity* 6" / 600 8" / 1,000 10" / 2,000 12" / 3,400 14" / 4,800 16" / 7,800 *Capacity in cubic feet/hour	Suitable for conveying most dry, fine (-150m) material that can be fluidized, such as cement, fly ash, polyvinyl chloride, alumina, bauxite, sodium sulphates, hydrated lime, flour, pulverized coal, petroleum coke, barium sulphate, phosphates, kiln dust

STOCKPILING OF MATERIALS

continued . . .

However, a slope of from 4 to 10 deg will be adequate for most installations. The length of conveyor is limited only by the elevation available for the slope of the unit. Most dry, fine (−150 mesh) material can be fluidized and conveyed.

Capacity of the air-trough type of conveyor ranges from 600 cu ft/hr to 7.800 cu ft/hr. Data on a typical conveyor of this type is provided in Table XXIII.

The heart of this conveying system is the porous aeration medium used to separate the compartments. Synthetic or cotton woven fabrics are used where temperatures do not exceed 180F. Aloxite blocks, made of sintered aluminum oxide, may be used up to 1.000F. Other available materials include porous plastic, sintered bronze, and asbestos sandwiched between wire screen.

Skip hoists usually consist of a bucket which is raised or loaded by a wire rope and drum hoist as it travels along a steel structure with tracks. When a single bucket is used, counterweights are generally required. For large capacity units, two buckets balancing each other are used.

Skip hoists travel along vertical or inclined paths and are especially suited to high-lift applications. They can handle a wide variety of abrasive or corrosive materials, large lumps or fines, at low or high rates of capacities. The skip hoist is not suited for very fine, light or fluffy materials, or those that are highly corrosive.

Since a skip hoist handles material in batches, a loading hopper or bin is required to meter the material in bucket-sized batches. Loading may be manual or automatic.

The skip hoist bucket is unloaded by up-ending it at the discharge point. Buckets are available in sizes ranging from 20 to 120-cu ft capacities. Lifts are available up to 200-ft high. Capacity of single-bucket units (for 200-ft lifts) is 236 tph; for balanced bucket-types: 472 tph.

Sidekar-carrier. This unit consists of a series of overlapping buckets attached to a chain and equipped with rollers. It travels in the horizontal plane on a track that may be open or encased. The conveyor is continuous, with horizontal sprockets at each corner. The buckets have open tops and the front and sides are vertical plates, while the back plate is sloped. The bottom of each bucket is fitted with an undercut gate which is used to unload the bucket over the discharge point.

The Sidekar-carrier can be used to convey material along a horizontal path of travel and can be arranged for automatic discharge to one of several points. This conveyor is compact and requires little head room. Little or no degradation or segregation is caused by the conveyor, and material is recirculated in buckets until discharged. Buckets are self-cleaning and subject to little abrasive wear.

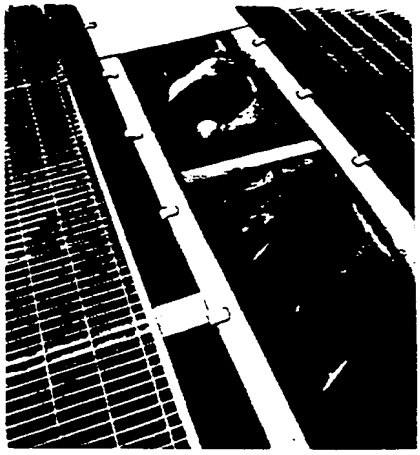
A wide range of capacities and lengths of travel can be obtained since chain pulls are relatively low per ton of material handled.

Gravity discharge conveyor-elevators consist of V-shaped buckets rigidly mounted at regular intervals between two strands of long-pitch steel chain. These units may be arranged to travel along horizontal or vertical paths. The horizontal runs actually perform as drag conveyors, with the buckets pushing the material along within a trough. On the vertical run, the material is transported as in an ordinary bucket elevator. Material may be loaded into the lower feed run at any point, while the discharge from the upper run is controlled by means of discharge gates in the bottom of the trough.

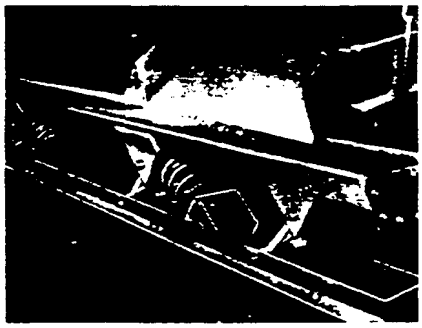
The pick-up and discharge of material is accomplished very gently, making this an ideal unit where breakage or degradation of conveyed material is an important consideration. It is suitable for handling lumpy materials, relatively large capacities, and other applications where relatively economical equipment is desired.

Capacities of these units range from 50 tph for the smallest to 200 tph for the largest, and lump sizes from 4 to 8 in. Lengths of these units are limited to 500-ft centers or less.

Peck carriers are capable of traveling along horizontal, inclined, and vertical paths. They consist of a series of buckets suspended from two bar-chains. The method of suspension keeps the bucket level at all times.



Screw conveyors—helical screw rotates in a stationary trough. Material is fed into the trough at one end (or several intermediate points), and is moved along its length by the rotation of the screw (Courtesy, Link-Belt Co.)



Oscillating conveyors—steel conveying trough is mounted on a series of steel springs or vibrating reeds. Trough is given an upward and forward oscillating motion (Courtesy, Link-Belt Company)

The buckets are designed with a lip that overlaps the adjacent bucket to provide a continuous carrier line which may be filled by an uninterrupted flow of materials.

Unloading of the buckets is accomplished by means of a tripper bar. These trippers may be stationary or movable depending on the requirements of the system.

Capacities of these units range from 40 tph to 500 tph (for 100 pcf material). Recommended maximum speeds are 40 fpm for the smaller units up to 80 fpm for the largest. Lengths of these units are generally limited to less than 500-ft centers.

Since there is little or no wearing action of material upon the buckets during transit, these units may be used with abrasive materials. They may also be used to handle materials at high temperature, such as ashes, coke, ore and cement clinker.

STOCKPILING OF MATERIALS, Part II-A

Buckets & related equipment answer many reclaiming problems

- **Dragscrapers, aerial tramways, rotary reclaimers and bucket wheel excavators are best for outdoor stockpiles**

The dragscraper has a cable-operated, bottomless, crescent-shaped scraper bucket, controlled by a drum boist. The hoist may be powered by electric motors or internal combustion engines. The bucket rides on the material which it is moving. When pulled forward, the bucket loads; when pulled backwards, it empties. The bucket can move material anywhere in the storage area within the radius of its operating cables. These machines can be used for stockpiling and reclaiming materials.

The dragscraper machine will give satisfactory results on the open ground or within a building. These units have been used successfully in bins as small as 40 sq ft or on ground areas of 10 or more acres. The length of haul cable is generally limited to 600 ft..

All kinds of bulk materials are handled by dragscrapers. These materials vary in weight from 20 to 200 lb/cu ft and include such diverse substances as sawdust, sugar, fine chemicals, coal, crushed stone, wet clay, fertilizers and ores.

Units are manufactured with scraper buckets ranging in size from ⅓ cu yd to 15 cu yd., and built for hourly capacities ranging from more than 1,000 cu yd/hr down to 10 cu yd/hr, with economical results.

The correct size and type of scraper machine for any given project can be determined only after considering all installation variables such as weight, flow qualities, and ease of digging of the material; size and shape of storage area, and operations desired.

Storage of any bulk material starts with the formation of an initial pile of material on the storage area in close proximity to the head post. The material may be placed in this initial pile by elevating or conveying equipment, from bins, or by dumping from cars or trucks on a trestle.

The functions of the dragscraper are: (1) to move material away from the initial pile as fast as received; (2) to find storage for a specified tonnage on the available space; (3) to provide for quick change-over from storing to reclaiming, and (4) to reclaim from all over the storage area and to deliver material to a designated point at a specified rate per hour.

Six basic types of scrapers solve most outdoor storage problems. These arrangements can be modified to meet

Bi-cable, jig-back aerial tramway (upper terminal)—total length of tramway is 1,959 ft, with a difference in elevation of 1,062 ft between terminals (Courtesy, Heron Engrg. Co.)

many different individual requirements. Sometimes it is desirable or mandatory that the scraper bucket be picked up at the dumping point and returned to storage through the air, as when the material is unusually abrasive, when there is a desire to avoid degradation of fragile material, or when material has a non-caving nature after storage.

The bucket is supported by a carrier which travels on a track cable. The pull-back cable returns the bucket above the level of the storage thus reducing contact with the material

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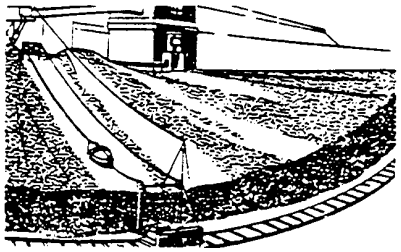
Six main types of drag scraper installations for open storage work (Courtesy, Sauerman Bros., Inc.)

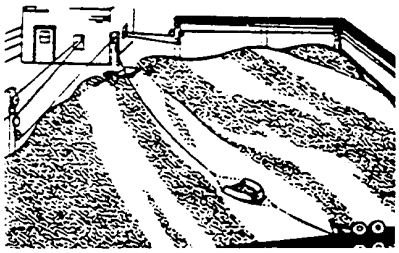


Radial installation with self-propelled tail tower and stationary head post

This is the most frequently used installation. Incoming material enters storage area in front of head post. Scraper bucket operates out from this cushion pile in radial lines toward the tail tower that circles the area.

Haulage cables, to which the bucket is attached, pass around the sheaves on tail tower and headpost, then lead from the headpost to the drum hoist. The operator can view the entire area. His station may be alongside or above the hoist in a conveyor headhouse or adjacent building.

By remote control, operator guides all movements of the tail tower and bucket. Tail tower can also be arranged to travel on crawlers

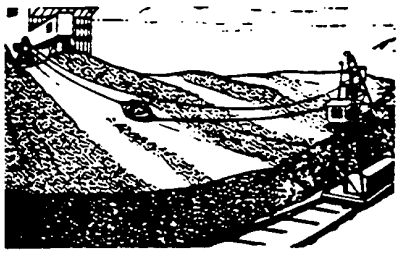


Radial installation with monorail and trolley

The use of a monorail and trolley is usually indicated where the storage area does not lend itself to the use of traveling tail tower.

The monorail system will support and move the tail block at the correct height without sacrificing area for tower trackage.

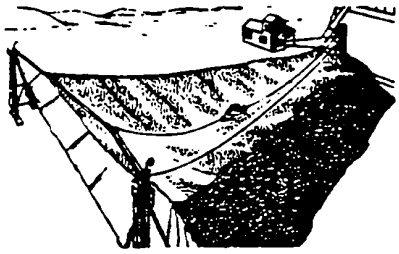
The tail trolley is moved by a motorized winch which is controlled from the scraper operator's station



Radial installation with self-propelled head tower

In some situations, it is not advisable to locate the scraper hoist and operator at the stationary end of the scraper system. In such cases, a high tower containing the operating machinery is installed to travel on a curved track.

The operator is posted in a cab well forward to top of the machinery tower so that he has the scraper bucket in view at all times, even after the pile attains maximum height



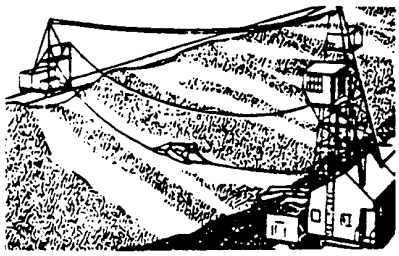
Radial installation with tail trolley on elevated bridle

Another type of radial system employs a tail block attached to a trolley which rides an elevated bridle cable suspended between two towers.

The bucket's line of operation is shifted by using a motorized winch to move tail trolley.

This arrangement can be used for temporary installations since they require less capital investment than the other radial installations.

As compared to the tail tower or monorail arrangement, the elevated bridle cables lose ground space because of cable sag. Multiple bridle spans are used if the width of the storage area so demands

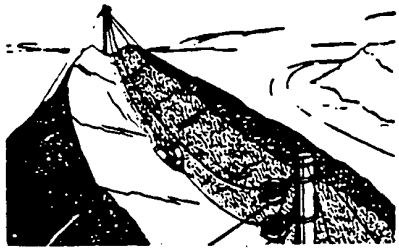


Parallel installation with head tower and tail tower moving along parallel tracks

On long windrow storage piles or when the layout and conditions of a project require that the bucket operate in parallel lines, an installation using traveling head and tail towers is suggested.

The operating machinery is carried on a head tower which moves in coordination with a tail tower. Two sets of parallel track are required for this installation.

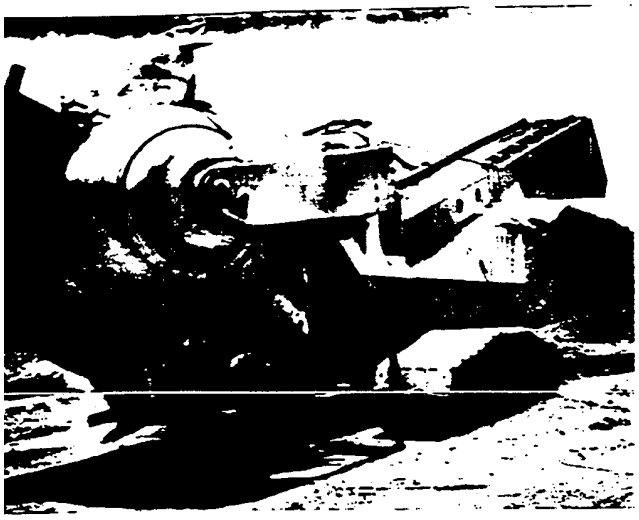
A loading ramp may be provided as shown to load cars, trucks, conveyors, or other means of transport



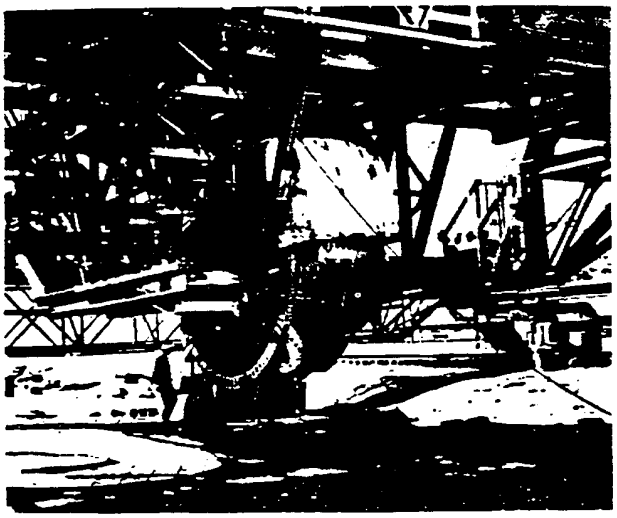
Straight-line installation with stationary tail mast

Where there is only one size of material to be handled and the total tonnage is not too great to be stored in a single long pile, the simple straight-line type of installation gives satisfactory service. The scraper bucket, when stocking out, operates in a single path between the headpost and a high tail mast.

The height of the pile is governed by the height of the mast. The base width varies with the angle of repose of the material. To recover all of the material from such a pile, it is necessary to attach angle bridles to either side of the tail mast so that the path of the bucket can be shifted sufficiently to reclaim from the side slopes



Model 700 MX bucket wheel excavator—theoretical capacity including wheel rim is 1,985 bank cu yd/hr. Rated capacity is 1,000 bank cu yd/hr in average material (Courtesy, Mechanical Excavators, Inc.)



At Kaiser Steel's Eagle Mountain mine, bucket wheel and rake are mounted on separate carriages that propel them independently across face of storage pile. Wheel measures 17½ ft in diam and carries 10 buckets (Courtesy, Link-Belt Company)

STOCKPILING OF MATERIALS

continued . . .

and thereby decreasing wear and degradation. The track cable method is also used to good advantage in non-caving materials, since the bucket can be set on top of pinnacles or high piles to bring them down.

Dragscraper storage machines in sizes from 6 to 15 cu yd would use a track cable system as standard equipment. Smaller sizes would be equipped with a straight haulage system or track cable, depending on the material requirements.

The aerial tramway seems to be thought of today, as a unit that belongs to another time. Perhaps this may be the result of unfamiliarity and a lack of information on the subject. Textbooks that make mention of tramways often contain frighteningly antique photos. Few people ever seem to get around to seeing and reading the few articles that come out describing modern installations.

The aerial tramway is excellently suited for certain applications and can compete with as modern a unit as the belt conveyor. A brief review of the factors that should be considered may be of value at this point.

The ideal capacity range for the aerial tramway is between 50 and 150 tph over distances in excess of 1,000 ft. Installations shorter than this are possible, but the relatively high cost of terminal structures gives them an adverse cost per foot of traverse.

The factors that make practical the use of aerial tramways, include:

1. Terrain—irregular surfaces make the tramway most attractive.

2. Difference in elevation—the aerial tramway can handle large differences without difficulty.

3. Clear distances that must be spanned—spans up to 5,000 ft may be accomplished under reasonably favorable conditions.

4. Low operating cost—being more or less automatic in operation, they require very few men. Any available power can be used, and under some conditions, they may be propelled by gravity.

Aerial tramways fall naturally into two classifications:

(1) The continuous type in which a number of carriers make a complete circuit without interruption or change of direction. (2) The oscillating type or jig-back, in which one or two buckets are arranged to travel forward and backward, each on its own individual rope—not too economical for distances over 2,000 ft.

Most tramways are double-rope or bi-cable. The single-line or mono-cable, in which one endless rope acts as both supporting and propelling member, is now used only for light loads and low tonnages (less than 50 tph). With the bi-cable type, steeper grades are safely negotiated and heavier individual loads can be handled readily.

Although there are many different arrangements in which the various types of tramways can be constructed, they all comprise certain features in common:

1. Two terminal stations—points at which material is loaded or unloaded.

2. Carriers—or containers of some type, suspended from a wheeled frame.

3. A rope track—a heavy wire rope which provides a track along which the wheels of the carriers travel.

4. Traction rope—a more flexible wire rope which propels or controls the carriers as the line is power drawn or gravity operated.

5. Intermediate supports—these tower structures are usually required on all but the very shortest tramways.

Terminal stations contain the loading chute, the drive or control sheaves, the tension mechanism for the track rope and the traction rope; and the unloading equipment. Carriers usually consist of a truck, with two or four trolley wheels; a bucket, box or other container; a pendant or supporting frame which connects the container to the trolley; and a grip or clip for attaching to the traction rope.

The ropes, both track and traction, are carefully selected for their respective duty. Towers for the support of the track and traction ropes are

required on most tramways of any length. The number, location and height of these towers will depend on the contour of the ground, the ground conditions, and the size and number of loads to be carried.

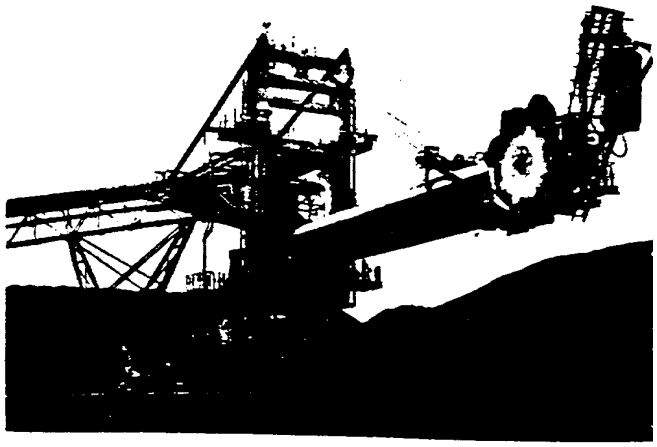
The Rotary Reclaimer is a special application of the rotary bucket wheel to the blending and reclaiming of bulk materials from stockpiles. This machine consists of a bucket wheel supported by a bridge structure that passes through the center of the wheel. The wheel is arranged to travel from one end of the bridge to the other.

Material picked up by the buckets is dropped onto a belt conveyor which operates within the truss section. The bridge is located parallel to the face of the stockpile from which material is being reclaimed. A harrow mounted in front of the bucket wheel dislodges particles from the face of the slope and starts them moving downward. The harrow is nonvibrating, but being mounted on the bucket wheel carriage, it moves transversely across the face of the pile. Material is thus moved sideways, and a blending of material is accomplished at the same time.

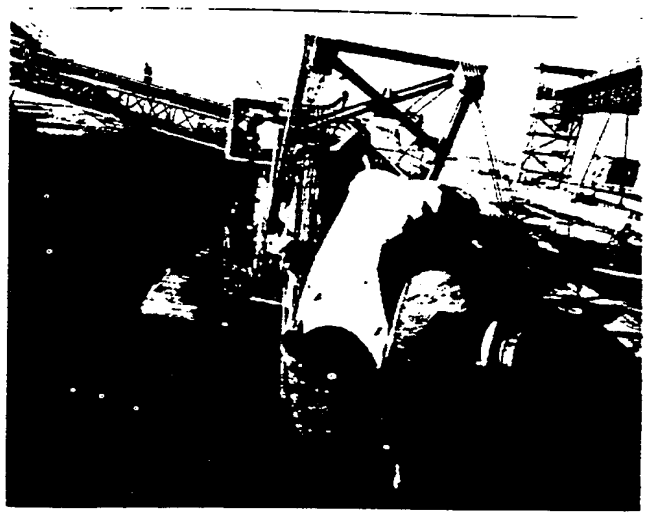
The bucket wheel moves back and forth across the face of the pile, picking up material as it travels along the toe of the stockpile face. Material discharges from the wheel onto the bridge conveyor, and then enters the conveying system to be delivered to process or transportation facilities.

The entire unit can be arranged for automatic operation. Presently, the rotary reclaimer is available in units ranging from 400 to 2,000 tph. There is really no limit to the size of unit that could be built. By increasing the number of wheels and enlarging the bridge conveyor, it is possible to design a unit in which the belt capacity would be the limiting factor. The minimum economical length of bridge is 90 ft, while 140 ft of span is the present maximum limit. Lengths greater than this are too flexible, and excessive deflections present some problems.

Bucket wheel excavators—the bucket wheel is actually a composite of several different machines. Basically, the bucket wheel or digging end must be considered as an independent excavation tool. This is usually combined with belt conveyors and suitable mountings to provide a great variety of arrangements, each designed to meet different specific requirements.



Stacker-reclaimer with tripper—in reclaiming, bucket wheel digs into 36-ft high coal pile in arc-like passes of its 86-ft boom. Machine has a stocking rate of 1,500 tph and a reclaiming rate of 700 tph. Gantry can travel along the 620-ft runway rails at 50 fpm (Courtesy, Drava Corporation)



Model 3560 MX bucket wheel reclaimer—machine is reclaiming iron ore pellets at 3,000 tph. Theoretical capacity is 6,000 tph (Courtesy, Mechanical Excavators, Inc.)

When applied to stockpiling operations, the units most commonly combine the stacking or placing function with the reclaiming or excavating function. In this way one piece of equipment is all that is required, and separate stackers are eliminated.

The bucket wheel machines are available on crawler or rail mountings. The rail-mounted units can be automated more readily, while the crawler-mounted machine is capable of complete stockpile reclamation because of its freedom of movement.

These machines are easy to operate, and their continuous non-cycling duty puts no strain on the machinery or operator. They are extremely reliable, can dig a clean floor, which generally eliminates the need for any auxiliary units such as dozers or loaders.

Bucket wheels are excellent blenders when reclaiming from properly-layered stockpiles. Smaller type units are being used indoors for reclaiming fertilizers, bauxites, cement raw materials, clinker, coal, salt, etc.

Although they are expensive machines, bucket wheels do provide low-cost reclamation of materials, highly reliable and trouble-free operation, and long machine life. But, their economy can only be realized by continuous use and high annual throughputs. The range of available capacities is very large, starting at 250 tph (170 cu yd of 100 pcf material) and reaching a maximum of 22,500 tph (15,000 cu yd of 100 pcf material).

The world's largest bucket wheel machine was recently placed in service in Canada. This combination stacker-reclaimer has a capacity of 3,000 tph of pellets. Its digging wheel is mounted at the end of a 215-ft boom. This unit cost in the neighborhood of $2 million.

Bucket wheel reclaimers—Heyl &

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STOCKPILING OF MATERIALS

continued . . .

Patterson, Inc., have developed a Stocker-Reclaimer to meet the need for low-cost, efficient equipment for stocking and reclaiming coal, ore, pellets, and other bulk materials. This new device uses a conventional conveyor belt on a swingable boom for stocking. It is also equipped with a special wheel for reclaiming.

Loading loosely stacked bulk materials onto a conveyor does not require massive digging equipment. These loosely packed materials are readily scooped up and are, therefore, easy to reclaim. Today's need is for equipment that does the reclaiming with a minimum of effort and can be installed with a minimum of capital expenditure. The H&P wheel, which is smaller, and lighter, can be readily mounted on a reinforced stacker boom for loading the reversed conveyor belt to its full capacity.

One model of the H&P reclaiming wheel is capable of reclaiming at a rate of 1,000 tph and weighs only about 6 tons. Therefore, it can be supported on a 1,000-tph conveyor boom without the necessity of more than a moderate increase in the boom weight and the size of the boom hoist equipment.

The paddle type reclaiming wheel is mounted forward of the tail pulley of the conveyor. Rotating in a direction opposite to that of other digging wheels, it pushes the material over the guiding shoe which protects the tail pulley and onto the reclaiming conveyor belt. The material is moved by the wheel at about the same speed and in the same direction as the belt motion, so that a smooth transfer from the wheel to belt is accomplished.

The boom is swung sideways to bring the wheel into contact with successive cuts of material. A cut equal to or slightly deeper than the wheel diameter can be made. The device is equipped with special plows for breaking down material and moving it into the wheel, thereby maintaining a uniform pile contour.

The reclaiming rate is a function of the depth of cut, the amount of forward movement between cuts and the rate of boom swing. Automatic controls govern the rate of swing needed to obtain the desired loading rate.

The lips of the paddles or blades on the wheel clear the bottom guide shoe by only a few inches. To guard against blade damage in case they encounter material which they cannot cut through, the wheel mounting is hinged to the framework. Thus it can lift to clear debris without damage to the blades or other parts.

The corner tips of the blades are equipped with special digging teeth that extend radially beyond the main portion of the blade tips. As the wheel is swung to the side, these teeth loosen all material and the blades then have only to slide the material up the guide shoe onto the belt.

The size of the wheel is determined by the reclaiming rate as well as the weight of the material reclaimed. A 6-ft diam wheel will suffice for rates up to 1,500 tph of coal. Such a wheel would be equipped with ten blades for the higher tonnages and as few as five or six blades for the lower tonnages. The 1,500 ton capacity is materially increased when handling heavier materials.

For reclaiming coal in the 3,000 tph and greater ranges, a 12-ft diam wheel would be used. The horsepower required to drive the wheel is very nominal as only a small amount of work is done in moving the material onto the belt.

To adjust the equipment to reclaim, the belt tripper is moved away from the reclaimer, its inclined belt is lowered to the reclaiming position and the tripper is then pulled back to the reclaimer structure.

When stocking out, the outer end of the conveyor is lowered by a motor-driven screw device so that the material being stocked passes out clear of the reclaiming wheel.

Dragscraper capacities

Machine size (cubic yards)	Capacity in cu yd/hr for average haul of 100 ft	200 ft	300 ft	400 ft	500 ft	800 ft	1,000 ft
½	40	24	18	14	—	—	—
¾	62	34	25	20	16		
1	82	48	35	27	21		
1½	130	75	53	42	33		
2	172	98	72	55	44		
3	293	172	120	93	76		
4	391	230	161	123	100		
5	488	288	200	155	126		
6	420	282	215	168	138	96	—
8	560	375	280	224	184	128	—
10	700	470	350	280	230	160	130
12	840	564	420	336	276	192	156
15	1,050	705	525	420	345	240	195

Note: Handling rates are based upon normal digging, free-caving material with an average weight of 3,000 lb/cu yd. Machines 1½ through 5 yd show capacities when equipped with torque converter diesel power (Courtesy, Sauerman Bros., Inc.)

Production data—Mechanical Excavators, Inc., wheel excavators

Data	Model 500	Model 700	Model 2000	Model 3560
Purchase cost	$166,000-	246,000.-	$570,000.—	$563,000.—
Rated capacity	500 cy/hr	1,000 cy/hr	2,500 cy/hr	4,500 tons/hr (iron ore pellets) (at 132 pcf)
Operating Costs				
Repair parts & mechanical labor	$4.30	$4.30	$7.05	$5.10
Fuel, oil, grease	2.90	3.10	5.46	5.46
1-Wheel operator	4.90	4.90	4.90	4.90
1-Oiler	—	3.75	3.75	3.75
Total direct cost (per hour)	$12.10	$16.05	$21.16 Excavator*	$19.21 Reclaimer*

* Note: Models 2000 and 3560 are the same basic machine, except one is fitted for service as an excavator and the other as a wheel reclaimer

STOCKPILING OF MATERIALS, Part 11-B

Buckets & related equipment answer many reclaiming problems

- **An examination of the bucket crane shows important points to consider when selecting a bucket crane**

The bucket crane is an efficient, low-cost, mover of bulk materials. When properly applied, it will give continuous trouble-free service for long periods of operation. It is the intention of this article to provide the reader with certain guidelines which will permit him to better evaluate the application of a bucket crane to his particular materials handling problem.

Generally speaking, bucket cranes are available in capacities ranging from 3 to 22 tons, or in terms of bucket capacities—from ½ to 7 cu. yd. With today's cranes, the bridge span, or width of runway, is limited to 150 ft. Spans greater than this are uneconomical, for maintaining squareness of the bridge becomes impossible and deflection of the bridge becomes excessive. For most standard units, the maximum lift is about 50 ft, while 300 ft is usually a practical limitation on the length of the runway. If the length of runway is greatly in excess of 300 ft, too much time will be spent in travel. In such cases, two cranes may provide a desirable solution.

In selecting a bucket crane, something should be known about the characteristics of the material to be handled, its weight or bulk density, its handling characteristics, and its abrasive and corrosive qualities. Next, the quantity of material to be moved per unit of time should be established. It is usually advisable to add 20 or 25 percent to the flow-sheet quantities, so that there will be some reserve capacity in the unit that is finally selected. Such an adjustment will compensate for variations in operation efficiency, and allow for an increase in

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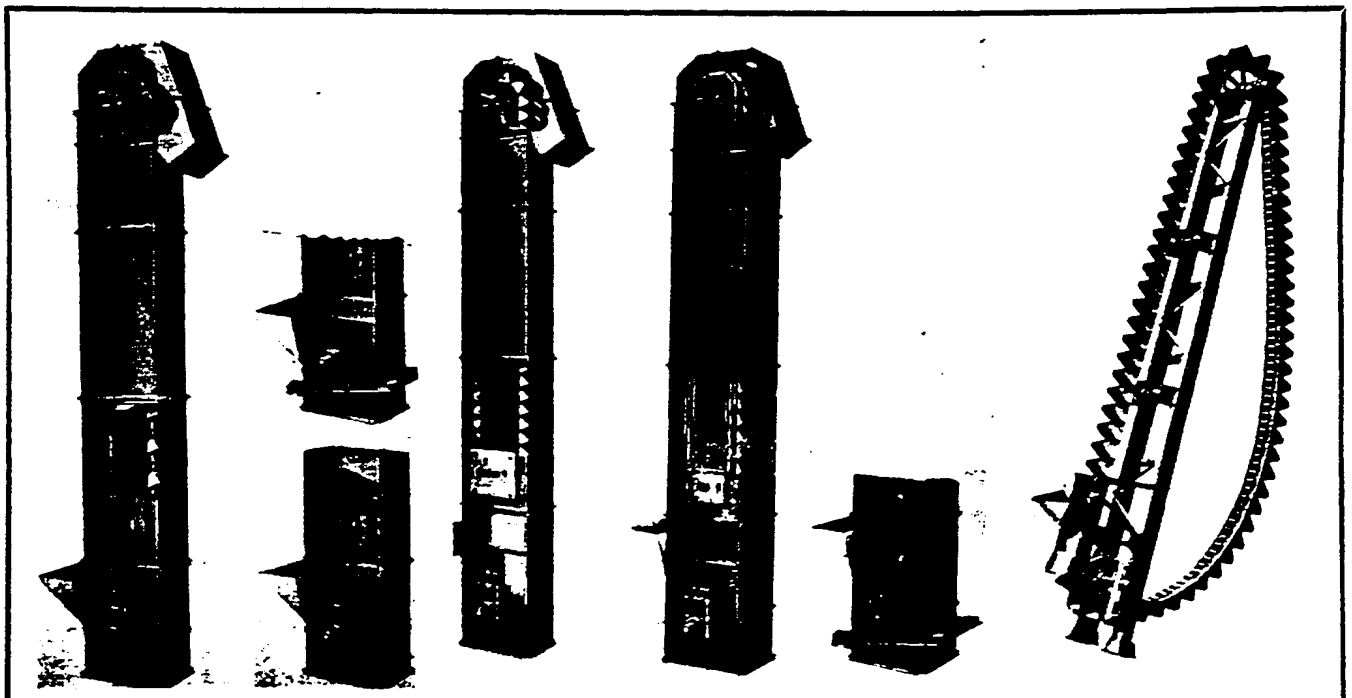
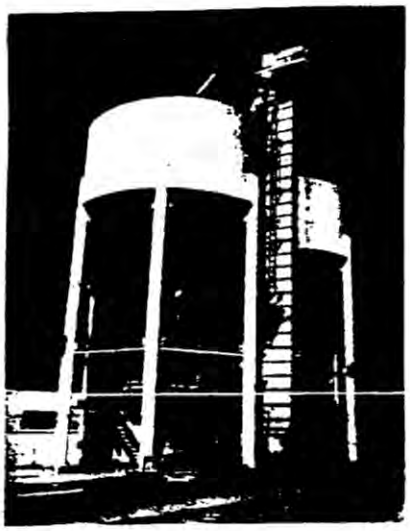


From left to right: Centrifugal discharge elevator—Note spaced buckets back-mounted on a single strand of chain. Partial view shows arrangement of elevator when using belt with spaced buckets back-mounted on belt. Upper partial view shows external gravity take-up. **Gravity discharge elevator**—Note continuous arrangement of buckets on a single strand of chain. Buckets are back-mounted. This type of mounting requires considerable punching of belt. **Gravity discharge elevator**—Note continuous arrangement of buckets end-hung between two strands of chain. This arrangement permits the use of larger buckets, thus increasing the capacity without high-speed operation. Partial view shows external gravity-type take-up at foot. **Bucket elevator supported on open frame**—Buckets are arranged on a single strand of chain and operate without an enclosed casing. Note the angle of inclination at which unit operates



Cement bulk loading station—This cement mill elevator elevates cement from bulk car into storage bins

STOCKPILING OF MATERIALS

continued . . .

the amount of material handled. There always seems to be a desire on the part of most operators to crowd a few extra tons through a plant.

Having established the quantity of material that is to be moved, in terms of tons per hour or cubic yards per hour, the next step calls for calculating the duty cycle of the operation.

Fig. 17. Bucket crane duty cycle, is a simplified version which has been used successfully in analyzing such problems. In order to do a satisfactory job of calculating the duty cycle, a sketch of the proposed layout, in plan and elevation, is generally desirable. The clearance diagram (Fig. 18) provides a convenient guide to the dimensions that need to be established. The more information that the crane designer receives, the more effectively he will provide a crane specification that meets the installation requirements.

In calculating the duty cycle for a bucket crane, the following speeds should be considered as limiting:

Hoist—100 to 300 fpm—lifting & lowering the load.

Trolley—150 to 250 fpm—travel across the runway.

Bridge—200 to 500 fpm—travel along the runway.

Bucket—10 to 20 sec—time required to open or close bucket.

It should be emphasized that bucket cranes in continuous material-handling service undergo severe operating loads. They must be ruggedly constructed, with long-wearing parts; and large, heavy-duty motors capable of running for long periods of time without excessive overheating. In order to maintain the required production rates, crane speeds should be as high as practical. Higher speeds require larger motors, brakes, and mechanical parts, which in turn increase the purchasing and operating costs.

In determining the capacity of the crane, the weights of material and bucket must be known. Bridges of bucket cranes are heavier than those of hook-type cranes, because bucket trolleys are larger and heavier than regular trolleys—they have two drum hoists instead of the usual one. One hoist is required to raise and lower the bucket, while the other opens and closes it.

For small capacity buckets, the two-line, lever arm type of bucket is most often used. The use of three-lines is recommended up to 5 cu yd, and four-lines are advised for 6 and 7 cu yd. The larger number of lines will reduce the tendency of the bucket to spin.

Buckets are reeved according to the digging conditions and speed requirements of the installation. For hard digging, a five-part reeving will provide digging power but the operation will be slow. For light digging, a three-part reeving will provide sufficient power, but will be much faster in operation. Most materials-handling operations do not require a strong digging force, but emphasize bucket operation speed.

For continuous materials-handling installations, the use of the bucket trolley and two, three or four line bucket is strongly recommended. In some cases, where the handling of bulk materials is done very intermittently and there is need for a crane for other purposes, it may be possible to consider an industrial service crane with a hook-on bucket. This bucket may be a single-line bucket, or an electric motor-operated bucket. It should be emphasized that this installation is not suitable for continuous duty and should only be considered for intermittent operations.

The bucket crane is an extremely flexible unit, and is capable of maintaining a high rate of production. It enjoys a moderate operating cost and a rather low maintenance cost. Since it is supported on an elevated structural steel framework that is rectangu-

Fig. 17—Bucket crane duty cycle

I—Material to be handled:

Name: _____

Chemical composition: _____

Abrasive properties: _____

Weight: _____ lb/cu ft; Particle size: _____

% Moisture: _____ Condition: _____

II—Tonnages to be handled:

Weight: _____ tons; Volume: _____ cu yd

Time available: _____ hours; _____ minutes

Flow rate: _____ tons per hour (short tons of 2,000 lb.)

III—Handling speed: **Time required for 1 round trip: Distance, Time**

Crane capacity _____ tons — Raise & lower _____

Hoist speed _____ fpm — Across & return _____

Trolley speed _____ fpm — Along & return _____

Bridge speed _____ fpm — Open & close _____

Bucket time _____ sec

Unit time required for one round trip _____ min.

Number of trips possible at 100% efficiency $= \frac{\text{Total Time}}{\text{Unit Time}} =$ _____ trips

IV—Bucket capacity:

Bucket type: _____ Manufacturer: _____

Bucket	Total tons handled in hours		
	100% loading	80% loading	% loading
_____ cu yd capacity	_____	_____	_____
_____ cu yd capacity	_____	_____	_____
_____ cu yd capacity	_____	_____	_____

V—Comments:

_____

_____

_____

lar in plan, it is readily installed inside of a building or under an open shed roof.

Where very long runways are required, or soil conditions make alignment of an overhead runway difficult, or the location of the runway is temporary and subject to being changed, the use of gantry cranes should be considered. In the gantry crane, the bridge is supported on two rigid bents which are arranged to roll on track located at or close to grade elevation. By raising the top of the bent above the bridge enough to permit the passage of the trolley through the legs, the bridge may be cantilevered outside of the runway tracks. This through-leg arrangement may be obtained at one or both ends of the bridge, and permits the crane to be used for loading and unloading railroad cars, trucks and barges.

In general, bucket cranes are well-suited to applications where the storage is confined to a relatively small area, where some degree of protection from the weather is required, and where the product cost is high enough to justify the relatively large capital investment required for a crane. Sand and gravel operations, for example, cannot justify the expense of a crane installation. On handling of cement clinker, however, the bridge crane is the item of equipment most commonly used.

To provide some concept of the materials-handling capability of the bucket crane, Table XXV was prepared. For the smaller bucket sizes, the time cycle ranges from 1.0 to 1.5 minutes while the larger buckets may run as high as 2.0 minutes.

The selection of the bucket to be used in materials handling applications should be based on many factors, mainly:

Material to be handled—The size and type of bucket will vary with the properties of the material to be handled. Factors such as density and weight of material, the degree to which it cakes or compacts, and the size of the particles should all be determined carefully. The abrasive properties of the material may call for special alloy construction or the addition of abrasion resistant liners or hard-facing. The corrosive properties may call for the use of stainless steel or other resistant materials.

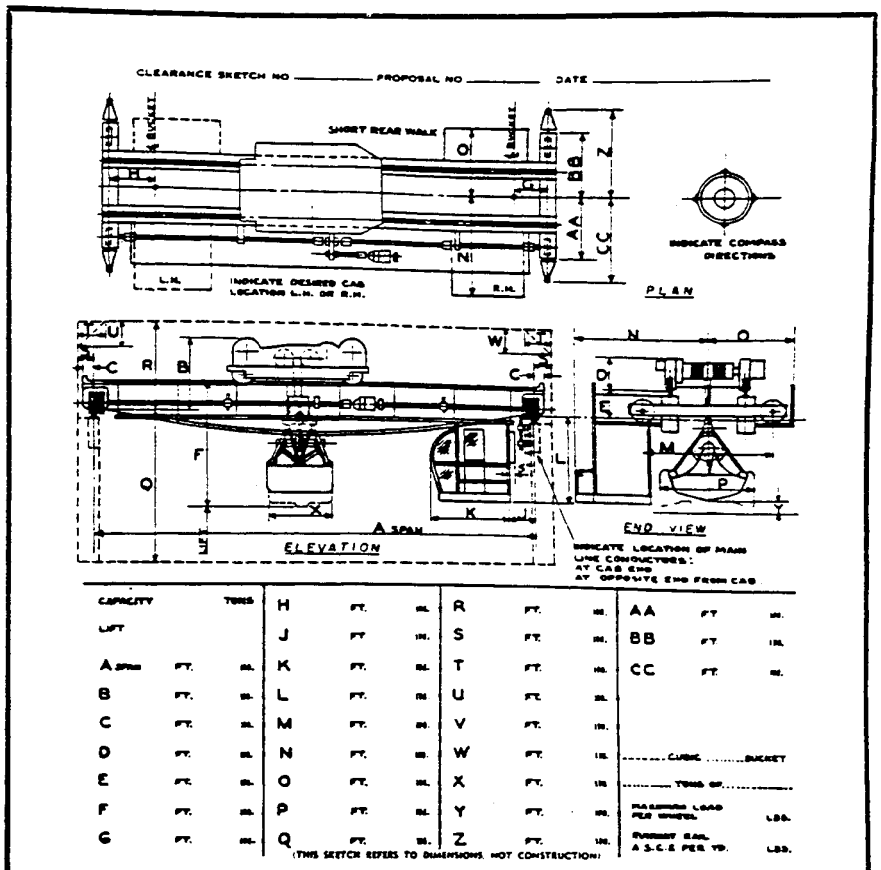


Fig. 18—Dimension guide (Courtesy, Harnischfeger Corp.)

Speed of bucket operation—The speed of bucket operation will be largely determined by the ease with which the material can be loaded and unloaded. If the material is hard to dig, the bucket must be reeved to provide the required force—which results in a slower rate of operation. If the material is loose and no digging force of any magnitude is required, the bucket may be reeved for fast operation. To attain rapid unloading, the bucket

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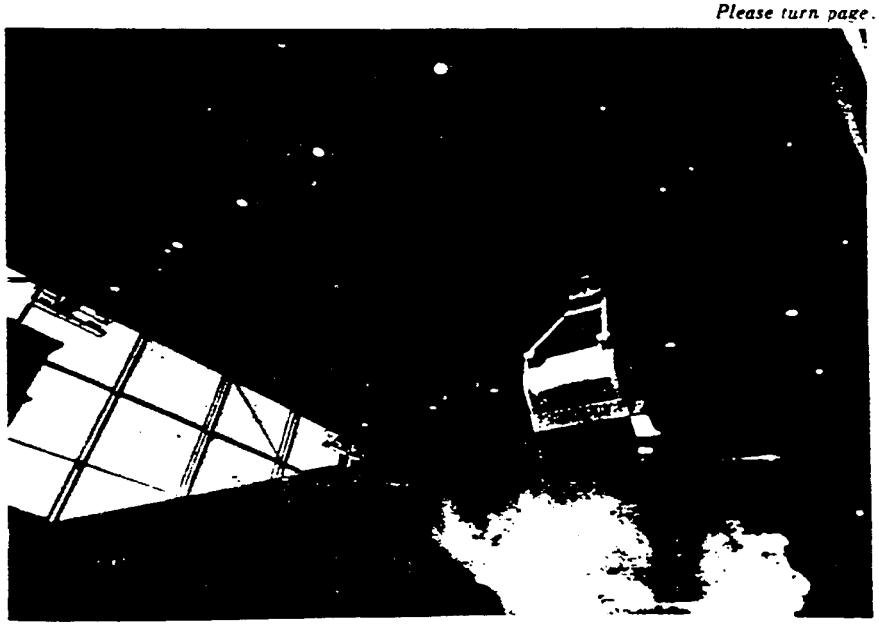


These two bucket cranes operate on a single runway

STOCKPILING OF MATERIALS

continued . . .

should have a wide-opening scoop and a smooth interior. This will lessen the possibility of material hang-up.

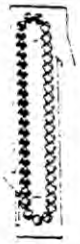
Clean-up requirements—For operations that require a high degree of clean-up, such as barge or railroad car unloading, consideration should be given to the area that the bucket can cover when no longer in unlimited digging areas. In such cases, the bucket that can cover the most space will reclaim more material and be the most productive.

Weight of bucket construction—Where a heavy bucket is required for digging, it is generally better to have the weight in the bucket parts, rather than using a light-weight bucket with counterweights. If the weight is not required for digging, the light-weight bucket will permit a large payload.

Bucket elevators

The typical bucket elevator consists of a series of buckets mounted on a continuous chain or belt and arranged to pass around a top (head) and bottom (foot) wheel or pulley. The

Fig. 19—Bucket elevator selection chart

Type of elevator	General information	Bucket size & capacity data	Materials handled
Centrifugal discharge—with spaced buckets—single chain			
	Most widely-used type. Low cost, simple design. Use for materials up to 500° F. Available to 80' nominal centers Chain speed: 200-300 fpm Single strand of chain. Capacities: 0 to 165 tph	6 x 4 — 15 tph 8 x 5 — 30 10 x 6 — 50 12 x 7 — 75 14 x 7 — 100 16 x 8 — 145 18 x 8 — 165	Used for relatively fine, free-flowing materials that range from 300 mesh to 2" max. lump size, such as: Anthracite, Ashes, Bauxite, Bentonite, Borax, Clinker, Cement, Chalk, Coal (Bit), Coal (Lig), Coke (Pet), Dolomite, Feldspar, Fluorspar, Gravel, Gypsum, Lime, Limestone, Phosphate Rock, Pumice, Pyrites, Iron, Salt, Shale, Slag, Slate, Soda Ash, Talc
Centrifugal discharge—with spaced buckets—belt			
	Use for abrasive material with Mohs hardness of 7 or more and high speed applications. Use for materials up to 300° F. Available to 120' centers Capacities: 0 to 150 tph	6 x 4 — 15 tph 8 x 5 — 30 10 x 6 — 50 12 x 7 — 70 14 x 7 — 100 16 x 8 — 150	Used for relatively fine, free-flowing abrasive materials from 300 mesh to 2" max. lump size, such as: Aluminum oxide, Coke breeze, Cullet, crushed, Grain, Phosphate sands, Sand, damp or dry, Wood chips
Gravity discharge—with continuous buckets—single chain			
	Slow-speed machine. Uses loading leg to fill buckets Available to 80' centers Chain speed: 125 fpm Available with belt, but not usually recommended Capacities: 0 to 125 tph	8 x 5 — 30 (2½") 10 x 5 — 40 (3") 10 x 7 — 50 (3") 12 x 7 — 60 (3½") 12 x 8 — 80 (3½") 14 x 7 — 70 (3½") 14 x 8 — 95 (3½") 16 x 8 — 110 (4½") 18 x 8 — 125 (5")	Used for very fluffy materials and material with a large percentage of lumps, 2" to 5", such as: Alum, lumpy or fine, Carbon black pellets, Chalk, pulverized, Charcoal, Coal, bituminous fines, Coal, bituminous pulv., Cork, ground dry, Feldspar, powder, Granite, broken, Iron ore, crushed, Lime, hydrated, Mica, flake, Marble chips, Potash, coarse, Potash fines, Soda ash, light, Traprock, cr., Taconite pellets, Titanium dioxide, Zinc ore, cr.
Gravity discharge—with continuous buckets—double chain			
	Heavy-duty units. Slow speed For extra-large capacity Severe operating conditions. Uses loading leg to fill buckets Available to 100' centers Chain speed: 80-120 fpm Capacities: 0 to 500 tph	18 x 9 — 150 (6") 24 x 9 — 200 (7") 30 x 9 — 250 (7") 36 x 9 — 300 (7") 30 x 13 — 310 (10") 36 x 13 — 370 (10") 42 x 13 — 430 (10") 48 x 13½ — 500 (10")	Used for relatively free-flowing materials with lump sizes up to 10" See material listings above Note: Capacities indicated are based on 100 pcf material, and buckets filled to 75% of catalog rating. Data adapted from catalogs of Rex Chainbelt, Inc. & Link-Belt

center distance between these two wheels is selected to suit the lift required. Standard units are available with lifts to 80 or 150 ft. Specially designed units have been built for considerably greater lifts. To compensate for variations in chain or belt length due to changes of temperature, atmospheric conditions, wear, and other factors: some form of take-up is required on one of the wheels. This take-up may be a manually adjustable screw, or a self-adjusting gravity take-up. Most generally, the take-up is located at the bottom wheel. However, where material tends to pack or requires frequent clean-out, head-end take-ups are recommended.

A steel casing, usually rectangular in cross-section, encloses the line of buckets and the head and foot wheels. The casing also provides the structural support required by the machinery. Access to the interior of the casing for servicing and clean-out should be provided at several points. Usually, the head section is formed of a split light-gauge sheet, to permit the removal of a considerable portion of the casing for access to the headshaft machinery as well as the buckets and chain or belt. A removable panel should be provided at an intermediate section at an elevation that is accessible from some platform level. The bottom section should also have a removable panel for clean-up of the boot and access to the tailshaft and take-up.

Some types of elevators have open steel supporting frames instead of casings. Sometimes the casings have been formed in circular sections of concrete. One cement company has cast the elevator tube as part of the silo into which the elevator will discharge. Usually, elevators are designed to operate with the vertical centerline held plumb. In some cases, these units can be operated with a lean that does not exceed 15 deg off the true vertical.

Elevators are classified in many different ways. For purposes of this discussion there are two major groupings —centrifugal discharge and gravity discharge. Within the centrifugal discharge group, two types of elevator are found—either spaced buckets mounted on a single strand of chain, or spaced buckets mounted on belting. Within the gravity discharge group there are three types of elevators. One with continuous buckets mounted on a single strand of chain; the second with continuous buckets mounted on belting. This last is not too commonly used since the material packing behind the bucket tends to pinch and damage the belt. The third type is the high-capacity type, which uses larger buckets suspended between two strands of chain. These groups are described in detail in Fig. 19 and recommendations given for their proper application.

Table XXV—Bucket crane production in cubic yards per hour

Bucket size, Cu yd	Time required for one complete cycle @ 100% loading 1.0 min.	1.5 min.	2.0 min.	2.5 min.	3.0 min.	3.5 min.	4.0 min.
1	60 cyh	40 cyh	30 cyh	24 cyh	20 cyh	17 cyh	15 cyh
2	120	80	60	48	40	34	30
3	180	120	90	72	60	51	45
4	240	160	120	96	80	68	60
5	300	200	150	120	100	85	75
6	360	240	180	144	120	102	90
7	420	280	210	168	140	119	105

Note: Calculate time required for one cycle of operation as shown in Fig. 17 (Bucket crane tuts cycle). Then, enter table with time in minutes and bucket size in cubic yards. Read-out cubic yards per hour. Apply correction for loadings other than 100 percent

In the selection of any bucket elevator, flowability of the material is an important consideration. Unit material density is also important—and it is advisable to test a sample in order to correctly evaluate this property. Some materials aerate in handling to such a degree that this property changes greatly. For example, portland cement in the bag weighs 94 lb/cu ft. With handling, however, this weight may become as low as 60 to 65 lb/cu ft. Such a variation requires a considerably larger elevator to handle the extra volume. Elevators are well suited to handling dry, free-flowing, fine materials. As a rule of thumb, it is said that an elevator of the centrifugal discharge type can handle successfully any material that is easily shoveled by hand. (C. R. Davis, Jr., "New Concepts for the Dependable Lifting of Bulk Solids by Bucket Elevator.") Where wet, damp, sticky materials or materials of temperatures over 500F are to be handled in a bucket elevator, the equipment manufacturer should be consulted for his recommendations.

Bucket elevators are compact and efficient units which may be used in combination with many different kinds of materials handling equipment. The vertical design of the bucket elevator saves valuable floor space, an important consideration in many of today's extremely compact operations. Discharge from an elevator is directed into a bin or hopper, or loaded onto a belt or screw conveyor.

Feed to the boot of an elevator may be delivered by many different kinds of conveyors, or loaded by means of a hopper with a feeding device. The hopper may be loaded by a dragscraper, clamshell, shovel or front-end loader. It is generally advisable not to feed surges of material to an elevator.

Three-and-a-quarter-ton capacity crane handles a 2-cu yd bucket. Unit is a five-motor gantry crane with 120-ft span and with one through leg to permit trolley to center over railroad cars for loading and unloading

STOCKPILING OF MATERIALS, Part 12

Mobile excavators— their use in stockpiling

- **Suggestions for economic operation and improved production rates of shovels, draglines and clamshells are outlined**

The use of mobile excavators such as shovels, draglines, and clamshells for bulk material handling has been a standard practice in industry for many years. Over this period of time, this equipment has developed a well-defined area of application.

Although the relatively recent introduction of speedier, more mobile units such as wheeled dozers and crawler or wheeled loaders has made some inroads into this area, there are still many instances where the older, established units are still most effectively used.

Adequate and economic production rate for shovels, draglines, and clamshells is determined by several relatively simple factors:

1. The amount of material that is handled in one bite. This is a function of the properties of the material being handled; bucket characteristics (type size and weight) and the skill of the operator.

2. The speed with which each load (or bite) of material is handled. This is a function of the capacity of the crane, the length of the boom, the maximum radius at which it can be operated, the capacity of the engine, the speed of bucket (or dipper) operation and the skill of the operator.

3. The time that the machine is available for production. This is a function of the machine's downtime or time required for maintenance operations.

All efforts to attain a high rate of production at satisfactory cost must consider these factors.

The shovel is primarily an excavating machine, and has been designed to develop great digging and lifting forces. Since these characteristics are only infrequently required in stockpiling operations, the use of the shovel in this area is somewhat limited.

The use of the shovel as a "stocking" machine is further restricted by its rather limited reach and the relatively low height of its bucket discharge. These two factors tend to produce small stockpiles. The effectiveness of the shovel is somewhat increased where it is used to load trucks which deliver the material into ramped or dozed stockpiles.

Shovel sizes are usually based on the struck capacity of the dipper, rather than the available lifting force. Generally, the shovel and back-hoe attachments are readily interchangeable, and require less counterweight than do draglines and clamshells.

Since there are so many variables that affect the performance of a shovel, it is difficult to provide any general data that will be exact. The table on power shovel output may be used as a rough guide for estimating production.

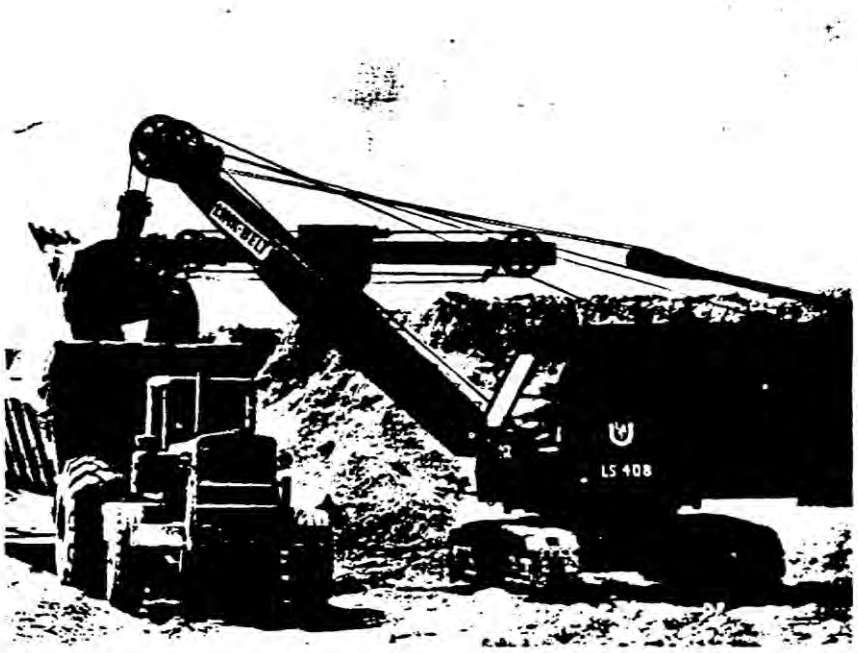
The rate at which a shovel dipper fills will vary with the type of material being handled, and the length of dipper travel through the material. The required length of travel will vary with the size of the dipper. Optimum depth of cut which produces the greatest output and gives the dipper a full load without undue crowding is shown in accompanying table.

Economic production rates for shovels can be obtained by following these suggestions:

1. Use a work pattern that minimizes the amount of swing required for loadout.

2. Work close to stockpile to minimize reach. Make required moves of machine while trucks are spotted.

3. Maintain an adequate digging



Although the shovel is primarily an excavating machine, it can be used to produce small stockpiles

face on pile. If face is too shallow, several passes may be required to fill dipper, thus reducing production.

4. On high, steep faces, remove material from the upper level first. This will reduce the hazard of bank-caving.

5. Avoid lowering dipper all the way on each pass. This requires extra time, reduces production, and is unnecessary unless clean-up is desired.

6. On loading bucket, start swing as soon as bucket is fully loaded and clear of face. Avoid all unnecessary movements and make those required as quickly as is compatible with safe operating procedures.

7. Maintain machinery in good repair, by inspecting and servicing at regular intervals. Emphasize the importance of clean equipment—it makes inspection and maintenance easier.

8. Maintain the surface of the ground in the stockpile area as near level as possible, except for drainage requirements. Eliminate ruts, chuck-holes and soft spots.

9. Adequate drainage around stockpiles is a must—if optimum efficiency is to be attained. Wet, soggy ground will slow down shovel operation and impede the movement of trucks.

10. Insure minimal downtime for repairs, by maintaining a good inventory of replacement parts.

The dragline is most effective for the excavation of material at ground level or below. Recovery of material from a pond is easily accomplished by this machine.

The stockpiles built by this machine are usually for short-term or surge storage, and are always part of the mining operation. The height of the pile is limited by the length of the boom and the height of the bucket. When placing materials in conical piles or parallel windrows, the maximum height of the pile will be approximately 50 percent of the boom length. This limitation is imposed by the angle of repose of the material and the clearances required by the machine and its rigging.

The dragline may be used for reclaiming materials from stockpiles. On the larger piles, it may be desirable to operate the machine on top of the stockpile so as to take full advantage of the operating characteristics of the dragline. The reclaimed material may be loaded directly into trucks, cars or hoppers for feeding onto conveyors.

Power shovel output

Dipper capacity (cu yd)	½	¾	1	1½	2	2½	3	4
Output (cu yd/hr)	90	125	170	240	300	355	405	510

Output shown is based on a 50-min hr, average conditions, 90-deg swing, and shovel loading into trucks or cars. These are approximate values only and will vary according to the ability of the operator, length of swing, height of pile, character of material, voids in dipper and supply of trucks or cars (Courtesy, Bucyrus-Erie Co.)

Optimum depth of cut in feet to fill dipper

	Shovel dipper sizes in cu yd								
Class of material	⅜	½	¾	1	1¼	1½	1¾	2	2½
Sandy clay, moist loam	3.8	4.6	5.3	6.0	6.5	7.0	7.4	7.8	8.4
Sand and gravel	3.8	4.6	5.3	6.0	6.5	7.0	7.4	7.8	8.4
Good common earth	4.5	5.7	6.8	7.8	8.5	9.2	9.7	10.2	11.2
Clay, hard, tough	6.0	7.0	8.0	9.0	9.8	10.7	11.5	12.2	13.3
Clay, wet and sticky	6.0	7.0	8.0	9.0	9.8	10.7	11.5	12.2	13.3

From Technical Bulletin No. 1—Power Crane & Shovel Assoc.

Placing material in stockpiles

	Dragline output							
Bucket capacity (cu yd)	½	¾	1	1½	2	2½	3	4
Output—(cu yd/hr)	70	95	125	170	210	250	290	350

Output shown is based on a 50-min hr, average conditions, 110-deg swing, and dragline casting excavated material. Allowances should be made for a greater angle of swing and for time required in spotting the bucket when loading cars or trucks. These are approximate values only and will vary according to the ability of the operator, angle of swing, height of pile and grade on which machine stands (Courtesy, Bucyrus-Erie Co.)

Loading material out of stockpiles

	Dragline output							
Bucket capacity (cu yd)	½	¾	1	1½	2	2½	3	4
Output (cu yd/hr)	50	66	88	120	147	175	203	245

Output shown is based on a 50-min hr, average conditions, 110-deg swing, and dragline loading cars and trucks. Allowance should be made for a greater angle of swing and any unusual factors that may delay spotting of cars or trucks. These are approximate values only and will vary according to the ability of the operator, angle of swing, height of pile and grade on which machine stands. Load-out output taken as 70 percent of placing rate. Costs increased 18½ percent over placing costs (Courtesy, Bucyrus-Erie Co.)

Clamshell output

Bucket capacity (cu yd)	½	¾	1	1½	2	2½	3	4
Output (cu yd/hr)	60	90	125	170	200	240	275	325

Output shown is based on a 50-min hr, average conditions, 110-deg swing, and a clamshell casting excavated materials. Allowances should be made for a greater angle of swing and for time required in spotting the bucket when loading cars or trucks. These are approximate values only and will vary according to the ability of the operator, angle of swing, height of pile and grade on which machine stands (Courtesy, Bucyrus-Erie Co.)

Dragline sizes are generally based on the lifting capacity of the crane for excavator duty. This usually requires the determination of bucket weight and payload allowable for a given length of boom and angle of boom inclination.

In selecting a dragline bucket for a given crane, the first step is the determination of the crane's capacity for the proposed length of boom. For crawler cranes on lifting duty, a limit of 75 percent of the allowable tipping load is generally used. Most crane capacity tables are based on this percentage. When used for excavating however, the allowable weight of load and bucket are limited to 66 percent of the tipping load. This is to allow for suction, heaping and bucket swing during the lifting of the bucket. When consulting crane capacity tables prepared for lifting duty, the tabulated value must be reduced to obtain the crane's performance capabilities as an

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STOCKPILING OF MATERIALS

continued . . .

excavator. The excavator-duty rating of a crane will be equal to 88 percent of its capacity on lift-duty.

This percentage is arrived at, as follows: Tipping Load = Crane Duty Rating/75 percent = Excavator Duty Rating/66 percent

Therefore: Excavator Duty Rating = 66/75 x Crane Duty Rating = 88 percent of Crane Duty Rating.

The payload will vary inversely with the weight of the bucket that is chosen. The use of lightweight buckets will permit larger payloads, but may result in shorter bucket life. The heavier buckets provide a smaller payload, but generally have a greater ability to withstand handling abuses and abrasion.

Some suggestions for proper dragline operation follow:

1. To choose the right bucket, make sure it has adequate capacity for the rating of your machine.

2. Dig in horizontal layers whenever possible. This results in easier digging, and requires less power than working in ditches. The most favorable digging zone is just inside the boom point.

3. Lower the bucket with all lines taut. When digging, however, the hoist line should be loose—and just barely support the riggings.

4. Pull the bucket through the material far enough to fill it. This should not require more than 2 or 3 lengths of the bucket. When the bucket is loaded, pick it up and start the swing. The shorter the swing, the greater the rate of production.

5. Keep the top edge of the digging face rounded off so there will be no tendency for the drag rope to be abraded.

6. After dumping the load, right the bucket and lower it carefully to the digging face.

7. Work close to the digging face, and avoid casting the bucket. The impact is hard on both bucket and rigging, and will greatly shorten bucket life.

8. Keep bucket clean. Material that sticks reduces the payload. Dig this material out—don't try to jar it loose by pounding the bucket against solid objects.

9. Maintain the working area of the machine as clear and level as possible.

10. Inspect and service the equipment at regular intervals. Keep the bucket teeth sharp for best digging efficiency. Reduce the rate of wear by using alloys or hard-face welding. Maintain an adequate supply of repair parts to reduce downtime for repairs.

Clamshells are well-suited for placing material in stockpiles because of their reach, dumping height and dumping accuracy. The clamshell can pick up material that is above or below the level of the machine itself, and can place material at a higher elevation than is possible with either the shovel or dragline or equivalent capacity.

The clamshell is especially effective for reclaiming from stockpiles since it operates in a vertical digging range. Its dumping accuracy makes it ideal for loading material into trucks, railroad cars, elevated storage bins or conveyor feed hoppers.

Clamshell sizes are generally based on the lifting capacity of the crane

Stockpiles built by draglines are generally for short-term or surge storage

being used—as derated for excavator duty. The derated capacity is taken as equal to 66 percent of the crane's tipping load.

This system of sizing requires determination of bucket weight and allowable payload for a given length of boom and angle of inclination.

Clamshell buckets fall into two broad categories: excavating and rehandling. Excavating buckets are heavier in construction and are equipped with teeth for digging into the material being excavated.

For stockpile operations, it is seldom necessary to employ the excavating type. The standard rehandling buckets are generally more effective, and are available in two widths. One the standard width, is more efficient where penetration is required over clean-up ability. These buckets are generally used for sand and gravel operations, rehandling material from stockpiles, and "stocking" or "reclaiming" in narrow enclosures. The extra wide bucket is recommended for jobs that require considerable clean-up duty. Such applications include: handling materials from railroad cars, barges or storage facilities where floor clean-up is extremely important.

The reeving of the bucket should be selected to suit the material being handled. For relatively easy handling jobs, the use of a minimum number of parts may speed operations, with no sacrifice of efficiency.

The use of alloy steel in the fabrication of the bucket will usually provide greater strength and maintain a low bucket weight-to-load ratio. Abrasion may be reduced by hard-surfacing the cutting lips, or employing special abrasion-resistant alloys such as T-1 in their construction. Double hinge-pin construction will minimize head-room problems and allow greater reach of the digging lips.

Some suggestions for effective clamshell operation:

1. The digging effectiveness of a clamshell bucket is dependent on its weight. A bucket should be chosen that has sufficient weight to dig the material to be handled. If a light bucket must be used, the addition of counterweights may be considered to improve its digging capabilities. However, too heavy a bucket will reduce the payload.

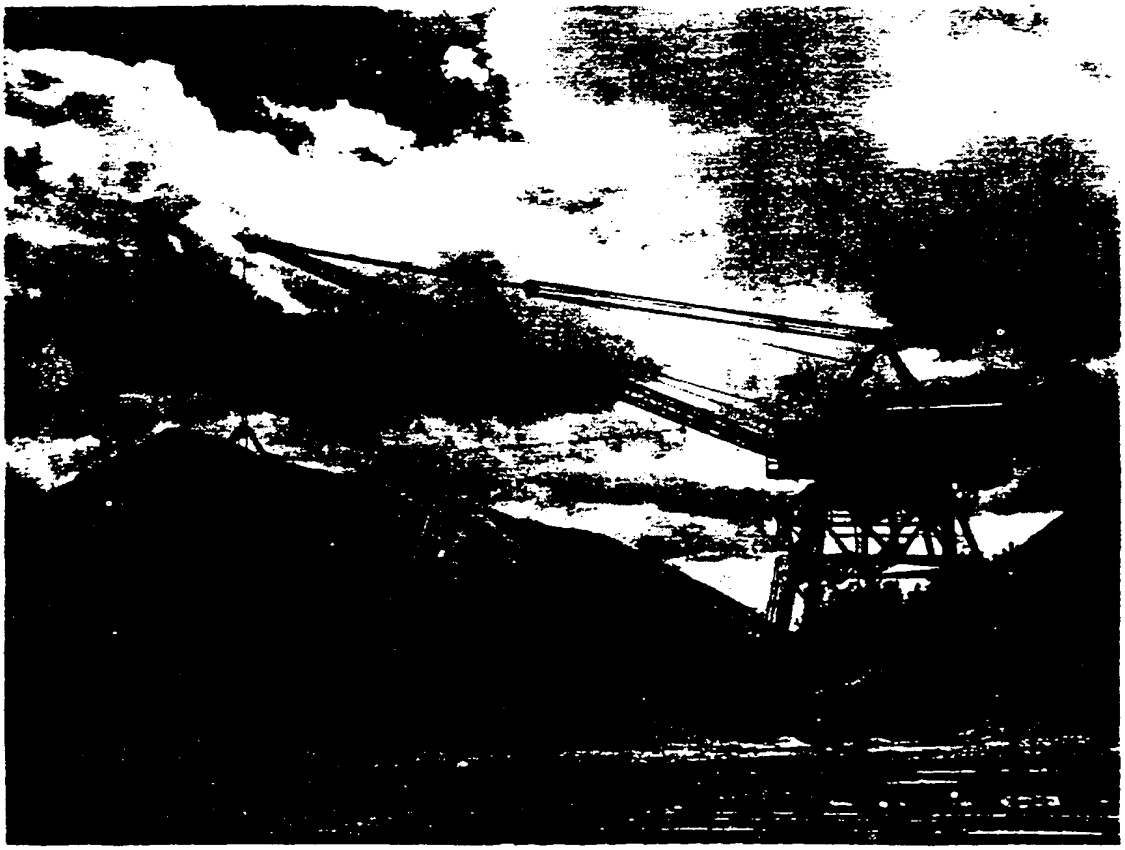
2. Choose the right reeving for your operation. The fewer the parts of line in the closing block, the greater the speed of closing and the stronger the line pull. This tends to lift the bucket out of the material and reduce its load. More parts of line will reduce the rope pull and lessen this lifting tendency, but will also reduce the speed of closing.

3. Do not drop the clamshell bucket into the material from too great a height, and make sure the bucket is fully opened at the same time. Otherwise bending of the bucket teeth may result.

4. Maintain the ground surface in the working area of the clamshell as clear and level as possible. This will result in easier movement of machines and trucks. It will also avoid a tilted axis of rotation which tends to reduce the speed of swing.

5. Booming up and down can be a waster of time. Whenever possible, it is most efficient to position the boom so that the bucket operates about a fixed radius.

6. Inspect and service the equipment at regular intervals. Keep bucket teeth and lips sharp for best digging efficiency. Maintain an adequate supply of repair parts.



Because of their reach, dumping height and dumping accuracy, clamshells are well-suited for placing materials in stockpiles

Utilizing dozers, loaders & scrapers in stockpiling

- **An examination of equipment that moves primarily on the surface of the stockpile and how it can successfully be employed**

The application of mobile units of equipment such as shovels, draglines and clamshells to stockpiling operations has been discussed. In most cases, the machine did not have to travel over the material's surface.

The description of mobile equipment which moves on the surface of the stockpiled material itself will be discussed in this section. These units —the tractor-dozer, loader (tractor-shovel) and scraper—have been widely used in general excavation work before being applied successfully to stockpiling operations.

Dozers

Dozers, as a class of equipment, consist of tractor units arranged with front-mounted blades. They are designed to dig material and push it along the surface of the ground. Today's dozers are capable of exerting a considerable digging force.

There are many variations within this broad classification. The tractor units may be gasoline or diesel powered, the drive train may contain a clutch or torque converter, and the tractive force may be applied through a four-wheel drive or endless crawler tracks. A variety of sizes and types of dozer blades, each best suited to a specific application, are also available.

The combining of these many features into one operating unit for optimum performance requires careful study and analysis of the particular operation to which the unit will be applied.

For example, wheeled tractor-dozers are faster, more mobile and simpler to operate than crawler-tread units. The crawler unit is most effective for distances up to 150 ft, whereas, the wheeled (rubber-tired) unit is effective for distances up to 250 ft. Wheeled units normally operate from 3 to 15 mph, with a top speed of 30.

The rubber-tired dozer develops ground-bearing pressures from 20 to 25 psi, while the crawler unit, with its larger supporting area, develops only 7 to 11 psi. This gives the wheeled unit an edge where compactive force is of importance. The crawler unit, however, is capable of moving along rougher and steeper sloping surfaces than its wheeled counterpart.

Rubber-tired dozers have another significant advantage, in sand and gravel operations, in the fact that tires do not grind and degrade the product as much as the iron tracks do when traveling over the material. There is some savings in footwear costs for rubber over endless track (see Table XXVI).

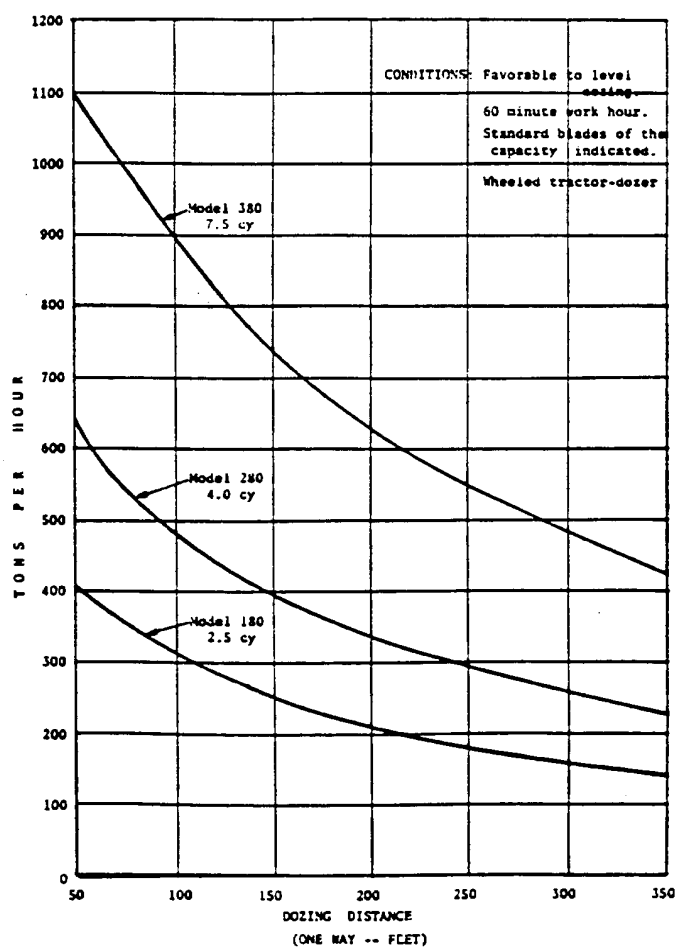


Fig. 20—Tractor-dozer production rates: trap or belt feeding

Applications for dozers

Dozers are well-suited for pushing material along the ground surface or ramping it into stockpiles. Generally, these stockpiles assume the shape of steeply-sloping ramps which cover a fairly large area of ground.

Since the material being handled must also sustain the weight of the equipment, this application is not suited for materials that are friable and therefore subject to disintegration, packing and excessive dusting. Contaminability of the material must also be considered.

Effective dozer applications include trap-loading, building and maintaining stockpiles and yard cleanup. Dozers may also be used for clean-up around a swing shovel, spreading of fill and other materials, towing of equipment and compaction of fill. Dozers may also be used for push-loading scrapers.

Dozer operation data

Estimating dozer performance is no easy task, because of the many variables involved. As a guide only, several different tables of production data are provided.

Fig. 20 provides the rate of production for several different sizes of wheeled dozer on trap feeding duty.

Tabulations in Tables XXVII & XXVIII provide alternate data, as well as an example of the production difference that is attained by two types of dozer blades and track-type tractors.

Tips on application of dozers

When rubber-tired dozers (or tractor-shovels) are being used in severe applications, such as rock or rocky soils, the use of protective chains should be considered.

Abrasion-resistant steel alloy links of high-tensile strength form a flexible protective skeleton around the tread and most of the sidewalls so that the tires are shielded from rocks and other large objects over 3 in. in diameter.

When external wear is rapid, the chains may be turned over to make use of the previously unused portion which was against the tire. Tire wear is reduced when chains are used, and

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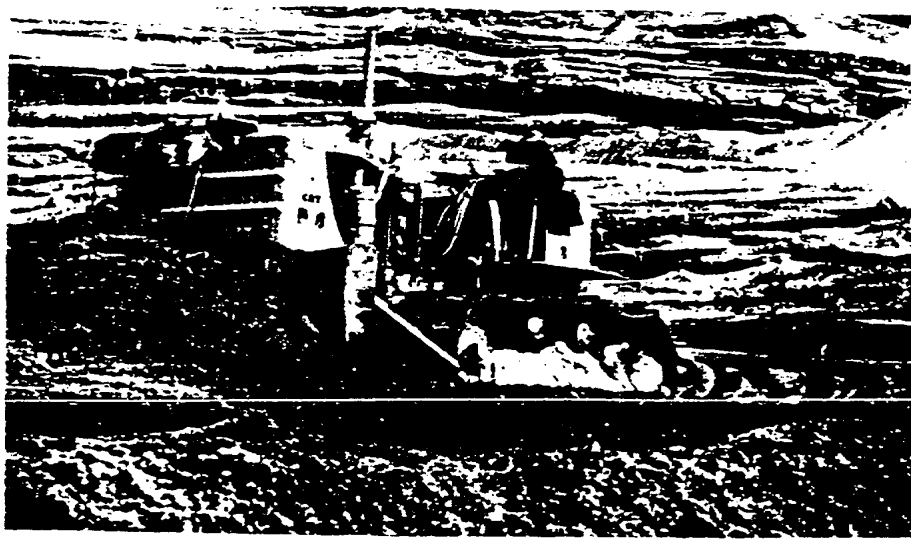


Dozers are particularly useful for pushing material along the ground surface or ramping it into stockpiles

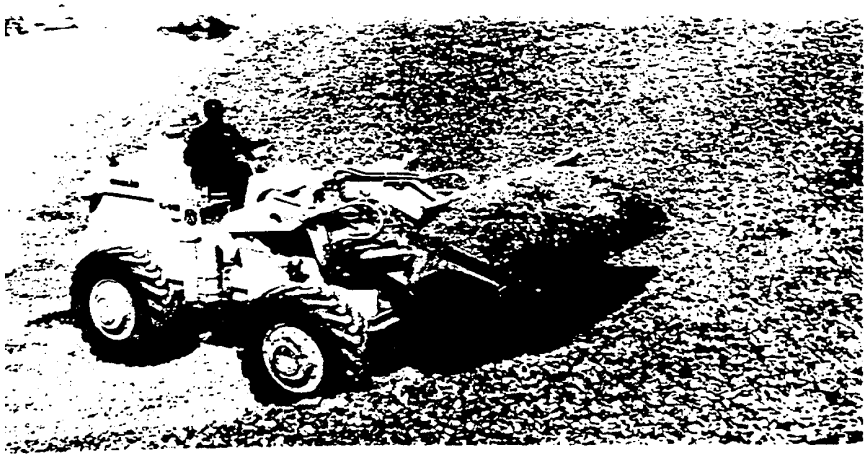
Table XXVI—Selection guide for dozers

Characteristic	Rubber-tired dozer	Crawler-track dozer
Speed & mobility	Best choice for utility machine shuttling between jobs, or for spreading fill. Best from 2 to 5 mph	Second best in this area
Drawbar pull	Requires heavier unit to match crawler drawbar pull	Tracks develop greater traction with less weight
Coefficient of traction	Ranges from 0.4 to 0.6	Ranges from 0.6 to 0.9
Maneuverability	Rigid frame difficult to steer near edge of embankments or lining up on scrapers	More difficult to operate, but skilled operator can perform satisfactorily
	Articulated units better in this regard. Also have less rolling resistance since wheels track	
Compaction & flotation	Standard tires give high compaction & low flotation	Low unit pressure of tracks give high flotation and low compaction
Working in wet ground	Wheels lose traction	Tracks hold better
Rock work	Good traction, but high tire wear	Develops less traction but has less wear
Side-hill work	Rear wheels tend to drift downhill	Holds footing better
Ripping, pioneering, clearing & grubbing	Second best in this area	Very effective in this work
Spreading fill	Speed and compactive force favor wheeled units	Effective for pulling compaction equipment
Pushloading	Where traction is good, wheels are best	Best for pushloading in cuts

Table XXVII—Guide to stockpile dozing with track-type tractors

Machine hp	Type of blade	Blade length	Loose cu yd per hr: 50 to 150 ft distance	Loose cu yd per hr: 250 to 350 ft distance
385	Straight	13 ft-5 in.	1,100 to 520	400 to 320
	U-blade	15 ft-1 in.	1,400 to 670	490 to 440
235	Straight	12 ft-9 in.	830 to 400	290 to 230
	U-blade	13 ft-5 in.	1,060 to 490	380 to 300

Condit[illegible] deg grade; no slot trench; 60 min. hr. For [illegible] wheel-type tractor.



Speed and mobility of tractor shovels make them suitable for a wide variety of tasks including digging, lifting and loading materials

one set of tires may outlast several sets of chains.

Loaders

Loaders or tractor shovels, as a class, consist of tractor units arranged to support and transport a scoop-shaped bucket. These units are capable of digging, lifting and dumping materials into trucks or above-grade hoppers. In addition to differences in motive power, drive trains, there are variations in the system of lifting arms and main frames for these units: four wheel drive, two wheel drive, front steer, rear steer, articulated frames etc. These units are also available with wheels or endless crawler treads.

The range of their effective operation will vary with conditions, but averages close to 400 ft. They can attain speeds up to 30 mph.

Rubber-tired tractor shovels now probably account for more than half of all front-end type digging and loading machinery.

In selecting loaders, consideration should be given to the tractive force available as well as the power provided in the boom and bucket arms. This power is a product of the geometry of the lever system, the hydraulic system and the weight and structural strength of the system.

The unit's power system must be adequate for the performance of two important functions: (1) To deliver sufficient power to the wheels to develop a crowding force commensurate with the weight of the machine. (2) To supply sufficient power to the hydraulic system to dig, lift and dump the anticipated loads.

The crowding force available is significant for it determines the ability of the unit to push the bucket into the material that is to be excavated. The magnitude of this force is determined by the reserve tractive force that is available, and the conditions underfoot. Obviously, four-wheel drive machines develop a greater percentage of machine weight in tractive effort than two-wheel drive units. Thus the four-wheel drive units crowd and dig appreciably better.

Maximum crowding force is attained when the machine spins its wheels. Wheel-spinning produces no additional force and results in reduced tire life.

Break-out force is the theoretical vertical force which can be developed at the cutting edge of the bucket. The magnitude of this force will be determined by cylinder size, hydraulic pressure and the lever system through which the hydraulic power is applied.

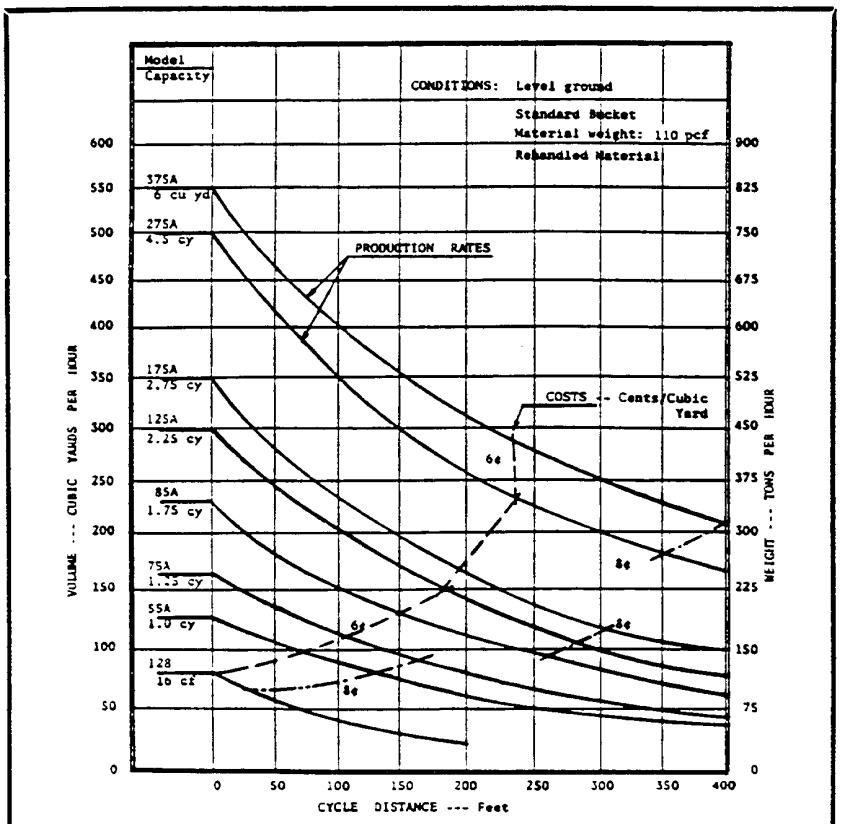


Fig. 21—Tractor-shovel production rates and costs

Applications for loaders

Loaders are extremely useful because of their speed and mobility and therefore are suited to a wide variety of tasks.

Loaders may be used to feed a trap or belt loader, charge an elevated hopper, clean-up around a swing shovel, strip shallow overburden, build and maintain stockpiles, spread fill and other materials, load material into truck bodies, tow equipment, etc.

For compacting fill the wheel loader has a slight edge over the crawler tread unit, since it will exert a higher unit pressure. Large rubber-tired units develop a soil loading of 20 to 25

psi, while crawler treads will develop 7 to 11 psi.

Either unit will serve to transport materials, but the wheeled unit is preferred because of its greater speed.

Neither unit is suited for use as a pushloader with scrapers.

Production rates for loaders (tractor-shovels)

Because of the many variables, it is difficult to accurately estimate rates of production for loaders as a group. For normal wheel loader production, assuming granular piled material similar to sand and gravel, a competent operator and average conditions; a time cycle of 0.5 min. may be used to estimate the basic loader cycle. This time includes an allowance for loading, dumping, four reversals of direction, full cycle of the hydraulics and minimal travel distance.

Factors such as the type of material, height to which it is piled, skill of the operator, repetitive pattern that may develop (or fail to develop), size of trucks and relative size of buckets will all have an effect on the final rate of production.

Care should be taken to determine the actual bulk density of the material, for a small error in this figure can change the actual field performance of the unit.

The use of heaped bucket capacities for estimating purposes can result in appreciable error, since this theoretical capacity may not be attained in the field.

Assuming optimum load-out conditions, with the truck set close to the loader, and the loader operated perpendicular to the face of the stockpile and requiring minimal travel distance, the rate of production in cubic yards per hour will approximate 120 times the rated bucket capacity. This rule of thumb appears to provide correct rates through the 4-cu yd bucket size. Above this size, the results are slightly larger than those attained in the field. See Fig. 21.

Tips on the application of loaders

In building stockpiles, it is a good idea to limit the slope of the pile ramp to a 20 deg grade (20 ft of rise in 100 ft of horizontal run or a bevel of 1 on 5). Grades steeper than this reduce the speed of the loader.

Scrapers are wheeled units which move along the surface and scrape a thin layer of material

If storage space is at a premium and maximum compaction of material is desired, rubber-tired units should be considered since they provide greater compaction than crawler-tread units.

C. E. Killebrew, vice president of Clark Equipment Co. writes:

"The first step in building a stockpile by tractor-shovel from the ground level is to develop a ramp by spreading material as it is cast from the bucket. The ramp slope should not exceed 1:5 for maximum production. By starting in this manner, the tractor-shovel is able to run on the top of the stockpiled material and to compact it into a firm base. When a sizable ramp exists, material is cast from the ramp in a circular pattern until sufficient area is available for the tractor to maneuver on the top of the stockpile. The compacted area is

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Table XXVIII—Guide to reclaiming with wheel-type tractors

Machine hp	Type of blade	Blade length	Tons per hr: 50 to 100 ft distance	250 to 300 ft distance	450 to 500 ft distance
360	Coal	20 ft	1,400 to 1,300	800 to 700	470 to 420
275	Coal	17 ft	1,100 to 950	600 to 500	350 to 340

Conditions: 0 deg grade; no slot trench; 60 min. hr. Adapted from data provided by Caterpillar Tractor Co.

Table XXIX—Stability factors for tractor shovels

Ground conditions	Travel speed in mph: 0	8	16
Smooth, level hard surface	1.00	0.75	0.50
Rough ground, mostly level; or up to 20 percent grade on smooth hard surface	0.75	0.50*	0.25
Rough ground, up to 20 percent grade; or to 40 percent grade on smooth, hard surface	0.50	0.25	0.00

*For average conditions, this is a good stability factor to choose. The calculated bucket capacity should be matched as closely as possible to standard-size buckets for the given loader

Table XXX—Production rates for wheel tractor-scraper

Capacity—cu yd (Struck heaped)	Tons per hr: 0.2 to 0.4 miles travel distance	1.0 to 1.2 miles travel distance	1.8 to 2.0 miles travel distance
40/54	1,200 to 950	600 to 540	410 to 380
32/44	850 to 650	400 to 350	260 to 240

Adapted from data provided by Caterpillar Tractor Co.

STOCKPILING OF MATERIALS

continued . . .

gradually increased by running the tractor nearer the leading edge of the stockpile before dumping. Safest and most efficient dumping is accomplished by erecting a parapet of material in from the edge of the stockpile. The tractor-shovel's reach is employed to dump material over the edge of the stockpile without undue danger to operator or machine. When sufficient material has been cast on the stockpile face, the parapet is dozed forward and compacted to extend the stockpile area."

Sizing of loaders

Truck loading from a stockpile should follow a Y-shaped pattern. Spot the truck at an angle of approximately 30 deg from the face of the stockpile. This allows the tractor shovel to travel a minimum distance while remaining perpendicular to the pile when digging. This results in a better loaded bucket and shorter time cycle.

When sizing a tractor shovel for truck loading service, consideration should be given to the following items: 1. Compare truck body capacity with bucket capacity. 2. Compare truck body length with bucket width and length. 3. Check the number of different truck sizes loaded per shift. 4. Check distance between stockpiles and loading point.

If bucket to truck capacity is correctly selected, a maximum of four passes will be required to fill the truck. Therefore, if high production is a prime factor, a 2½-cu yd machine would be the smallest tractor-shovel to be used with 10-cu yd trucks.

If truck bodies are short (less than 9 ft), the width of the bucket must be checked. Wide buckets result in excessive tailgate spillage.

When loading elevated hoppers, make certain that the maximum attainable bucket height will clear the top of the hopper. In order to utilize the full reach of the loader, provide a horizontal and level section at the discharge point. A rubber-tired tractor shovel is especially economical for this duty when material must be moved 200 ft or more. Over this distance, its speed is greater than that of a dozer pushing material along the ground.

Suggestions for selecting a bucket for your loader.

In order to choose the correct bucket for a given application, it is necessary to consider three factors: 1. The bulk density of the material, in pounds per cubic foot or pounds per cubic yard. 2. The correct "stability factor", which corrects for: a. roughness of the ground surface b. the ground slope or grade, in terms of deg, or feet per hundred feet c. the travel speed of the loader, in miles per hour 3. The bucket sizes available for the loader model.

The formula for determining bucket capacity is:

Bucket capacity (BC) = [Machine lifting capacity (L) (in lb) x (S) (Stability factor)] / (M) Material weight (pcf).

The Society of Automotive Engineers' Tractor-Shovel Sub-Committee has established the maximum stability factor at 1.00 stability factors for various operating conditions are given in Table XXIX.

Applications of dozers, loaders and scrapers

Operations	Type of equipment: Crawler dozer	Wheeled dozer	Crawler loader	Wheeled loader	Scraper
Feed trap or belt	OK	OK	OK	OK	NG
Charge hopper	NG	NG	OK	OK	NG
Shovel cleanup	OK	OK	OK	OK	NG
Strip overburden	OK	OK	OK	OK	OK
Build & maintain stockpiles	OK	OK	OK	OK	OK
Pushloading	OK	OK	NG	NG	—
Fill spreading	OK	OK	OK	OK	OK
Truck loading	NG	NG	OK	OK	NG
Transport material	NG	NG	NG	OK	OK
Tow equipment	OK	OK	OK	OK	NG
Compaction of fill	Fair	Good	Fair	Good	—

Scrapers

Scrapers, as a class, consist of wheeled units which are moved along a material surface and "scrape" a thin layer of material into an elongated rectangular box. The material is pushed into the box-like compartment by the pressure of preceding layers of material.

Variations on this concept include different elevating mechanisms which pick up the material as soon as it enters the box and move it into the back of the unit. By this means, a full load is assured with considerably less tractive force being applied.

Some scrapers are arranged to be tractor drawn. Others, are self-propelled units traveling on their own power. Others are fitted with extra power units on the rear wheels, thus eliminating the need for separate push-loader units.

The range of effective operation varies with conditions, but seems to be close to 700 ft minimum. The hauling capabilities of the scraper make it ideal for large, sprawling stockpiles, especially for large rates of production. Scrapers usually operate in the 18 to 25 mph range.

Applications for scrapers

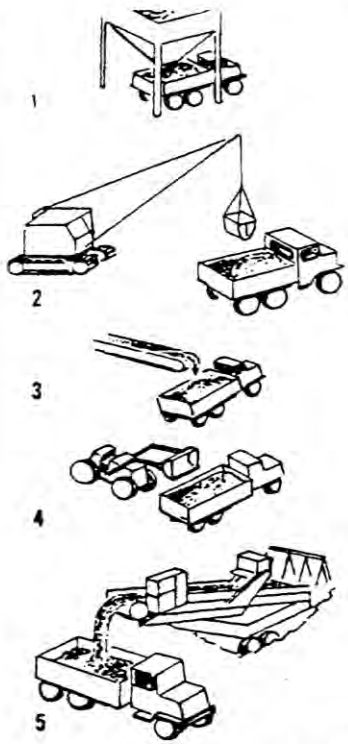
Scrapers are mobile, high-speed units capable of covering large areas. The large ramped types of stockpiles such as are required for the storage of large quantities of coal are ideally suited for scraper operation.

In order for the scraper to perform most satisfactorily, the following factors must be considered: a. the material should be relatively freeflowing, with little or no rock or shale particles. b. Cuts into the material should be of limited depth. c. Mixing the materials is not required. d. A controlled spread of material is required.

This last is important, for it permits material to be placed in the stockpile in uniform layers of relatively shallow depth. Passage of the machine over this thin layers helps to compact the material into a dense mass.

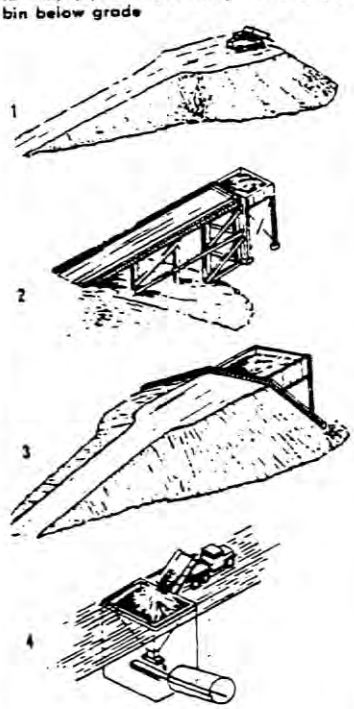
Scraper operating data

The tabulations in Table XXX provide general data on the rates of production attainable with various sizes of scraper over several different haul distances.



Various methods of loading trucks with bulk materials: (1) from bin, (2) with mobile excavator, (3) from process, (4) with front-end loader, (5) with belt-loader

Several methods of unloading bulk materials from trucks: (1) dump on ground or ramped stockpile, (2) trestle to bin, (3) earthern ramp to bin, (4) bin below grade



STOCKPILING OF MATERIALS, Part 14

Trucks—suppliers of mobility & versatility in stockpiling

- **A comprehensive study of the 2 classes of trucks, on-highway and off-highway, in relation to stockpiling—how to select the right truck to perform best under the conditions that prevail and for the type of material being hauled**

At some point in practically every stockpiling operation, there is need for the versatile and highly mobile dump truck. It is necessary to recognize that there are two distinct classes: on-highway trucks and off-highway trucks.

The on-highway truck is limited in size and load-carrying capability to meet the legal size and weight restrictions. The off-highway truck, intended for use around mines, quarries, pits and plants, is free of these limitations and can be built as large as materials of construction permit. Trucks, for off-highway use, are built and sold as complete units, and include chassis, engine, body and all accessories.

Trucks for on-highway use, are generally not purchased as complete units. Usually, the dump body and hoist are obtained from one source, while the truck chassis is purchased from another. First, a dump body is selected that matches the requirements of the intended service. Then a hoist is chosen to suit the body. Finally, a size and type of truck chassis is selected. The selection of the body, truck chassis, and components should be done in consultations with both the body and hoist builder and the truck manufacturer's agent. A properly balanced unit will be obtained which will be more likely to provide maximum service with minimum downtime.

In choosing a body size and type for on-highway use, information on the following should be available:

- Characteristics of the material to be hauled.
- Hourly load requirements.
- Length and type of haul.
- Type of operation and terrain.
- Method of loading truck.
- State or local size and weight limits.

Type of material hauled

When the material to be hauled is a commonly-handled product, its properties may be predicted from standard tables or approximated from the operating experience of others. (See Table XXXI). For the unusual material which may have certain peculiar or unknown properties it is always desirable to run a few simple tests on actual samples of the material. This will usually detect unusual and troublesome properties, such as a tendency to pack, aerate, fluidize, or abrasive, or corrosive effects. The last two will greatly influence the choice of the materials from which the truck body is constructed.

Some materials exhibit a tendency to dry out in transit and are highly susceptible to wind. Knowing these characteristics in advance, the operator can take proper precautions—and either wet the material down, spray it with a binder or provide a plastic cover. Some thixiotropic materials.

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STOCKPILING OF MATERIALS

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such as fine filter cakes, retain a large percentage of water, and are no problem. The vibration while traveling down the highway, can, however, turn this material into a quaking and highly fluid ooze. Without some type of continuous liner in the body, this material may end up flowing through the tail gate and distributing it along the traveled way.

Load requirements—daily or hourly

Once the daily or hourly load requirements are established, the size and number of trucking units to maintain the desired production, can be determined. Table XXXII illustrates a simple method of analyzing production for a given cycle time. Each specific problem should be analyzed in a similar manner, to determine the most appropriate capacity and number of units.

Length and type of haul

The length and type of haul should be studied, for it determines many important elements such as, the size and type of body and hoist, the payload weight, the size of truck, the truck's gradability requirements and the necessary highway speeds.

For all types of hauls it is desirable to maximize the payload weight, since this determines usually the charge for the haul. In the case of off-highway operations, the only limitations on axle load are the size and capacity of the truck unit. For on-highway operations, the legal load limits require that axle loads be held below certain maximums—usually, 18,000 lb for single-axle, and 36,000 lb. for tandem-axle units. Working within these limits, the only way in which the payload can be increased is to reduce the weight of items on the truck itself, such as: body, hoist and accessories. It is for this reason, that many haulers find it desirable to consider aluminum bodies and telescopic hoists.

When the haul run is confined to a definite, known stretch of highway, road conditions, grades and speed limits should be carefully studied for their effect on the performance of the truck selected.

Type of operation and terrain

The type of operation and terrain will determine the type of body and hoist that is specified, as well as the hoist and body accessories, truck components and tires. When the terrain is rough and irregular, it is desirable to use the arm-type of hoist because of its sturdier construction. Accordingly, the truck frame and body should be of heavy construction to withstand the twisting forces that will tend to rack and distort it. Tires, for use on sharp, jagged rocks, should be larger and of heavier construction.

When the area of truck operation is relatively smooth, the use of lighter bodies and telescopic hoists is feasible. Under such conditions, all components will be subject to far less stresses, and lighter weight construction will attain greater payloads without sacrificing strength or increasing maintenance costs excessively. It is, however, impossible to generalize on this factor because of the infinite variety of the operating conditions.

Method of loading truck

The method by which material is loaded into the truck body will greatly influence the choice of body type and materials of body construction, for

Table XXXI—Approx. weights of materials (commonly transported in trucks)

Material	lb/cu ft	lb/cu yd
Alabaster	160	4,320
Andesita stone	180	4,850
Asbestos	153	4,130
Ashes, coal (packed)	45	1,215
Barytes, mineral	280	7,550
Basalt rock	185	5,000
Bauxite	160	4,320
Bluestone	120	3,240
Borax	110	2,970
Chalk	137	3,700
Charcoal—oak	33	890
—pine	23	620
Coal, broken—anthracite	60	1,600
—bituminous	45	1,200
Coke	30	800
Diabase	185	5,000
Diorite	185	5,000
Dolomite	181	4,890
Feldspar	160	4,320
Flint	185	5,000
Gneiss—solid	160	4,320
—crushed	95	2,565
Granite—solid	175	4,725
—crushed	96	2,590
Graphite	170	4,590
Greenstone—solid	187	5,050
—crushed	107	2,900
Gypsum	150	4,050
Hornblende	200	5,400
Limestone—solid	166	4,480
—crushed	95	2,565
Magnesite	187	5,050
Manganese	475	12,825
Marble—solid	165	4,455
—crushed	95	2,565
Marl	140	3,800
Mica	185	5,000
Nickel	537	14,500
Ore—most ores are 15 to 20 percent heavier than the rock which forms the bulk of the ore		
Peat	50	1,350
Phosphate rock	200	5,400
Porphyry	172	4,645
Pumice	40	1,080
Pyrites	315	8,500
Quartz	165	4,450
Rip-rap stone	65	1,750
Sandstone—solid	147	3,970
—crushed	86	2,325
Shale—solid	172	4,645
—crushed	92	2,485
Slate	175	4,725

example, when loading is done by a shovel or dragline, a heavy-duty body must be used. When loading is done from a hopper or by means of a front-end loader, a medium body must be used.

State or local size and weight limits

State and local traffic laws impose restrictions on the conditions under which vehicles may use the public highways. These restrictions are needed to protect the pavement and various structures such as bridges, tunnels, overpasses, etc.

Knowledge of the legal limits placed on size and weight of vehicles, is essential before finalizing on the selection of any trucking unit. The local reps for the body and truck manufacturers can be of great assistance in this area.

Table XXXIII provides an approximate guide to current highway restrictions on size and weight of vehicles, in the various states. Before operating any unit on the highway, consult with the local authorities regarding the details of the conditions under which you may do so.

Table XXXII—Number of trucks required

Rate of production (cu yd/hr)	Dump truck bodies 2 cy	5 cy	10 cy	15 cy	Trailer bodies 10 cy	15 cy
5	1	1	X	X	X	X
50	X	5	3	2	3	2
100	X	10	5	4	5	4
200	X	X	10	7	10	7
300	X	X	15	10	15	10
400	X	X	X	14	X	14
500	X	X	X	17	X	17

Note: This tabulation assumes 30 min time required for one round trip. X indicates that this selection is uneconomical for the conditions assumed

Table XXXIII—Summary of size and weight laws

Item	Range of limits	Most common limitation
Size restrictions		
Width (in.)	96-102	96
Height (ft)	12½-14	13½
Lengths		
Single units (ft)	35-55	35
Trailer (ft)	35-40	NR
Tractor semi-trailer (ft)	50-65	55
Min. tandem axle spacing (in.)		
Pounds per in. of tire width	36-48	40
Load per axle (1,000 lb)	450-800	600
Tandem axle (1,000 lb)	18-22.4	18
(4-ft apart)	26-40.6	32
Gross weight limits (1,000 lb)		
Pneumatic tires only		
2-Axle single units	27-55	36
3-Axle single units	42-60	50
Max. allowable gross weight	60-88	73.2

Selecting a body and hoist

Once the conditions of intended service have been determined, it is advisable to discuss the problem with a body manufacturer's representative.

In choosing a dump body, it is desirable to obtain one that will stand up under the service conditions. However, it must be recognized that every pound of excess weight that is supplied in body weight means a loss of that same pound in the payload.

As an aid to determining the cubic capacity of various truck dump bodies refer to Table XXXIV for varying depths of material. The volumes are given in cu ft. To convert to a cu yd, divide the tabular value by 27.

Selecting a truck chassis

In selecting a truck for a given application, the following items must be considered:

- Horsepower requirements
- Driveline selection
- Wheelbase selection

When these items have been studied correctly, the vehicle should perform satisfactorily under the load and expected service conditions, and should allow the maximum load carrying capability within the existing legal load limits.

Horsepower requirements: In establishing the horsepower requirements, the following data must be available or approximated from experience for:

Average load (lb)
Maximum legal load
Road speed desired
Road surface (use worst conditions)
Altitude (feet above sea level)
Grade required at top speed
Maximum grade to be encountered
Trailer dimensions, for air resistance
Tires used
Probable driveline—transmission/axle

With this information, the truck manufacturer will be able to calculate the probable horsepower required, and make specific recommendations as to the type of transmission and axle that will prove most satisfactory.

Wheelbase selection: The problem of wheelbase selection is simple to resolve. This requires only that the center of gravity of the load in the truck body be so positioned that the weight will be properly distributed between front and rear wheels. Failure to attain a reasonable proportioning of weight can have rather hazardous and costly consequences.

If body is too long, weight will be concentrated at the rear. This will reduce the effectiveness of the steering mechanism and front wheels in controlling the direction of movement of the vehicle. The front axle is not carrying its share of the load, and the excess load on the rear will certainly shorten the life of load-carrying components there. Front wheels will literally "float" in the air, giving the operator a sense of uneasiness about his ability to steer satisfactorily.

If body is too short, weight will be shifted to the front axle of the vehicle. This will limit the driver's control of the steering and reduce traction at the rear wheels. The overload-

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ing will also shorten the life of axles and springs as well as the tires.

Improving payloads

The gain in payload that may be realized by the careful matching of body to chassis has already been mentationed. If this same size of body is fabricated from a lightweight metal, an additional gain may be realized. The use of an aluminum dump body generally allows more than 1,000 lb greater payload to be hauled, without increasing gross vehicle weight or axle loads.

In addition to increasing income from hauling, aluminum bodies allow some cost savings, by reducing tire and brake wear, reducing fuel consumption on the return runs (when empty) and lowering body maintenance costs.

The use of transfer trailers and dump bodies is an interesting method for increasing payload without violating state load limits. This unit consists of a special dump body and a special trailer-mounted dump box. The dump truck hauls the trailer unit with a special drawbar. Both units are loaded in the conventional manner.

Upon arriving at the dump site, the driver uncouples the trailer. The trailer brakes lock automatically, and the dump truck proceeds to dump its load. It then returns to the parked trailer and backs up to the rear of the unit. By means of an electric drive unit, the trailer body is moved into the dump truck body in 10 to 15 sec. A special cam bar holds the trailer body securely in place, permitting the trailer load to be dumped. The truck returns to the trailer, releases the cam bar, and the box is returned to its position on the trailer. When the trailer is recoupled to the truck, the two units are ready to return to the loading point. The total elapsed time for the operation described is said to be about six minutes.

The advantages of this system are that it gets double production from every dump truck. Driver cost is cut in half, since one man can handle both loads.

The use of multi-axle units is another means for increasing the payload for dump trucks, without violating legal limits. Since one driver can now haul a greater load, costs per unit of load are reduced.

Tires

The proper selection of tires for a given service is extremely important. Improper selection can result in high tire wear and repair costs.

Tires are designed to operate under various loads and at different inflation pressures. In order to carry loads without excessive flexing and with adequate road contact, tires must be inflated according to the load carried.

The design of most tires allow for the pressure build-up that occurs after a tire has been in operation.

The load carried on each tire is an important factor to be considered. When large tires have been installed on the rear wheels to carry the load,

Special dump body and a special trailer-mounted dump box are popular in the west. Dump truck hauls the trailer unit with a special drawbar. Both units are loaded in the conventional manner (Courtesy, Challenge-Cook Bros., Inc.)

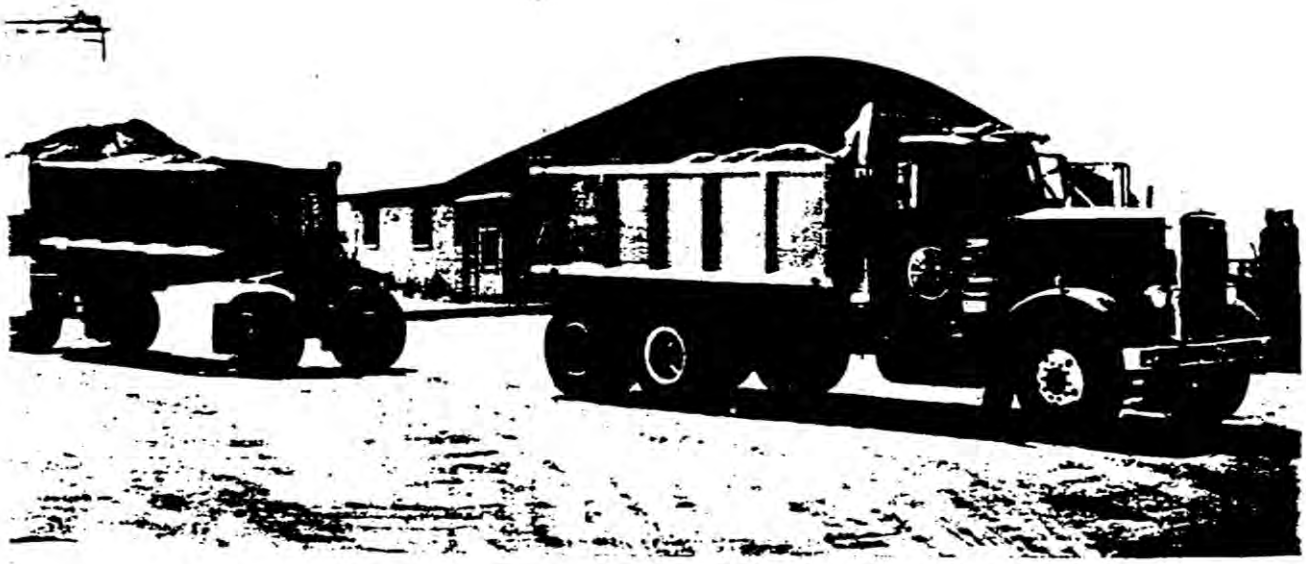

Table XXXIV—Volume of truck bodies (in cu ft) at various depths, assuming level loading of body

Body size (ft)		Area	Depth of material (in.)									
Length	Width	Sq ft	12	15	18	21	24	27	30	33	36	48
8 ft 0 in.	6 ft 6 in.	52.0	52.0	65.0	78.0	91.0	104.0	117.0	130.0	143.0	156.0	208.0
	7 ft 0 in.	56.0	56.0	70.0	84.0	98.0	112.0	126.0	140.0	154.0	168.0	224.0
9 ft 0 in.	6 ft 6 in.	58.5	58.5	73.1	87.75	102.4	117.0	131.6	146.25	160.9	175.5	234.0
	7 ft 0 in.	63.0	63.0	78.75	94.5	110.25	126.0	141.75	157.5	173.25	189.0	252.0
10 ft 0 in.	6 ft 6 in.	65.0	65.0	81.25	97.5	113.75	130.0	146.25	162.5	178.75	195.0	260.0
	7 ft 0 in.	70.0	70.0	87.5	105.0	122.5	140.0	157.5	175.0	192.5	210.0	280.0
11 ft 0 in.	7 ft 0 in.	77.0	77.0	96.25	110.5	134.75	154.0	173.25	192.5	206.75	231.0	308.0
12 ft 0 in.	7 ft 0 in.	84.0	84.0	105.0	126.0	147.0	168.0	189.0	210.0	231.0	252.0	336.0
13 ft 0 in.	7 ft 0 in.	91.0	91.0	113.75	136.5	159.25	182.0	204.75	227.5	249.25	273.0	364.0
14 ft 0 in.	7 ft 0 in.	98.0	98.0	122.5	147.0	175.0	196.0	220.5	245.0	269.5	294.0	392.0
15 ft 0 in.	7 ft 0 in.	105.0	105.0	131.25	157.5	183.75	210.0	236.25	262.5	288.75	315.0	420.0

and the same size tire is installed on the front as a matter of convenience. it is important that the load on front and rear wheels be determined and tires sufficiently inflated to suit their actual loading.

Over-inflated tires on the front wheels are often responsible for the transfer of road shock to front-end parts, hard-riding qualities, unstable steering and excessive tire wear. Too much or too little air pressure reduces tire life.

Stockpiling applications

Trucks are rather widely used for transporting materials to plants, from plants, and, sometimes, within the plant area. There are many different methods in current use for loading and unloading these trucks. There is no way in which these different methods can be evaluated here, for their real utility and effectiveness is largely dependent on the plant process and the equipment available.

Methods of loading trucks: The simplest method of loading trucks is provided by means of an elevated hopper equipped with a simple clamshell gate. The truck is driven under the hopper or bin, the gate opened until the truck is loaded, and then closed. The truck moves out, and another empty one moves into place beneath the bin. This system is especially effective when the flow rates of material are small, the product is being delivered by a conveyor or similar unit, and minimal

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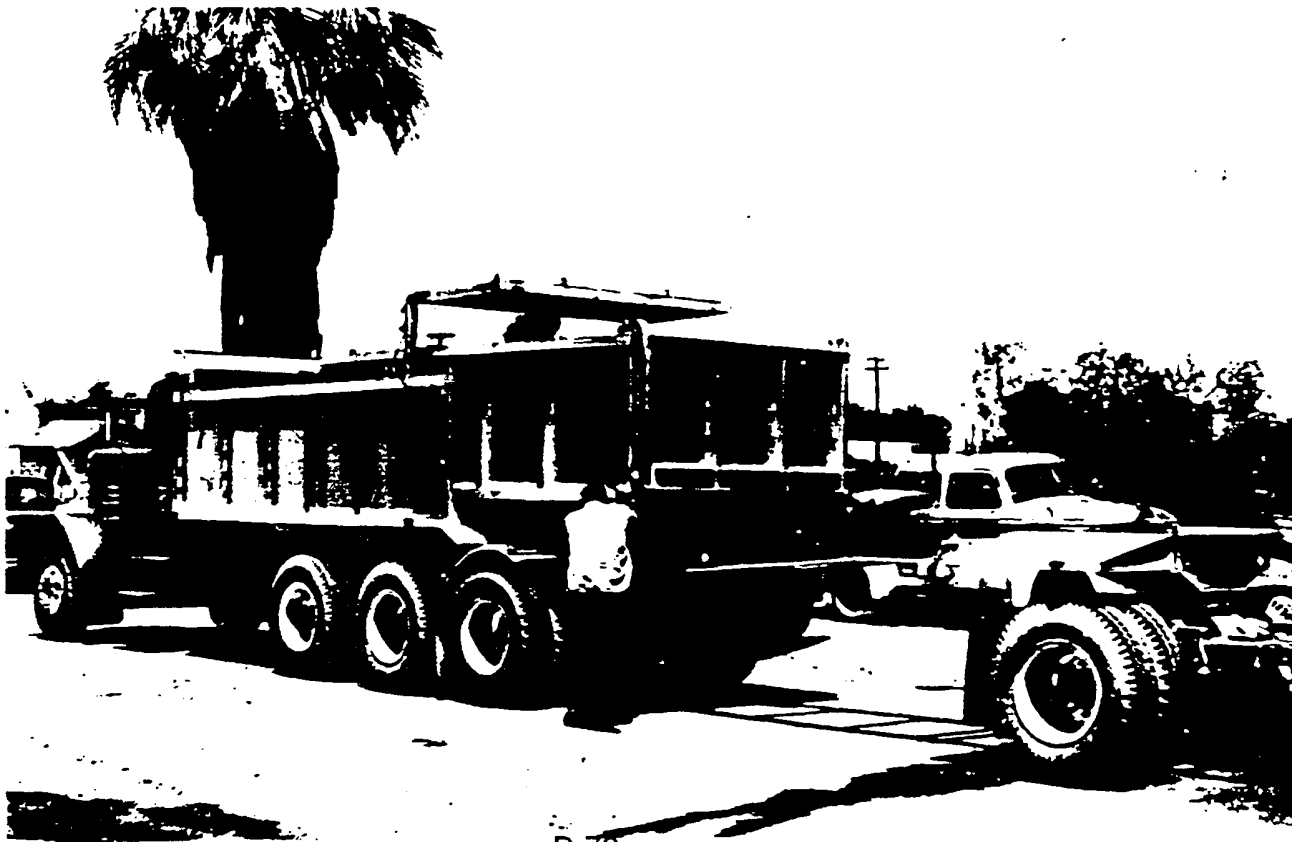
After unloading by means of an electric drive unit, trailer body is moved in dump truck body in 10 to 15 sec. A special cam bar holds trailer body securely in place; then, using the same hoist, the dump box is unloaded (Courtesy, Challenge-Cook Bros., Inc.)



STOCKPILING OF MATERIALS

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truck loading time is desired. In planning such a system, size the bin large enough to contain 3 or 4 truck loads. This will provide both surge for the plant operation and storage for the truck load-out.

When mobile excavators are used for loading trucks, there is no need for an intermediate hopper, unless the excavating equipment is extremely small. The principal consideration again, is truck-loading time. For an economical operation, the time interval must be held to a minimum.

In a few cases, it may prove reasonable to park a trailer under the point of discharge from the plant equipment, and load it directly. When a trailer is full, it is moved out of position and replaced by an empty unit. This may be done by means of a transfer chute—if an adequate degree of elevation is available.

In many small and medium-sized plants, the front-end loader provides the most effective method of loading out trucks. The loaders' speed and mobility, plus low operating cost, make it a most attractive choice. When not required for load-out, the unit may be put to other uses around the plant.

Belt loaders (traps with belt conveyors-feeders) fed by a dozer or dozers provide another effective means for loading trucks.

Methods of unloading trucks: The problem of unloading the truck may appear to be relatively simple. The tailgate is unfastened, the hoist actuated, and the material dumped on the ground. This is the simplest method, if the material is waste rock and will not be reclaimed.

In most cases, the material is going into process or storage from which it must be reclaimed. Each time that material must be picked up and rehandled, operating costs may be expected to register an increase.

Accordingly, then, most operators prefer to deposit the trucked material into a bin or hopper, so that it may be moved by conveyor into the plant process stream.

If the bin is above grade, it becomes necessary to elevate the truck by means of a ramp or trestle. The trestle is an economical structure, if there is a large difference in elevation. In such cases, a road is built to gain the required height above the bin, and a series of bents arranged to support the roadway. For temporary or economy installations, a wood pole structure with a timber deck is very adequate. In designing such a structure, care must be taken to adequately brace the bents so they will carry the horizontal thrust of the truck that will be developed as it first rolls onto the roadway and as it brakes to a stop at the dumping point.

When the terrain is relatively level, an earthen ramp will provide the most economical means of elevating the truck. The slope of the incline should be held around 6 to 8 ft of rise per 100 ft of run (horizontal travel), 10 ft per 100 is a maximum. Provide a level stretch of road (at least as long as the wheelbase of the longest truck that will be used) at the dumping point to insure complete dumping of the load.

A wheel stop-block should be provided at the point of maximum backward travel for the truck. In most cases, it is desirable to securely anchor this block so that it will carry the impact of the truck. Cables or rods tied back to buried dead-men of wood or concrete may be required.

The earth in the ramp will tend to flood around the bottom of the bin and interfere with access to the feeder and conveyor required there. In order to contain the earth fill, a concrete retaining wall with wing-walls is often provided on permanent or high-fill installations. For fairly low or temporary structures, a box-crib of wooden poles or timbers may be employed. If the interior of the box is filled with coarse rock, the structure will prove to be rather stable. Another alternate would be fabricated steel cribbing material.

If the receiving bin is capable of holding only one or two hours of feed material, it is prudent to make provisions for a small surge pile as close to the ramp as possible. Then, in the event of truck breakdown, accident or traffic delays, or inclement weather, the bin may be kept supplied by a loader.

In the case of coarse rock coming from the pit or mine, it is often desirable to dump the trucked material directly into a crusher. The crusher may be situated at the end of a ramp or trestle in place of the bin. However, in most cases, because of the weight and forces to be handled, it is best to consider an installation below grade. A reinforced concrete structure in the form of a simple box will provide the required support for the equipment and retain the surrounding earth. A tunnel conveyor may be used to elevate the material as it leaves the crusher or truck hopper.

Estimating truck loading requirements

1. **Loading & hauling conditions**

Method of loading:	Time (sec)	Method of unloading	Time (sec)
a. Bin discharge	____ - ____	a. On grade	____ - ____
b. Excavator	____ - ____	b. On stockpile	____ - ____
c. Conveyor	____ - ____	c. In bin (ramp)	____ - ____
d. Loader	____ - ____	d. In bin (grade)	____ - ____

Road conditions:

Section	Distance (ft)	Grade %	Pavement	Lanes	Speed Limit

2. **Truck cycle time**

a. Travel time

Section of road	Start time	Accel. time	Travel time	Decel. time	Load time	Spot time	Other time	Dump time	Total time

Total cycle time . . ____

b. Corrections: Allowance for adverse weather or road conditions ____

Total cycle time . . . ____

3. **Trucks required**

Truck capacity (average) _____ Flowrate required: _____

Total cycle time _____

Rate per truck = (Tons per load x 60)/Cycle time in min. = _____

No. of trucks = Flowrate/Rate per truck = _____ (in round numbers)

STOCKPILING OF MATERIALS, Part 15

Economical reclaiming— try subterranean conveyors

- **Reclaiming by tunnel conveyor system can be most economical from the standpoint of maintenance, depreciation and cost of operating labor**

The use of belt conveyors under stockpiles is well established as an economical method of reclaiming certain materials. The stockpiled material must be capable of flowing into the drawpoint and the volume of material handled should be enough to justify the expenditure. Usually, for the small installation, the cost of the tunnel structure, control gate, feeder, and conveyor will closely approximate the price of a crane or front-end loader. However, the maintenance and depreciation of the tunnel is usually less, and the cost of operating labor is considerably lower.

For the large installation, in which great volumes of material are handled, the reclaim tunnel conveyor system is the most economical means of recovery. It should be emphasized that cost alone should not be the deciding factor. When handling materials that are sluggish, sticky and have a tendency to "hang up," this mode of recovery is not practical. In some cases where tunnel conveyors have been incorrectly applied to such materials, the operator has been forced to reduce the storage pile to the minimum and use a loader or dozer to move material into the drawpoint hopper.

Tunnel arrangements

The tunnel structure is usually arranged with the conveyor located on one side of the centerline of tunnel and a walkway on the other. This provides the operator with ready access to all moving parts of the conveyor and allows him to reach the control gates or feeders for manual adjustment, inspection and servicing.

In the long tunnel, it is often desirable to provide a rear emergency exit, or a ventilation entry. This section of tunnel can be of reduced dimensions. However, if expansion is a possible consideration, it may be more desirable to retain the same cross-section throughout.

Drainage of water into the tunnel is another factor that needs to be considered. In most cases, the tunnel runs horizontally below grade until it clears the main body of the pile, then it rises on a slope to the surface. The portal of the tunnel should rise slightly above the level of the ground surface so that water cannot run into the tun-

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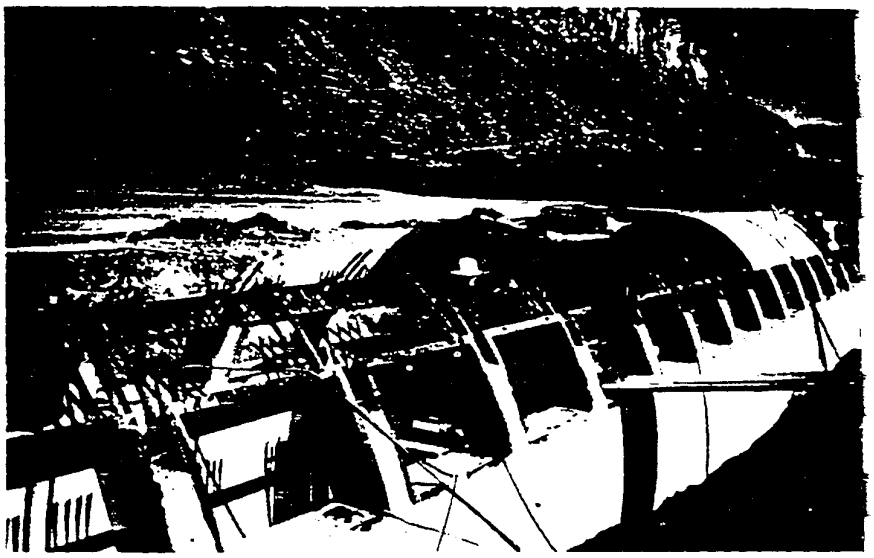
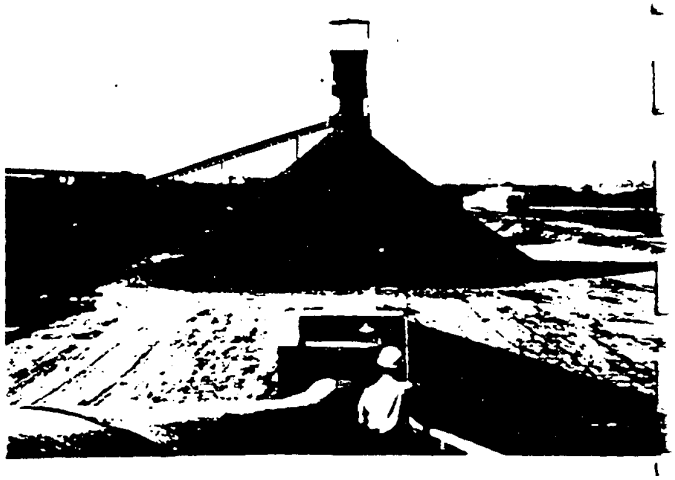


Above: Construction of a tunnel section employed a rotary plow feeder which removed material from two shelves—one on each side of tunnel. Framed openings allow material to flow onto shelf inside tunnel (Courtesy, Texas Gulf Sulphur Co.)



Rectangular tunnel section emerging from under stockpile (Courtesy, Alpha Portland Cement Co.)

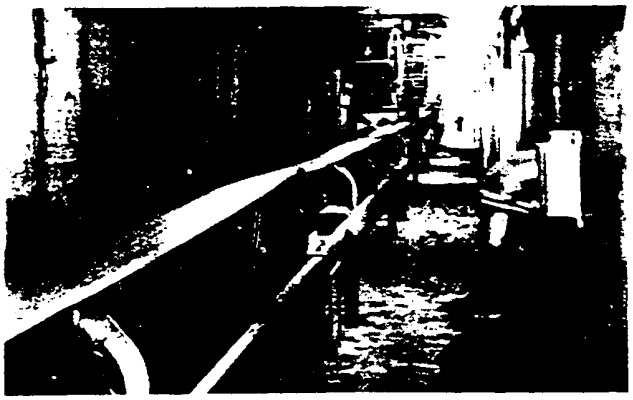
STOCKPILING OF MATERIALS

continued . . .

nel. Also, the open end of the tunnel should be cut on a plumb line so that rain does not fall directly into the tunnel opening. In spite of all precautions, some rain may enter the tunnel—perhaps through the drawpoints. It is desirable therefore, to give the tunnel floor a slight slope toward a small floor sump. If the flow of water is small, the sump can be bailed out periodically by bucket. If there is a possibility of greater flows of water, provision should be made for the later addition of a small sump pump by installing an electrical outlet near the sump.

As a general rule, it is desirable to install electric lights in these tunels. Lights should be located at all drawpoints and along the length of the walkway. Lamps of 150w intensity spaced at intervals of 20 to 25 ft should be adequate. To permit the repair of equipment in place, electrical receptacles should be provided at each light.

Tunnel cross-sections are usually rectangular or round, depending on the materials of construction used.



Interior view of a rectangular tunnel section (Courtesy, Link-Belt Co.)

This view shows tunnels in place before backfilling (Courtesy, Metal Products Div., Armco Steel Corp.)

Table XXXV—Gauge table—corrugated steel pipe (galvanized)

Diameter	Height of stockpile (ft) 1-20	21-30	31-40	41-50	51-60
72	10	10	10	10	10
78	8	8	8	8	8
84	8	8	8	8	—
90	Pipe is available in these sizes				
96	Consult manufacturer for application				

Gauges shown are minimum structural requirements for use with backfill of adequate quality and compaction to hold structure to its fabricated shape when under load

Table XXXVI—Weight per ft—corrugated steel pipe (galv.)

Diameter	Gauge of metal 10	8
72	130	159
78	142	173
84	153	186

For approximate pricing: use 20¢ per lb (1965)

When round tunnels are constructed, a segment of the bottom should be paved to provide for safer and easier walking. Fig. 22 illustrates one method of arrangement that has been used with success.

Materials of construction

Reclaim tunnels may be constructed of wood, steel or concrete; or a combination of these materials. The choice of material will be largely a function of the loading imposed on the structure by the stockpiled material, the space requirements of gates, feeders, conveyors and access passages; as well as the anticipated economic life of the project. The use of wood should be limited to the smaller stockpiling operations or those that are of a temporary nature.

Wooden structures

If wood is chosen, consideration should be given to the use of treated timbers. Such timber will enjoy a much greater life in the unfavorable environment that is likely to prevail under a stockpile that is exposed to snow, rain and surface drainage.

Wooden tunnels are usually of rectangular section and of post and beam construction.

Steel structures

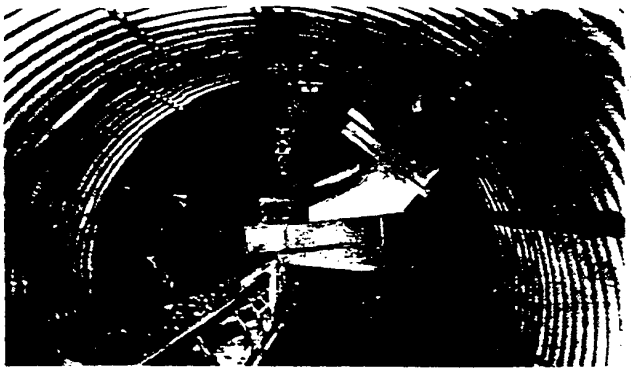
Steel tunnels can be economically constructed by the use of several different fabricated materials that are readily available. These include standard corrugated steel pipe (CSP); curved segments of corrugated plate (Multi-plate), or tunnel liner plate.

Standard corrugated steel pipe

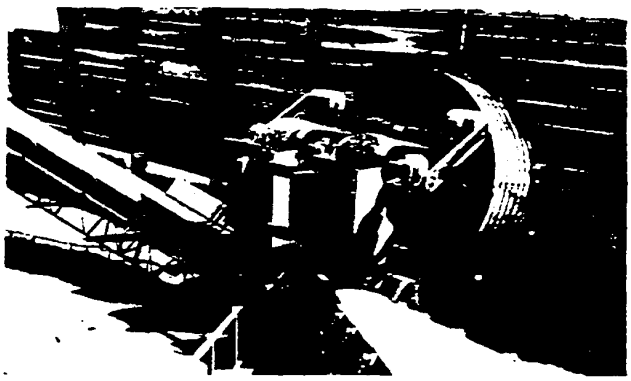
This pipe is available in several different gauges and up to 96 in. in diameter. Installation of these large sizes

must be made by open trenching. The material is furnished in black or galvanized finish. Openings can be shop or field fabricated. For following vertical curves it is desirable to have the pipe cut on a bevel in the shop. Jointing is accomplished by securing wide bands of steel sheet around the outer circumference of the pipe sections.

The allowable loading for standard corrugated steel pipe and approximate weights and prices are given in Tables XXXV and XXXVI. This is not a complete listing of sizes, but only those that are considered suitable for stockpile application.



Interior view, multi-plate tunnel at junction (Courtesy, Metal Products Div., Armco Steel Corp.)



End view of tunnel (Courtesy, Iowa Manufacturing Co.)

Segmented corrugated plate—Multi-plate

Multi-plate is available as curved segments of corrugated metal of different gauges. By bolting together several of these segments, a circular pipe or a pipe-arch on a concrete footing can be obtained. This material may be formed into tunnels up to 30 ft in diameter, and is available in black or galvanized finish.

Multi-plate is always installed in an open trench. Delivered to the job site in knocked-down sections, the material is quickly and easily assembled.

The allowable loading for Multi-plate and approximate weights and prices are given in Tables XXXVII and XXXVIII. This is not a complete listing of sizes, but only those that are considered suitable for stockpile application.

Multi-plate is used for tunnel construction of the type discussed here more often than either corrugated steel pipe or liner plate.

Tunnel liner plate

Tunnel liner plate is a deeply ribbed segment of curved plate available in many different gauges. By joining together several segments of different curvature, circular tunnel sections up to nearly 14 ft in diameter may be obtained. Liner plate is usually installed by tunneling, but can be readily placed in open trenches. This material is available in black or galvanized finish.

The allowable loading for tunnel liner plate and approximate weights and prices are given in Tables XXXIX and XL. This is not a complete listing of sizes, but only those that are suitable for stockpile application.

The use of liner plate is recommended for applications where the tunnel section must be built by tunneling or a new structure is to be installed inside of an existing tunnel structure. Liner plate is available in a greater variety of cross-sectional shapes and diameters than is Multi-plate. Also, liner plate is fabricated in diameters that vary by multiples of 2 in. whereas Multi-plate is available in 6 in. multiples only.

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Table XXXVII—Gauge table—Multi-plate pipe

Diameter (In.)	Height of stockpile (ft)										
	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
72	12	12	10	10	8	7	5	5	5	3	1
78	12	12	10	8	8	7	5	3	3	1	1a
84	12	10	10	8	7	5	5	3	1	1a	1a
90	12	10	10	8	7	5	3	1	1a	1a	1a
96	12	10	8	8	7	5	3	1	1a	1a	1b
102	12	10	8	7	5	3	1	1a	1a	1b	1b
108	12	10	8	7	5	3	1	1a	1a	1b	1b
114	10	10	8	7	5	3	1a	1a	1b	1b	—
120	10	10	8	5	3	1	1a	1a	1b	1b	—

Unless noted, all plate uses 4 bolts per ft; Note (a) indicates that 6 bolts per ft are required; Note (b) indicates that 8 bolts per ft are required. Design based on the Ring Compression Method of Design, which requires thorough compaction of the surrounding fill so that the corrugated steel pipe acts as a thin ring in compression with uniformly distributed forces acting along the periphery of the structure

Installation of metal tunnel structure

The strength of corrugated steel structures is largely dependent on the adequacy of the backfilled material that surrounds the pipe structure. Corrugated metal structures build up side support as they deflect under load. Therefore, for maximum load-bearing capacity, it is necessary that the backfill consist of suitable material.

Selected backfill is preferred, but most local fill materials may be used if they are carefully placed and compacted. Any fill material that is used should be free of large rocks and hard lumps or clods over 3 in. in size. Material containing sod, cinders, earth with a high content of organic matter or frozen soil should never be used. Granular material that contains a small amount of clay or silt is ideal since it makes a dense, stable fill. For large permanent installations, it is recommended that the services of a soils engineer be retained.

Fill material should be placed alternately on each side of the pipe. To insure adequate compaction, the layers should not exceed 6 in. in thickness. Keeping the fill at the same level on both sides of the pipe will reduce the possibility of distorting the shape of the pipe.

Tamping can be done with hand or mechanical equipment depending upon field conditions. The type of equipment is not so important as is the care with which the tamping is done. Do not attempt to compact by puddling or jetting with water. These methods do not produce reliable backfills for corrugated metal structures.

Table XXXVIII—Weight per ft—Multi-plate pipe

Diameter (In.)	Gauge of pipe metal						
	12	10	8	7	5	3	1
72	130	163	196	213	246	280	313
78	139	175	211	228	264	301	336
84	148	187	225	244	283	321	360
90	166	208	250	271	313	356	398
96	175	220	265	287	332	377	422
102	185	232	279	303	350	398	445
108	194	244	294	319	369	420	469
114	204	256	309	335	387	441	493
120	213	268	323	351	406	461	516

For approximate pricing: use 20¢ per lb (1965)

Table XXXIX—Gauge table—tunnel liner plate

Diameter (In.)	Height of stockpile							
	1-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60
72	12	10	8	5	5	5	5	5
78	10	8	7	5	5	5	5	5
84	10	8	5	5	5	5	5	3
90	8	7	5	5	5	5	3	—
96	8	5	5	5	5	3	—	—
102	8	5	5	5	5	3	—	—
108	5	5	5	5	3	—	—	—
114	5	5	5	5	3	—	—	—
120	5	5	5	3	—	—	—	—

Note: Data shown assumes stable soil: for unstable soils heavier gauge should be used and soil investigation made before construction is started

Table XL—Weight per ft—tunnel liner plate

Diameter (In.)	Gauge of metal					
	12	10	8	7	5	3
72	126	160	192	208	240	274
78	140	170	206	222	260	294
84	148	188	224	244	280	320
90	158	198	238	258	298	340
96	168	208	252	272	316	360
102	180	226	270	294	340	386
108	190	236	185	308	357	407
114	200	254	304	330	380	435
120	210	264	318	344	398	454

For approximate pricing: use 24¢ per lb (1965)

Table XLI—Sizes of reinforced concrete pipe suitable for tunnels

Pipe Diam. (In.)	Standard wall		Thick wall	
	Wall thickness	Weight—lb/ft	Wall thickness	Weight—lb/ft
72	6 in.	1.700	7¾ in.	2.230
78	6½ in.	1.990	8¼ in.	2.520
84	7 in.	2.300	8¾ in.	2.920
90	7½ in.	2.640	9 in.	3.300
93	7¾ in.	2.810	9½ in.	3.500
96	8 in.	3.000	—	—

Concrete structures

Concrete tunnel structures may be constructed by three methods:

- Reinforced concrete pipe.
- Precast reinforced box culverts, or pipe of rectangular section.
- Field-placed concrete structures.

Reinforced concrete pipe, of the type that is commonly used for the conveyance of water, may also be used for the construction of conveyor reclaim tunnels. Pipe of 84 to 96-in. diam, properly reinforced for the loading imposed, have been used successfully for this purpose.

This pipe is available in a wide range of diameters, two different wall thicknesses, and many different load-carrying capacities (depending on the amount of reinforcing steel that is used). The standard length of these pipe sections is 8 ft. Openings for feed inlets (draw-points) and feeder supports are usually cast in the pipe at the time of fabrication.

A cross-section of a typical installation is shown in Fig. 23.

Reinforced steel concrete pipe: To provide designers and operators with some means for examining the potential of this material. Tables XLI and XLII are included.

Enter Table XLI and select the diameter of pipe that will best suit the tunnel arrangement that you have in mind. Then enter Table XLII with that diameter and read across until you find a height of stockpile that matches your design, then read up to the class of pipe noted at the top of the column.

Note that an approximate price of each diameter and class of pipe may be read from this same table.

Note the limitations that are listed below this last table. These values of load are based on a careful bedding and backfilling of the pipe.

Reinforced concrete pipe appears to have a definite place among the various materials in common use. Some of its advantages are: strength, corrosion resistance, ease of handling, rapidity of installation, simplicity of joint detail and rigidity of section which allows backfilling to immediately follow installation.

Table XLII—Maximum stockpile height (ft) & approximate prices

Pipe diam. (In.)	Standard wall		Thick wall	
	Class II 1000 D	Class III 1350 D	Class IV 2000 D	Class V 3000 D
72	20 ft $24.00	25 ft $26.00	36 ft $33.00	52 ft
78	20 ft $30.00	25 ft $33.00	36 ft $36.00	Special
84	20 ft $34.00	25 ft $35.00	36 ft	Special
90	20 ft $39.00	25 ft $43.00	36 ft	Special
93	20 ft $41.00	26 ft. $46.00	36 ft	Special
96	20 ft $43.00	26 ft $50.00	Special	Special

Overfill heights are based on State of Calif. Div. of Highways Method "A" installation. "Special" indicates special design required. Prices shown are approximate 1965 estimates; check local suppliers for exact costs. Note: Other classes of intermediate strength are available that may provide a more economical design

Concrete structures—Precast reinforced box culverts: The use of precast concrete structures in many new and different forms continues to increase. On a recent project in Denver, Colo., one company furnished precast tunnel sections that measured 12 ft in span width x 5 ft inside clear height x 8 ft long. These sections were joined together to form a flume through which irrigation water was carried under a highway pavement. Success in fabricating, transporting, and erecting these large sections suggests that the similar, but smaller sections required by reclaim tunnels are entirely feasible.

These structures could readily be cast in the shops of any pre-cast concrete company, where exact control of mix and curing would permit the attainment of 5,000 psi concrete with little effort. After curing, the sections could be loaded on a truck and delivered to the jobsite. With the foundation previously excavated and prepared to receive the tunnel sections, placement would proceed rapidly. Within a relatively short time a complete reclaim tunnel could be erected.

The sections of tunnel could be made as shown in Fig. 24. Lifting lugs would be provided to permit easy handling. Joints would be butt end joints, ordinarily; but if conditions required, a groove could be provided to receive an O-ring or gasketing.

The advantages of this method of construction are numerous. The concrete obtained is of higher quality and strength than could be obtained by field placement. Fabrication of the sections can be proceeding at the same time that excavation and foundation preparation are being accomplished. The shape of the tunnel can be selected which provides the best arrangement for equipment and personnel accessways. Delays due to weather are reduced to a minimum, and the hazards that accompany placement of concrete in freezing weather are eliminated.

Obviously, however, the use of these structures must be limited to areas that have such casting facilities within economical trucking distance. Also mobile cranes must be available

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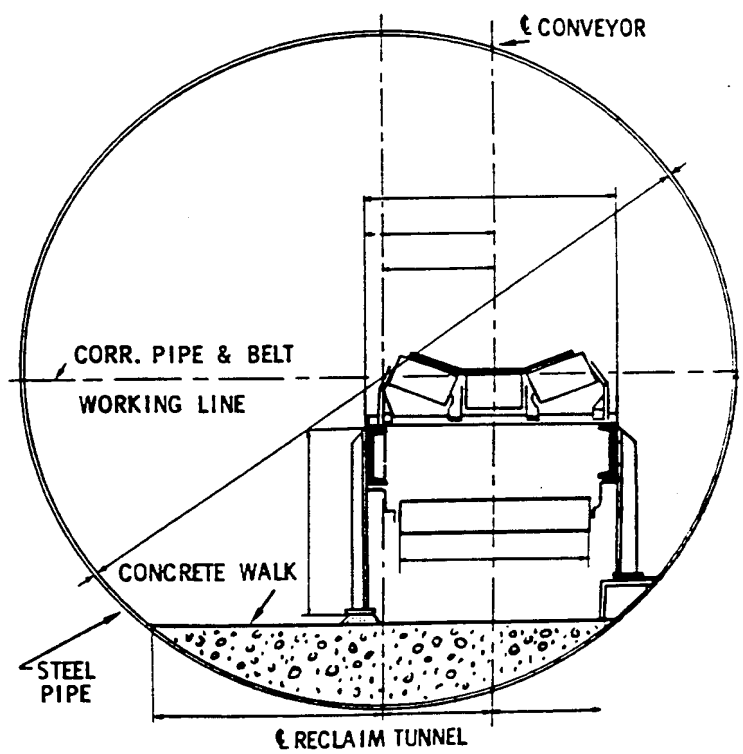

Fig. 22—Conveyor tunnel with paved section to provide safer walking

STOCKPILING OF MATERIALS

continued . . .

for handling and placing the sections.

The cost of the sections will vary from one locality to another, but a reasonable cost at the shop should run from $30 to $40 per ft. Actual cost will depend on the wall and slab thicknesses and the amount of reinforcement that is actually used. Each structure would have to be carefully designed for loads to be imposed on it.

It will be obvious that in some cases, the use of a shape other than a round one will prove more efficient and useful. For such cases, the use of the special oval or arch-shaped sections may be considered.

The approximate sizes of flat base pipe available ranges from 46x46 in. to 97x97 in. Such a shape will provide more convenient walkway space and allow more usable space above the conveyor. Since this pipe should be specially designed for any given application, no table of loadings has been provided.

Concrete structures—field-placed tunnel sections

In many cases, requirements of equipment and personnel do not permit the use of prefabricated sections. In such instances, the only reasonable recourse is to form and place the tunnel sections in place in the field.

To this point, we have described the use of various tunnel sections for placing a belt conveyor under a stockpile in order to facilitate recovery of material. In many cases, the conveyor emerges from the below-grade tunnel and rises above grade to discharge the material into trucks, rail cars, or other means of transportation.

In a project now nearing completion, a most unusual extension of this idea has been undertaken. At this coal preparation plant, an entire train of cars travels beneath the pile and emerges from the other end of the tunnel, loaded with coal and ready to move on to its destination! To provide a better picture of the magnitude of this concept, a few details are given.

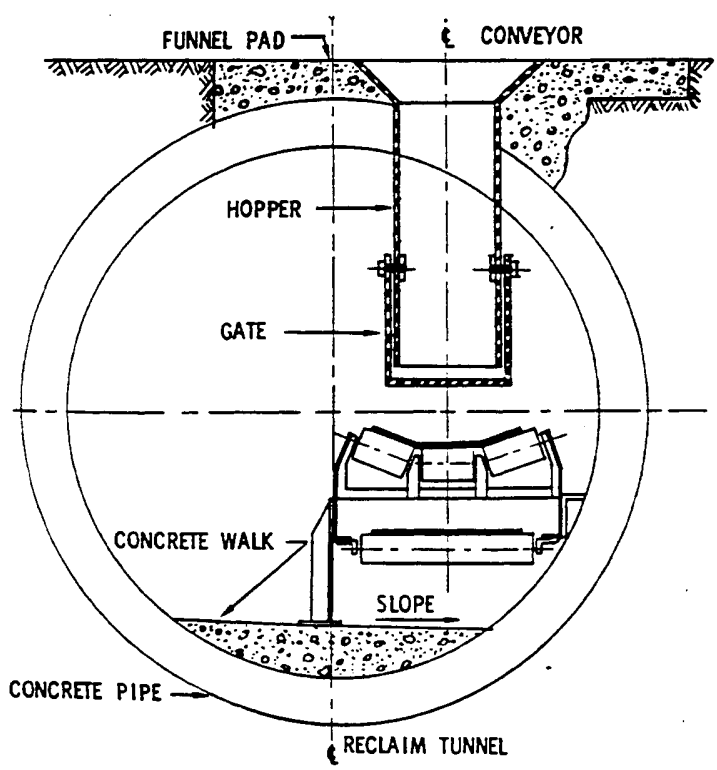

Fig. 23—Concrete pipe used as reclaim tunnel

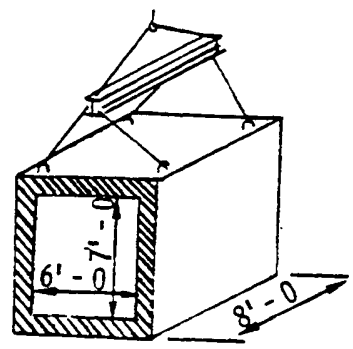

Fig. 24—Precast concrete sections with lifting lugs to provide easy handling

The stockpile containing 3x0 washed coal is a single conical pile approximately 300 ft in diameter and 135 ft above the single outlet above the load point. It is estimated that approximately 14,500 tons of live storage are available, based on an angle of draw-off of 55 deg.

At the center of the pile there is a concrete structure 21 ft long and 22 ft 6-in. wide. This concrete structure holds a conical steel hopper to which the hydraulically operated undercut gate is attached. A hinged loading chute directly below the gate directs material into the cars. This hinged gate can be raised to provide 22 ft 6-in. locomotive clearance under the load point. Also, included in the loading arrangement is a counterweighted emergency cut-off gate between the hopper outlet and the hydraulically operated undercut gate.

A control cab for the operator is provided adjacent to the load point. A 42-in. diameter escape and ventilation pipe will be installed from the upper area of the concrete section to the edge of the stockpile at grade. An exhaust fan at the discharge point will remove the dust-laden air.

There is approximately 204 ft of steel tunnel on the uptrack side of the concrete section, and 214 ft on the downtrack side—a total of 418 ft. The steel section consists of a 24-ft diameter material flattened on the sides to produce an ellipse. The vertical dimension being 26 ft 8 in. and the horizontal dimension 21 ft 10 in.

The success of this concept should certainly inspire other forward-looking innovations in the area of reclaiming material from stockpiles.

STOCKPILING OF MATERIALS, part 16

Ten ways to ease materials through bins & hoppers

- **Many accessories and design improvements are being marketed to conquer rat-holing, bridging, stove-piping and stoppages that so often occur in stockpiling**

You can't avoid it. In every stockpiling operation it is necessary at some point for the material to pass through a bin or hopper. It may be for the purpose of temporary surge storage, or for metering, or the hopper may simply function as a large chute or funnel. In any case, problems are likely to occur.

Most problems develop when the material is being removed from the bin or hopper. In bin design, it is important that the discharge opening be large enough and the slope of the plate bottom steep enough to insure the ready movement of the material.

The slope of the valleys is particularly important. Generally, the slope of the valley angle should seldom if ever be less than 45 deg. To obtain such a slope in the square bin with a pyramidal bottom, the angle of the flat plates must be approximately 54 deg off the horizontal.

The problem of improving flow characteristics of bins and hoppers has been approached in two ways. The first is the development of accessory items which, when added to the bin, ease the removal of material. The second approach has been to investigate the forces within the stored material to determine which help and which hinder the flow. (The different approaches are illustrated in Fig. 25.)

Both efforts claim success, so it is difficult to say which is the better. Proper combination of both methods seems to be the answer, but don't expect trouble-free operation of a storage bin without first carefully studying the materials being handled. A laboratory test that costs a few hundred dollars may save many thousands later on, not to mention many hours of operating time and grief.

Some of the accessory items often used to improve flow characteristics of bin-stored materials are vibrators, aerators, internal vibrators, arch breakers, multiple screw feeders and augur-type unloaders. Bin Activators and the Gyrated and Whirlpool hoppers.

On the other hand, research into the area of bin configuration has resulted in valuable design concepts such as the Easy-Flo bin device and the Bin-Dicator Hyperbolic Outlet.

Accessories

Vibrators—These units can be readily applied to most existing installations. They are simple, relatively easy to install and therefore can be used on bins, hoppers and chutes. They come in many sizes and driving capacities, so it is easy to match the demands of the storage structure. They can be either air or electric-powered.

Vibrators should be used where the material tends to arch over the outlet, or where rat-holing or stove-piping occur. In the case of arching, the vibrator should be mounted on the sloping surface at a point lower than the ends of the arch. In the case of stove-piping, the vibrator is often mounted on the vertical surface.

Vibrators should not be operated unless the bin or hopper is open to flow. If this rule is not observed, the vibrator may impede flow by packing material together too tightly.

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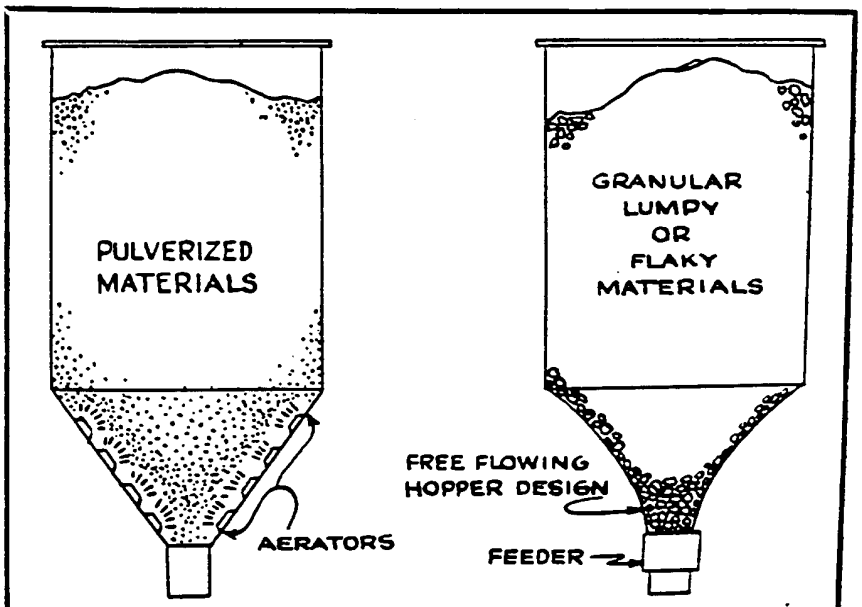
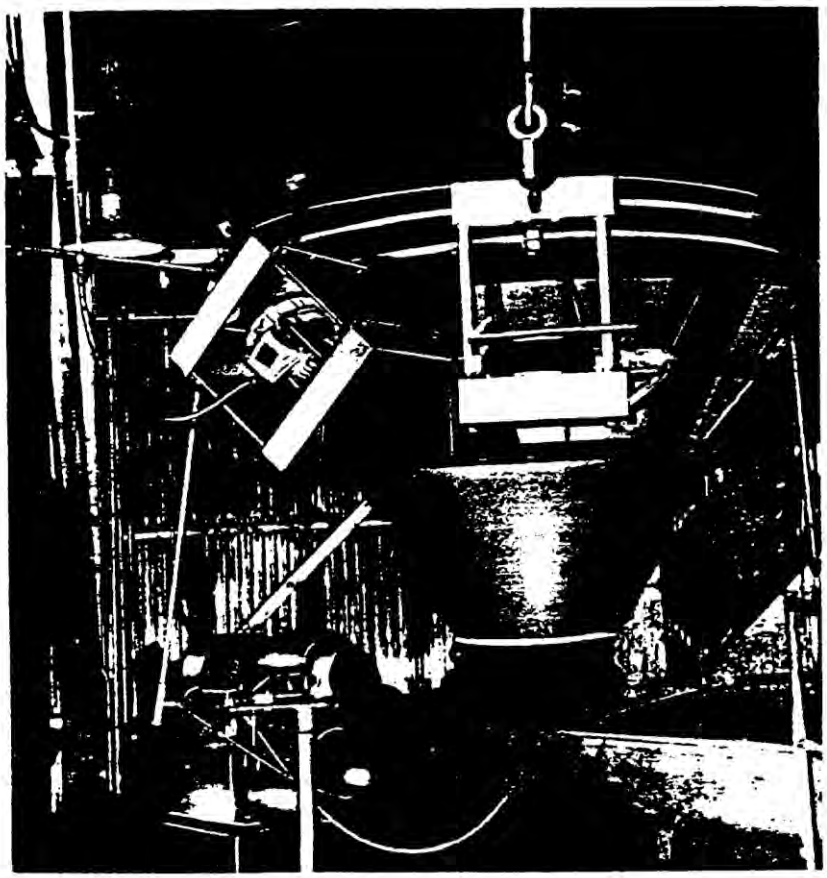


Fig. 25—Two ways to improve material discharge from bins: Left, accessory devices—aerators—are attached to the bin; right, design improvements ease the flow

tively with any dry, pulverized material that tends to pack during storage. The aerator injects a controlled amount of air through a fabric diffuser into the material. As the air permeates the material, the material recovers its fluid characteristics and tends to flow more freely. The unit can be arranged for continuous or intermittent operation, and can be manually or automatically controlled.

Aerators can be used with conical, pyramidal or flat-bottomed bins. Usually they are applied in rows near the points of restricted flow. Number of units required depends on size and shape of bin and spacing of units. Aerators also may be applied to sloping bottoms of discharge chutes.



Above: An 8-ft diam Whirlpool Hopper mounted beneath a storage silo discharges a very fine coal into a screw feeder which discharges it into a dryer. The "whirlpool" action is designed to improve material flow in stockpiles as well (Courtesy, Carrier Mfg. Co.)

The vibrations of the gyrating baffle on this Bin-Activator cause the material to flow smoothly. The unit has not yet been applied to stockpiles, but one has been installed in the flat concrete floor of a large sand silo (Courtesy, Vibra Screw Feeders, Inc.)

Internal vibrators—A special device developed for application in bunkers is the Internal Bunker Vibrator (Syntron Co.) This unit consists of a long strip of steel sheet with a rotary vibrator mounted on it at a predetermined location to obtain maximum vibration of the sheet. The vibrations applied to this "reed" increase in intensity along its length, and it is designed so that the maximum amplitude occurs at the point of arching or plugging. The ideal mounting location is on the bin or hopper centerline, the end of the reed within several inches of the discharge opening.

Arch breaker on a Circular Bin Discharger—This unit (Stephens-Adamson Manufacturing Co.) consists of a vaned beam mounted at one end on a universal at the bottom center of the bin; the other end rests against the sloping bin wall. The drive mechanism moves the vaned beam around the surface of the bin and undercuts any arching that may develop. A second stage of feeding is available for moving the material out of the bin. This feeder consists of a vane-type bin which rotates about a vertical axis.

The unit comes with an inside bin diameter of from 2-5 ft. and is capable of handling material at a flow rate of from 11 to 76 tph.

Augur type unloaders—For materials that tend to pack or cake, a live-bottom bin may be the only practical solution. If the bin is small, the effect can be accomplished by placing a series of screw conveyors or feeders side by side. With this method, there is no single point of discharge, but rather a series of discharges.

For larger diameter bins, an augur is arranged to rotate about an axis on the centerline of the bin, with the outer end of the augur reaching the bin wall. Material is pulled or screwed to a central opening where it drops into a radial conveyor which travels below the bin floor and delivers the material to the outside of the bin.

Bin-Activator—Another device that may be used to overcome bridging and rat-holing is the Bin-Activator from Vibra-Screw Feeders, Inc.

This unit consists of a circular baffle plate and a shallow conical section which are installed at the bottom of a bin. The bin bottom may be flat or sloping, made of steel or concrete.

The gyrating baffle imparts its vibrations directly into the column of material above. This fluidizing action produces an appreciable "head" in the column, causing a flow of material through the annual opening formed by the vibrating baffle and the vibrating bottom section. The cone funnels the flow onto a feeder or conveyor. Flow from the storage unit is controlled by starting and stopping of the gyrating baffle.

This unit has been successful in moving dry materials out of bins, but has not yet been applied to stockpiles. Recently, however, a Bin-Activator was installed in the flat concrete floor of a large sand silo. This indicates that the unit could be effective in stockpiles, when the material is dry and protected from the weather.

Bin-Activators are available in sizes from 3-9 in. in diam.

Gyrated Hopper and Whirlpool Hopper—Carrier Manufacturing Co. has developed a new type of vibrating hopper called the Gyrated Hopper. The entire hopper vibrates in an elliptical direction parallel to the ground. The vibration is designed to give a gentle fluidization to the material in the hopper, causing it to flow. Gates, spouts and other optional equipment can easily be added. The diameter of the hopper top is from 26 to 170 in.; discharge openings from 4 to 20 in. in diameter.

A companion hopper, the Whirlpool, has an even more radical design. Directionally imparted vibrations cause the entire volume of material in the hopper to be conveyed round and round in a "whirlpool" fashion, attaining a circular motion like the vortex in a bathtub drain. The hopper is designed so that material being discharged will not bridge or stick to it.

Material flow is controlled by valves beneath the hopper. The Whirlpool has discharge openings from 4 to 20 in. in diam. and hopper tops from 26 to 170 in. in diam.

Design concepts

Easy-Flo bin device—This device was developed by Bituminous Coal Research, Inc., the national research association for the bituminous coal industry. It has proven effective in overcoming arching, rat-holing and funneling in coal storage bins, and can be applied to other bulk solids such as sand, gravel and abrasives in the form of dust, prills, pellets and granules in a dry, semi-dry or moist condition.

The device can be attached to a 3-ft opening in the bottom of any bin, and could conceivably be used under a stockpile with a tunnel conveyor for reclaiming. Material flow through the device is assured because the forces acting on the material are controlled and conditions which normally cause stoppages in conventional bins cannot develop. The need for expensive, heavy-duty gates and cut-off devices is eliminated because of the low pressures that develop within the Easy-Flo. It provides reliable delivery of coal ¼x0 inches and up to 15 percent surface moisture.

Koppers Co. and McNally Pittsburg Manufacturing Corp. are currently selling the devices.

Bin-Dicator Hyperbolic Outlet—This is a recent development in the design of drawpoints. The patented outlet (BHO) from Bin-Dicator Corp. has been adapted from bins to stockpile drawpoints with satisfactory success, according to the manufacturer. It is recommended for use with granular or lump materials, and is said to insure free gravity flow.

This pre-engineered outlet is designed to eliminate or lessen bridging, rat-holing and erratic flow, thus reducing the need for vibrators, probing or hammering. Since the Hyperbolic Outlet is available in standard sizes, its cost is reasonable when compared with custom made units.

The efficiency of the outlet is due to the effect of its curved surfaces on the two principal forces acting in granular and lump bulk materials. These two forces are:

(1) the pressure (P_w) normal to the outlet walls, which are primarily responsible for flow interruptions and stoppage at the outlet, and

(2) the discharge pressure (P_d).

In outlets of conventional design, the flow-restricting pressures, P_w, are high and oppose the discharge pressure, P_d. When the sum of forces P_w reaches or exceeds the pressure P_d, the material loses its ability to flow freely, and bridging or rat-holing begins. The Hyperbolic Outlet design reduces the flow-restricting pressures, P_w, and results in a greater net driving force, P_d, for easier material discharge. (Fig. 26 is a sketch of the unit.)

To facilitate handling, larger outlets can be shipped in two or three sections which are square in cross-section and designed for field welding.

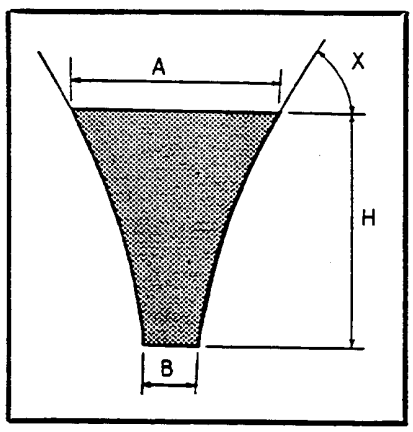


Fig. 26—Bin-Dicator's Hyperbolic Outlet is designed to improve material flow by reducing the forces which restrict flow. Dimensions are given in the table below

DIMENSIONS OF STANDARD BIN-DICATOR HYPERBOLIC OUTLETS

OUTLET SIZE	SLOPE OF CONVENTIONAL HOPPER											
	X = 45°		X = 50°		X = 55°		X = 60°		X = 65°		X = 70°	
B	A	H	A	H	A	H	A	H	A	H	A	H
12" x 12"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70" x 70"	117"	58" x 58"	105"	44" x 44"	88"
16" x 16"	[illegible]	[illegible]	105" x 105"	120"	87" x 87"	108"	70" x 70"	95"	58" x 58"	83"	44" x 44"	66"
20" x 20"	120" x 120"	114"	105" x 105"	105"	87" x 87"	93"	70" x 70"	80"	58" x 58"	68"	44" x 44"	51"
24" x 24"	120" x 120"	102"	105" x 105"	93"	87" x 87"	81"	70" x 70"	68"	58" x 58"	56"	44" x 44"	39"

■ Shipped in 3 sections □ Shipped in 2 sections □ Shipped in 1 section

STOCKPILING OF MATERIALS, PART 17

Gates—vital link in a reclaiming system

- **When reclaiming from storage, the control and regulation of material flow depends upon proper gate design**

eeders are used to regulate the rate of flow of materials out of storage, yet a well-designed stockpiling installation will include some type of gate for stopping the flow to allow for feeder maintenance.

Frequently the gate is used for both control (on-off) and regulation (variation) of the material flow. It is very difficult to select and size a gate for regulatory service, but many operators try—and a surprisingly large number seem to succeed.

Gates fall into two basic categories:

(1) Slide type: radial, undercut, flat plate and others which move a flat or curved plate through the stream of material, and

(2) Rotary type: rotary or vane-type gates and several other kinds of valves.

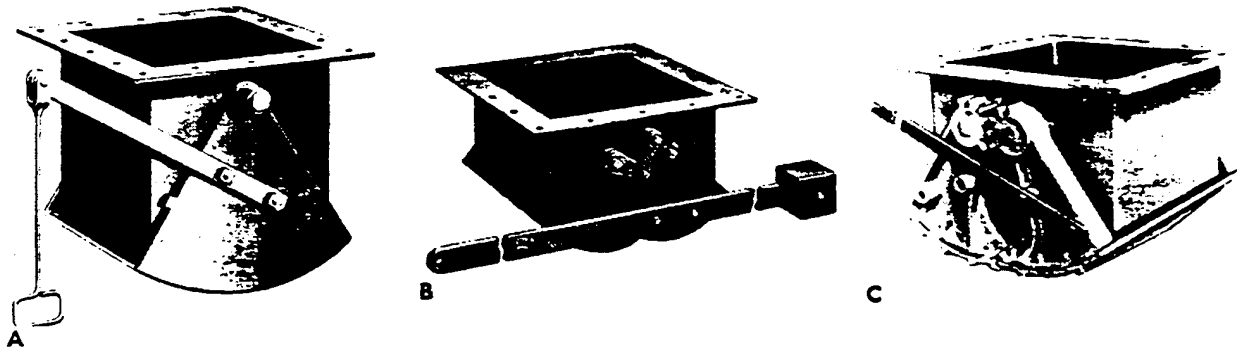
The successful use of gates depends on several factors. Among these are the 'head' on the opening; the properties of the material, such as flowability, and the performance characteristics of the conveyor which it may be supplying.

In selecting gates for flow control, there are several important details to consider. First, the size of the feed opening should be established in relation to the maximum size and the size distribution of the particles being handled. A good rule of thumb to apply to coarse material is that the smallest dimension of the opening be at least 2½ to 3 times the largest particle size. When this dimension is used, the possibility of large pieces jamming the opening will be greatly reduced. (For more detailed guidelines see "How to reclaim successfully," ROCK PRODUCTS, November 1965, p. 92)

Arrangement of the feed opening also influences the choice of gate type. The shape of the bin or hopper and the slope of the plate surfaces must also be considered. Headroom limitations can prove critical, especially in reclaim tunnels. Where feeders are being used, the flat slide type gates are particularly effective. When used without a feeder, the undercut and tunnel gates are most suitable. Duplex (clamshell) gates have worked well in handling taconite pellets.

Please turn page

Types of gates used to control material flow



A—Radial gate (with manual operating lever)—Designed for attachment to the bottom opening of hoppers and bins and are available in steel plate or gray iron. Radial gates are suitable for handling sized coal, gravel, crushed rock, stone, ore, and similar materials. This gate may jam part way open but, handling sized material, it will not leak much (Courtesy, Link-Belt Co.)

B & C—Duplex gate (with manual operating lever)—Designed for attachment to the bottom openings of hoppers and bins and are available in steel plate or gray iron. The two gate plates move in unison to provide complete opening with minimal movement of lever. Duplex gates are suitable for the same materials as the radial gate. Compactness and fast action are features of the duplex gate. Center: Welded steel construction (Courtesy, Link-Belt Co.), Right: Gray iron construction (Courtesy, Stephens-Adamson Mfg. Co.)

D—Duplex gates (low headroom design)—This gate design is well-suited to locations where vertical clearance is limited. The saving in head room can also be used to give chutes and spouts a steeper slope and to effect construction economies. Hand levers are furnished with the smaller sizes. Larger sizes should be arranged for power operation. Gate in half-open position (Courtesy, Stephens-Adamson Mfg. Company)

E—Undercut gate (with manual operating lever)—Designed for attachment to the bottom openings of hoppers and bins and are available in steel plate or gray iron castings. Undercut gates are suitable for handling coal, gravel, crushed rock, stone, ore and similar materials. These gates are probably the best choice to avoid jamming in open position by lumps and consequent dribbling of fines. Gate in closed position (Courtesy, Link-Belt Co.)

F—Rolling blade gates (with air operator)—Designed for attachment to the bottom openings of hoppers and bins and are available in welded steel plate construction. Suitable for use with fines, powders, granulars and mixed-size materials. Closing action of these gates is accomplished by means of a return spring, aided by the force of the flowing material (Courtesy, Cleveland-Armstrong Corp.)

G—Tunnel gate (with manual operating lever)—Designed for attachment to the bottom openings of hoppers, bins and in reclaim tunnels. These gates are of welded steel plate construction and are available with either a fixed or hinged chute. A hinged loading chute, arranged to pivot on the gate shaft, maintains minimum clearance from the conveyor belt when lowered, and so gently lowers the material onto the belt. Material flow is controlled by segmental gate. Handles same materials as the radial gate (Courtesy, Link-Belt Co.)

H—Slide gate (w/rack & pinion operator)—Designed for attachment to the bottom openings of hoppers and bins, but are frequently used beneath coal bunkers or track hoppers. These gates are of welded steel construction throughout. Photo shows a manually operated gate; other models are available with motor of pneumatic cylinder operators. These gates are suitable for handling coal, gravel, crushed rock, stone, ore, sand and similar materials. They are subject to the same woes as radial gates, but can be easily automated. Dribble is a problem when handling fines (Courtesy, Link-Belt Company)

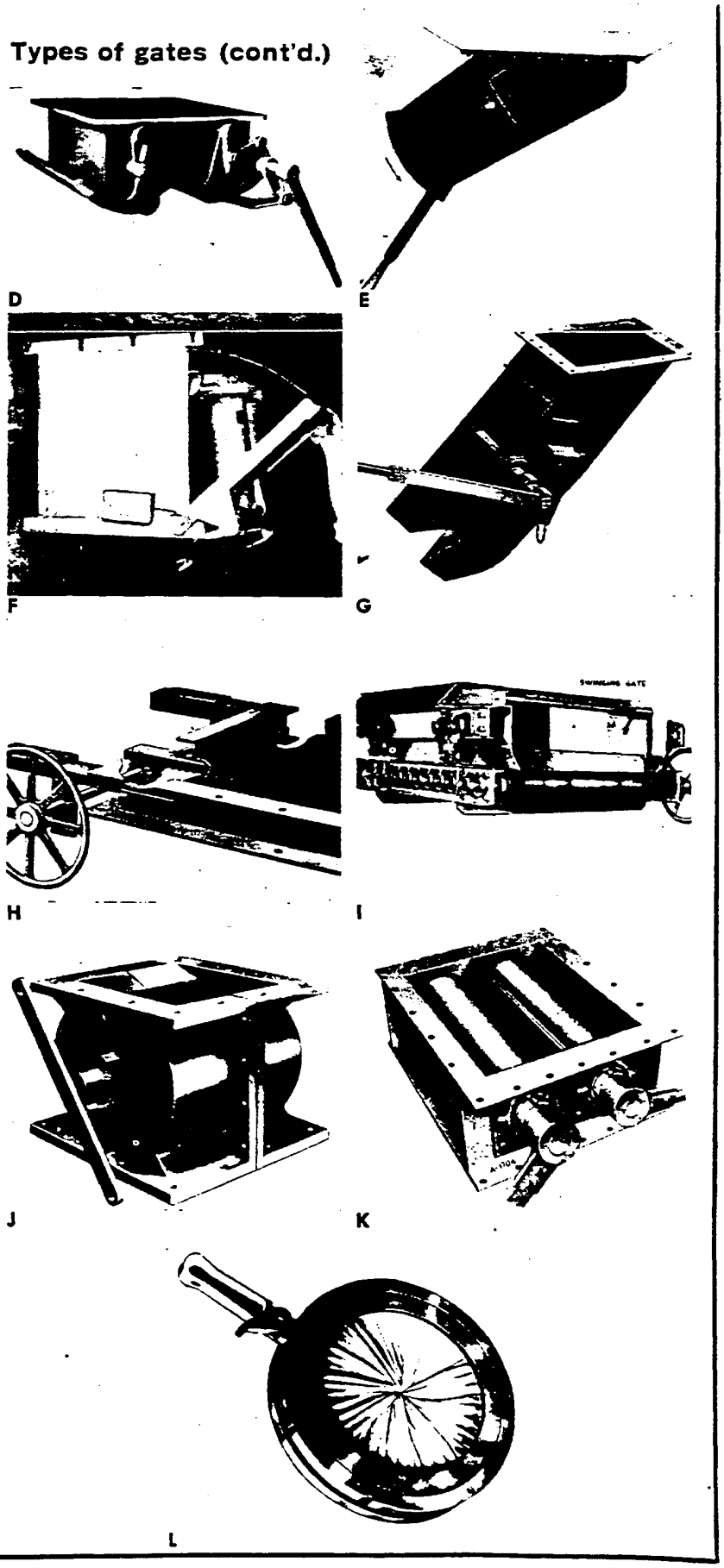
I—Moore bin gate (manual operation)—Designed for attachment to large openings in bin bottoms. They are suitable for handling heavy, lumpy materials such as stone and ore. The openings in the gates are large enough to prevent bridging; little headroom is required, and there is no complicated mechanism to foul or hinder operation. Turning the hand wheel moves the whole apron back from under the gate opening or forward under the opening. The heavy-duty type of gate is shown here in the closed position (Courtesy, Stephens-Adamson Mfg. Co.)

J—Rotary cut-off valve (manual operation)—Designed for attachment to the bottom openings of hoppers, bins, batchers or other process equipment. These valves are of gray iron or welded steel construction. The rotary cut-off valve is fully enclosed and dust-tight. Turns thru arc of 90 deg and returns. These valves are suitable for handling finely pulverized, free-flowing materials such as cement, hydrated lime and pulverized coal (Courtesy, Link-Belt Company)

K—Rotary cut-off valve (with double rotors)—Has two identical rotors, each operated by an independent lever. One rotor will ordinarily pass the volume required, but the double valve presents a larger area which will break practically any material arch above the opening. A tapped hole is provided above rotor for an air-line connection. Valve has rotor that interrupts flow at two points with an air-lock between which effectively stops surging of aerated material. This unit can be motorized and installed with remote controls (Courtesy, Stephens-Adamson Mfg. Co.)

L—"Iris" flow valve—Designed for attachment to the bottom openings of fixed or portable hoppers, bins, chutes, blenders and other process equipment. This valve consists of a fixed outer aluminum (or optional stainless steel) frame, and a movable inner bronze (or optional stainless steel) control ring, between which is fastened a flexible cylindrical sleeve of nylon or rubber. Various other sleeve materials as dictated by the application are available. Rotating one end of the sleeve 180 deg about a vertical axis causes it to open or close. Intermediate degrees of rotation produce concentric apertures of different diameters. Suitable for flow regulation or shut-off, these valves can handle free-flowing bulk materials such as sand, cement, plastics, ceramics, crystalline or powdered chemicals (Courtesy, Syntron Co.)

Types of gates (cont'd.)



Type of gate	Standard sizes	Materials of construction	For use with materials such as:	Maximum particle size
Radial	8" x 8" 10" x 10" 12" x 12" 12" x 16" 16" x 16" 16" x 20" 18" x 18" 20" x 20"	Gray iron Gray iron Iron or steel Steel Iron or steel Iron or steel Steel Steel	Sized coal, gravel, crushed rock, crushed stone, crushed ore	Depends on the material. Max. sized piece may lodge under gate plate and allow dribble. Best for —⅛" particles
Duplex, standard	12" x 12" 14" x 14" 16" x 16" 18" x 18" 20" x 20" 24" x 24" 26" x 26"	Iron or steel Steel Iron or steel Iron or steel Iron or steel Iron Iron	Coal, gravel, crushed rock, crushed stone, crushed ore, sand	Same as for radial gate. Best for —½" particles
Duplex, low head	12" x 12" 18" x 18" 20" x 20" 24" x 24" 30" x 30"	Gray iron	Coal, sand, gravel, ores	Same as for standard duplex
Undercut	10" x 14" 12" x 12" 14" x 16" 20" x 24" 42" x 24"	Gray iron	Coal, gravel, crushed rock, crushed stone, crushed ore	Best for unsized mat'l. Max. sized particle not more than ⅓ least dimension of gate opening
Rolling blade®	6" x 6" 8" x 8" 10" x 10" 12" x 12" 14" x 14" 16" x 16"	Steel		
Tunnel	Opening length 22"—all sizes. Width of Opening / Belt 16" / 24" 20" / 30" 24" / 36" 28" / 42" 32" / 48"	Welded steel	Coal, gravel, crushed rock, crushed stone, crushed ore, sand	Same as for undercut gate. Best for on-off control only
Slide	12" x 12" 14" x 14" 16" x 16" 18" x 18" 24" x 24" 30" x 30" 36" x 36" 36" x 48"	Welded steel	Coal, gravel, crushed rock, crushed stone, crushed ore, sand	Same as for radial gate. Best for uniform, sized, free-flowing material
Moore	30" x 24" 30" x 30" 36" x 24" 36" x 30" 36" x 36"	Steel	Heavy lump, stone and ore	
Rotary, cut-off valve	Nominal / Actual 6" / 4¼ x 6½ 9" / 6¼ x 9½ 12" / 8 x 12½ 14" / 9¼ x 14½	Gray iron—standard Welded steel—special	Cement, hydrated lime, pulverized coal	Finely pulverized, free-flowing materials. ¼" ø x 1" long pellets (max.)
Rotary, air-lock valve	Dischg. open'g. / Clear open'g. 9 x 9" / 5½ x 9 12 x 12 / 7½ x 12 12 x 16 / 7½ x 16 12 x 18 / 7½ x 18	Gray iron	Cement, hydrated lime, pulverized coal	Same as for rotary cut-off valve. ¼" ø max. pellets
Rotary, double rotor	Dischg. open'g. / Clear open'g. 20 x 14 / 6 x 14 20 x 18 / 6 x 18 20 x 24 / 6 x 24 Note: clean open dimension is for one rotor	Rotar-gray iron, housing-steel	Same as for rotary air-lock valve	Same as for rotary air-lock valve
Iris, flow valve	4" diam. 6" 8" 10" 12"	Aluminum or stainless steel frame, with nylon or rubber sleeve	Sand, cement, powdered chemicals	Works well with any free-flowing bulk materials less than 1"

The characteristics of the material being handled—its abrasiveness, fineness, corrosiveness—as well as all environmental factors should also be considered when choosing the materials of construction of a gate.

When installing gates, remember it is highly desirable that they be removable. In order to do this, bolts should be used to secure the gate in its place. Welding should be avoided, unless bolting is not feasible.

In cases where a bin must be secured to the underside of a concrete floor, it is desirable to consider the use of pipe sleeves and plate washers. The sleeve is cast in the concrete, and at installation the gate is secured by means of a bolt which passes through the sleeve, with a large plate washer to retain the head of the bolt. This arrangement will permit ready replacement of a broken or damaged bolt whenever the stored material has been removed from the area.

In some installations, headroom does not permit the use of a standard gate ahead of the feeder. In some cases, a low-head gate may prove satisfactory. For "tight" situations, the feeder can be arranged with a slight space (⅜ to ½ in.) between the top of the feeder hopper and the bottom surface of the storage structure. Then, in the event that the flow of material must be stopped (for feeder removal or repair), flat bars of steel (spiling) may be driven through the openings from all sides until the opening is closed off. On small openings, the space can be arranged to permit the hammer driving of a flat plate across the opening.

In a few cases, chutes have been tried for regulating the flow of fairly free-flowing materials, and worked well with minor modifications.

Gates may be operated manually, or by means of pneumatic and hydraulic cylinders, or electric motors. The mode of operation chosen will depend on economic factors, the accessibility of the gate, the need for remote control, the sensitivity of the process and the nuisance value of excessive spillage.

Table XLIII provides a potential gate user with some information on the various types available and their most appropriate application. It is intended to provide a few guidelines for gate selection and application: any final choice should be made only after study of the materials handled and consultation with the manufacturer.

STOCKPILING OF MATERIALS, Part 18

Quality control begins with effective sampling

- **How, why, where and when make the big difference in taking effective samples. Automatic samples are a big step toward greater accuracy**

In the handling and stockpiling of bulk materials, constant change is taking place in the characteristics of the material because of attrition, aggregation, wind erosion, and other forces. In order to produce a final product to meet the required specifications, it is necessary to identify these changes and discover where they are occurring. The most effective method of dealing with this is through some program of quality control.

Quality control is only as effective as the data on which it is based. Information about the material being controlled is the key to successful control, and sampling is simply a tool for obtaining reliable information.

There is some degree of confusion on the subject of sampling, and whether it works for or against the user. For some, sampling is a panacea; for others, it has become frustrating.

Before going further it seems desirable to define what we mean by "sampling." Sampling is a technique or method for obtaining objective information about a reality. This reality may be a material product or an activity about which information is desired. Since it is usually impossible to measure all of this reality, we must be content to select certain samples and hope these parts are representative of the whole. However the reality from which the sample was taken no longer exists. If properly taken the sample contains only the facts that are available on the subject slice of reality. Any conclusions drawn about the total reality are merely inferences and subject to verification.

There are two fundamental requirements. First, the sample must be taken at random, without a systematic plan. This usually means taking samples at various times and during various phases of any cyclic occurrences that may exist. Second, all of the material in the flowstream must be available for sampling. Failure to test the entire cross-section of the stream results in the sampling of a sample, yielding a partial sample that may not be representative of all the material.

When these two requirements are met, the sample should be representative of the material passing the sampling point at the instant the sample was taken. The more often samples are taken, the more accurate the inferences made about all the material.

A few illustrations may be desirable to dispel the notion that this is so much gobbledegook and that sampling is a simple matter. To appreciate the real complexity of the problem, remember that everything in this world is constantly changing. Truly, "all is flux." Try describing your own personal activities for one day by taking samples at intervals. In order to present a representative picture of your functioning, at what moments and with what frequency would you take your samples during the span of this reality?

Suppose the samples were taken at 8, 12, and 4 o'clock, moments during which you are arriving at the job, going to lunch, or preparing to go home, all essentially personal and non-productive activities. Would samples at 8, 10, 12, 2 and 4 catch you enjoying a cup of coffee or a brief smoke. Would such samples be truly representative of your work efforts? Consider, then, how much different a picture would be obtained if these slices of reality were taken at 15 or 30 minute intervals. Moments of relaxation would then be balanced by intervals of productivity, and your true value as a worker would become evident to the sample analyst.

Consider the problem of an aggregate producer. He is required, by the specifications of his customers, to produce a product of a certain quality, size, and gradation. To do so requires many unit operations in which the structure, size and shape of the material are altered. At what point in this sequence of operations shall he sample his material? Shall it be sampled during the processing, as it enters the stockpile or bin, as it is being reclaimed and loaded out, or as it is being unloaded at its final destination? How many samples should be taken and how large should they be?

Obviously, there will be many different answers to these questions—depending on the desired results. Perhaps we need to ask not what sampling *can* do for us, but rather what we *want* it to do. This may be one more situation in which our expectations are coloring our evaluations far more than we realize.

If we remember that sampling is a technique for obtaining objective information about a reality, then we will be less likely to expect too much from it and begin to recognize that it can serve many different purposes.

Let us apply this thought to a typical plant and test its correctness. Samples of material taken ahead of a bin or stockpile will tell the efficiency level at which the equipment in the plant is performing.

To illustrate this point is the story of an aggregate shipper who had several lots rejected by an inspector because of excess coarse material. Investigation disclosed that a screen had developed a sizable hole in the screen cloth, through which the coarse material was passing along with the fine. It was a simple matter to repair the screen and run the material through the plant again. But whose profit was reduced by the extra transportation cost and the reprocessing expense?

An automatic sampling installation

would have detected the failure of the screen cloth before any sizable amount of this material was placed in the stockpile. If only the load-out of the material had been sampled, the shipper would still have saved himself many dollars transportation cost. In either case, the sampling installation would have done much to save the cost of its own purchase price!

In another instance, material (minus 1¼x¼ in.) was conveyed by belt for several hundred ft and the finer material sifted down through the coarser rock. At the point of discharge, most of the fines came off close to the belt, while the coarse was thrown on a longer trajectory. Hand samples taken from part of the stream failed to discover this. An automatic sampling installation, using a cutter which sampled the entire width of the stream, would have obtained a representative sample and given a true picture of the material gradation and size.

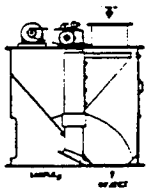
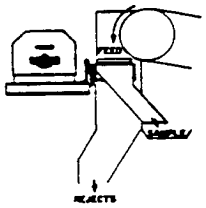
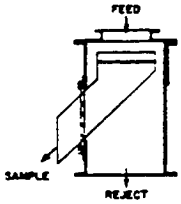
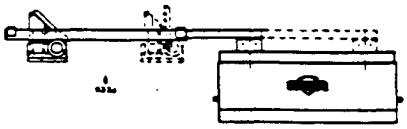
Moving through this typical plant, we arrive at the storage section. As soon as the material falls into a stockpile or bin, natural forces start changing its character. Gravity tends to move the coarser particles closer to the bottom of the slope, wind may remove some of the finer particles or bring in and deposit foreign matter to contaminate the product, and rain may alter the moisture content.

Obviously, samples taken ahead of storage are not representative of the material as it rests in storage. Samples taken from the stockpile, at random, will yield some information on the extent of segregation, contamination, or other changes that have taken place. This provides some guidance to the need for blending or other corrective action. Such samples, however, cannot be regarded as representative of the material that will be shipped at a later time.

Sampling the product as it is loaded into a truck will provide data on the grade, size, and gradation of the product going into that particular truck. Such data will also aid in evaluating the effectiveness of blending methods.

A sampler installed at the load-out point can be adjusted to sample the

SAMPLER TYPES AND RECOMMENDED USES

Sampler type	Description of sampler unit
Vezin sampler 	Vezin samplers have rotary horizontal sample cutters that pass through a falling vertical stream and take increment samples. They are dust-tight and available for either continuous or intermittent operation. The continuously operating sampler will remove a sample approximately 5% of the flow rate for each cutter. The intermittent unit is controlled by an adjustable automatic timer and takes increment samples at predetermined intervals of time.
Automatic sampler 	The automatic sampler is a straight-line sampler. The sample cutter moves through the falling stream, at a right angle, and at uniform speed to take an accurate increment sample. It may operate continuously or intermittently. Intermittent operation is controlled by an adjustable automatic timer. Available in standard, heavy duty and extra-heavy duty models, and slow (7.5 and 12″/sec) or high (18″ and 30″/sec)
Chute sampler 	This unit is a pre-engineered package designed to fit installations where the material is handled in chutes or pipes. Reliable sampling is attained with a minimal loss of headroom and minimum wear and abrasion. The unit consists of an automatic sampler mechanism, sample cutter and welded plate steel housing. The cutter opening is sealed when the cutter is not in the stream of material.
Bottom dump 	The bottom dump sampler employs an automatic sampler mechanism and a specially designed cutter. This cutter is designed to hold the sample without overflowing until the cutter reaches the discharge point. The unit may be arranged to dump the sample at the end of each interval, or at the end of two intervals. It is intended for use with chute-type installation and many other special designs

batch as it is being delivered to the trucks. An example of such an installation is shown in the illustration. By taking such samples, the shipper can assure himself that the material as loaded out did conform to the buyer's specifications. In such cases, duplex or triplex sample cutters can be used to secure two or three identical samples; one for the buyer, one for the producer, and one for a referee.

At the unloading point, sampling will tell the condition of the material that arrived at the job site. It may also yield some startling information about the effect of transportation on the product. A rough trip may produce excessive segregation of the product or dusty roads might leave an excess of fines on the top of the load. These samples can in no way report on the good size gradation produced at the plant. Only the uninformed would have such an expectation!

When a shipper must transport material several miles over rough roads the load may arrive at its destination very effectively segregated. In certain areas of the truck load, the fines will have "floated" to the upper levels, while the coarse materials will have "sunk" to the bottom. Road dust, an undesired contaminant, may be accumulated on the surface of the load. An inspector who simply grabs a sample from the top of such a load is not obtaining a representative sample. In fact, there is no reliable way of obtaining a representative sample, except by dumping the entire load, mixing it, quartering and splitting it down. The shipper who can present evidence of the product "mix" based on the use of a well-designed sampling installation at the loading station, is going to have fewer problems of this nature. As specs become more exacting, the importance of correct sampling procedures will become more apparent.

After this tour of a typical plant it seems obvious that there are many points at which samplers may be applied to obtain valuable data for the operation and control of the plant, and to insure a desired end product.

In some industries, the analysis of the sample has become much more sophisticated than the method of sampling. In many cases, the sample analyst is provided with elaborate and costly equipment for making the required analysis, while relatively primitive methods of sampling are still employed. It seems absurd to spend tens of thousands on analyzing equipment while the lab assistant merely takes a grab sample, with a tin cup nailed to a wooden pole—an investment of 75¢ in sampling gear!

I recall recently viewing a promotional film on cement manufacture in which the narrator glowingly described the company's concern for product quality. To illustrate this concern and how it was insured, the aforementioned lab assistant marched out and took a grab sample of a process stream. Even in living color, the operation failed to look very effective, although the pole and cup did photograph well.

Certainly there is a limit to the amount of money that can be spent for sampling equipment, just as there are limitations on the amount of analysis equipment that can be afforded. But a better balance between the two phases is necessary. In selecting sampling equipment, consideration should be given to initial cost, projected maintenance expense, and the amount of operator time that will be required. Automatic sampling equipment, although slightly higher in initial cost, can save many hours of costly operator time, while producing more reliable and representative samples. In most cases the investment in samplers will still be a fraction of what is expended for analysis. But the analysis can be only as reliable as the sample delivered to the laboratory.

Recommended uses	Sizes available
Suited for cement, feed and fertilizer plants, or any operation where dust control is a problem. Generally used with material that is —¼" in size.	Nom. size: Opening: 20"—C & I 5" x 5" 28"—C & I 7" x 7" 40"—C & I 12" x 12" 48"—C & I 16" x 16" 60"—C 20" x 20" Unit is sized by feed chute dimensions.
Suited for general sampling uses on fine powders to coarse rock. Type C cutter made in two widths: ¼" to 1½" and 1⅝" to 3" with replaceable cutter blades. Wet or dry operation.	Cutter travel: 16½" Heavy duty cutter travel—24" to 96" 18" 21" 24" Extra heavy duty cutter travel—30" to 120" + 27" 30" 36"
Suited for installations where material is handled in chutes or pipes. See automatic sampler for further conditions.	Available in wide range of sizes. May be used for wet or dry applications.
Ideally suited for installations where headroom is restricted. Also good when adding samplers to existing installations.	Available to suit a wide range of conditions. Units are specially designed for the size of particle, amount of sample, etc.

STOCKPILING OF MATERIALS, Part 19

Portable trap-loaders speed production

- **The versatility of a belt-loader allows it to be moved as needed and handle a variety of materials, reducing costs and increasing production**

Traps of a permanent nature have long been used as a means for loading materials on a belt. In the main, these have been limited to feeding material to a plant or process with a dozer.

Usually, the structure supporting the hopper above the belt was constructed of wood or concrete and was not movable. Although the introduction of rubber-tired machines has appreciably increased their range, dozers have a rather limited radius of effective action, which limits the utility of this arrangement to plants with a fairly small throughput.

Portable trap-loaders, or belt-loaders, or top-loaders emerged as an off-the-shelf item about 1960. The top-loader, a relative new-comer, has had a surprisingly good reception. In some applications it has successfully replaced shovels and scrapers. Their low operating cost per unit of volume handled, and their high rate of production have established the top-loader among present day excavating and materials-handling equipment.

For success in applying this unit, material should be relatively free-flowing; depth of cut, or height of bank should be in excess of 20 ft, although the area available for approach ramps will affect this value, and crawler dozers should have a working radius of 200 ft, though wheeled dozers can extend this limit to 400 or 500 ft.

These units can be used to load trucks, trailers, scrapers or other means of conveyance. In addition, grizzlies or screens can be installed on the loader discharge to obtain a sized product. By this means, over-sized material may be removed at the borrow pit, rather than removing it from the fill with rock rakes.

The belt loader is capable of a high rate of production. The latest units will load up to 3,600 cu yd per hour and handle rocks up to 3 or 4 ft in dimension. In determining the capacity of a belt loader, a common mistake is for the designer to base his design on the average rate of material flow, rather than on the peak loads. In practice, most conveyors are forced to carry a widely fluctuating load, which in extreme cases may be two or three times the hourly average.

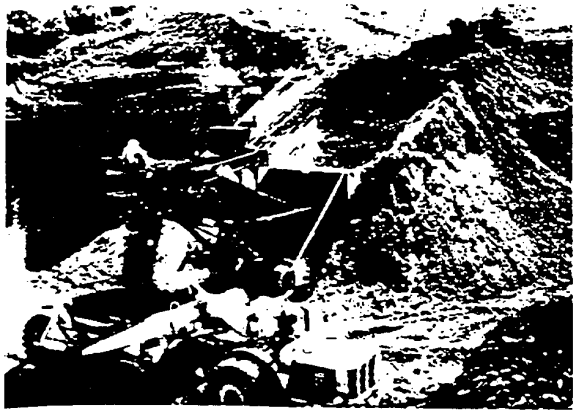
A convenient chart, from which the capacity of any given belt may be read, is provided in Table XLIV. Note at the extreme right of the table the maximum lump size that is recommended for each belt width. Very often on belt loaders handling coarse material, the size of the belt will be determined by lump size rather than tonnage requirements.

In general, belt loaders will operate at somewhat slower speeds than comparable size belt conveyors. Fragile, abrasive or dusty materials will usually be carried at a slower speed. With dusty materials, 300 fpm must be considered the maximum. A high percentage of large lumps will also limit practical belt speed.

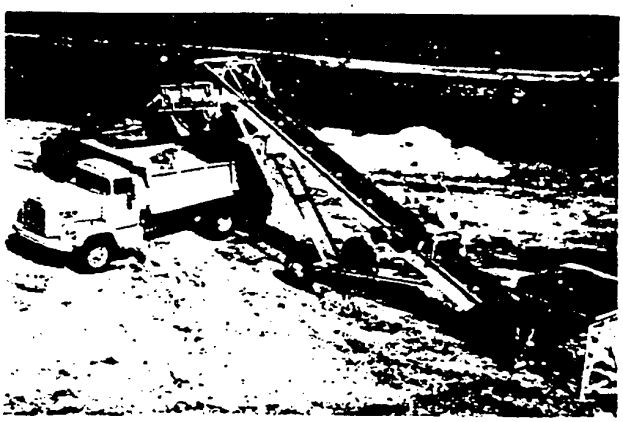
Since belt loaders load trucks from the top, and place the material uniformly, there is little or no damage done to the truck bodies. Accuracy of truck-spotting is easy since the loader operator is positioned at the belt discharge—above the truck road.

To set up a portable belt loader is a fairly simple operation. First, a shallow trench is cut into a hillside or bank of material. Then, the loader trap is backed into this cut, and stockpiled material is dozed up around it to form a ramp on which the dozer may operate. Crawler or wheeled dozers can then be used in the usual manner, to charge the trap.

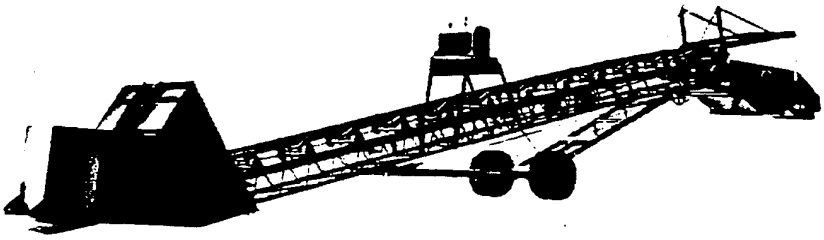
As the effectiveness of a given set-up is reduced by increased dozing distances, the trap and loader can be moved and relocated in a matter of several hours. If desired, these traps can be arranged for feeding by a



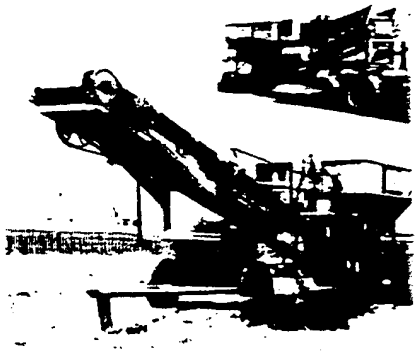
Left: Typical high-capacity loading operation teaming a dozer and portable belt loader (Courtesy, Barber-Greene)



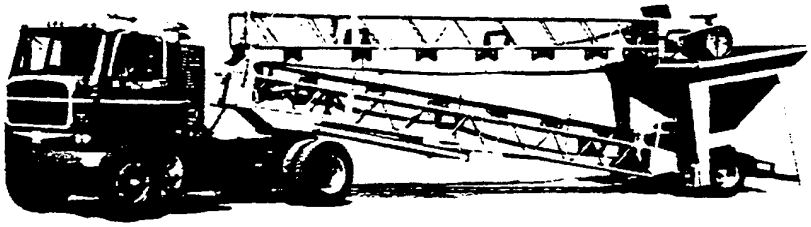
Right: Elevated hopper allows the use of a front-end loader to feed unit. Notice use of small screen to make two products and load a pair of trucks simultaneously (Courtesy, Atlas Conveyor Co.)



Left: Unit equipped with both trap and buzzer screen (Courtesy, Pioneer Engineering Div.)



This completely self-contained unit offers hopper capacities from 12-20 cu yd and loading capacities from 440-1,975 tph (Courtesy, Kolman Div., Athey Products Corp.)



Left: Many large units are hinged for travel (Courtesy, Rex Chainbelt Inc.

shovel, clamshell, dragline, or front-end loader.

The belt loaders are capable of handling many different materials, including salt, sand, gravel, dirt, clay, rock, and slag. In aggregate plants, these machines may be combined with a screen and used for re-screening stockpiled materials and removing excess fines, before crushing, etc.

Units should be selected for size of particles to be handled and the production rate that is desired. At present, light-duty units are available in 18, 24, and 36-in. belt widths, and in standard lengths up to 50 ft. Heavy-duty units are available in 48, 60, and 72-in. belt widths, and in lengths up to 50 or 60 ft. The 48-in. loader will deliver material (up to 3 ft. maximum) at a rate of 2,000 cu yd per hour, while a 60-in. unit will deliver material up to 4 ft in maximum dimension at the rate of 3,600 cu yd per hour.

Table XLIV—Belt loader speed, size and capacity chart

Belt Width	Wt. per cu. ft. of Mat'l.	Capacity in tons per hour — Belt speed in fpm. 100	150	200	250	300	350	400	450	500	550	600	650	Max. size uniform size	Lump in. with 90% fines	Normal speed fpm.	Cu. yd. per hr. at 100 fpm.
18	50	27	40	54	67	81	94	108	122	135							
	75	40	60	80	100	121	140	160	180	200							
	100	54	81	108	135	162	189	216	243	270				3	5	250	39.8
	125	67	100	134	167	200	234	268	301	335							
	150	81	121	162	201	243	284	324	365	406							
20	50	33	49	66	82	99	115	132	148	165	182						
	75	50	75	100	125	150	175	200	225	250	175						
	100	67	100	134	167	200	234	258	292	326	360	394		3½	6	300	39.7
	125	84	126	168	210	252	294	336	378	420	462	504					
	150	100	150	200	250	300	350	400	450	500	550	600					
24	50	49	73	98	122	147	171	196	220	245	275	300					
	75	74	111	148	185	222	250	296	332	370	407	444					
	100	99	148	198	248	298	346	396	445	495	544	593		4½	8	300	73.5
	125	125	188	250	314	375	438	500	562	625	687	748					
	150	149	222	298	373	447	521	596	670	745	819	894					
30	50	80	120	160	200	240	280	320	360	400	440	480	520				
	75	120	180	240	300	360	420	480	540	600	660	720	780				
	100	160	240	320	400	480	560	640	720	800	880	960	1040	6	11	350	118
	125	200	300	400	500	600	700	800	900	1000	1100	1200	1300				
	150	240	360	480	600	720	840	960	1080	1200	1320	1440	1560				
36	50	116	174	232	290	348	406	464	522	580	638	696	760				
	75	174	261	348	435	522	610	696	783	870	956	1044	1131				
	100	233	350	466	582	700	815	932	1050	1165	1281	1398	1515	8	15	400	173.7
	125	294	441	588	735	882	1028	1176	1324	1470	1617	1769	1911				
	150	348	522	696	870	1044	1218	1392	1565	1740	1912	1088	2262				
42	50	164	246	328	410	492	574	656	738	820	902	984	1070				
	75	245	368	490	612	735	857	980	1102	1225	1348	1470	1593				
	100	328	492	656	820	984	1148	1312	1475	1640	1804	1968	2132	10	18	400	245
	125	405	608	810	1012	1215	1418	1620	1822	2025	2225	2430	2632				
	150	492	738	984	1230	1476	1722	1968	2208	2460	2704	2952	3198				
48	50	220	330	440	550	[illegible]	770	880	990	1100	1210	1320	1430				
	75	330	495	660	825	[illegible]	1155	1320	1485	1650	1815	1980	2144				
	100	440	660	880	1100	1320	1540	1760	1980	2200	2420	2640	2860	12	21	400	328
	125	550	825	1100	1375	1650	1925	2200	2475	2750	3025	3300	3575				
	150	660	990	1320	1650	[illegible]	[illegible]	2640	2970	3300	3630	1960	4290				
		Maximum belt speed, fpm. Abrasive Mat'l.							Average Mat'l.				Free Flow				

STOCKPILING
OF MATERIALS, Part 20

Calculating the size of stockpiles

This concluding section features charts and tables for calculating volumes, areas and tonnages of stockpiles

The preceding parts of this series have described the various types of stockpiles and the methods and equipment used in stockpiling operations. This section presents selected charts and tables that will aid those designing stockpiling systems or concerned with the calculation of volumes, areas, and tonnages.

The four areas covered are:

1—Material properties, with information on

(a) Bulk material classification—To provide the designer with general data on the physical properties of common bulk materials.

(b) Minimum angles of slide—Of interest to those who must design and specify bin and chute construction.

(c) Comparative hardness guide—A correlation of the Mohs hardness scale with the Brinnel scale.

2—Conical stockpiles

(a) Volume and tonnage of conical files—Tabular data on conical stockpiles.

(b) Correction table for angles of repose over 37 deg—To permit the quick adjustment of tabulated values to suit other angles of repose.

(c) Correction table for live storage availability—When conical piles are reclaimed through tunnel conveyors, the live storage available is greatly reduced. This table correlates angle of repose with angle of draw-off to develop a set of useful coefficients.

(d) Nomograph—Total volume of conical stockpiles

(e) Nomograph—Surface areas of conical stockpiles—This will provide a helpful tool to those who must be concerned with covering stockpiles to reduce fines loss or air contamination.

3—Windrow stockpiles

(a) Volume and tonnage of tent-shaped windrows—Tabular data.

(b) Volume and tonnage of kidney-shaped windrows—Tabular data.

(c) Nomograph—Volume of tent-shaped windrows.

4—Bin storage

(a) Capacity of cylindro-conical bins—Tabular data.

(b) Determination of valley angles for bins and hoppers.

(c) Capacity of pyramidal hoppers—Live storage volume for 45-deg valley angles.

(d) Capacity of pyramidal hoppers—Live storage volume for 60-deg side slopes.

Material properties—Before handling or stockpiling any material, it is advisable that the properties of that material be known. If possible, it is best that the material be sampled and tested. If not feasible, then the following data may provide some useful guidance.

Bulk material classification

Material	Avg. Wt. (lb. cu. ft.)	Abrasiveness	Flowability	Notes	
Asbestos ore or rock	81	Very	Free flow	Granular;	-½"
Ashes, coal, dry, ½" or under	35-40	Mildly	Sluggish	Granular;	
Ashes, coal, dry, 3" or under	35-40	Mildly	Sluggish	Lumpy	
Ashes, coal, wet, ½" or under	45-50	Mildly	Sluggish	Granular;	4, 11
Ashes, coal, wet, 3" or under	45-50	Mildly	Sluggish	Lumpy;	4, 11
Asphalt, crushed, ½" or under	45	None	Free flow	Granular	
Barite	180	Very	Free flow	Lumpy	
Bauxite, crushed, 3" or under	75-85	Very	Free flow	Lumpy	
Bentonite, crude	34-40	Mildly	Sluggish	Lumpy	11
Bentonite, 100 mesh or under	50-60	Mildly	Free flow	Very fine	10
Cement, portland	65-85	Mildly	Free flow	Very fine	10
Cement clinker	75-80	Very	Free flow	Lumpy	
Chalk, lumpy	85-90	Mildly	Sluggish	Lumpy	11
Chalk, 100 mesh or under	70-75	Mildly	Sluggish	Very fine	10, 11
Chrome ore	125-140	Very	Free flow	Granular	
Clay, calcined	80	Very	Free flow	Fine	6
Clay, fine, dry	100-120	—	—	—	
Clay, lumpy, loose	60-75	—	—	—	
Coal, anthracite	60	Mildly	Free flow	Granular	4
Coal, bituminous, mined, -50 m.	50	None	Sluggish	Fine	4
Coal, bituminous, run-of-mine	50	None	Free flow	Lumpy	4
Coal, bituminous, sized	50	None	Free flow	Lumpy	4, 7
Coal, bituminous, slack, -½"	50	None	Sluggish	Granular	4
Coal, bituminous, not cleaned	50	Mildly	Sluggish	Lumpy	4
Coal, char	24	Mildly	Free flow	Fine	6, 10
Coke, loose	23-32	Very	Sluggish	Lumpy	7, 9
Coke, petroleum, calcined	35-45	Very	Free flow	Lumpy	9
Copper ore	120-150	Very	Free flow	Lumpy	
Dolomite, lumpy	90-100	Mildly	Free flow	Lumpy	
Ebonite, crushed, -½"	65-70	None	Free flow	Granular	
Feldspar, ground, ⅛" or under	65-70	Mildly	Free flow	Fine	
Feldspar, powdered	75	Mildly	Sluggish	Very fine	
Fluorspar	82	Mildly	Sluggish	Granular	
Granite, broken	95-100	Very	Free flow	Lumpy	
Gravel, screened	90-100	Mildly	Free flow	Lumpy	
Gypsum, calcined, ½" or under	55-60	Mildly	Free flow	Granular	
Gypsum, calcined, powdered	60-80	Mildly	Free flow	Very fine	
Gypsum, raw, 1" or under	90-100	Mildly	Free flow	Lumpy	
Ilmenite ore	140	Very	Free flow	Fine	
Iron ore	125-150	—	—	—	
Kaolin clay, 3" or under	163	Mildly	Free flow	Lumpy	
Kaolin talc, 100 mesh or under	42-56	Mildly	Sluggish	Very fine	
Lignite, air-dried	45-55	None	Free flow	Lumpy	
Lignite, raw	40-45	—	—	—	
Lime, ground, ⅛" or under	60	None	Sluggish	Fine	11
Lime, hydrated, ⅛" or under	40	None	Free flow	Fine	10, 11
Lime, pebble	53-56	None	Sluggish	Lumpy	
Limestone, agricultural, -⅛"	68	Mildly	Free flow	Fine	
Limestone, crushed	85-90	Mildly	Free flow	Lumpy	
Limestone dust	75	Mildly	Sluggish	Very fine	10
Lithopone	45-50	None	Free flow	Very fine	10
Manganese ore	125-140	—	—	—	
Marble, crushed, ½" or under	90-95	Very	Free flow	Lumpy	
Mica, ground	13-15	Mildly	Free flow	Fine	
Mica, pulverized	13-15	Mildly	Free flow	Very fine	10
Mica flakes	17-22	Mildly	Free flow	Fine	8, 10
Nickel-cobalt sulphate ore	70-80	—	—	—	
Phosphate sand	90-100	Very	Free flow	Fine	
Pumice, ⅛" or under	42-45	Very	Sluggish	Fine	
Pyrites, pellets	120-130	Mildly	Free flow	Granular	
Sand, bank, damp	110-130	Very	Sluggish	Fine	
Sand, bank, dry	90-110	Very	Free flow	Fine	
Sand, foundry, prepared	90	Very	Sluggish	Fine	
Sand, foundry, shakeout	90	Very	Free flow	Lumpy	
Sand, silica, dry	90-100	Very	Very Free	Fine	
Shale, crushed	85-90	Mildly	Free flow	Granular	
Slag, furnace, granular	60-65	Very	Free flow	Granular	
Slag, furnace, lumpy	160-180	Very	Sluggish	Lumpy	9
Slate, crushed, ½" or under	80-90	Mildly	Free flow	Granular	
Slate, ground, ⅛" or under	82	Mildly	Free flow	Fine	
Soda ash, heavy	55-65	Mildly	Free flow	Fine	
Soda ash, light	20-35	Mildly	Free flow	Very fine	8
Taconite, pellets	116-130	Very	Free flow	Lumpy	7
Traprock, crushed	105-110	Very	Free flow	Lumpy	9
Vermiculite, expanded	16	Mildly	Sluggish		8
Vermiculite ore	80	Mildly	Free flow	Lumpy	
Zinc concentrate residue	75-80	Very	Free flow	Fine	
Zinc ore, crushed	160	—	—	—	

Bulk material class descriptions

Size	Very fine—100 mesh and under	
	Fine —⅛-inch mesh and under	
	Granular—½-inch and under	
	Lumpy —containing lumps over ½-in.	
	Irregular—being fibrous, stringy or the like	
Flowability	Very free flowing—Angle of repose up to 30°	
	Free flowing—Angle of repose 30° to 45°	
	Sluggish —Angle of repose 45° and up	
Abrasiveness	Non-abrasive	
	Mildly abrasive	
	Very abrasive	
Other characteristics	Contaminable, affecting use or saleability	1
	Hygroscopic	2
	Highly corrosive	3
	Mildly corrosive	4
	Gives off dust or fumes harmful to life	5
	Contains explosive dust	6
	Degradable, affecting use or saleability	7
	Very light and fluffy	8
	Interlocks or mats to resist digging	9
	Aerates and becomes fluid	10
	Packs under pressure	11

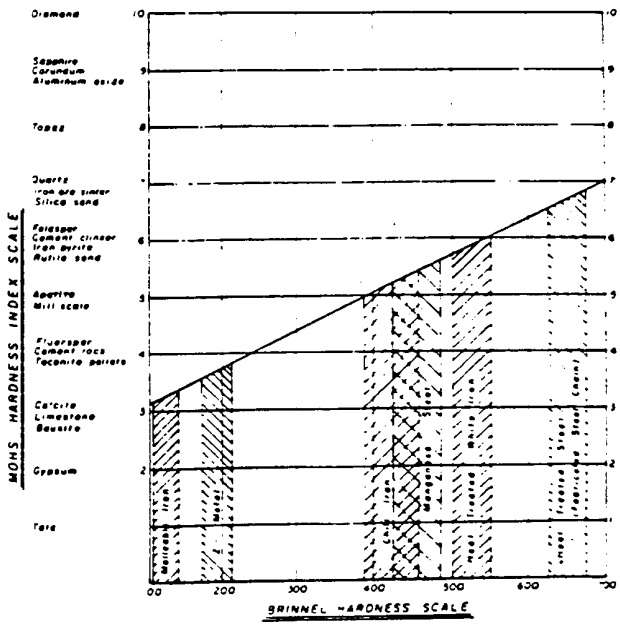
Adapted from Tables for Bulk Material Classifications, pp. 563-565, Link-Belt Co. Catalog 1000

Minimum angles of slide for various materials

Material	Ave. Wt. (lb. cu. ft.)	Minimum Angle
Ash, bituminous coal	35—45	40°
Ash, damp	40—50	50
Barytes, granular	144	30
Bauxite, calcined (granular)	70	26
Bauxite, ground, dried	68	35
Bauxite, mine run	85	31
Bentonite, pulverized	50	42
Cement, portland	90—100	39
Chalk, powdered (precipitated)	18	45
Cinders, (coal, ash, clinkers)	40—45	35
Cinders, blast furnace	57	35
Clay, dry- in lump, loose	40—100	35
Clay, ground	60—100	35
Coal, anthracite (loose, broken- any size)	52—57	22
Coal, bituminous, minus ¼", slack, dry	40—50	29
Coal, bituminous, minus ¼", slack, moderate wet	45—55	40
Coal, bituminous, minus ¼", slack, very wet	50—60	33
Coke, pulverized	25	34
Coke, petroleum, crushed	45—56	27
Copper, oxide, powdered	100	40
Copper, sulphate, ground	75	31
Dolomite, pulverized	46	41
Feldspar, pulverized	70—80	40
Feldspar, crushed	100	32
Gravel	120	30
Gypsum	112	45
Gypsum, in irregular lumps	82	30
Ilmenite, granulated	148	31
Kaolin, green, crushed	64	35
Kaolin, pulverized	22	45
Lime, burned, pebble (sized)	53	30
Lime, burned, pulverized	27	43
Limestone, pulverized	85	42
Limestone, mixed sizes	105	35
Limestone, coarse, sized	98	25
Limestone, dust	55—65	38
Mica, ground	13.5	36
Phosphate, powdered	60	40
Phosphate, Florida, #20, mesh, air-cleaned	93	27
Rutile, powdered	107	40
Salt, granulated	81	31
Salt, rock, crushed, sized	75	25
Sand, mine run	90—120	35
Sand, coarse, sized	90—100	30
Sand, very fine	90—110	32
Sand, voids full of water	110—130	45
Silica flour	80	45
Slag, furnace, granulated	122	25
Slate, fine ground	82	35
Slate, granules, flaky	87	28
Slate, flour	45	45
Soda ash, light	25—35	37
Soda ash, dense	66	32
Talc, micaceous, granulated	62	36
Zinc ore, roasted, granular	110	38

Adapted from tables in Stephens-Adamson Mfg. Co. Catalog 66, pp. 634—636

Comparative hardness guide—Under Mohs hardness scale, select bulk material that most closely matches your material; then, read across horizontally to intersection with sloping line for recommended material of construction for chutes and parts (Adapted from Rex Chainbelt Co. Bulletin 6092)



Conical stockpiles—Since the conical stockpile is the most commonly encountered in stockpiling operations, we have given this form the greatest coverage. The charts and tables presented here will provide the plant operator and engineer with a simplified method of solving problems that involve cone volumes, surface areas, total tonnages and live tonnages

Conical Piles (Angle of Repose: 37 deg.)

Diameter Ft.	Base of Pile Circumference Ft.	Area Sq. Ft.	Cone Height Ft.	Cone Volume Cu. Ft.	Cone Tonnage (at 100 lb. cu. ft.)
1	3.14	0.78	0.38	0.098	
2	6.28	3.14	0.75	0.785	
3	9.42	7.07	1.13	2.65	
4	12.57	12.57	1.50	6.29	
5	15.71	19.63	1.88	12.27	
6	18.85	28.27	2.25	21.2	1.06
7	21.99	38.48	2.63	33.7	1.68
8	25.14	50.27	3.00	50.27	2.52
9	28.27	63.62	3.38	71.57	3.57
10	31.41	78.54	3.75	98.17	4.91
11	34.56	95.03	4.13	130.67	6.53
12	37.70	113.10	4.50	169.65	8.48
13	40.84	132.73	4.88	215.69	10.78
14	43.98	153.94	5.25	269.39	13.47
15	47.12	176.72	5.63	331.35	16.57
16	50.26	201.06	6.00	402.12	20.11
17	53.41	226.98	6.38	482.33	24.12
18	56.55	254.47	6.75	572.56	28.67
19	59.69	283.53	7.13	673.38	33.67
20	62.83	314.16	7.50	785.40	39.3
21	65.97	346.36	7.88	909.30	45.5
22	69.12	380.00	8.25	1,045.00	52.2
23	72.26	415.50	8.63	1,194.56	59.8
24	75.40	452.40	9.00	1,357.20	67.9
25	78.54	490.90	9.38	1,534.06	76.7
26	81.68	530.90	9.75	1,725.43	86.7
27	84.82	572.60	10.13	1,932.53	96.6
28	87.96	615.80	10.50	2,155.30	107.7
29	91.11	660.50	10.88	2,394.31	119.7
30	94.25	706.90	11.25	2,650.88	132.5
32	100.53	804.25	12.0	3,220	161.0
34	106.81	907.92	12.75	3,850	192.5
36	113.10	1,017.88	13.50	4,575	228.7
38	119.38	1,134.11	14.25	5,390	269.5
40	125.66	1,256.64	15.00	6,280	314.0
42	131.95	1,385.44	15.75	7,270	363.5
44	138.23	1,520.53	16.50	8,400	420.0
46	144.51	1,661.90	17.25	9,550	477.5
48	150.8	1,809.56	18.00	10,850	542.5
50	157.08	1,963.50	18.75	12,280	614.0
52	163.36	2,123.7	19.5	13,800	690
54	169.7	2,290.2	20.25	15,460	773
56	175.9	2,463.0	21.0	17,250	862
58	182.2	2,642.1	21.75	19,200	960
60	188.5	2,827.4	22.5	21,200	1,060
62	194.8	3,019.1	23.25	23,400	1,170
64	201.1	3,217.0	24.0	25,700	1,285
66	207.4	3,421.2	24.75	28,200	1,410
68	213.6	3,631.7	25.5	30,800	1,540
70	219.9	3,848.5	26.25	33,700	1,685
72	226.2	4,071.5	27.0	36,600	1,830
74	232.5	4,300.9	27.75	39,800	1,990
76	238.7	4,536.5	28.5	43,000	2,150
78	245.0	4,778.4	29.25	46,500	2,325
80	251.3	5,026.5	30.0	50,260	2,513
82	257.6	5,281.0	30.75	54,100	2,705
84	263.9	5,541.7	31.50	58,200	2,910
86	270.2	5,808.8	32.25	62,500	3,125
88	276.5	6,082.1	33.0	67,000	3,350
90	282.7	6,361.7	33.75	71,500	3,575
92	289.0	6,647.6	34.5	76,300	3,815
94	295.3	6,939.8	35.25	81,500	4,075
96	301.6	7,238.2	36.0	86,800	4,340
98	307.9	7,542.9	36.75	92,300	4,615
100	314.1	7,854.0	37.50	98,200	4,910

The table above is based on an angle of repose of 37 deg. While this is a good average value to use for most calculations, it may prove rather inexact for some materials. If you are working with such material, see table below for appropriate correction factor

Correction table for angles of repose other than 37 deg.

Volumes shown in Conical Pile and Windrow tables are based on an assumed angle of repose of 37 deg. For materials having a different angle of repose, select a multiplier for that angle from the table below. You may then correct height, volume and tonnage by applying that factor to the tabulated value

Angle of repose:	Multiplier:
20	0.483
25	0.619
30	0.766
35	0.929
37	1.000
40	1.114
45	1.327
50	1.582
55	1.893
60	2.299

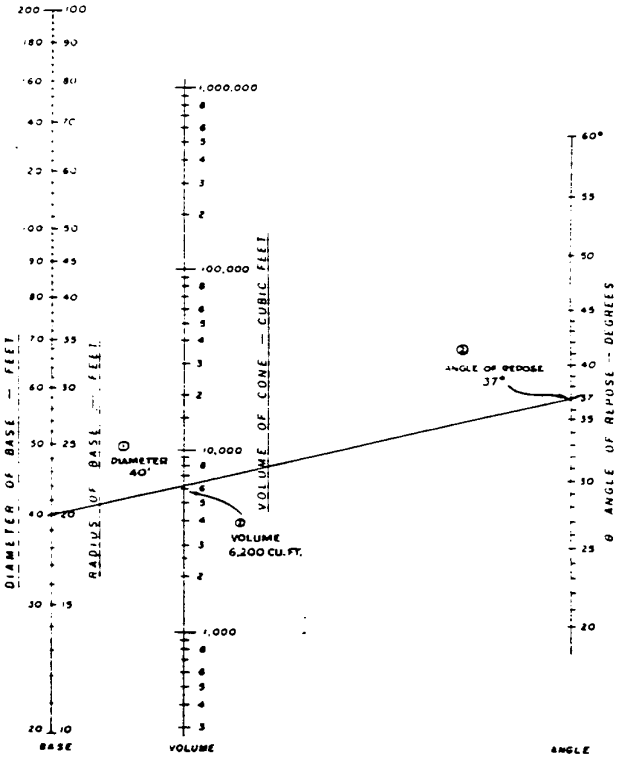
Example: For material having a bulk density of 100 pcf and an angle of repose of 30 deg. find height, volume and tonnage in a stockpile that measures 20 ft across base. Enter Correction table with 30 deg; read out multiplier of 0.766.

Results should be as follows:

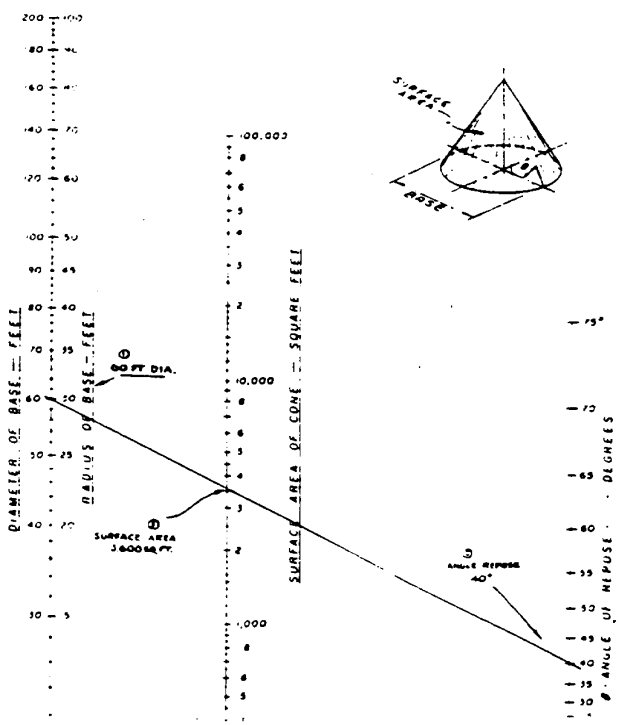
	Height	Volume	Tonnage
For Conical Piles			
Tabulated value: 20-ft. diam	7.50	785.4	39.3
Corrected value:	5.75	601.6	30.1
For Windrow piles	Height	Vol/Ft	Tons/Ft
Tabulated value: 20-ft base width	7.50	75.0	3.75
Corrected value:	5.75	57.5	2.87

Right: For those who prefer to use nomographs of tabulated data, the following alignment charts are provided for cone volume and surface area. (The Correction table above for differing angles of repose and

Conical stockpile volumes (based on formula: Volume $= \frac{1}{3} \pi r^2 \tan \theta$)—Enter with base diameter and angle of repose; read volume at intersection



Conical stockpile—surface areas (based on equation: SA $= \pi r^2 / \cos A$)—This nomograph provides an easy method of determining surface area for plastic cover and chemical binder requirements. Enter with base diameter and angle of repose; read surface area at intersection



Windrow stockpiles—Windrow stockpiles generally take two shapes—long tent-like piles, or curved kidney-shaped piles. The following tables and nomograph should make volume and tonnage calculations simpler and less time-consuming

Windrow storage (Angle of repose: 37 deg.—9/12 bevel)

Base width (B) Ft.	Height (H) Ft.	Cross-section area Sq. Ft.	Volume per foot Cu. Ft.	Tons per foot (at 100 lb./cu. ft.)
1	0.38	0.19	0.19	.009
2	0.75	0.75	0.75	.037
3	1.13	1.70	1.70	.085
4	1.50	3.00	3.00	.15
5	1.88	4.70	4.70	.23
6	2.25	6.75	6.75	.34
7	2.63	9.20	9.20	.46
8	3.00	12.00	12.00	.60
9	3.38	15.20	15.20	.76
10	3.75	18.75	18.75	.94
11	4.13	22.80	22.80	1.14
12	4.50	27.00	27.00	1.35
13	4.88	31.75	31.75	1.58
14	5.25	36.80	36.80	1.84
15	5.63	42.30	42.30	2.11
16	6.00	48.00	48.00	2.10
17	6.38	54.30	54.30	2.71
18	6.75	60.80	60.80	3.04
19	7.13	67.80	67.80	3.39
20	7.50	75.0	75.0	3.75
21	7.88	82.90	82.90	4.15
22	8.25	90.80	90.80	4.54
23	8.63	99.30	99.30	4.96
24	9.00	108.00	108.00	5.40
25	9.38	117.2	117.2	5.86
26	9.75	126.8	126.8	6.34
27	10.13	137.0	137.0	6.85
28	10.50	147.0	147.0	7.35
29	10.88	157.8	157.8	7.89
30	11.25	167.0	167.0	8.35
32	12.00	192.0	192.0	9.60
34	12.75	217.0	217.0	10.85
36	13.50	243.0	243.0	12.15
38	14.25	271.0	271.0	13.55
40	15.0	300.0	300.0	15.00
42	15.75	331.0	331.0	16.50
44	16.5	363.0	363.0	18.15
46	17.25	397.0	397.0	19.85
48	18.0	432.0	432.0	21.60
50	18.75	469.0	469.0	23.45
52	19.50	507	507	25.35
54	20.25	547	547	27.35
56	21.00	588	588	29.4
58	21.75	630	630	31.5
60	22.50	675	675	33.75
62	23.25	721	721	36.05
64	24.00	768	768	38.4
66	24.75	817	817	40.85
68	25.50	868	868	43.4
70	26.25	920	920	46.0
72	27.00	972	972	48.6
74	27.75	1,028	1,028	51.4
76	28.50	1,085	1,085	54.25
78	29.25	1,140	1,140	57.0
80	30.00	1,200	1,200	60.0
82	30.75	1,260	1,260	63.0
84	31.50	1,325	1,325	66.25
86	32.25	1,388	1,388	69.4
88	33.00	1,450	1,450	72.5
90	33.75	1,520	1,520	76.0
92	34.50	1,590	1,590	79.5
94	35.25	1,658	1,658	82.9
96	36.00	1,730	1,730	86.5
98	36.75	1,800	1,800	90.0
100	37.50	1,875	1,875	93.75

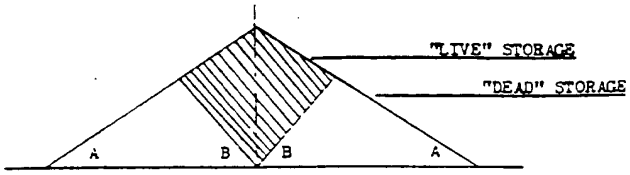
In many cases, conical stockpiles are emptied by means of a central outlet which loads a belt conveyor. It is often assumed that the angle of draw-off is the same as the angle of repose of the material. Since this is seldom the case, estimates of available live storage are often inaccurate. The following table provides a simple solution to this tedious task by giving the proper multiplier for various combinations of the angle of repose and draw-off

LIVE STORAGE AVAILABLE IN CONICAL STOCKPILES

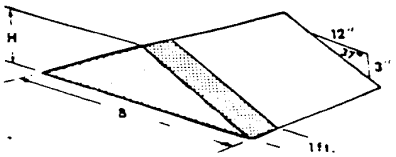
Angle of repose (Angle "A")	Values of multiplier "R" — Angle of draw-off (Angle "B") 20	25	30	35	40	45	50	55	60
20	0.2500	0.1922	0.1495	0.1170	0.0915	0.0712	0.0547	0.0413	0.0302
25	0.3153	0.2500	0.1996	0.1598	0.1276	0.1011	0.0791	0.0606	0.0450
30	0.3762	0.3061	0.2500	0.2043	0.1662	0.1340	0.1065	0.0829	0.0625
35	0.4329	0.3603	0.3004	0.2500	0.2069	0.1696	0.1370	0.1082	0.0829
40	0.4864	0.4132	0.3509	0.2972	0.2500	0.2082	0.1707	0.1370	0.1065
45	0.5375	0.4651	0.4019	0.3459	0.2957	0.2500	0.2082	0.1696	0.1340

Note: To find "live" or available storage in a conical pile having one central draw-point, multiply Total Storage in pile by the value of "R" for the angles of repose and draw-off shown above

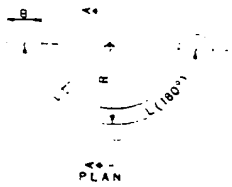
$$\text{"R"} = \frac{\text{Live Storage}}{\text{Total Storage}} = \frac{\tan^2 A}{(\tan A + \tan B)^2}$$



Tent-shaped windrows—parallel stackers



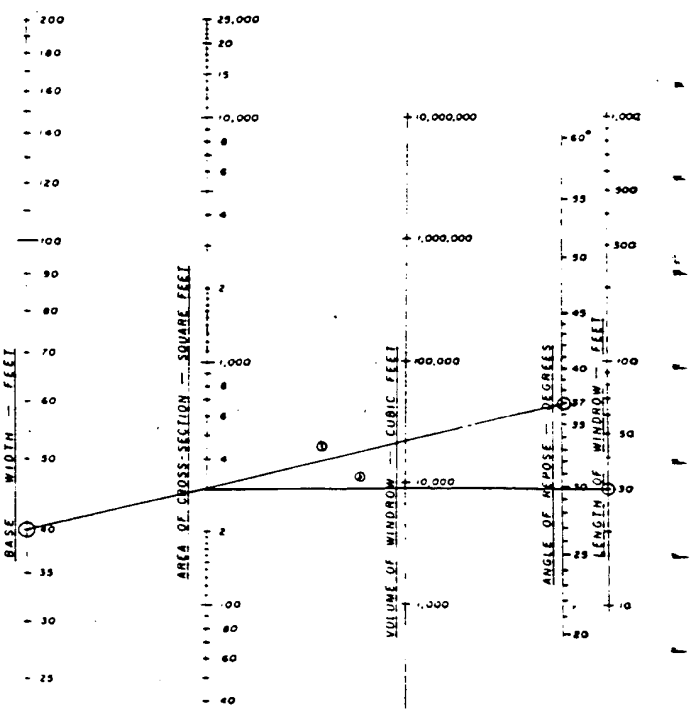
Kidney-shaped windrows—radial stackers



Storage pile tonnages—180° stacker

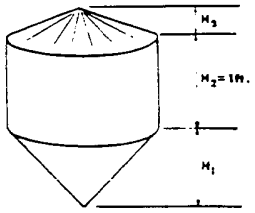
R radius (Ft.)	L arc length (Ft.)	Pulley W/P height (Ft.)	Pile height (Ft.)	B base width (Ft.)	Cone tonnage @ 100 pcf.	Windrow tonnage @ 100 pcf.	Total tonnage @ 100 pcf.
Conveyor slope: 4"/12" (18°-26')							
50	107	20	17	46	477	2,123	2,600
60	188	23	20	54	770	5,140	5,910
70	220	26	23	62	1,170	7,940	9,110
80	251	30	27	72	1,830	12,200	14,030
90	283	33	30	80	2,513	17,000	19,513
100	314	36	33	88	3,350	22,750	26,100
Conveyor slope: 3½"/12" (16°-15')							
50	107	18	15	40	314	1,600	1,914
60	188	21	18	48	542	4,060	4,602
70	220	24	21	56	862	6,470	7,332
80	251	27	24	64	1,285	9,650	10,935
90	283	30	27	72	1,830	13,750	15,580
100	314	33	30	80	2,513	18,850	21,363

Windrow stockpile volumes—The nomograph below may be used for the calculation of volume and tonnage of other sizes of radial stockpiles. Simply calculate length of arc of radial pile; then enter nomograph with base width and angle of repose, and read-out area of cross section. Connect area to length by a straight line, and read-out volume at intersection



Bin storage—Since bins play an important part in every bulk material handling and stockpiling operation, the following capacity data is included. The table on valley angles should be carefully considered when using pyramidal bottom bins or hoppers

Capacity estimations for cylindro-conical bins—Volumetic capacity of cylindro-conical bins can be quickly determined from this tabulation. Calculations are based on a 45-deg. bottom cone, 1-ft. cylindrical mid-section, and a 37-deg. top cone

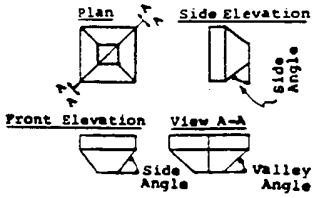


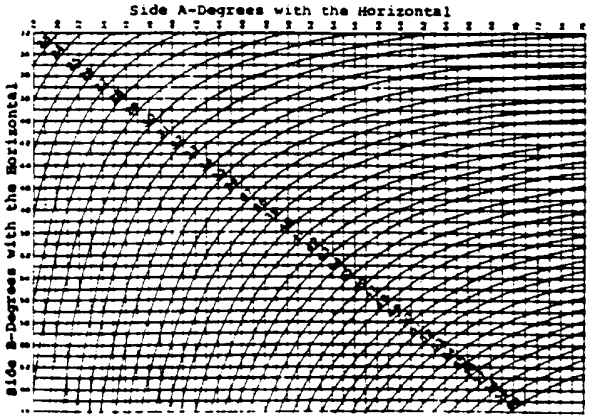
Cylindro-conical bins—45 deg. bottom cone—37 deg. 9 in./12 in. top cone

D Inside Diam. Ft.	H_1 Bottom cone Ft.	H_3 Top cone Ft.	Ht Total height Ft.	V_1 Volume 45 deg. cone	V_2 Volume 1 ft. cyl.	V_3 Volume 37 deg. cone	Vt Total vol. W. Ft.
10	5.0	3.750	9.750	130.9	78.54	98.20	307.64
11	5.5	4.125	10.625	171.2	95.03	130.10	399.63
12	6.0	4.500	11.500	226.2	113.10	169.80	509.10
13	6.5	4.875	12.375	287.2	132.73	215.50	635.43
14	7.0	5.250	13.250	359.2	153.94	269.50	782.64
15	7.5	5.625	14.125	441.6	176.76	331.50	949.86
16	8.0	6.000	15.000	536.2	201.06	402.12	1.139.38
17	8.5	6.375	15.875	643.8	226.98	482.50	1.353.28
18	9.0	6.750	16.750	763.4	254.47	572.50	1.590.37
19	9.5	7.125	17.625	896.5	283.53	673.00	1.853.03
20	10.0	7.500	18.500	1.047.2	314.16	785.50	2.146.86
21	10.5	7.875	19.375	1.212.4	346.40	909.30	2.468.10
22	11.0	8.250	20.250	1.394.6	380.00	1.045.00	2.819.60
23	11.5	8.625	21.125	1.591.4	415.50	1.194.56	3.201.46
24	12.0	9.000	22.000	1.809.6	452.40	1.357.20	3.619.20
25	12.5	9.375	22.875	2.017.1	490.90	1.534.05	4.072.06
26	13.0	9.750	23.750	2.298.8	530.90	1.725.13	4.555.13
27	13.5	10.125	24.625	2.576.7	572.60	1.932.53	5.081.83
28	14.0	10.500	25.500	2.875.8	615.80	2.155.30	5.646.90
29	14.5	10.875	26.375	3.216.6	660.50	2.391.31	6.271.41
30	15.0	11.250	27.250	3.531.5	706.90	2.650.88	6.892.28

Valley angles for various side slopes—The valley angle at all times should be greater than the angle of repose of the material which is being handled. The valley angle is the angle with the horizontal formed by the line of intersection of any two adjacent sides of the hopper. If the angles that the sides of bunkers or hoppers make with the horizontal are A and B respectively, the valley angle formed is read at the intersection of the lines representing these angles on the chart below.

Where lump material such as run-of-mine coal is being handled in track hoppers, the clearance between the sides of the hopper and the beams supporting the T-rails should be sufficient to allow the free passage of the material being handled. For run-of-mine coal, this clearance is usually made 24 in. as a minimum (Courtesy, Rex Chainbelt Co.)



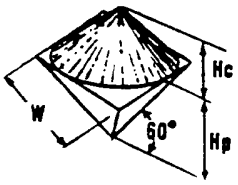


Volumes of pyramidal hoppers having 45-deg. valley angles (54-deg.-44-ft. side slope)—In practice, the bottom of pyramid must be cut to provide a discharge opening. To obtain true bin volume, deduct volume of pyramid having width of opening from "Vt"

"W" Width of sides	"Hp" Height of pyramid	"A" Area of base	"Hc" Height of 37-deg. cone	"Ht" Total ht. Hp + Hc	"Vp" Volume of pyramid	"Vc" Volume of 37-deg. cone	"Vt" Total volume
1	0.707	1	0.38	1.09	0.24	0.10	0.35
2	1.414	4	0.75	2.16	1.88	0.78	2.66
3	2.121	9	1.13	3.25	6.36	2.66	9.02
4	2.828	16	1.50	4.33	15.08	6.28	21.36
5	3.535	25	1.88	5.42	29.46	12.30	41.76
6	4.242	36	2.25	6.49	50.90	21.20	72.10
7	4.949	49	2.63	7.58	80.83	33.74	114.57
8	5.656	64	3.00	8.66	120.66	50.27	170.93
9	6.363	81	3.38	9.74	171.80	71.88	243.68
10	7.070	100	3.75	10.82	235.67	98.17	333.84
11	7.777	121	4.13	11.91	313.67	130.83	444.50
12	8.484	144	4.50	12.98	407.23	169.64	576.87
13	9.191	169	4.88	14.07	517.75	215.91	733.66
14	9.898	196	5.25	15.14	646.64	269.39	916.03
15	10.605	225	5.63	16.24	795.37	331.63	1127.00
16	11.312	256	6.00	17.31	965.29	402.12	1367.41
17	12.019	289	6.38	18.40	1157.83	482.71	1640.54
18	12.726	324	6.75	19.48	1374.40	572.55	1946.95
19	13.433	361	7.13	20.56	1616.44	673.85	2290.29
20	14.140	400	7.50	21.64	1885.33	785.40	2670.73

Live storage volume of pyramidal hoppers having 50-deg. - 40-ft. valley angles (60-deg. side slopes)—For exact volume of truncated pyramidal hopper, subtract volume of pyramid having width "W" equal to the width of hopper opening

"W" Width of sides	"Hp" Height of pyramid	"A" Area of base	"Hc" Height of 37-deg. cone	"Ht" Total ht. Hp + Hc	"Vp" Volume of pyramid	"Vc" Volume of 37-deg. cone	"Vt" Total volume
1	0.866	1	0.375	1.241	0.29	0.10	0.39
2	1.730	4	0.750	2.480	2.31	0.79	3.10
3	2.60	9	1.125	3.725	7.80	2.65	10.45
4	3.43	16	1.50	4.930	18.29	6.29	24.58
5	4.33	25	1.875	6.205	36.08	12.27	48.35
6	5.20	36	2.25	7.45	62.40	21.20	83.60
7	6.06	49	2.625	8.685	98.98	33.67	132.65
8	6.93	64	3.000	9.93	147.84	50.27	198.11
9	7.80	81	3.375	11.175	210.60	71.57	282.17
10	8.66	100	3.75	12.41	288.67	98.17	386.84
11	9.53	121	4.125	13.655	385.04	130.67	515.71
12	10.40	144	4.50	14.90	499.20	169.65	668.85
13	11.26	169	4.875	16.135	634.31	215.69	850.00
14	12.12	196	5.250	17.370	791.84	269.39	1061.23
15	13.00	225	5.625	18.625	975.00	331.35	1306.35
16	13.85	256	6.00	19.850	1182.00	402.12	1584.12
17	14.72	289	6.375	21.095	1418.00	482.33	1900.33
18	15.60	324	6.750	22.350	1685.00	572.56	2257.56
19	16.45	361	7.125	23.575	1980.00	673.38	2653.38
20	17.30	400	7.50	24.800	2306.00	785.40	3091.40



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