Portland Cement Concrete Level III Technician Course

"Manual of Instructions for Design of Concrete Mixtures"

Prepared and Published by
Illinois Department of Transportation
Bureau of Materials

Springfield, Illinois

January 1, 2018

LAKE LAND COLLEGE
INSTRUCTOR AND COURSE EVALUATION

Course: PCC Level III Technician Course **Section:** ___________ **Date:** ___________________

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 respects 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**. Your frankness and honesty are appreciated.

First, please record your general impressions and/or comments on the following:

Course ____

____

Instructor ____

For each remaining item, circle the number from the scale which seems most appropriate to you for the instructor and course that you are evaluating. You are strongly encouraged to make any comments that will clarify particular rating on the back of this form; please refer to each item you are discussing by its number.

OBJECTIVES AND APPROPRIATENESS OF THE COURSE:

			WEAK				SUPERIOR
1.	**Clarity of Objectives**	The objectives of the course were clearly identified. Objectives were adequately covered.	1	2	3	4	5
2.	**Selection content**	Content was relevant and met the level of the class.	1	2	3	4	5

ORGANIZATION AND CONTENT OF LESSONS:

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

OVER

LAKE LAND COLLEGE
INSTRUCTOR AND COURSE EVALUATION

(PAGE 2)

			WEAK				SUPERIOR
PERSONAL CHARACTERISTICS AND STUDENT RAPPORT:							
8.	**Vocabulary**	Instructor's vocabulary level was appropriate for the class.	1	2	3	4	5
9.	**Pupil participation and interest**	Instructor encouraged students to ask questions and actively participate in class.	1	2	3	4	5
10.	**Personal attributes**	Instructor indicated an interest and enthusiasm for teaching the subject matter.	1	2	3	4	5
11.	**Personal attributes**	Instructor was familiar with current industry practices.	1	2	3	4	5
12.	**Personal attributes**	Instructor's mannerisms were pleasing.	1	2	3	4	5
13.	**Instructor-student rapport**	Instructor indicated a willingness to help you in times of difficulty.	1	2	3	4	5
14.	**Instructor-student rapport**	Instructor was fair and impartial in dealings with you.	1	2	3	4	5
EXAMINATION:							
15.	**Exam material**	The exam correlated to the materials being covered in class.	1	2	3	4	5
SUMMARY:							
16.	Considering everything, how would you rate this instructor?		1	2	3	4	5
17.	Considering everything, how would you rate this course?		1	2	3	4	5
LAPTOP COMPUTER:							
18.	If you brought a laptop computer, was the class training adequate for learning the PCC Mix Design software?		1	2	3	4	5

COMMENTS: (Please use the area below to add any additional comments regarding the class and exam.)

____

____

COURSE REQUIREMENTS FOR SUCCESSFUL COMPLETION

Student must attend all class sessions.

- PREREQUISITE COURSES — Either the Mixture Aggregate Technician Course (3-day) or the Aggregate Technician Course (5-day), and the Portland Cement Concrete Level I & II Technician Courses are required.

- WRITTEN TEST — The test is open book. The time limit is 2.5 hours. A minimum grade of 70 is required.

  Note: The Department has no out-of-state reciprocity.

- WRITTEN RETEST — If the student fails the written test, a retest can be performed. The retest is open book. The time limit is 2.5 hours. A minimum grade of 70 is required. A retest will not be given on the same day as the initial test. A retest must be taken by the end of the academic year that the initial test was taken. The academic year runs from September 1st to August 31st. Failure of a written retest, or failure to comply with the academic year retest time limit, shall require the student to retake the class and the test. The student shall be required to pay the appropriate fee for the additional class.

- NOTIFICATION — The student will be notified by letter of their test score. A certificate of completion will be issued if the student passes the course, and 12 professional development hours earned will be indicated on the certificate. Once trained, the Department will not require the individual to take the class again for recertification purposes.

PREFACE

This manual has been prepared to train the student to become a Level III Portland Cement Concrete (PCC) Technician. The main focus of the manual is to provide a procedure to design concrete mixes for Illinois Department of Transportation (herein referred to as “IDOT” or the “Department”) Quality Control/Quality Assurance (QC/QA) projects. The manual summarizes various specifications, but project contract specifications shall govern in all cases. The manual provides basic information and is intended to be a useful reference tool. This manual is applicable for the April 1, 2016, Standard Specifications for Road and Bridge Construction (link embedded) and the Supplemental Specification and Recurring Special Provisions, Adopted: January 1, 2018 (link embedded).

The American Concrete Institute (ACI) procedure for determining the mix design target strength from the minimum specification strength requirement, statistical average/standard deviation, workability and other information in this manual were obtained from a course sponsored by the Federal Highway Administration (FHWA) and the Iowa Department of Transportation (DOT). The course “Introduction to Designing and Proportioning Portland Cement Concrete Mixtures” explained the American Concrete Institute’s method for concrete mix design. Portions from that manual have been reproduced herein as permitted by the FHWA and Iowa DOT.

Revision History and Document Control

The Portland Cement Concrete Level III Technician Course Manual will be reviewed annually by the Engineer of Concrete and Soils for adequacy and updated as necessary to reflect current policies and technology changes. Updates are made to the electronic file as needed and hard copies are uncontrolled. Archive versions are available to examine in the Bureau of Materials.

Revision Date	Description	Approval
January 1, 2018	Updated Preface to refer/link to 2018 Supplemental Specifications.	Dan Tobias
January 1, 2018	Updated Applicable Specifications to refer/link to 2018 Supplemental Specifications.	Dan Tobias
January 1, 2018	Updated link to COST software in 1.2.2.	Dan Tobias
January 1, 2018	Updated air content ranges for Class PP concrete in Table 2.7 Air Content.	Dan Tobias
January 1, 2018	Updated notes in Table 6.1 Slump.	Dan Tobias
January 1, 2018	Corrected references from 312.26 to 312.09 in Appendix F Cement Aggregate Mixture II (CAM II).	Dan Tobias
January 1, 2018	Corrected calculations in Appendix P Bridge Deck Latex Concrete Overlay Mix Design.	Dan Tobias

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

Appendices

DEFINITIONS

Absolute Volume — The solid volume, excluding the voids between the particles. It is expressed as the ratio of the loose materials mass (weight), to the solid mass (weight) per volume, of the same material.

Absorption — The moisture content at which the saturated surface-dry condition occurs.

Alkali-Silica Reaction — The reaction of alkalies in cement with siliceous material in some aggregates. The reaction requires water and produces a gel which expands and cracks the concrete.

Blended Cement — A hydraulic cement which meets the requirements of AASHTO M 240 (ASTM C 595). The hydraulic cement consists of portland cement and one or more inorganic constituents.

Cement Aggregate Mixture II (CAM II) — A lean (low cement and finely divided mineral) concrete mixture for stabilized subbase.

Cement Factor — The number of kilograms of cement per cubic meter (metric). The number of pounds of cement per cubic yard (English). Cement factor is the same as cement content. Cement is packaged in bags of 42.6 kg (94 lb) nominal weight.

Cementitious Material — A general term to indicate fly ash, ground granulated blast-furnace slag, microsilica, or high-reactivity metakaolin. However, the term is misleading because none of these materials have cementitious characteristics. The term may be used interchangeably with Finely Divided Mineral.

Chips — The aggregate particle size range between the 4.75 mm (No.4) and 12.5 mm (1/2 in.) sieves.

Coarse Aggregate — A gradation number CA 1-19 as defined by the Standard Specifications. For an aggregate blend, the coarse aggregate portion is normally considered to be all material retained on or above the 4.75 mm (No. 4) sieve.

Concrete — A mixture consisting of cement, water, and aggregates as a minimum. Admixtures and finely divided minerals may be added.

Consistency — The ability of freshly mixed concrete to flow. Consistency is measured by the slump test.

Controlled Low-Strength Material (CLSM) — A self-consolidating mortar mixture, which is typically used as a backfill.

Final Set – The point of time where the concrete is no longer plastic and finishing no longer can take place. This will typically occur 5 to 8 hours after batching the concrete.

Fine Aggregate — A gradation number FA 1-10, 20, and 21 as defined by the Standard Specifications. For an aggregate blend, the fine aggregate portion is normally considered to be all material passing the 4.75 mm (No. 4) sieve.

Finely Divided Mineral — A general term to indicate fly ash, ground granulated blast-furnace slag, microsilica, or high-reactivity metakaolin. The term may be used interchangeably with Cementitious Material.

Fineness Modulus — The Fineness Modulus (FM) is an index of the fineness of an aggregate. The higher the FM, the coarser the aggregate. The Fineness Modulus is used to estimate proportions of fine and coarse aggregate in concrete mixtures.

Fly Ash — The fine residue that results from the combustion of ground or powdered coal.

Gap Graded — Aggregates which have specific particle sizes omitted, or the specific particle sizes are minimal.

Ground Granulated Blast-Furnace (GGBF) Slag — The glassy granular material formed when molten blast-furnace slag is rapidly chilled, and then finely ground. Also known as slag cement.

High-Reactivity Metakaolin (HRM) — A manufactured product formed by calcining purified kaolinite, at a specific temperature range.

Hundredweight (cwt) — A unit of measure equal to 100 pounds.

Initial Set — The point of time where the concrete begins to become firm. This will typically occur 2 to 4 hours after batching the concrete.

Maximum Size — The smallest sieve on which 100 percent of the aggregate sample particles pass.

Microsilica — The extremely fine by-product that results from the manufacture of silicon or silicon alloys.

Mix Design Target Strength — The average strength the concrete mix must attain to ensure the specified strength is met.

Mortar — The fine aggregate, cement, finely divided minerals, water, and air in a concrete mixture.

Mortar Factor — The volume of mortar per volume of dry rodded coarse aggregate.

Nominal Maximum Size — The largest sieve which retains any of the aggregate sample particles.

Oven-Dry Condition — The aggregates have been heated until completely dry. There is no free moisture on the surface of the individual aggregate particles. There is no absorbed moisture in the pores of the individual aggregate particles.

Oven-Dry Specific Gravity — The ratio of the mass (weight) of a volume of oven dry material, to the mass (weight) of an equal volume of water.

Paste — The cement, finely divided minerals, water, and air in a concrete mixture.

Plasticity — The ease of molding the concrete. A plastic concrete mixture will maintain suspension of the aggregates.

Pervious Concrete — A permeable concrete that allows water to infiltrate the concrete and drain into the soil beneath it. The zero slump concrete mixture has little or no fine aggregate.

Portland Cement — A hydraulic cement which meets the requirements of AASHTO M 85 (ASTM C 150).

Saturated Surface-Dry Condition — There is no free moisture on the surface of the individual aggregate particles. All possible moisture which can be absorbed into the pores of the individual aggregate particles has occurred.

Saturated Surface-Dry Specific Gravity — The ratio of the mass (weight) of a volume of saturated surface-dry material, to the mass (weight) of an equal volume of water.

Standard Specifications — The Standard Specifications for Road and Bridge Construction.

Supplementary Cementitious Material — See definition for Cementitious Material.

Ternary Mix Design — A mix design consisting of cement and two finely divided minerals. The finely divided mineral in portland-pozzolan cement or portland blast-furnace slag cement shall count as one of the two finely divided minerals allowed.

Trial Batch — A batch of concrete tested by the Engineer to verify the Contractor's mix design will meet specification requirements.

Trial Mixture — A batch of concrete tested by the Contractor to verify the Contractor's mix design will meet specification requirements.

Uniformly Graded — Aggregates which do not have a large deficiency or excess of any particle size.

Voids — The volume of voids per unit volume of dry rodded coarse aggregate. In other words, voids is the ratio of the volume of empty spaces in a unit volume of coarse aggregate to the unit volume of coarse aggregate.

Wash Water — Residual rinse water in the drum of a truck mixer or truck agitator.

Water/Cement Ratio — The mass (weight) of water, divided by the mass (weight) of cement. The water shall include mixing water, water in admixtures, free moisture on the aggregates, and water added at the job site.

When fly ash, ground granulated blast-furnace slag, microsilica, or high-reactivity metakaolin are used in a concrete mix, the water/cement ratio will be based on the total cement and finely divided minerals contained in the mixture.

Workability — A measure of how easy or difficult it is to place, consolidate, and finish concrete.

Yield — The volume of freshly mixed concrete from a known quantity of materials.

APPLICABLE SPECIFICATIONS

Standard Specifications for Road and Bridge Construction

The Level III PCC Technician shall be familiar with the following Sections or Articles of the April 1, 2016, Standard Specifications for Road and Bridge Construction.

Article 285.05	Fabric Formed Concrete Revetment Mat
Article 312.09	Proportioning (Cement Aggregate Mixture II)
Article 540.06	Precast Concrete Box Culverts (Class SI Between Sections)
Section 543	Insertion Lining of Pipe Culverts
Section 1001	Cement
Section 1003	Fine Aggregate
Section 1004	Coarse Aggregate
Section 1010	Finely Divided Minerals
Section 1019	Controlled Low-Strength Material
Section 1020	Portland Cement Concrete
Section 1021	Concrete Admixtures

To view or download the Standard Specifications for Road and Bridge Construction (link embedded) on the Internet go to http://www.idot.illinois.gov/; Doing Business; Procurements; Engineering, Architectural & Professional Services; Consultant Resources; Standard Specifications. In addition to the Standard Specifications, it is important for the Level III PCC Technician to be familiar with the Supplemental Specification and Recurring Special Provisions (link embedded) document and the Bureau of Design and Environment (BDE) Special Provisions (link embedded). They are also found under Consultant Resources (scroll down to Letting Specific Items to find the BDE Special Provisions) and may be downloaded. The Supplemental Specifications are a supplement to the Standard Specifications. The Recurring Special Provisions are frequently included by reference, in selected contracts. The BDE Special Provisions are frequently included, by insertion, in selected contracts.

Guide Bridge Special Provisions

The Level III PCC Technician shall also be familiar with the following Guide Bridge Special Provisions (GBSP) (link embedded).

Deck Slab Repair
Bridge Deck Microsilica Concrete Overlay
Bridge Deck Latex Concrete Overlay
Bridge Deck High-Reactivity Metakaolin (HRM) Concrete Overlay
Concrete Wearing Surface
Structural Repair of Concrete
Bridge Deck Fly Ash or Ground Granulated Blast-Furnace Slag Overlay
Bridge Deck Construction
Drilled Shafts

To view or download the GBSP, go to http://www.idot.illinois.gov/; Doing Business; Procurements; Engineering, Architectural & Professional Services; Consultant Resources; Supplemental Specifications and Recurring Special Provisions. The GBSP are frequently included, by insertion, in selected contracts.

CLASS OF CONCRETE

Class Designation	Description
PV	Pavement
PP	PCC Patching
RR	Railroad Crossing
BS	Bridge Superstructure
PC	Precast Concrete
PS	Precast Prestressed
DS	Drilled Shaft
SC	Seal Coat
SI	Structures (except superstructure)

Refer to Article 1020.04 for additional information.

UNITS OF MEASURE CONVERSION

Conversion	From English	To Metric	Multiply Quantity by*
LENGTH	inch (in.)	millimeter (mm)	25.4
	foot (ft)	millimeter (mm)	304.8
	foot (ft)	meter (m)	0.3048
	yard (yd)	meter (m)	0.9144
AREA	square inch ($in.^2$)	square mm (mm^2)	645.16
	square foot (ft^2)	square meter (m^2)	0.092903
	square yard (yd^2)	square meter (m^2)	0.836127
VOLUME	cubic inch ($in.^3$)	cubic mm (mm^3)	16387.06
	cubic foot (ft^3)	cubic meter (m^3)	0.028316
	cubic yard (yd^3)	cubic meter (m^3)	0.764555
	gallon (gal)	liter (L)	3.78541
MASS	ounces (oz)	grams (g)	28.349523
	pound (lb)	kilogram (kg)	0.453592
FORCE	pound (lb)	Newton (N)	4.44822
MASS/AREA	oz/yd^2	kg/m^2	0.0339057
	lb/ft^2	kg/m^2	4.8824
	lb/yd^2	kg/m^2	0.5425
MASS/VOLUME	lb/ft^3	kg/m^3	16.01894
	lb/yd^3	kg/m^3	0.5933
TEMPERATURE	English to Metric: $°C = \frac{(°F - 32)}{1.8}$	Metric to English: $°F = 1.8 \times °C + 32$	

* To convert from metric to English, ***divide*** metric quantity by value given in table. For example, 380 mm equals 15.0 in. (380 ÷ 25.4 = 14.96).

SIGNIFICANT DIGITS AND ROUNDING

Significant Digits:

Whole Number: Cement, Finely Divided Minerals, Coarse and Fine Aggregate, Batch Water

One Digit to Right of Decimal: Basic Water Requirement (English), Air Content

Two Digits to Right of Decimal: Specific Gravity, Unit Weight, Water/Cement Ratio, Basic Water Requirement (Metric), Mortar Factor, Voids

Three Digits to Right of Decimal: Absolute Volume

Rounding:

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.

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
BDE	Bureau of Design and Environment
CA	Coarse Aggregate
CAM II	Cement Aggregate Mixture II
CCRL	Cement and Concrete Reference Laboratory
CLSM	Controlled Low-Strength Material
DEF	Delayed Ettringite Formation
DOT	Department of Transportation
FA	Fine Aggregate
FM	Fineness Modulus
FDM	Finely Divided Mineral
FHWA	Federal Highway Administration
GBSP	Guide Bridge Special Provision
GGBF Slag	Ground Granulated Blast-Furnace Slag
HRM	High-Reactivity Metakaolin
ITP	Illinois Test Procedure
MISTIC	Materials Integrated System for Test Information and Communication
NIST	National Institute of Standards and Technology
PCA	Portland Cement Association
PCC	Portland Cement Concrete
QC/QA	Quality Control/Quality Assurance
SSD	Saturated Surface-Dry

1.0 MIX DESIGN OVERVIEW

1.1 MIX DESIGN SUBMITTAL

The Department's mix design method is based upon previously established properties of the materials and the intended use of the concrete. The original design criteria can be found in the University of Illinois Engineering Experiment Station Bulletin No. 137, published in October 1923. The document is entitled "The Strength of Concrete and Its Relation to the Cement Aggregates and Water" by Arthur N. Talbot and Frank E. Richart.

The requirements for providing a mix design are specified in Article 1020.05, which states, "For all Classes of concrete, it shall be the Contractor's responsibility to determine mix design material proportions and to proportion each batch of concrete. A Level III PCC Technician shall develop the mix design for all Classes of concrete, except Classes PC and PS." However, refer to Appendix A for a special provision that can be inserted by the District into a contract allowing it to provide mix designs.

A mix design submittal shall include the following:

- Submittal date
- Class or type of concrete
- Source of materials
- Fine aggregate type (a classification related to water demand provided by the Department's District office)
- Aggregate gradation designations
- Coarse aggregate voids
- Specific gravities of materials
- Material proportions (batch weights or mass)
- Water/cement ratio
- Mortar factor
- Type and proposed dosage of admixtures
- Target slump, air content, and strength

For self-consolidating concrete, the submittal is the same except target slump flow (instead of slump), and target J-ring value or L-box blocking ratio are also required.

Once the Engineer verifies the Contractor's mix design, according to 9.0 "Department Concrete Mix Design Verification," it will be entered into the Department's Materials Integrated System for Test Information and Communication (MISTIC) database and also provided a Department mix design number.

During construction, changes may occur which will affect the mix design. The following items will require re-submittal and verification of a mix design:

- Voids of the coarse aggregate change more than 0.02.
- Specific gravity of an aggregate changes more than 0.02.
- Specific gravity of the cement or a finely divided mineral changes more than 0.04.
- Mortar factor is changed more than 0.05.
- Water/cement ratio is increased more than 0.04.
- A change in materials.

1.2 MIX DESIGN SOFTWARE

1.2.1 Department Software

An Excel spreadsheet, “PCC Mix Design,” is available from the Department’s website to facilitate the calculation and submittal of a PCC mix design using the IDOT method. To download the program, go to http://www.idot.illinois.gov/; Doing Business; Material Approvals; Concrete; References; Guides/Spreadsheets.

1.2.2 Available Software Applications

For those individuals who want to expand their mix design knowledge, the following websites have useful information.

- **COST, developed by the Federal highway Administration (FHWA) and the National Institute of Standards and Technology (NIST).**

  The website is https://www.nist.gov/services-resources/software/concrete-optimization-software-tool.

  COST (Concrete Optimization Software Tool) is an online design/analysis system to assist in determining optimal mixture proportions for concrete.

- **COMPASS, developed by The Transtec Group, Inc. for the FHWA.**

  The website is http://www.pccmix.com/.

  COMPASS (Concrete Mixture Performance Analysis System Software) grew out of the web-based application tool COST. COMPASS has two key components, a knowledge base and a set of four computer modules. The knowledge base supplies information on concrete properties, testing methods, and material characteristics and compatibilities. The computer modules allow the user to define inputs such as importance of the project, type of pavement, climatic conditions, construction constraints, environmental exposures, and criteria (such as strength, cost, and permeability) that are specific to the project.

- **ConcreteWorks** developed at the Concrete Durability Center at the University of Texas as part of research for the Texas Department of Transportation.

  The website is http://www.txdot.gov/inside-txdot/division/information-technology/engineering-software.external.html.

  The ConcreteWorks software includes ConcreteWorks and MixProportions. The ConcreteWorks program can calculate mass concrete temperature development. The MixProportions is a concrete mixture proportioning program based on ACI 211.

The above software applications are not to replace the Department’s software, but may be used to improve/optimize designs created using the Department’s method.

2.0 CONCRETE MIX DESIGN DEVELOPMENT USING IDOT METHOD

2.1 INTRODUCTION – ABSOLUTE VOLUME

The basic materials required for concrete are cement, finely divided minerals, fine and coarse aggregates, water, and entrained air (for Illinois' freeze-thaw environment). Concrete meeting the requirements of strength and durability will demand accurate proportioning of these basic materials.

The Department's mix design method is based on a volume of 1 cubic yard (1 cubic meter) of concrete. Therefore, the basis of concrete proportioning is determining the volume of the component materials.

With respect to granular materials (e.g., aggregates, cement, etc.), the volume used in mix design calculations is the absolute volume, which is defined as the solid volume of those materials. That is, because granular materials stack, what we normally think of as volume is actually the apparent volume, which is larger than the absolute volume because it includes the spaces between particles. Thus, the absolute volume (volume of solids) is used because the space between particles will be filled by smaller particles (e.g., the space between coarse aggregate particles will be filled by fine aggregate and paste).

The absolute volume of a material is calculated based on its weight (mass) and specific gravity.

2.2 CEMENT FACTOR

Through years of laboratory experimentation and field experience, the Department has determined the approximate amount of cement, represented as the cement factor, needed to meet durability requirements after construction. Note that when finely divided minerals are also to be utilized, the cement factor essentially represents the amount of total cementitious material.

2.2.1 Cement Factor for Class or Type of Concrete

Cement is specified in terms of hundredweights per cubic yard (kilograms per cubic meter). The number of hundredweights of cement used per cubic yard (kilograms per cubic meter) of concrete is the cement factor.

Refer to Table 2.2.1 "Cement Factor for Class or Type of Concrete" for the required cement factor when using portland cement, portland-pozzolan cement, portland blast-furnace slag cement, or portland-limestone cement.

2.2.2 Allowable Cement Factor Reduction – Admixture

For Class PV, PP-1, RR, SC, and SI concrete, the cement factor may be reduced a maximum 0.30 cwt/yd^3 (18 kg/m^3) when using a water-reducing admixture or a high range water-reducing admixture. However, a cement factor reduction will not be allowed for concrete placed underwater.

Table 2.2.1 Cement Factor for Class or Type of Concrete

Class or Type of Concrete	Minimum Cement Factor cwt/yd^3 (kg/m^3)	Maximum Cement Factor cwt/yd^3 (kg/m^3)
PV	5.65 (335)[1,2] 6.05 (360)[1,3]	7.05 (418)
PP-1	6.50 (385)[1] 6.20 (365)[1,4]	7.50 (445) 7.20 (425)[4]
PP-2	7.35 (435)	8.20 (485)
PP-3	7.35 (435)[5]	7.35 (435)[5]
PP-4	6.00 (355)[6]	6.25 (370)[6]
PP-5	6.75 (400)[7]	6.75 (400)[7]
RR	6.50 (385)[1] 6.20 (365)[1,4]	7.50 (445) 7.20 (425)[4]
BS	6.05 (360)	7.05 (418)
PC	Wet Cast: 5.65 (335) Dry Cast: 5.65 (335)[4]	Wet Cast: 7.05 (418) Dry Cast: 7.05 (418)[4]
PS	5.65 (335)	7.05 (418)
	5.65 (335)[4]	7.05 (418)[4]
DS	6.65 (395)	7.05 (418)
SC[8]	5.65 (335)[1,2] 6.05 (360)[1,3]	7.05 (418)
SI	5.65 (335)[1,2] 6.05 (360)[1,3]	7.05 (418)
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5	Refer to PP-1, 2, 3, 4, and 5
Formed Concrete Repair	6.65 (395)	6.65 (395)
Concrete Wearing Surface	Refer to Class BS Concrete	Refer to Class BS Concrete
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay[9]	Refer to Class BS Concrete	Refer to Class BS Concrete
Bridge Deck Microsilica Concrete Overlay[10]	5.65 (335)	5.65 (335)
Bridge Deck High-Reactivity Metakaolin Concrete Overlay[11]	5.65 (335)	5.65 (335)
Bridge Deck Latex Concrete Overlay[12]	6.58 (390)	6.58 (390)

Notes:

1. Refer to 2.2.2 “Allowable Cement Factor Reduction – Admixture” for allowable cement factor reduction.
2. Central-mixed.
3. Truck-mixed or shrink-mixed.
4. Type III cement.
5. In addition to the Type III portland cement, 100 lb/yd^3 (60 kg/m^3) of ground granulated blast-furnace slag and 50 lb/yd^3 (30 kg/m^3) of microsilica (silica fume) shall be used. For an air temperature greater than 85 °F (30 °C), the Type III portland cement may be replaced with Type I or II cement.
6. The cement shall be a rapid hardening cement from the Department’s “Approved/Qualified Product List of Packaged, Dry, Rapid Hardening, Cementitious Materials for Concrete Repair” for PP-4.
7. The cement shall be calcium aluminate cement for PP-5.
8. For Class SC concrete and for any class of concrete that is to be placed under water, except Class DS concrete, the cement factor shall be increased by ten percent.
9. The portland cement shall be replaced with 25 percent Class F fly ash, or 25-30 percent Class C fly ash, or 25-35 percent ground granulated blast-furnace slag.
10. In addition to the cement, 33 lb/yd^3 (20 kg/m^3) of microsilica is required in the mix design.
11. In addition to the cement, 37 lb/yd^3 (22 kg/m^3) of high-reactivity metakaolin is required in the mix design.
12. In addition to the cement, 24.5 gallons (121.3 liters) of latex admixture is required in the mix design.

2.3 CEMENT ABSOLUTE VOLUME CALCULATION

The absolute volume in cubic yards (cubic meters) of cement can be determined as follows:

English (Metric):

The absolute volume of cement, $V_{Cement} = \frac{Weight\ (Mass)\ of\ Cement}{Specific\ Gravity\ of\ Cement \times Unit\ Weight\ of\ Water}$

The “weight (mass) of cement” is provided by the cement factor converted to pounds per cubic yard (kilograms per cubic meter) minus the weight (mass) of any finely divided minerals also used. The “specific gravity of cement” is normally assumed to be 3.15, but the actual value may be used. The “unit weight of water” is 1,683.99 pounds per cubic yard (1,000.00 kilograms per cubic meter).

Be advised that blended cements (e.g., portland-pozzolan, portland-limestone, etc.) may have a specific gravity which is significantly different from 3.15, and this value should be verified with the District.

If the specific gravity of the cement changes more than 0.04 from the original mix design value, a new mix design will be required.

2.4 FINELY DIVIDED MINERALS ABSOLUTE VOLUME CALCULATION

A portion of cement may be replaced with finely divided minerals. The replacement is commonly done to reduce the unit cost of the concrete, to mitigate for alkali-silica reaction, to lower the heat of hydration, and/or to lower the concrete’s permeability, which will slow chloride penetration.

Note: For the various Classes of concrete, the portland cement content in the mixture shall be a minimum of 400 lb/cu yd (237 kg/cu m), unless the mix design is shown to be freeze-thaw durable according to AASHTO T 161. Refer to Articles 1020.04 and 1020.05(a) for additional information. Furthermore, the minimum portland cement content may be lower when required to control the heat of hydration for structures according to Article 1020.15.

Finely divided minerals (FDMs) are measured in pounds (kilograms). The absolute volume in cubic yards (cubic meters) of a finely divided mineral is determined as follows:

English (Metric):

The absolute volume of a finely divided mineral,

$$V_{FDM} = \frac{Weight\ (Mass)\ of\ FDM}{Specific\ Gravity\ of\ FDM \times Unit\ Weight\ of\ Water}$$

The “weight (mass) of FDM” is provided in pounds per cubic yard (kilograms per cubic meter). The “unit weight of water” is 1,683.99 pounds per cubic yard (1,000.00 kilograms per cubic meter).

The specific gravity of a finely divided mineral is obtained from the “Approved/Qualified Producer List of Finely Divided Minerals” available online at http://www.idot.illinois.gov; Doing Business; Materials; Cement; Qualified Product Lists. It is found under the “Average Specific Gravity” column.

If the specific gravity of a finely divided mineral changes more than 0.04 from the original mix design value, a new mix design will be required.

For Class PP-3 concrete, bridge deck fly ash or GGBF slag overlay, bridge deck microsilica overlay, and bridge deck high-reactivity metakaolin overlay, refer to 2.2.1 “Cement Factor for Class or Type of Concrete” for additional information regarding required use of finely divided minerals.

2.4.1 Cement Replacement with Finely Divided Minerals and the Optional Use of Microsilica and High Reactivity Metakaolin (HRM)

2.4.1.1 Fly Ash

The following information is according to Article 1020.05(c)(1).

Fly ash may partially replace portland cement in cement aggregate mixture II and the following Classes PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, and SI.

When Class F fly ash is used in cement aggregate mixture II, Class PV, BS, PC, PS, DS, SC, and SI concrete, the amount of cement replaced shall not exceed 25 percent by weight (mass).

When Class C fly ash is used in cement aggregate mixture II, Class PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, and SI concrete, the amount of cement replaced shall not exceed 30 percent by weight (mass).

Measurements of fly ash shall be rounded up to the nearest 5 lb/yd^3 (2.5 kg/m^3).

The following information is according to the applicable Guide Bridge Special Provisions (GBSP):

- For bridge deck microsilica and high-reactivity metakaolin concrete overlays, only Class C fly ash may be used to replace portland cement. The amount of cement replaced shall not exceed 30 percent by weight (mass).
- For bridge deck fly ash concrete overlay, the portland cement content shall be replaced with 25 percent Class F Fly ash or 25 – 30 percent Class C fly ash.

2.4.1.2 Ground Granulated Blast-Furnace Slag

The following information is according to Article 1020.05(c)(2).

Ground granulated blast-furnace (GGBF) slag may partially replace portland cement in the following Classes: PV, PP-1, PP-2, PP-3, RR, BS, PC, PS, DS, SC, and SI.

When GGBF slag is used in Class PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, and SI concrete, the amount of cement replaced by GGBF slag shall not exceed 35 percent by weight (mass). For Class PP-3 concrete, GGBF slag shall be used according to Article 1020.04, Table 1, Note 8.

Measurements of GGBF slag shall be rounded up to the nearest 5 lb/ yd^3 (2.5 kg/m^3).

The following information is according to the applicable Guide Bridge Special Provisions (GBSP):

- For bridge deck microsilica and high-reactivity metakaolin concrete overlays, the portland cement may be replaced with GGBF slag. The replacement shall not result in a mixture with portland cement content less than 400 lb/cu yd (237 kg/cu m).
- For bridge deck GGBF slag concrete overlay, the portland cement content shall be replaced with 25 – 35 percent GGBF slag.

2.4.1.3 Microsilica

According to Article 1020.05(c)(3), at the Contractor's option, microsilica may be added at a maximum 5.0 percent by weight (mass) of the cement and finely divided minerals summed together.

Microsilica shall be used in Class PP-3 concrete according to Article 1020.04 and in bridge deck overlay concrete according to the GBSP for Bridge Deck Microsilica Concrete Overlay.

2.4.1.4 High Reactivity Metakaolin (HRM)

According to Article 1020.05(b)(4), at the Contractor's option, HRM may be added at a maximum 5.0 percent by weight (mass) of the cement and finely divided minerals summed together. HRM shall be used in bridge deck overlay concrete according to the GBSP for Bridge Deck High-Reactivity Metakaolin Concrete Overlay.

2.4.2 Use of Finely Divided Minerals in Ternary Concrete Mix Designs

Refer to Article 1020.(c)(5) for allowable use of finely divided minerals in ternary mix designs.

2.4.3 Mitigation of Alkali-Silica Reaction with Finely Divided Minerals

Alkali-silica reaction (ASR) is the reaction of alkalies in cement with siliceous material in some aggregates. The reaction requires water and produces a gel which expands and cracks the concrete. Refer to Article 1020.05(d) for required use of finely divided minerals to mitigate alkali-silica reaction. Also, it may be helpful to refer to the alkali-silica reaction specification flow chart in Appendix P.

2.4.4 Use of Finely Divided Minerals in Mass Concrete

Refer to Article 1020.15 for use of finely divided minerals to reduce heat of hydration in massive structures.

2.5 WATER ABSOLUTE VOLUME CALCULATION

The Basic Water Requirement is measured in gallons per hundredweights (liters per kilograms) of total cement and finely divided minerals. The absolute volume in cubic yards (cubic meters) of water is determined as follows:

English (Metric):

The absolute volume of water, $V_{Water} = \frac{Weight\ of\ Water}{Unit\ Weight\ of\ Water}$

The “weight of water” is provided in pounds per cubic yard (kilograms per cubic meter). Note that one gallon of water equals 8.33 pounds. Because the specific gravity of water is 1.00, it can be ignored. The “unit weight of water” is 1,683.99 pounds per cubic yard (1,000.00 kilograms per cubic meter).

2.5.1 Basic Water Requirement

Since the amount of cement and finely divided minerals used in concrete is basically specified for the various types of construction, the amount of water used is a very important variable of the design.

The Department has a method to determine the basic water requirement according to the angularity of the aggregates. As the angularity of the particles increases, the amount of water required in the concrete increases.

2.5.1.1 Fine Aggregate Basic Water Requirement

For fine aggregate, the Department will classify the aggregate as Type A, B, or C, according to the Illinois Method for Fine Aggregate Classification:

- “Type A” fine aggregate is composed completely of rounded particles.
- “Type C” fine aggregate is composed completely of angular particles.
- “Type B” fine aggregate is composed of a mixture of rounded and angular.

Therefore, a Type A fine aggregate has the least water demand, and a Type C fine Aggregate has the highest, summarized as follows:

FA Type	**Basic Water Requirement for Cement and Finely Divided Minerals**
A	5.1 gal/cwt (0.42 L/kg)
B	5.3 gal/cwt (0.44 L/kg)
C	5.5 gal/cwt (0.46 L/kg)

If blending fine aggregates that are not the same Type, select the highest water requirement.

The fine aggregate classification as a Type A, B, or C will be provided by the Department’s District office.

2.5.1.2 Coarse Aggregate Basic Water Requirement

Due to a greater surface area, crushed coarse aggregate will have greater water demand than rounded coarse aggregate. Furthermore, aggregate particles that are flat and elongated will increase water demand because of greater surface area. If necessary, ITP 4791 can be used to determine the percentage of flat and elongated particles.

Based on experience, the Department allows an additional 0.1 to 0.4 gal/cwt (0.008 to 0.033 L/kg) for the coarse aggregate as follows:

- 0 gal/cwt (0 L/kg) is commonly used for rounded gravel.
- 0.2 gal/cwt (0.017 L/kg) is commonly used for crushed gravel and stone.
- 0.4 gal/cwt (0.033 L/kg) is commonly used for a lightweight slag aggregate.

Contact the Department's District office if you have any questions.

2.5.1.3 Basic Water Requirement Total

The basic water requirement total is the summation of the water required based on the fine and coarse aggregate angularity. An example calculation for determining basic water requirement is as follows:

Given: Fine Aggregate: Type B
Coarse Aggregate: Crushed Stone

Calculations:

English:
Basic Water Requirement Total $= 5.3_{FA} + 0.2_{CA}$
$= 5.5$ gallons/cwt

Metric:
Basic Water Requirement Total $= 0.44_{FA} + 0.017_{CA}$
$= 0.46$ liter/kg

Remember, the Basic Water Requirement is determined in terms of gallons per hundredweight (liters per kilogram) of total cement and finely divided minerals. Thus in terms of batching, if the cement factor is 5.65 cwt/yd^3 (335 kg/m^3), for example, the amount of water contributed by the basic water requirement is as follows:

English:
5.65 cwt/yd^3 $\times$ 5.5 gal/cwt = 31.1 gal/yd^3

Converting to pounds, 31.1 gal/yd^3 $\times$ 8.33 lb/gal = 259 lb/yd^3

Metric:
335 kg/m^3 $\times$ 0.46 L/kg = 154.1 L/m^3

Converting to kilograms, 154.1 L/m^3 $\times$ 1 kg/L = 154.1 kg/m^3

2.5.2 Adjustment to Basic Water Requirement

The Basic Water Requirement can be adjusted using Table 2.5.2 "Adjustment to Basic Water Requirement". An example calculation for adjusting the basic water requirement is as follows:

Given: A water-reducing admixture is used, and the water content reduction is assumed to be 10 percent. The basic water requirement is 5.5 gal/cwt (0.46 L/kg).

Calculations:

Adjusting the basic water requirement uses the following equation:

$$\text{Adjusted Basic Water Requirement} = W_{Basic} - \left(W_{Basic} \times \frac{\%Adjustment}{100}\right)$$

Where: W_{Basic} = Basic Water Requirement, gallons/cwt (L/kg)

English:

Adjusted Basic Water Requirement $= 5.5 - (5.5 \times \frac{10}{100})$

$= 5.0$ gal/cwt

Metric:

Adjusted Basic Water Requirement $= 0.46 - (0.46 \times \frac{10}{100})$

$= 0.41$ L/kg

Thus, continuing the previous example for Basic Water Requirement Total, the amount of batch water after adjustment is as follows:

English:

5.65 cwt/yd^3 $\times$ 5.0 gal/cwt = 28.3 gal/yd^3

Converting to pounds, 28.3 gal/yd^3 $\times$ 8.33 lb/gal = 236 lb/yd^3

That is 2.8 gal/yd^3 (23 lb/yd^3) less the basic water requirement total.

Metric:

335 kg/m^3 $\times$ 0.41 L/kg = 137.4 L/m^3

Converting to kilograms, 137.4 L/m^3 $\times$ 1 kg/L = 137.4 kg/m^3

That is 17 L/m^3 (17 kg/m^3) less the basic water requirement total.

If a significant amount of admixtures (such as latex) are to be used, the Contractor shall take this into account when checking the water/cement ratio. Refer to 2.6 "Adjusted Basic Water Requirement and Water/Cement Ratio" for more information. Also, refer to Appendix P "Bridge Deck Latex Concrete Overlay Mix Design" for more information about one way to account for latex admixtures in volumetric mix design.

Table 2.5.2 Adjustment to Basic Water Requirement

Water Adjustment	Suggested Range	Adjustment Percentage
Aggregate shape and texture: (Note 1)		
Baseline (cubical crushed stone)	(0%)	
Rounded, smooth	(-5 to 0%)	
Flat, elongated, rough	(0 to +5%)	
Combined aggregate grading:		
Well-graded	(-10 to 0%)	
Gap-graded	(0 to +10%)	
Admixture(s):		
Air-entraining admixture — 1 to 3% air content	(0%)	
Note: Use allowable minimum specification air content to select the appropriate range at right. — 4 to 5% air content	(-5%)	
6 to 10% air content	(-10%)	
Normal range water-reducing admixture	(-10 to -5%)	
Mid-range water-reducing admixture	(-15 to -8%)	
High range water-reducing admixture (superplasticizer) (Note 2)	(-30 to -12%)	
Finely Divided Minerals:		
Fly Ash (Note 3)	(-10 to 0%)	
Microsilica	(0 to +15%)	
High-Reactivity Metakaolin (HRM)	(-5 to +5%)	
Ground Granulated Blast-Furnace (GGBF) Slag	(0%)	
Other factors:		
Coarse cement, water/cement ratio >0.45, concrete temperature <60 °F (15 °C)	(-10 to 0%)	
Fine cement, water/cement ratio <0.40, concrete temperature >80 °F (27 °C)	(0 to +10%)	
Enter the sum of the adjustment percentages. The suggested maximum water reduction recognizing overlapping effects of individual factors is -30%. The required minimum water/cement ratio also needs to be considered.		

Notes:

1. For aggregate shape and texture; it is recommended to make the adjustment as described in 2.5.1.2 "Coarse Aggregate Water Requirement" and 2.5.1.3 "Basic Water Requirement."
2. A polycarboxylate high range water-reducing admixture may be able to reduce the water content up to 40%.
3. For each 10% of fly ash in the total cementitious, it is recommended to allow a water reduction of at least 3%.

2.5.3 Required Use of Admixtures

Note: To view or download the Qualified Product List of Air-Entraining Admixtures for Controlled Low-Strength Material (CLSM), Qualified Product List of Concrete Admixtures, and Qualified Product List of Corrosion Inhibitors, go to http://www.idot.illinois.gov/; Doing Business; Material Approvals; Concrete; Qualified Product Lists.

The following information on admixtures is found in Article 1020.05(b).

Air-Entraining Admixture
Except for Class SC concrete (see 2.5.4 "Optional Use of Admixtures") and bridge deck latex concrete overlays, all concrete and cement aggregate mixture II shall contain entrained air. Normally, an air-entraining admixture is used in lieu of air-entraining cement.

For CLSM, based on the mix design selected, an air-entraining admixture may be required (refer to Article 1019.02).

Retarding Admixture[1]
When the atmospheric or concrete temperature is 65 °F (18 °C) or higher, a retarding admixture shall be used for Class BS concrete and concrete bridge deck overlays.

For Class PP-4 concrete, a retarding admixture shall be used for stationary or truck-mixed concrete.

For Class DS concrete, a retarding admixture shall be used. In addition, the concrete mixture shall be designed to remain fluid throughout the anticipated duration of the pour plus one hour.

Water-Reducing Admixture[1]
A water-reducing admixture shall be used for cement aggregate mixture II.

If Class C fly ash or GGBF slag is used in Class PP-1 or RR concrete, a water-reducing or high range water-reducing admixture shall be used.

For Class DS concrete involving dry excavations 10 ft (3 m) or less, a high range water-reducing admixture may be replaced with a water-reducing admixture if the concrete is vibrated.

High Range Water-Reducing Admixture (Superplasticizer)[1]
A superplasticizer shall be used for Class PP-2, PP-3, PP-4, PP-5 concrete, formed concrete repair, bridge deck, concrete wearing surface, bridge deck fly ash or GGBF slag overlay, bridge deck microsilica concrete overlay, or bridge deck high-reactivity metakaolin concrete overlay.

If Class C fly ash or GGBF slag is used in Class PP-1 or RR concrete, a water-reducing admixture or superplasticizer shall be used.

A superplasticizer shall be used for Class DS concrete, except a water-reducing admixture may be used as discussed in the previous paragraph.

[1] Refer to 2.2.2 "Allowable Cement Factor Reduction – Admixture" for allowable cement factor reduction.

Accelerating Admixture
A non-chloride accelerating admixture shall be used for Class PP-2, PP-3, and PP-5 concrete. For Class PP-2 concrete, the non-chloride accelerating admixture shall be calcium nitrite when the air temperature is less than 55 °F (13 °C). For Class PP-3 concrete, the accelerating admixture shall be calcium nitrite.

A calcium chloride accelerator is allowed only by special provision in the contract. If a special provision is used, it normally involves Class PP-2 concrete.

Latex Admixture
A latex admixture shall be used for bridge deck latex concrete overlay. The latex admixture dosage is 24.5 gal/yd^3 (121.1 L/m^3). Also, refer to Appendix P regarding latex admixture in bridge deck latex concrete overlay mix designs.

Corrosion Inhibitor
In some instances, the contract documents may require the use of a corrosion inhibitor. Refer to Article 1020.05(b)(10).

Other Applications
The Contractor shall be responsible for using admixtures and determining dosages for all Classes of concrete that will produce a mixture with suitable workability, consistency, and plasticity.

2.5.4 Optional Use of Admixtures

The following information on admixtures is found in Article 1020.05(b).

Air-Entraining Admixture
An air-entraining admixture may be used in Class SC concrete at the option of the Contractor.

Retarding Admixture
A retarding admixture may be used in Class PP-4 concrete when using a mobile portland cement concrete plant, provided it is approved by the Engineer.

Water-Reducing Admixture
A water-reducing admixture may be used in Class PV, PP-1, PP-2, PP-3, PP-4, RR, BS, SC, and SI concrete. This also applies to bridge deck microsilica concrete overlay and bridge deck high-reactivity metakaolin concrete overlay.

High-Range Water-Reducing Admixture (Superplasticizer)
A high range water-reducing admixture may be used in Class PP-1 or RR concrete.

Accelerator
A non-chloride accelerator may be used in Class PP-1 or RR concrete. The non-chloride accelerating admixture shall be calcium nitrite when the air temperature is less than 55 °F (13 °C).

Other Applications
The Contractor has the option to determine the use of additional admixtures in the various concrete Classes and other applications. However, the Contractor

shall obtain the approval from the Engineer to use an accelerator when the concrete temperature is greater than 60 °F (16 °C), except for Class PP, RR, PC, and PS concrete. Note that a calcium chloride accelerator is only allowed by special provision.

2.6 ADJUSTED BASIC WATER REQUIREMENT AND WATER/CEMENT RATIO

The water/cement ratio is defined as the weight (mass) of water divided by the weight (mass) of cement plus any finely divided minerals. The water shall include mixing water, water in admixtures, free moisture on the aggregates (i.e., water on the surface of the individual particles), and water added at the job site.

Refer to Table 2.6 “Water/Cement Ratio” for the specified water/cement ratio. Many mix designs use a water/cement ratio in the 0.40 to 0.44 range to ensure complete hydration of the cement, as well as to reduce the dependence on admixtures for workability (as may be the case when the water/cement ratio is less than 0.40). If a maximum water/cement ratio is not specified, it shall not exceed 0.45 to ensure durability of the concrete. In addition, the water content shall not be reduced to a level which restricts cement hydration; that is, the water-cement ratio shall not be lower than 0.32, except as allowed for bridge deck latex concrete overlay and dry cast Class PC items.

Remember to consider the water content in admixtures, which is most often significant when using a high range water-reducing admixture (superplasticizer), calcium chloride accelerator, or latex admixture. Generally, when water from admixtures is significant, Article 1020.05(b) states the Contractor shall calculate 70 percent of the admixture dosage as water, except for a latex admixture, in which case, refer to Appendix P for more information.

Refer to the Portland Cement Concrete Level II Technician Course manual for additional information on water in admixtures.

A new mix design will be required if the water/cement ratio is increased more than 0.04 from the original mix design value. The value shall not exceed specified limits.

An example calculation for determining water/cement ratio based on the adjusted basic water requirement is as follows:

Given: Adjusted Basic Water Requirement = 5.0 gal/cwt (0.41 L/kg)
1 gallon of water = 8.33 lb of water
1 liter of water = 1 kg of water

English:

Calculation: w/c = (5.0 gal/cwt × 8.33 lb/gal) ÷ 100 lb/cwt
w/c = 0.42

Metric:

Calculation: w/c = 0.41 L/kg × 1 kg/L
w/c = 0.41

Table 2.6 Water/Cement Ratio

Class or Type of Concrete	Water/Cement Ratio
PV	0.32 – 0.42
PP-1	0.32 – 0.44
PP-2	0.32 – 0.38
PP-3	0.32 – 0.35
PP-4	0.32 – 0.50
PP-5	0.32 – 0.40
RR	0.32 – 0.44
BS	0.32 – 0.44
PC	Wet Cast: 0.32 – 0.44
	Dry Cast: 0.25 – 0.40
PS	0.32 – 0.44
DS	0.32 – 0.44
SC	0.32 – 0.44
SI	0.32 – 0.44
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5
Formed Concrete Repair	Refer to Class SI Concrete
Concrete Wearing Surface	Refer to Class BS Concrete
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay	Refer to Class BS Concrete
Bridge Deck Microsilica Concrete Overlay	0.37 – 0.41
Bridge Deck High-Reactivity Metakaolin Concrete Overlay	0.37 – 0.41
Bridge Deck Latex Concrete Overlay	0.30 – 0.40[1]

Notes:

1. In addition, the maximum water content (including free moisture on the fine and coarse aggregates) is 157 lb (93.1 kg).

2.7 AIR CONTENT ABSOLUTE VOLUME CALCULATION

The next step is calculating the volume of air to be entrained in the mix. Table 2.7 "Air Content" contains a list of air content ranges specified for all Department mix design classes and types. In general, use the midpoint of the range to select an air content value for calculating volume. However, since it can be more difficult to entrain air when slipforming Class PV, BS, and SI concrete, a value lower than the midpoint may be used in these cases.

While the specified ranges for air content are in terms of the total volume of concrete, the volume of air is based on what is required to provide adequate air entrainment in the paste (i.e., water, cement, and finely divided minerals). The specification air content is in terms of the total volume because it is a value that is easy to measure.

The absolute volume in cubic yards (cubic meters) of air is determined as follows:

English (Metric):

The absolute volume of air, $V_{Air} = \frac{\%Air}{100}$

Table 2.7 Air Content

Class or Type of Concrete	Air Content, Percent
PV	5.0[1] – 8.0
PP-1	4.0 – 8.0
PP-2	4.0 – 8.0
PP-3	4.0 – 8.0
PP-4	4.0 – 8.0
PP-5	4.0 – 8.0
RR	4.0 – 7.0
BS	5.0[1] – 8.0
PC	5.0 – 8.0
PS	5.0 – 8.0
DS	5.0 – 8.0
SC	Optional[2] (6.0 Maximum)
SI	5.0[1] – 8.0
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5
Formed Concrete Repair	Refer to Class SI Concrete
Concrete Wearing Surface	Refer to Class BS Concrete
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay	Refer to Class BS Concrete
Bridge Deck Microsilica Concrete Overlay	5.0 – 8.0
Bridge Deck High-Reactivity Metakaolin Concrete Overlay	5.0 – 8.0
Bridge Deck Latex Concrete Overlay	7 Maximum

Notes:

1. For slipform construction, the minimum air content is 5.5 percent.
2. When not using an air-entraining admixture, 2.0 percent air content is assumed.

2.7.1 Minimum Air Content

If air content is not specified for a concrete mix design, a value can be calculated in cubic yards (cubic meters) as follows:

English (Metric):

$$\text{Minimum Air Content (\%)} = [0.18 \times (V_{Water} + V_{Cement} + \sum V_{FDM})] \times 100$$

Where:
V_{Water} = Absolute Volume of Water per yd^3 (m^3),
V_{Cement} = Absolute Volume of Cement per yd^3 (m^3), and
$\sum V_{FDM}$ = Sum of Absolute Volumes of each Finely Divided Mineral per yd^3 (m^3)

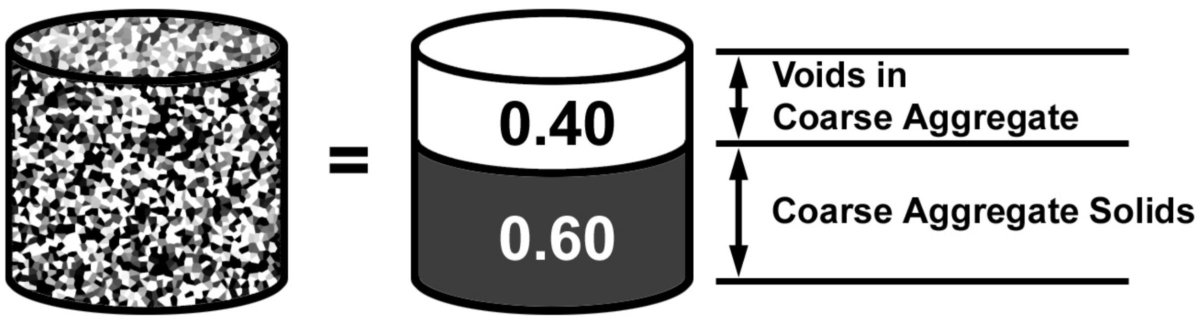
This is based on needing a minimum 18 percent air content in the paste for moderate or extreme freeze/thaw exposure conditions, which are typical in Illinois.

2.8 FINE AND COARSE AGGREGATE ABSOLUTE VOLUME CALCULATIONS

Knowing the amount of cement, finely divided minerals, water, and air needed, only the absolute volumes of the fine and coarse aggregates are unknown. In order to determine these volumes, certain characteristics of the coarse aggregate must first be examined.

2.8.1 Voids in Coarse Aggregate

The first characteristic is the volume of voids in the coarse aggregate. Voids (*V*) is defined as the volume of voids per unit volume of dry rodded coarse aggregate. In other words, voids is the ratio of the volume of empty spaces in a unit volume of coarse aggregate as illustrated in Figure 2.8.1.



$$1.00_{\text{(Aggregate Volume)}} = 0.40_{\text{(Voids Volume)}} + 0.60_{\text{(Solids Volume)}}$$

Figure 2.8.1 Voids in Coarse Aggregate

The coarse aggregate voids are determined according to Illinois Test Procedure 306 (refer to Appendix C). The test shall be performed at least twice to ensure an accurate value is obtained. If the coarse aggregate is furnished in two or more gradations, the voids test shall be performed on the combination of the coarse aggregates.

It is important to know that a change in coarse aggregate particle shape will change the voids as it will change how the particles pack. Refer to the Portland Cement Concrete Level II Technician Course for additional information on aggregate particle shape.

If the voids of a coarse aggregate change more than 0.02 from the original mix design value, a new mix design will be required. A change of 0.02 will change the coarse aggregate batch weight (mass) approximately 3 times more than a similar change in saturated surface-dry (SSD) specific gravity.

The coarse aggregate voids will typically range from 0.36 to 0.41 for non-crushed gravel and 0.39 to 0.45 for crushed gravel or crushed stone. The overall range for coarse aggregate is normally from 0.30 to 0.50.

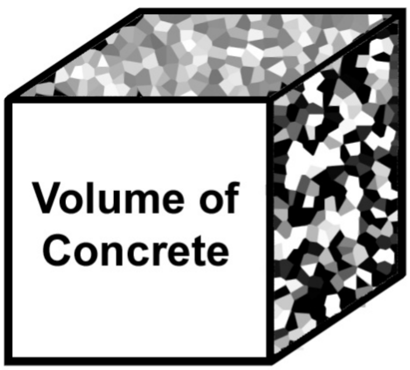
The coarse aggregate voids are to be provided to the Department's District office. However, the District may provide a value to use.

2.8.2 Mortar Factor

2.8.2.1 General Concept

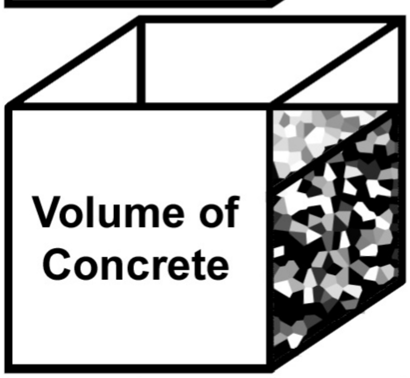
The second coarse aggregate characteristic of concern is the amount of mortar used to fill the voids between, as well as disperse, the coarse aggregate particles for workability (refer to Appendix D for additional information).

Mortar is the total amount of fine aggregate, cement, finely divided minerals, water, and air (i.e., everything but the coarse aggregate) in a concrete mixture. The volume of mortar per volume of dry rodded coarse aggregate in a unit volume of concrete is called the Mortar Factor. In other words, mortar factor is the ratio of total volume of mortar to total apparent volume of coarse aggregate (i.e., volume of coarse aggregate solids and voids).



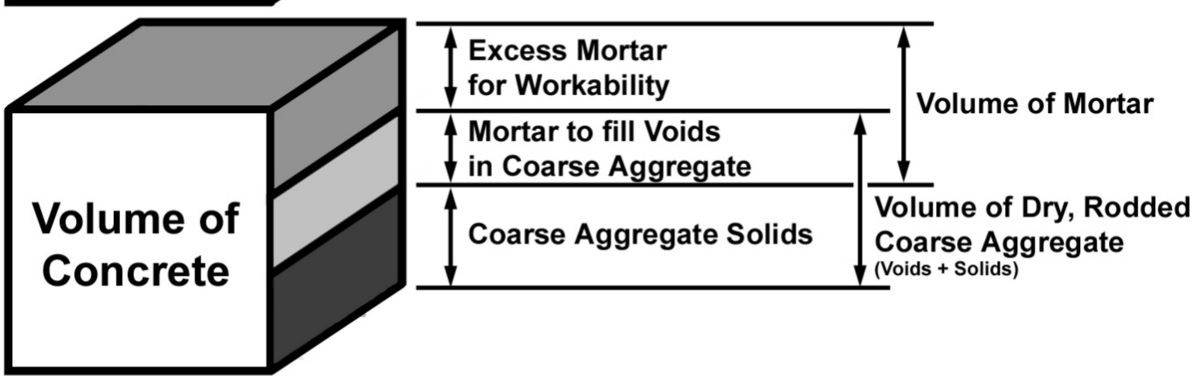
Imagine a unit volume of concrete consisting entirely of coarse aggregate. Everything else in the concrete mixture (i.e., mortar) would be limited to filling the spaces (voids) between coarse aggregate particles.

A concrete mixture consisting entirely of coarse aggregate and only enough mortar to fill the voids between coarse aggregate particles would have poor workability.



To increase workability, the coarse aggregate particles need to be dispersed. Thus, in order to maintain the same unit volume of concrete, some of the coarse aggregate needs to be removed.

If we add mortar to replace what was removed, we will have a more workable concrete mixture because the unit volume of concrete now has enough mortar to disperse and lubricate the coarse aggregate particles.

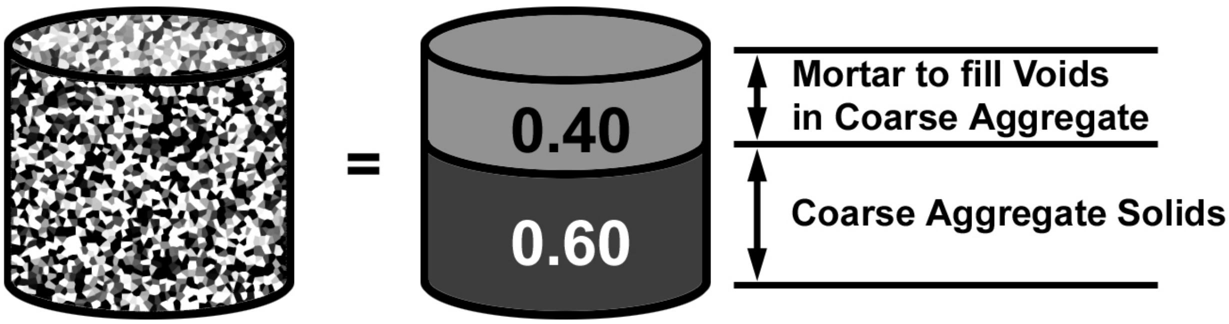


$$\textbf{MORTAR FACTOR} = \frac{\textbf{Volume of Mortar}}{\textbf{Volume of Dry, Rodded Coarse Aggregate}}$$

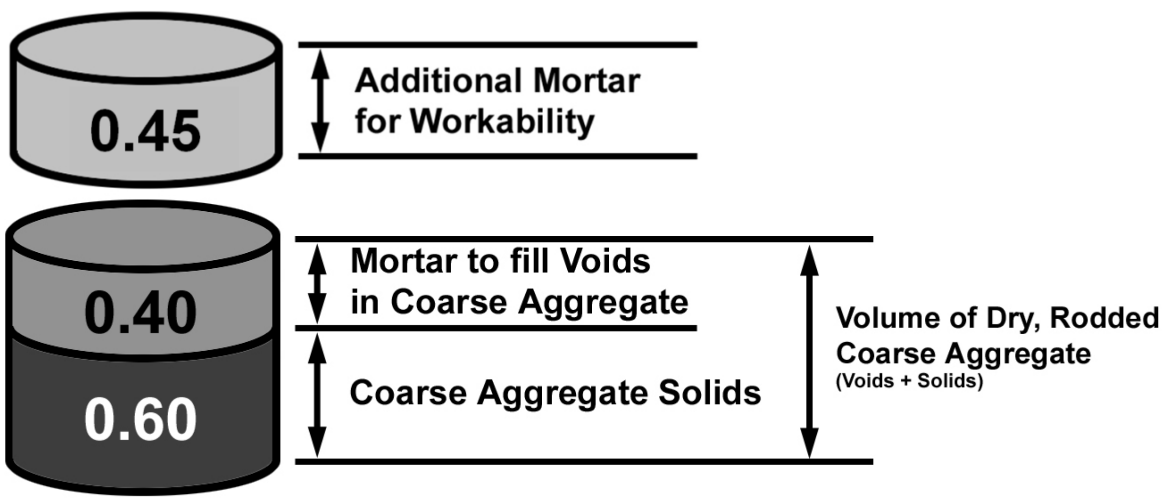
To quantify the concept of Mortar Factor, first determine the volume fraction of coarse aggregate solids based on the volume of voids (*V*) in a unit volume of dry rodded coarse aggregate:

$$\text{Volume Fraction of Coarse Aggregate Solids} = 1 - V$$

For example, consider a unit volume of crushed stone with *V* equal to 0.40. The mortar can fill the voids between coarse aggregate particles as illustrated in the figure below, but this will not result in a workable mixture.



An additional volume of mortar must be added. The amount of mortar added for workability is represented as a fraction of the volume of dry rodded coarse aggregate volume as illustrated in the figure below.



The volume fraction of mortar to fill the voids plus the volume fraction of mortar added for workability is the Mortar Factor (0.40 + 0.45 = 0.85).

In terms of the resulting unit volume of concrete, the total volume fraction of mortar per unit volume of concrete can be determined as follows:

$$\text{Volume Fraction of Mortar Per Unit Volume of Concrete} = \frac{\text{Mortar Factor}}{\text{CA Solids} + \text{CA Voids} + \text{Additional Mortar}}$$

$$= \frac{0.85}{0.60 + 0.40 + 0.45} = 0.59$$

Alternatively, the previous equation can be revised to use the inputs determined either by test method (Coarse Aggregate Voids) or selection (Mortar Factor) as follows:

$$\text{Volume Fraction of Mortar Per Unit Volume of Concrete} = \frac{\text{Mortar Factor}}{(1-\text{V}) + \text{Mortar Factor}}$$

$$= \frac{0.85}{(1-0.40)+0.85} = 0.59$$

2.8.2.2 Design Mortar Factor

This concept of Mortar Factor is unique to the Department's mix design method; for example, the ACI or PCA methods do not utilize mortar factor as a design input. For the Department mix design method, mortar factors are selected on the basis of construction application and experience with local materials.

Changing the mortar factor will adjust the coarse and fine aggregate proportions; for example, increasing the mortar factor will decrease the coarse aggregate content and increase the fine aggregate content. A higher mortar factor may be used to facilitate placement and finishing, and to improve the finish of the formed surface. A higher mortar factor may also be needed to ensure sufficient sand content to entrain air. Refer to Table 2.8.2.2 for allowable mortar factor ranges, as well as allowable coarse aggregate gradation, per Class of Concrete or type of construction.

A new mix design will be required if the mortar factor is changed ± 0.05 or more from the original mix design value.

As noted in Table 2.8.2.2, for self-consolidating concrete, in order for the fine aggregate proportion to be a maximum 50 percent by weight (mass) of the total aggregate used, the maximum mortar factor shall not apply. In most cases, for the fine aggregate proportion to be 50 percent by weight (mass) of the total aggregate used, the mortar factor will be greater than 1.00.

Another case in which the mortar factor may be greater than 1.00 is when proportioning structural lightweight concrete (i.e., unit weight between 90 and 115 lb/ft^3) using lightweight coarse aggregate. In this case, the mortar factor can be greater than 1.00 so as to adjust the proportions to achieve the desired unit weight of concrete, pumpability, strength, and so on.

Table 2.8.2.2 Design Mortar Factor

Class or Type of Concrete	Coarse Aggregate Gradation[1]	Mortar Factor Range for Department Mix Design
PV	CA 5 & CA 7, CA 5 & CA 11, CA 7, CA 11, or CA 14	0.70 – 0.90[5]
PP-1[2], PP-2[2], PP-3[2], PP-4[2], PP-5[2]	CA 7, CA 11,	0.70 – 0.93[5]
	CA 13, CA 14, or CA 16	0.79 – 0.99[5]
RR	CA 7, CA 11, or CA 14	0.70 – 0.90[5]
BS[2,3,7]	CA 7, CA 11, or CA 14	0.70 – 0.86[5,6]
PC[7]	CA 7, CA 11, CA 13, CA 14, CA 16, or CA 7 & CA 16	0.70 – 0.90[5]
PS[7]	CA 11[4], CA 13, CA 14, or CA 16[4]	0.79 – 0.99[5]
DS[7,8]	CA 13, CA 14, CA 16, or a blend of these gradations	Not Applicable
SC	CA 3 & CA 7, CA 3 & CA 11, CA 5 & CA 7, CA 5 & CA 11, CA 7, or CA 11	0.79 – 0.90[5]
SI[7,9]	CA 3 & CA 7, CA 3 & CA 11, CA 5 & CA 7, CA 5 & CA 11	0.71 – 0.83
	CA 7, CA 11, CA 13, CA 14, or CA 16	0.70 – 0.90[5]
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5	Refer to PP-1, 2, 3, 4, and 5
Formed Concrete Repair	CA 16	Refer to Class SI Concrete
Concrete Wearing Surface	Refer to Class BS Concrete	Refer to Class BS Concrete
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay	CA 11, CA 13, CA 14, or CA 16	Refer to Class BS Concrete
Bridge Deck Microsilica Concrete Overlay	CA 11, CA 13, CA 14, or CA 16	0.88 – 0.92
Bridge Deck High-Reactivity Metakaolin Concrete Overlay	CA 11, CA 13, CA 14, or CA 16	0.88 – 0.92
Bridge Deck Latex Concrete Overlay[10]	CA 13, CA 14, or CA 16	Not Applicable

Notes:

1. Alternate combinations of gradation sizes may be used with the approval of the Engineer. Refer also to Article 1004.02(d) for additional information on combining sizes.
2. For Class BS or PP concrete used in bridge deck patching, the coarse aggregate gradation shall be CA 13, CA 14, or CA 16, except CA 11 may be used for full-depth patching.
3. 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.
4. The nominal maximum size permitted is 3/4 in. Nominal maximum size is defined as the largest sieve which retains any of the aggregate sample particles.
5. If the fine aggregate is one hundred percent stone sand, the maximum mortar factor shall be 0.85.
6. May be increased to 0.95 if slipformed.
7. For self-consolidating concrete, the coarse aggregate gradations shall be CA 11, CA 13, CA 14, CA 16, or a blend of these gradations. However, the final gradation when using a single coarse aggregate or combination of coarse aggregates shall have 100 percent pass the 1 in. (25 mm) sieve, and minimum 95 percent pass the 3/4 in. (19 mm) sieve. The fine aggregate proportion shall be a maximum 50 percent by weight (mass) of the total aggregate used. Therefore, the maximum mortar factor shall not apply.
8. The coarse aggregate shall be 55 to 65 percent by weight (mass) of total aggregate. The only exception is self-consolidating concrete. See Note 7.
9. CA 3 or CA 5 may be used when the nominal maximum size does not exceed two-thirds the clear distance between parallel reinforcement bars, or between the reinforcement bar and the form. Nominal maximum size is defined in Note 4.
10. The coarse aggregate shall be 42 to 50 percent by weight (mass) of total aggregate.

2.8.3 Coarse Aggregate Absolute Volume Calculation

Knowing the volume fraction of mortar, the absolute volume in cubic yards (cubic meters) of coarse aggregate can be determined as follows:

English (Metric):

Absolute Volume of Coarse Aggregate, V_{CA} = 1 - Volume Fraction of Mortar

For example, from 2.8.2.1:

Absolute Volume of Coarse Aggregate, V_{CA} = 1 - Volume Fraction of Mortar
= 1 - 0.59
= 0.41

The absolute volume of coarse aggregate per cubic yard (cubic meter) of concrete is a total encompassing all coarse aggregates used. If more than one coarse aggregate is used, the total coarse aggregate absolute volume is multiplied by the percentage (as a decimal) of each coarse aggregate to be used; this will provide the absolute volume of each coarse aggregate. Typically, two coarse aggregates are blended to improve a gap graded coarse aggregate. The more uniformly graded combined aggregate will reduce water demand and improve the pumping characteristics of the mix. Refer to Appendix E “Aggregate Blending” for additional information.

Note: The equation below is used in the Department’s Excel PCC Mix Design program to simplify the calculation from two steps (calculating volume fraction of mortar to calculate absolute volume of coarse aggregate) to one:

$$\text{Absolute Volume of Coarse Aggregate } (V_{CA}) = \frac{1}{1+\left(\frac{\text{Mortar Factor}}{1-\text{Voids}}\right)}$$

2.8.4 Fine Aggregate Absolute Volume Calculation

Knowing the amount of cement, finely divided minerals, water, air, and coarse aggregate needed, the only unknown is the absolute volume of fine aggregate. This is easily found by subtracting all of the known absolute volumes from 1.

English (Metric):

The absolute volume of fine aggregate = 1 - ($V_{Cement}+\Sigma V_{FDM}+V_{Water}+V_{Air}+V_{CA}$)

The absolute volume of fine aggregate per cubic yard (cubic meter) of concrete is a total encompassing all fine aggregates used. If more than one fine aggregate is used, the total fine aggregate absolute volume is multiplied by the percentage (as a decimal) of each fine aggregate to be used. This will provide the absolute volume of each fine aggregate. Two fine aggregates may be blended for economic purposes such as when using a natural sand and a stone sand. Blending of fine aggregate may also be done to improve the overall gradation of the mix for air entrainment and pumping. Refer to Appendix E “Aggregate Blending” for additional information.

2.8.5 Converting Aggregate Absolute Volume to Weight (Mass)

Finally, to convert the absolute volume of aggregate to pounds (kilograms), the saturated surface-dry (SSD) specific gravity of the aggregate is required, which can be found on the Department's Specific Gravity (Gsb) List available online at http://www.idot.illinois.gov/, Doing Business, Material Approvals, Aggregate, Qualified Product Lists. Refer to the Portland Cement Concrete Level II Technician Course manual for additional information on SSD specific gravity. If it is suspected that the SSD specific gravity has changed or is incorrect, notify the District.

Whenever the specific gravity of any aggregate deviates by more than 0.02 from the original mix design value, a new mix design will be required.

English (Metric):

Weight (mass) = absolute volume × SSD specific gravity × unit weight of water

Where the "unit weight of water" is 1,683.99 pounds per cubic yard (1,000.00 kilograms per cubic meter).

2.9 EXAMPLE PROBLEM

Given:

- Continuous reinforced portland cement concrete pavement to be built using central mixed concrete and slipform equipment.
- Type I cement with >0.60 alkalies will be used.
- Class C fly ash with a calcium oxide of 25.1 percent and specific gravity of 2.61 will be used.
- A Type B fine aggregate (027FA01) with a saturated surface-dry specific gravity of 2.66 will be used. The alkali-silica reaction expansion for the fine aggregate sand is in the >0.16% – 0.27% range.
- A crushed stone coarse aggregate (022CA11) with a saturated surface-dry specific gravity of 2.68 will be used. The coarse aggregate voids are 0.39. The alkali-silica reaction expansion for the coarse aggregate limestone is an assigned value of 0.05%. The aggregate is freeze/thaw durable.
- A water-reducing admixture will be used to take advantage of a cement reduction and meet the water/cement ratio requirement. The target water reduction is 10 percent.

Significant Digits:

- Whole Number: Cement, Batch Water, Finely Divided Minerals, Coarse and Fine Aggregate
- One Digit to Right of Decimal: Basic Water Requirement (English), Air Content
- Two Digits to Right of Decimal: Specific Gravity, Unit Weight, Water/Cement Ratio, Basic Water Requirement (Metric), Mortar Factor, Voids
- Three Digits to Right of Decimal: Absolute Volume

Rounding:

- When the digit next beyond the last place to be retained is equal to or greater than 5, increase by 1 the digit in the last place retained.

2.9.1 Example Using English Units

Step 1 Determine the absolute volume of cement and finely divided minerals.

- From Table 2.2.1 "Cement Factor for Class or Type of Concrete," the minimum cement factor is 5.65 cwt/yd^3 for Class PV concrete from a central mixed plant.
- From 2.2.2 "Allowable Cement Factor Reduction – Admixture," the cement factor may be reduced by 0.30 cwt/yd^3 when using a water-reducing admixture.

The resulting cement factor is 5.65 $-$ 0.30 = 5.35 cwt/yd^3

- From 2.4.1.1 "Fly Ash," the Class C fly ash can replace up to 30 percent of the cement. From 2.4.3 "Mitigation of Alklai-Silica Reaction with Finely Divided Minerals," it is determined that the aggregate combination is in Group II. Thus, a minimum 25.0 percent Class C fly ash is required to reduce the risk of a deleterious alkali-silica reaction. It is decided to use 25 percent fly ash since a larger replacement would reduce the portland cement content below 400 lb/yd^3.

The calculation is 5.35 $\times$ 0.25 = 1.34 cwt/yd^3 of fly ash.

The calculation for the cement is 5.35 $-$ 1.34 = 4.01 cwt/yd^3

After rounding up to the nearest 5 lb/ yd^3, the values are 4.05 cwt/yd^3 for cement and 1.35 cwt/yd^3 for fly ash.

The absolute volume of cement per cubic yard of concrete
= (4.05 cwt/yd^3 $\times$ 100 lb/cwt) $\div$ (3.15 $\times$ 1,683.99 lb/yd^3) = 0.076 yd^3

The absolute volume of fly ash per cubic yard of concrete
= (1.35 cwt/yd^3 $\times$ 100 lb/cwt) $\div$ (2.61 $\times$ 1,683.99 lb/yd^3) = 0.031 yd^3

Step 2 Determine the absolute volume of water. Note: The water from admixtures is not considered significant in this example.

- From 2.5.1.1 "Fine Aggregate Basic Water Requirement," the fine aggregate water requirement is 5.3 gallons/cwt of cement and fly ash.
- From 2.5.1.2 "Coarse Aggregate Basic Water Requirement," the coarse aggregate water requirement is 0.2 gallon/cwt of cement and fly ash.
- From 2.5.1.3 "Basic Water Requirement Total," the design water is 5.3 + 0.2 = 5.5 gallons/cwt of cement and fly ash.
- As given, the target water reduction is 10 percent.

The design water based on using a water-reducing admixture
= 5.5 $-$ (5.5 $\times$ 0.10) = 5.0 gallons/cwt of cement and fly ash when rounded.

Additional adjustments to the design water, which are allowed by 2.5.2 "Adjustment to Basic Water Requirement" were ignored.

- Verify the water/cement ratio is not exceeded in 2.6.1 “Water/Cement Ratio.”

  The initial calculation is (5.0 gallons/cwt $\times$ 8.33 lb/gallon) = 41.7 lb/cwt

  Then, the water/cement ratio is easily obtained knowing that water/cement ratio is pounds of water divided by pounds of total cementitious material.

  The water/cement ratio = 41.7 lb/cwt $\div$ 100 lb/cwt = 0.417 or 0.42, when rounded.

  The alternate method to calculate water/cement ratio is to determine the number of pounds of water in one cubic yard and divide by the number of pounds of cement and fly ash in one cubic yard.

  The number of pounds of water per cubic yard
  = (5.0 gallons/cwt $\times$ 8.33 lb/gallon) $\times$ (4.05 cwt/yd^3 + 1.35 cwt/yd^3)
  = 225 lb/yd^3

  The number of pounds of cementitious material per cubic yard
  = (4.05 cwt/yd^3 + 1.35 cwt/yd^3) $\times$ 100 lb/cwt
  = 540 lb/yd^3

  The water cement ratio = 225 lb/yd^3 $\div$ 540 lb/yd^3 = 0.42 after rounding.

  This value meets the 0.42 maximum water/cement ratio allowed for Class PV concrete in 2.6.1 “Water/Cement Ratio.”

  The absolute volume of water per cubic yard of concrete
  = [41.7 lb/cwt $\times$ (4.05 cwt/yd^3 + 1.35 cwt/yd^3)] $\div$ (1.00 $\times$ 1,683.99 lb/yd^3)
  = 0.134 yd^3

Step 3 Determine the absolute volume of air.

- From 2.7.1 “Air Content,” the midpoint of the air content range for Class PV concrete is 6.5 percent.

The absolute volume of air per cubic yard of concrete = 6.5 percent $\div$ 100 = 0.065 yd^3

Step 4 Determine the absolute volume of coarse aggregate.

Select a mortar factor for Class PV concrete from 2.8.2.1 “Design Mortar Factor.” A mortar factor value of 0.83 is a good starting point.

The coarse aggregate voids are 0.39.

The absolute volume of coarse aggregate per cubic yard of concrete

$$= \frac{1}{1+\left(\frac{0.83}{1-0.39}\right)} = 0.424 \text{ yd}^3$$

Another way to determine absolute volume of coarse aggregate is to calculate percent mortar volume in decimal form and subtract it from 1. If it is not mortar, it must be coarse aggregate.

The absolute volume of coarse aggregate per cubic yard of concrete

= 1 – Volume Fraction of Mortar

$$= 1 - \frac{M_O}{(1-V)+M_O} = 1 - \frac{0.83}{(1-0.39)+0.83} = 0.424 \text{ yd}^3$$

Step 5 Determine the absolute volume of fine aggregate.

The absolute volume of fine aggregate is found by subtracting all of the known volumes from 1. Therefore,

The absolute volume of fine aggregate per cubic yard
= 1 – (0.076 + 0.031 + 0.134 + 0.065 + 0.424) = 0.270 yd^3

Step 6 Convert the absolute volume of the coarse and fine aggregate to pounds.

Coarse aggregate = 0.424 $yd^3 \times 2.68 \times$ 1,683.99 lb/yd^3 = 1,914 lb

Fine aggregate = 0.270 $yd^3 \times 2.66 \times$ 1,683.99 lb/yd^3 = 1,209 lb

Step 7 Summarize the mix design.

Cement	= 4.05 cwt/yd^3 or 405 lb/yd^3
Fly Ash	= 1.35 cwt/yd^3 or 135 lb/yd^3
Batch Water	= 5.0 gallons/cwt of cement and fly ash = 5.0 gallons/cwt $\times$ (4.05 cwt/yd^3 + 1.35 cwt/yd^3) = 27 gal/yd^3 or = 41.7 lb/cwt of cement and fly ash = 41.7 lb/cwt $\times$ (4.05 cwt/yd^3 + 1.35 cwt/yd^3) = 225 lb/yd^3
Air Content (Target)	= 6.5 percent
Coarse Aggregate	= 1,914 lb/yd^3
Fine Aggregate	= 1,209 lb/yd^3
Admixture	= water-reducing admixture (target reduction of 10 percent)
Mortar Factor	= 0.83
Voids	= 0.39
Slump (Target)	= 1-1/2 inch*
Strength (Minimum)	= 3500 psi at 14 days
Water/Cement Ratio	= 0.42

* Experience has been that the slump at the paver will most likely be 1-1/2 inches to aid in achieving a smooth pavement.

To confirm the proportions will produce a satisfactory mix (i.e., meeting workability and constructability expectations, in addition to specification requirements), perform a trial mixture (see 6.0 “Concrete Mix Design—Trial Mixture” for more information).

2.9.2 Example Using Metric Units

Step 1 Determine the absolute volume of cement and finely divided minerals.

- From Table 2.2.1 “Cement Factor for Type or Class of Concrete,” the minimum cement factor is 335 kg/m^3 for Class PV concrete from a central mixed plant.
- From 2.2.2 “Allowable Cement Factor Reduction – Admixture,” the cement factor may be reduced by 18 kg/m^3 when using a water-reducing admixture.

The resulting cement factor is 335 – 18 = 317 kg/m^3

- From 2.4.1.1 “Fly Ash,” the Class C fly ash can replace up to 30 percent of the cement. From 2.4.3 “Mitigation of Alklai-Silica Reaction with Finely Divided Minerals,” it is determined that the aggregate combination is in Group II. Thus, a minimum 25.0 percent Class C fly ash is required to reduce the risk of a deleterious alkali-silica reaction. It is decided to use 25 percent fly ash since a larger replacement would reduce the portland cement content below 237 kg/m^3.

The calculation is 317 × 0.25 = 79 kg/m^3 of fly ash

The calculation for the cement is 317 – 79 = 238 kg/m^3

After rounding up to the nearest 2.5 kg/ m^3, the values are 240 kg/m^3 for cement and 80 kg/m^3 for fly ash.

The absolute volume of cement per cubic meter of concrete
$= 240 \text{ kg/m}^3 \div (3.15 \times 1{,}000.00 \text{ kg/m}^3) = 0.076 \text{ m}^3$

The absolute volume of fly ash per cubic meter of concrete
$= 80 \text{ kg/m}^3 \div (2.61 \times 1{,}000.00 \text{ kg/m}^3) = 0.031 \text{ m}^3$

Step 2 Determine the absolute volume of water. Note: The water from admixtures is not considered significant in this example.

- From 2.5.1.1 “Fine Aggregate Basic Water Requirement,” the fine aggregate water requirement is 0.44 liter/kg of cement and fly ash.
- From 2.5.1.2 “Coarse Aggregate Basic Water Requirement,” the coarse aggregate water requirement is 0.017 liter/kg of cement and fly ash.
- From 2.5.1.3 “Basic Water Requirement Total,” the (design water) is 0.44 + 0.017 = 0.46 liter/kg of cement and fly ash after rounding.
- As given, the target water reduction is 10 percent.

The design water based on using a water-reducing admixture
= 0.46 – (0.46 × 0.10) = 0.41 liter/kg of cement and fly ash.

Additional adjustments to the design water, which are allowed by 2.5.2 “Adjustment to Basic Water Requirement” were ignored.

- Verify the water/cement ratio is not exceeded in 2.6.1 “Water/Cement Ratio.”

  The water/cement ratio is easily obtained knowing that water/cement ratio is kilograms of water divided by kilograms of total cementitious material. In addition, remember that 1 liter of water equals 1 kilogram of water.

  The water/cement ratio = 0.41 kg $\div$ 1 kg = 0.41

  The alternate method to calculate water/cement ratio is to determine the number of kilograms of water in one cubic meter and divide by the number of kilograms of cement and fly ash in one cubic meter.

  The number of kilograms of water per cubic meter
  = (0.41 liter/kg $\times$ 1 kg/liter) $\times$ (240 kg/m^3 + 80 kg/m^3)
  = 131 kg/m^3

  The number of kilograms of cementitious material per cubic meter
  = (240 kg/m^3 + 80 kg/m^3)
  = 320 kg/m^3

  The water cement ratio = 131 kg/m^3 $\div$ 320 kg/m^3 = 0.41 after rounding.

  This value meets the 0.42 maximum water/cement ratio allowed for Class PV concrete in 2.6.1 “Water/Cement Ratio.”

  The absolute volume of water per cubic meter of concrete
  = [(0.41 liter/kg $\times$ 1 kg/liter) $\times$ (240 kg/m^3 + 80 kg/m^3)] $\div$ (1.0 $\times$ 1,000.00 kg/m^3)
  = 0.131 m^3

Step 3 Determine the absolute volume of air.

- From 2.7.1 “Air Content,” the midpoint of the air content range for Class PV concrete is 6.5 percent.

The absolute volume of air per cubic meter of concrete = 6.5 percent $\div$ 100 = 0.065 m^3

Step 4 Determine the absolute volume of coarse aggregate.

Select a mortar factor for Class PV concrete from 2.8.2.1 “Design Mortar Factor.” A mortar factor value of 0.83 is a good starting point. The coarse aggregate voids are 0.39.

The absolute volume of coarse aggregate per cubic meter of concrete

$$= \frac{1}{1+\left(\frac{0.83}{1-0.39}\right)} = 0.424 \text{ m}^3$$

Another way to determine absolute volume of coarse aggregate is to calculate percent mortar volume in decimal form and subtract it from 1. If it is not mortar, it must be coarse aggregate.

The absolute volume of coarse aggregate per cubic yard of concrete

= 1 – Volume Fraction of Mortar

$$= 1 - \frac{M_O}{(1-V)+M_O} = 1 - \frac{0.83}{(1-0.39)+0.83} = 0.424 \text{ m}^3$$

Step 5 Determine the absolute volume of fine aggregate.

The absolute volume of fine aggregate is found by subtracting all of the known volumes from 1. Therefore,

The absolute volume of fine aggregate per cubic meter
= 1 – (0.076 + 0.031 + 0.131 + 0.065 + 0.424) = 0.273 m^3

Step 6 Convert the absolute volume of the coarse and fine aggregate to kilograms.

Coarse aggregate = 0.424 m^3 × 2.68 × 1,000.00 kg/m^3 = 1,136 kg

Fine aggregate = 0.273 m^3 × 2.66 × 1,000.00 kg/m^3 = 726 kg

Step 7 Summarize the mix design.

Cement	= 240 kg/m^3
Fly Ash	= 80 kg/m^3
Batch Water	= 0.41 liter/kg of cement and fly ash
	= 0.41 liter/kg × (240 kg/m^3 + 80 kg/m^3)
	= 131.2 liters/m^3
	or
	= 131.2 kg/m^3 since 1 liter of water = 1 kilogram
Air Content (Target)	= 6.5 percent
Coarse Aggregate	= 1,136 kg/m^3
Fine Aggregate	= 726 kg/m^3
Admixture	= water-reducing admixture (target reduction of 10 percent)
Mortar Factor	= 0.83
Voids	= 0.39
Slump (Target)	= 38 mm*
Strength (Minimum)	= 24,000 kPa at 14 days
Water/Cement Ratio	= 0.41

* Experience has been that the slump at the paver will most likely be 38 mm to aid in achieving a smooth pavement.

To confirm the proportions will produce a satisfactory mix (i.e., meeting workability and constructability expectations, in addition to specification requirements), perform a trial mixture (see 6.0 “Concrete Mix Design—Trial Mixture” for more information).

2.10 SUMMARY OF MIX DESIGN EQUATIONS

Volume of Cement & Finely Divided Minerals

	Equation	Variable	Definition
English	Absolute Volume, $V_{Cement} = \dfrac{Weight}{G_{sp} \times 1{,}683.99}$ $V_{FDM} = \dfrac{Weight}{G_{sp} \times 1{,}683.99}$	V_{Cement}	Absolute Volume of Cement, yd^3 (m^3)
		V_{FDM}	Absolute Volume of Finely Divided Minerals, yd^3 (m^3)
		Weight	Weight of Material (lb)
Metric	Absolute Volume, $V_{Cement} = \dfrac{Mass}{G_{sp} \times 1{,}000.00}$ $V_{FDM} = \dfrac{Mass}{G_{sp} \times 1{,}000.00}$	G_{sp}	Specific Gravity of Material*
		Mass	Mass of Material (kg)
		1,683.99	Unit Weight of Water (lb/yd^3)
		1,000.00	Unit Weight of Water (kg/m^3)

Basic Water Requirement—IDOT Method

	Equation	Variable	Definition
English & Metric	Basic Water Requirement, $W_{Basic} = W_{FA} + W_{CA}$	W_{Basic}	Basic Water Requirement, gal/cwt (L/kg)
		W_{FA}	Fine Aggregate Water Requirement, gal/cwt (L/kg)
		W_{CA}	Coarse Aggregate Water Requirement, gal/cwt (L/kg)

Adjusted Basic Water Requirement

	Equation	Variable	Definition
English & Metric	Adjusted Basic Water Requirement, $W_{Adj} = W_{Basic} - (W_{Basic} \times \dfrac{\%Adjustment}{100})$	W_{Adj}	Adjusted Basic Water Requirement, gal/cwt (L/kg)
		W_{Basic}	Basic Water Requirement, gal/cwt (L/kg)
		%Adjust-ment	Adjustment (± percent)

Water/Cement Ratio

	Equation	Variable	Definition
English	Water/Cement Ratio, $W/C = \dfrac{W_{Adj} \times 8.33}{100}$	*W/C*	Water/Cement Ratio
		W_{Adj}	Adjusted Basic Water Requirement (gal/cwt)
		8.33	Conversion Factor (lb/gal)
		100	Conversion Factor (lb/cwt)
Metric	Water/Cement Ratio, $W/C = W_{Adj} \times 1.00$	W_{Adj}	Adjusted Basic Water Requirement (L/kg)
		1.00	Conversion Factor (kg/L)

Volume of Water

	Equation	Variable	Definition
English	Absolute Volume, $V_{Water} = \dfrac{Weight}{1{,}683.99}$	*Weight*	Weight of Water (lb)
Metric	Absolute Volume, $V_{Water} = \dfrac{Mass}{1{,}000.00}$	*Mass*	Mass of Water (kg)
		1,683.99	Unit Weight of Water (lb/yd^3)
		1,000.00	Unit Weight of Water (kg/m^3)

Volume of Entrained Air

	Equation	Variable	Definition
English & Metric	Absolute Volume, $V_{Air} = \dfrac{\%Air}{100}$	V_{Air}	Absolute Volume of Air, yd^3 (m^3)
		% Air	Air Content (percent)

Minimum Percent Air Content		Variable	Definition
English & Metric	Minimum Percent Air $= [0.18 \times (V_{Water} + V_{Cement} + \Sigma V_{FDM})] \times 100$	V_{Water}	Absolute Volume of Water, yd^3 (m^3)
		V_{Cement}	Absolute Volume of Cement, yd^3 (m^3)
		ΣV_{FDM}	Sum Total of Absolute Volumes of Finely Divided Minerals, yd^3 (m^3)
Volume Fraction of Coarse Aggregate & Mortar			
English & Metric	Fraction of CA Solids = 1- V	V	Voids in Coarse Aggregate
	Volume Fraction of Mortar = $\frac{M_O}{M_O + F_{CA}}$	M_O	Mortar Factor
Volume of Coarse Aggregate			
English & Metric	Absolute Volume, V_{CA} = 1 – Volume Fraction of Mortar OR $V_{CA} = \dfrac{1}{1+\left(\dfrac{M_O}{1-V}\right)}$	V_{CA}	Absolute Volume of Coarse Aggregate, yd^3 (m^3)
		M_O	Mortar Factor
		V	Voids in Coarse Aggregate
Volume of Fine Aggregate			
English & Metric	Absolute Volume, $V_{FA} = 1 - (V_{Cement} + \Sigma V_{FDM} + V_{Water} + V_{Air} + V_{CA})$	V_{FA}	Absolute Volume of Fine Aggregate, yd^3 (m^3)
		V_{Cement}	Absolute Volume of Cement, yd^3 (m^3)
		ΣV_{FDM}	Sum Total of Absolute Volume of Finely Divided Minerals, yd^3 (m^3)
		V_{Water}	Absolute Volume of Water, yd^3 (m^3)
		V_{Air}	Absolute Volume of Air, yd^3 (m^3)
		V_{CA}	Absolute Volume of Coarse Aggregate, yd^3 (m^3)
Aggregate Content			
English	Weight of Aggregate (lb) $= V_{CA} \times G_{SSD} \times 1{,}683.99$ $= V_{FA} \times G_{SSD} \times 1{,}683.99$	V_{CA}	Absolute Volume of Coarse Aggregate, yd^3 (m^3)
		V_{FA}	Absolute Volume of Fine Aggregate, yd^3 (m^3)
		G_{SSD}	Specific Gravity of Aggregate @ Saturated Surface-Dry Condition
Metric	Mass of Aggregate (kg) $= V_{CA} \times G_{SSD} \times 1{,}000.00$ $= V_{FA} \times G_{SSD} \times 1{,}000.00$	1,683.99	Unit Weight of Water (lb/yd^3)
		1,000.00	Unit Weight of Water (kg/m^3)

* For cement and finely divided minerals, there are no pores for the material to absorb water. Therefore, a saturated surface-dry condition cannot exist as it can for aggregates. Thus, the term “apparent specific gravity” may be used to describe this type of specific gravity.

3.0 SPECIALTY MIXTURES

3.1 HIGH-EARLY STRENGTH CONCRETE MIXTURES

Projects will frequently have requirements for high-early-strength portland cement concrete pavement (jointed and continuously reinforced), base course, and base course widening. A high-early-strength portland cement concrete mix is defined as follows: "A concrete mix that will meet mix design strength requirements prior to the test of record. Typically, the concrete strength is obtained in 3 days or less."

Projects requiring high-early-strength concrete mixtures frequently involve intersections and entrances to business establishments. In addition, portland cement concrete railroad crossings are always a high-early-strength mixture because the required strength is to be obtained in 48 hours. The accelerated strength is needed to minimize disruptions to the public.

The following options are used to obtain a high-early-strength concrete mixture. The Contractor may submit other options for approval by the Engineer.

- Option 1. Replace the cement with Type III high-early-strength cement.
- Option 2. Increase the amount of cement to 7 bags. This would be 658 lb/yd^3 (390 kg/m^3). However, such mix designs typically use 650 lb/yd^3 (386 kg/m^3) or 655 lb/yd^3 (389 kg/m^3).

  In addition, limit the total aggregate water requirement to 4.9 – 5.1 gal/cwt (0.41 – 0.43 L/kg). As a result of the water limitation, a water-reducing admixture is frequently used.
- Option 3. Use a non-chloride accelerator. Normally, only a non-chloride accelerator is allowed in new concrete construction. For concrete repairs, the District has the option to allow a chloride accelerator, which is normally only done for Class PP-2 concrete. Refer also to 2.5.3 "Required Use of Admixtures" and 2.5.4 "Optional Use of Admixtures" for additional information on accelerators.

3.2 OTHER MIXTURES

The following appendices provide additional information on other specialty mixtures:

- Appendix F "CEMENT AGGREGATE MIXTURE (CAM) II"
- Appendix G "CONTROLLED LOW STRENGTH MATERIAL (CLSM)"
- Appendix H "STAMPED OR INTEGRALLY COLORED CONCRETE
- Appendix I "CONCRETE REVETMENT MATS"
- Appendix J "INSERTION LINING OF PIPE CULVERTS (GROUT)"
- Appendix K "INSERTION LINING OF PIPE CULVERTS (CELLULAR CONCRETE)"
- Appendix L "CLASS SI CONCRETE BETWEEN PRECAST CONCRETE BOX CULVERTS"
- Appendix M "PERVIOUS CONCRETE"
- Appendix P "BRIDGE DECK LATEX CONCRETE OVERLAY MIX DESIGN"

3.3 SYNTHETIC FIBERS

The Department may require synthetic fibers for thin concrete overlays. The fibers are used as reinforcement to improve the concrete's resistance to cracking. Contractors also have the option to use synthetic fibers in slipformed concrete for gutter, curb, median, and paved ditch. The synthetic fibers reduce concrete tearing, which is a labor savings for finishing operations.

In terms of mix design, it is suggested to ensure adequate mortar is available to coat the fibers. This may require a slightly higher mortar factor, or a small increase in the total amount of cement and finely divided minerals in the mixture. It is best to consult with the supplier of the fibers when developing the mix design. The Level III PCC Technician is also reminded that the slump test is not a good indicator of workability for a mixture containing fiber reinforcement.

4.0 TERNARY CONCRETE MIX DESIGNS

A ternary concrete mix design consists of cement and two finely divided minerals. The finely divided mineral in portland-pozzolan cement or portland blast-furnace slag cement shall count as one of the two finely divided minerals. Article 1020.05(c)(5) provides the specification for mixtures with multiple finely divided minerals. The Department encourages the use of a high percentage of finely divided minerals in a mix design for the following reasons:

- The risk of alkali-silica reaction is further reduced.
- The concrete permeablility will be lower which increases the time before steel reinforcement will corrode.
- Improved workability and less slump loss in hot weather.
- Higher long term strengths.
- A more economical and environmentally friendly mix.

The one disadvantage of concrete mixtures with a high percentage of finely divided minerals is when cool weather occurs, which can cause slower strength gain.

5.0 MASS CONCRETE MIX DESIGNS

According to Article 1020.15, the Contractor shall control the heat of hydration for concrete structures when the least dimension for a drilled shaft, foundation, footing, substructure, or superstructure concrete pour exceeds 5.0 ft (1.5 m). The primary purpose is to control volume changes induced by the high concrete temperatures. Excessive volume changes may crack the concrete. Very high concrete temperatures may also produce a phenomenon known as delayed ettringite formation (DEF), which is an expansive distress that will crack the concrete. This ettringite will form after the concrete has hardened, provided there is adequate moisture.

In terms of designing a mass concrete pour mix design, specifications recommend a uniformly graded mix with preference given to larger size aggregate. The purpose is to reduce the total amount of cement and finely divided minerals required to coat the aggregate surface area, which will also help reduce the total heat of hydration. Per Department specifications, the total required cement and finely divided minerals may be lower for mass concrete pours.

Mass concrete pour mix designs will also normally have a high percentage of finely divided minerals to control the heat of hydration. For example, the finely divided minerals may constitute a maximum of 65.0 percent of the total cement and finely divided minerals in a mix design.

If the Level III PCC Technician is required to develop a mass concrete pour mix design, the Department recommends the use of a Consultant that specializes in this area. Various field methods for pre-cooling and post-cooling the concrete are available, and these methods will dictate the required mix design.

6.0 CONCRETE MIX DESIGN—TRIAL MIXTURE

Once a mix design is completed, a trial mixture is recommended to verify the mix design will meet slump, air content, and strength requirements as summarized in 2.7.1 “Air Content,” 6.1 “Slump,” and 6.2 “Strength.” If a trial mixture is performed, it is a good idea to notify the Department’s District office. The District may wish to observe the trial mixture or possibly perform some of its own testing.

A trial mixture differs from a trial batch (see 9.0 “Department Concrete Mix Design Verification”) in that it is initiated and performed at the mix designer’s discretion, not the Engineer’s. Thus, it should be considered an opportunity for the mix designer to pre-verify that his or her design meets expectations for workability, strength, and specification requirements. Furthermore, allowing the District a chance to observe the trial or providing test results from it may alleviate any concerns the Engineer may have that would cause him or her to require a trial batch.

6.1 SLUMP

The slump test (Illinois Modified AASHTO T 119) is used to determine the batch-to-batch consistency of concrete. Per Article 1020.04, different slump ranges are specified for different construction applications (also refer to Table 6.1).

Mix design target slump values near the maximum of the specified range are recommended to aid finishing and handwork, as well as potentially improving the effectiveness of air-entraining admixtures (that is, additional water benefits air-entraining admixtures). Furthermore, high slumps at the plant can help anticipate slump loss due to high temperature and long haul time, which otherwise could result in a mixture that may be difficult to place and finish in the field. For example, experience has shown that for slipformed pavement construction on a very hot day, a slump of 2-1/2 inches (64 mm) at the plant can fall up to 1-1/2 inches (38 mm) by the time it reaches the paver. A slump of 1/2 to 1-1/2 inches (13 to 38 mm) at the paver is typical for slipform construction, but many Contractors desire 1-1/2 inches (38 mm) to obtain a smooth pavement.

6.2 STRENGTH

One of the most important properties of concrete is its strength. The purpose of strength testing is to verify the strength potential of the concrete. Per Article 1020.04, different minimum strengths are specified for different construction applications (also refer to Table 6.2).

Additional information regarding determining target strength can be found in 7.0 “Determining the Concrete Mix Design Target Strength.”

Table 6.1 Slump

Class or Type of Concrete	Slump inches (mm)	
PV	2-4 (50-100)[1,2]	
PP-1	2-4 (50-100)[2]	
PP-2	2-6 (50-150)[2]	
PP-3	2-4 (50-100)[2]	
PP-4	2-6 (50-150)[2]	
PP-5	2-8 (50-200)	
RR	2-4 (50-100)[2]	
BS	2-4 (50-100)[2]	
PC	Wet Cast:	1-4 (25-100)[2]
	Dry Cast:	0-1 (0-25)
PS	1-4 (25-100)[2,3]	
DS	6-8 (150-200)[4]	
SC	3-5 (75-125)[2,5]	
SI	2-4 (50-100)[2]	
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5	
Formed Concrete Repair	5-7 (125-175)	
Concrete Wearing Surface	Refer to Class BS Concrete	
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay	Refer to Class BS Concrete	
Bridge Deck Microsilica Concrete Overlay	3-6 (75-150)	
Bridge Deck High-Reactivity Metakaolin Concrete Overlay	3-6 (75-150)	
Bridge Deck Latex Concrete Overlay	3-6 (75-150)	

Notes:

1. The slump range for slipform construction shall be 1/2-2 1/2 in. (13-64 mm).
2. The maximum slump may be increased to 7 in. (175 mm), when a high range water-reducing admixture is used.
3. For Class PS, the maximum slump may be increased to 8 1/2 in. (215 mm) if the high range water-reducing admixture is the polycarboxylate type.
4. If concrete is placed to displace drilling fluid, or against temporary casing, the slump shall be 8-10 in. (200-250 mm) at the point of placement. If a water-reducing admixture is used in lieu of a high range water-reducing admixture according to Article 1020.05(b)(7), the slump shall be 2-4 in. (50-100 mm).
5. The maximum slump may be increased to 8 in. (200 mm), when a high range water-reducing admixture is used.

Table 6.2 Strength

Class or Type of Concrete	Compressive Strength psi (kPa)	Flexural Strength psi (kPa)
PV	3,500 (24,000)[1,2]	650 (4,500)[1,2]
PP-1	3,200 (22,100)[3,8]	600 (4,150)[3,8]
PP-2	3,200 (22,100)[4,8]	600 (4,150)[4,8]
PP-3	3,200 (22,100)[5,8]	600 (4,150)[5,8]
PP-4	3,200 (22,100)[6,8]	600 (4,150)[6,8]
PP-5	3,200 (22,100)[7,8]	600 (4150)[7,8]
RR	3,500 (24,000)[3]	650 (4,500)[3]
BS	4,000 (27,500)[1]	675 (4,650)[1]
PC	Refer to Section 1042	Refer to Section 1042
PS	Refer to Section 1020	Refer to Section 1020
DS	4,000 (27,500)[1]	675 (4,650)[1]
SC	3,500 (24,000)[1]	650 (4,500)[1]
SI	3,500 (24,000)[1]	650 (4,500)[1]
Deck Slab Repair	Refer to PP-1, 2, 3, 4, and 5	Refer to PP-1, 2, 3, 4, and 5
Formed Concrete Repair	4,000 (27,500)[1]	675 (4,650)[1]
Concrete Wearing Surface	Refer to Class BS Concrete[9]	Refer to Class BS Concrete[9]
Bridge Deck Fly Ash or GGBF Slag Concrete Overlay	Refer to Class BS Concrete	Refer to Class BS Concrete
Bridge Deck Microsilica Concrete Overlay	4,000 (27,500)[1]	675 (4,650)[1]
Bridge Deck High-Reactivity Metakaolin Concrete Overlay	4,000 (27,500)[1]	675 (4,650)[1]
Bridge Deck Latex Concrete Overlay	4,000 (27,500)[1]	675 (4,650)[1]

Notes:

1. 14 day strength
2. If Type III cement is used, the indicated strength shall be achieved in 3 days.
3. 48 hour strength
4. 24 hour strength
5 16 hour strength
6. 8 hour strength
7. 4 hour strength
8. For Class PP concrete used in bridge deck patching, the mix design shall have 72 hours to obtain a 4,000 psi (27,500 kPa) compressive or 675 psi (4,650 kPa) flexural strength.
9. When Steel Bridge Rail is used in conjunction with concrete wearing surface, the 14 day mix design shall be replaced by a 28 day mix design with a compressive strength of 5,000 psi (34,500 kPa) and a flexural strength of 800 psi (5,500 kPa).

6.3 PROCEDURE FOR TRIAL MIXTURE

The applicable test methods for a conventional concrete trial mixture are Illinois Modified AASHTO R 60, T 22, T 23, T 119, T 121, T 152, T 177, T 196, and Illinois Modified ASTM C 1064. A summary of test methods is shown in Table 6.3. Testing should be performed or overseen by an individual who has successfully completed the Portland Cement Concrete Level I Technician training.

For self-consolidating concrete, applicable test methods for a trial mixture are Illinois Test Procedures SCC-1, SCC-2, SCC-3, SCC-4, SCC-6, and Illinois Modified AASHTO R 60, T 22, T 23, T 121, T 152, T 177, T 196, and Illinois Modified ASTM C 1064. Refer to Article 1020.04 to review the self-consolidating concrete specifications.

A unit weight test (Illinois Modified AASHTO T 121), which also provides yield, should be performed to check the accuracy of proportioning.

The Contractor is reminded that when a trial mixture is done, the water in admixtures should be taken into account. Refer to 2.6 “Adjusted Basic Water Requirement and Water/Cement Ratio.”

A trial mixture may be mixed in the laboratory according to AASHTO R 39 or in the field. The volume of the laboratory trial mixture is determined by the laboratory equipment. The volume of the field trial mixture should be a minimum of 2 yd^3 (1.5 m^3), but 4 yd^3 (3.0 m^3) is strongly recommended to more accurately evaluate the influence of mixing.

The Portland Cement Concrete (PCC) Laboratory used to perform a trial mixture should be approved according to the Bureau of Materials Policy Memorandum, “Minimum Private Laboratory Requirements for Construction Materials Testing or Mix Design.” Field equipment used to perform a trial mixture should be approved according to the Bureau of Materials Policy Memorandum, “Approval of Concrete Plants and Delivery Trucks.”

For the trial mixture, it is recommended to batch the mixture at or near the maximum water/cement ratio. The air content should be within 0.5 percent of the maximum allowable specification value. Since it is difficult to entrain air in slipformed concrete, a value below the midpoint of the range is permissible. The slump should be within the allowable specification range. If batching self-consolidating concrete (SCC), applicable SCC tests should be within the allowable specification range. Determine the concrete temperature, and if desired, perform a unit weight test which also provides yield.

It needs to be mentioned that concrete temperature will have a significant influence on strength gain. If a cold weather concrete mix is being developed, a temperature in the 50 to 60 ºF (10 to 16 ºC) range may be more appropriate for the trial mixture. Similarly, a warm weather concrete mix should be developed with a concrete temperature in the 80 to 90 ºF (27 to 32 ºC) range.

Once the mix design is within the allowable tolerance for slump and air content, or applicable SCC tests, evaluate the mix for consistency, plasticity, and workability. After this is done, make strength specimens. The Contractor has the option to make compressive or flexural specimens, or a combination of both. The Contractor is advised that in some instances flexural strength is specified, and compressive strength may be used only with the approval of the Engineer (refer to Articles 503.05 and 503.06 of the Standard Specifications). As a minimum, make strength specimens to determine the test of record. The test of record shall be the day indicated in the Standard Specifications, and is the minimum required strength. However, the Department recommends the development of a strength curve with testing at 3, 7, 14, 28, and 56 days. (Note: A 56 day break is not needed for a cement only mixture.) In the case of patching mixes, testing is measured in terms of hours. Therefore, a strength curve should be generated as recommended by the Engineer. For the test of record, or for testing at other ages, strength will be based on the average of a minimum two 6- by 12-in. (150- by 300-mm) cylinder breaks, three 4- by 8-in. (100- by 200-mm) cylinder breaks, or two beam breaks tested according to Illinois Modified AASHTO T 22 or T 177. Per Illinois Modified AASHTO T 23, cylinders shall be 6 by 12 in. (150 by 300 mm) when the nominal maximum aggregate size of the coarse aggregate exceeds 1 in. (25 mm). Nominal maximum size is defined as the largest sieve which retains any of the aggregate sample particles.

After the Contractor has evaluated the test results for specification compliance and the characteristics of the mix for field placement, the Contractor can accept it as is, adjust it, or re-design it. If the mix design is adjusted or re-designed, another trial mixture is recommended.

Table 6.3 Test Methods

Test Method	Title
IL Mod. AASHTO R 60	Sampling Freshly Mixed Concrete
IL Mod. AASHTO T 22	Compressive Strength of Cylindrical Concrete Specimens
IL Mod. AASHTO T 23	Making and Curing Concrete Test Specimens in the Field
IL Mod. AASHTO T 119	Slump of Hydraulic Cement Concrete
IL Mod. AASHTO T 121	Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
IL Mod. AASHTO T 152	Air Content of Freshly Mixed Concrete by the Pressure Method
IL Mod. AASHTO T 161	Resistance of Concrete to Rapid Freezing and Thawing
IL Mod. AASHTO T 177	Flexural Strength of Concrete (Using Simple Beam with Center Point Loading)
IL Mod. AASHTO T 196	Air Content of Freshly Mixed Concrete by the Volumetric Method
IL Mod. ASTM C 672	Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
IL Mod. ASTM C 1064	Temperature of Freshly Mixed Portland Cement Concrete
ITP 306	Voids Test of Coarse Aggregate for Concrete Mixtures
ITP SCC-1	Sampling, Determining Yield and Air Content, and Making and Curing Strength Test Specimens of Self-Consolidating Concrete
ITP SCC-2	Slump Flow and Stability of Self-Consolidating Concrete
ITP SCC-3	Passing Ability of Self-Consolidating Concrete by J-Ring and Slump Cone
ITP SCC-4	Passing Ability of Self-Consolidating Concrete by L-Box
ITP SCC-6	Static Segregation of Hardened Self-Consolidating Concrete Cylinders

7.0 DETERMINING THE CONCRETE MIX DESIGN TARGET STRENGTH

Since the Department's mix design method is very conservative, often resulting in strength test results exceeding the minimum strength requirement, a statistical analysis of strength test results is not normally performed. However, the American Concrete Institute (ACI) has developed a statistical method to determine a mix design target strength.

The mix design target strength (f'_{cr}) is defined as the average strength the concrete mix must attain to ensure the specified strength (f'_c) is met. Note that "average" strength implies that half of the samples tested are stronger than the average, and half of the samples tested are weaker than the average. Thus, the mix design target strength must be a value greater than the minimum strength requirement.

The mix design target strength is based on statistics, and will vary between concrete producers. The purpose of the target strength is to allow for variations in water, air content, aggregate gradation, concrete mixing, producer quality control, and other parameters which affect strength. The mix design target strength ensures that the variations will not cause individual strength test results to drop below the minimum specification strength requirement.

Ultimately, the adjustment of the average to obtain the target strength for a given mix design depends on the precision of test results. The precision is quantified as the standard deviation from a series of test results on a similar mix design. Refer to Appendix N "Average and Standard Deviation" for additional information.

Procedures for determining the mix design target strength from the minimum specification strength requirement can be found in the ACI 301 "Specifications for Structural Concrete," summarized below:

- The average strength of any three consecutive tests* may not be below the specified value of compressive strength, f'_c.
- The strength of any one test* may not exceed 500 psi (3,450 kPa) below f'_c when f'_c is 5000 psi (34,475 kPa) or less; or may not exceed $0.10f'_c$ below f'_c when f'_c is more than 5000 psi (34,475 kPa).

* One test is the average of two 6- by 12-in. (150- by 300-mm) cylinder breaks or three 4- by 8-in. (100- by 200-mm) cylinder breaks.

Using the above criteria, there is only a 1 percent chance that the average of any three consecutive test values will be less than the specified strength (f'_c). In addition, there is only a 1 percent chance that the strength of any one test will be more than 500 psi (3,450 kPa) below the specified strength (f'_c) when f'_c is no more than 5000 psi (34,475 kPa); or will be more than 10 percent below the specified strength (f'_c) when f'_c is more than 5000 psi (34, 475 kPa).

In order to calculate the mix design target strength, the standard deviation (S) must be determined. The standard deviation shall be based on: actual tests of the mix design using materials, quality control procedures, and conditions similar to those expected; test results within 1,000 psi (6,900 kPa) of the strength requirement for the mix design; and at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests are required (no group having less than 10 tests). For 30 tests, this means that 30 separate batches of concrete have been tested. The time period for the 30 tests may be up to one year, or as determined by the Engineer.

The standard deviation shall be based on at least 30 test results. Smaller data sets may be used when a modification factor (*m*) is applied to S as follows:

Number of Tests	Modification Factor (*m*)
≥ 30	1.00
25	1.03
20	1.08
15	1.16

After the standard deviation is determined, the mix design target strength (f'_{cr}) can be determined using the larger value calculated from the following two equations:

For $f'_c \leq 5000$ psi (34,475 kPa):

$f'_{cr} = f'_c + (1.34 \times mS)$ (English and Metric),

or

$f'_{cr} = f'_c + (2.33 \times mS) - 500$ psi (English); $f'_{cr} = f'_c + (2.33 \times mS) - 3{,}450$ kPa (Metric)

For $f'_c > 5000$ psi (34,475 kPa):

$f'_{cr} = f'_c + (1.34 \times mS)$ (English and Metric),

or

$f'_{cr} = 0.90 f'_c + (2.33 \times mS)$ (English and Metric)

If there are less than 15 tests or no test data available, the mix design target strength (f'_{cr}) is determined as follows:

Less Than 15 Tests or No Test Data Available:	Mix Design Target Strength
If $f'_c < 3{,}000$ psi	$f'_{cr} = f'_c + 1{,}000$ psi
If f'_c is 3,000 – 5,000 psi	$f'_{cr} = f'_c + 1{,}200$ psi
If $f'_c > 5{,}000$ psi	$f'_{cr} = 1.10 f'_c + 700$ psi

Less Than 15 Tests or No Test Data Available:	Mix Design Target Strength
If $f'_c < 20{,}685$ kPa	$f'_{cr} = f'_c + 6{,}895$ kPa
If f'_c is 20,685 – 34,475 kPa	$f'_{cr} = f'_c + 8{,}274$ kPa
If $f'_c > 34{,}475$ kPa	$f'_{cr} = 1.10 f'_c + 4{,}826$ kPa

Per ACI, f'_c is based on 28 day tests or as otherwise specified. For Department mix designs, f'_c will frequently be based on 14 day tests when f'_c is no more than 4000 psi (4,650 kPa) and 28 day tests when f'_c is greater than 4000 psi (4,650 kPa).

8.0 REQUIREMENTS FOR CONCRETE DURABILITY TEST DATA

The Department does not normally test concrete for freeze/thaw and salt scaling durability because of the following requirements:

- Concrete mix design procedures are specified.
- Concrete mix design parameters are specified, such as minimum cement, maximum finely divided minerals, maximum water/cement ratio and amount of air entrainment.
- Concrete coarse aggregates are specified to be freeze/thaw durable for certain construction items.

If the Contractor desires to create a new concrete mix design which is not within the mortar factor limits as listed in 2.8.2.2 "Design Mortar Factor," durability test data will be required by the Engineer. In no case shall the mortar factor exceed 0.86 for Class BS concrete, except when using structural lightweight concrete as noted in 2.8.2.2. Furthermore, in no case shall the fine aggregate portion exceed a maximum 50 percent by weight (mass) of the total aggregate used.

The Contractor shall have the durability tests performed by an independent laboratory accredited by the AASHTO Accreditation Program for AASHTO T 161 and ASTM C 672. Durability test data shall consist of the following:

- The new concrete mix design shall be tested according to AASHTO T 161, Procedure A or B. The new concrete mix design shall have a relative dynamic modulus of elasticity which is a minimum 80 percent of the initial modulus, after 300 cycles.
- The new concrete mix design shall be tested according to Illinois Modified ASTM C 672. An identical control mix shall be tested, except it shall have 565 lb/yd^3 (335 kg/m^3) of cement and no finely divided minerals. The average visual rating of the new mix design divided by the average visual rating of the control mix design shall not exceed 0.8 after 60 cycles.

9.0 DEPARTMENT CONCRETE MIX DESIGN VERIFICATION

9.1 VERIFICATION BY THE ENGINEER

A new concrete mix design will be verified by the Engineer from test information provided by the Contractor (optional), testing performed by the Engineer, applicable Department historical test data, target strength calculations, and previous Department experience.

For a mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department's historical test data shows compliance with specification requirements.

Verification of a mix design shall in no manner be construed as acceptance of any mixture produced. Tests performed at the jobsite will determine if a mix design can meet specifications.

9.2 TESTING PERFORMED BY THE ENGINEER

For a new mix design to be verified, the Engineer may require the Contractor to provide a batch of concrete for testing if one of the following applies:

- When the Engineer has a concern the mix design will not meet minimum strength requirements. As an example, this may occur for a mix that will be used in cool weather or requires high-early-strength.
- When the Engineer has a concern the mix design will not provide adequate workability, consistency, and plasticity in the field. As an example, this may occur when the mix is to be pumped or stone sand is to be used.
- When the District lacks experience or historical test data for the design parameters, gradations, or material sources used in the mix design.
- When the Contractor desires to use a mortar factor outside the limits as listed in 2.8.2.1 "Design Mortar Factor." Refer to 8.0 "Requirement for Concrete Durability Test Data" for additional information.

In addition, the Engineer may require the Contractor to provide a trial batch per Articles 1001.01(b); 1001.01(c); 1020.04, Table 1, Note 12; 1020.05(c)(1)d.; and 1020.05(c)(2)c.

The batch of concrete shall be provided at no cost to the Department.

The Engineer may require the Contractor to provide a sample of coarse aggregate, at no cost to the Department, to verify the coarse aggregate voids test value.

The Engineer may require the Contractor to provide material, at no cost to the Department, to perform durability testing according to ITP 161 and Illinois Modified ASTM C 672.

9.2.1 Procedure for Trial Batch

The procedure that follows shall be used to perform a trial batch unless specified otherwise in the contract plans.

The trial batch shall be performed in the presence of the Engineer, and the Engineer will perform all tests. The Contractor has the option to perform their own tests. The volume of the trial batch shall be a minimum of 2 yd^3 (1.5 m^3), but 4 yd^3 (3.0 m^3) is strongly recommended to more accurately evaluate the influence of mixing. If the mixer has a capacity less than 2 yd^3 (1.5 m^3), then the volume of the trial batch shall be no less than the capacity of the mixer.

For conventional concrete, batch at or near the maximum water/cement ratio or as requested by the Engineer. The air content should be within 0.5 percent of the maximum allowable specification value or as requested by the Engineer. Since it is difficult to entrain air in slipformed concrete, consult with the Engineer on an acceptable value. The slump should be within the allowable specification range. Testing will be performed according to Illinois Modified AASHTO R 60, T 23, T 119, T 152 or T 196, and Illinois Modified ASTM C 1064.

For the self-consolidating concrete, batch at or near the maximum water/cement ratio or as requested by the Engineer. The air content should be within 0.5 percent of the maximum allowable specification value or as requested by the Engineer. The slump flow, visual stability index, and J-ring value or L-box blocking ratio should be within the allowable specification range. Testing will be performed according to Illinois Test Procedures SCC-1, SCC-2, SCC-3, SCC-4, SCC-6, and Illinois Modified AASHTO R 60, T 23, T 152 or T 196, and Illinois Modified ASTM C 1064. Refer to Article 1020.04 to review the self-consolidating concrete specifications.

For all trial batches, strength will be determined for the test of record or at other ages determined by the Engineer. The test of record shall be the day indicated in Article 1020.04 or as specified. In all cases, strength will be based on the average of a minimum two 6- by 12-in. (150- by 300-mm) cylinder breaks, three 4- by 8-in. (100- by 200-mm) cylinder breaks, or two beam breaks tested according to Illinois Modified AASHTO T 22 or T 177. Per Illinois Modified AASHTO T 23, cylinders shall be 6 by 12 in. (150 by 300 mm) when the nominal maximum aggregate size of the coarse aggregate exceeds 1 in. (25 mm). Nominal maximum size is defined as the largest sieve which retains any of the aggregate sample particles.

As an option for all trial batches, Illinois Modified AASHTO T 121 may be performed.

9.2.1.1 Verification of Trial Batch, Voids Test, and Durability Test Data

The trial batch will be verified by the Engineer if Department test results meet specification requirements. The coarse aggregate voids will be verified by the Engineer if the Department test result is within 0.02 of the Contractor’s value. The Contractor’s durability test data will be verified by the Engineer if Department test results meet the requirements of 8.0 “Requirements for Concrete Durability Test Data.”

Note: Based on the concrete temperature used in the trial batch, the Engineer may request another trial batch to take into consideration the year round use of a mix design. For example, a mix design evaluated at a warm concrete temperature may need another evaluation at a cool concrete temperature to show the mix design is appropriate for cold weather.

Illinois Department of Transportation

PORTLAND CEMENT CONCRETE

LEVEL III

TECHNICIAN COURSE

APPENDICES

Revised: January 1, 2018

APPENDIX A

CONCRETE MIX DESIGN – DEPARTMENT PROVIDED (BDE)

Effective: January 1, 2012
Revised: January 1, 2014

For the concrete mix design requirements in Article 1020.05(a) of the Supplemental Specifications and Recurring Special Provisions, the Contractor has the option to request the Engineer determine mix design material proportions for Class PV, PP, RR, BS, DS, SC, and SI concrete. A single mix design for each class of concrete will be provided. Acceptance by the Contractor to use the mix design developed by the Engineer shall not relieve the Contractor from meeting specification requirements.

80277

This Page Reserved

APPENDIX B

PCC MIX DESIGN
MISTIC PRINTOUT AND INSTRUCTIONS

```
PROGRAM: DTGMIRFD              PCC MIX DESIGN                    MMTY3110.DOC
    TRANS: 110           CREATE, UPDATE, DELETE SCREEN
   SCREEN: DTY03110             (NEW  7/09/96)
ACTIVATED: /FOR DTY03110
  +--------------------------------------------------------------------------------+
LN¦COLS ....1.........2.........3.........4.........5.........6.........7.........8¦
NO¦1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0¦
  +--------------------------------------------------------------------------------¦
 1¦    DTT03110                     PCC DESIGN MIX                                 ¦
 2¦  CREATE: 1    UPDATE:        DELETE:                                   DATE    ¦
 3¦ PCC MIX #: ---3-----  MATERIAL: ---4----- --------5----------  EFFECT: --6---  ¦
 4¦ REF DESIGN #: ---7-----  CLASS: 8- -- -- -- --  LAST YR USED: 9-  TERM: -10--- ¦
 5¦ RESP: 11- ***12****** LAB: 13 ----14------- REVIEWED BY: --15------- DFLAG:16- ¦
 6¦ MIX PROD: --17---- -------18---------- CONTRACT: -----19----------             ¦
 7¦ BATCH     H20% FINE  %         (Z)   MORTOR  {TYPE}   {H20 L/kg}   {ABS. VOL}  ¦
 8¦ CU m  ADX RED  MOD  AIR VOIDS CEMENT FACTOR  ASH  FA   FA    CA    CA,B  FA,A  ¦
 9¦ -20^- -21 22^- -^23 24^  ^25  -26-   --^27   28   29   ^30-  ^31-  ^/32/ ^/33/ ¦
10¦                                               %BLEND/ %MOIST/ {kg/CU m}   LBS/ ¦
11¦ MATERIAL  PROD NO  PROD NAME           SP G  Z RATIO REPL    SSD   ADJ   CU YD¦
12¦ --34----- ---35--- ****36************** -^37-  38-^-  39^--   /40/  /41/  /42/ ¦
13¦ --------- -------- ******************** -^---  ---^-  --^--   ////  ////  //// ¦
14¦ --------- -------- ******************** -^---  ---^-  --^--   ////  ////  //// ¦
15¦ --------- -------- ******************** -^---  ---^-  --^--   ////  ////  //// ¦
16¦ --------- -------- ******************** -^---  ---^-  --^--   ////  ////  //// ¦
17¦ --------- -------- ******************** -^---  ---^-  --^--   ////  ////  //// ¦
18¦ {CA + FA}              {RATIOS}                      ADJ H20(kg:LBS) /43/  /44/ ¦
19¦       MIX H20: ^/45/  ASH/CMT WT: 46^/       TOTAL BATCH WT(kg:LBS) /47/  /48/ ¦
20¦   RED MIX H20: ^/49/                                                           ¦
21¦ TOTAL CEMENTITIOUS MATL: /50/                   THEO. WATER(kg:LBS) /51/  /52/ ¦
22¦ REMARKS: ---53------------------------------------------ THEO H20(GAL) 54^/   ¦
23¦ REMARKS: -----55----------------------------------------  ADJ H20(GAL) 56^/   ¦
24¦MESSAGES:                                                         PROCESS: _    ¦
  +--------------------------------------------------------------------------------¦
  ¦0........1.........2.........3.........4.........5.........6.........7.........8¦
  ¦1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0¦
  +--------------------------------------------------------------------------------+
 NOTES: 1). Messages:
             - ?? indicates required info is missing.
             - $$ indicates illegal field contents.
             - highlighted fields must be numeric.

 LEGEND
 / - Represent Calculated fields; /'s would NOT display on Create\Update screen.
 ^ - Represent the decimal position within a field; ^'s would NOT display on screen.
 > - Represent new fields and or lables; >'s would not appear on the screen.
 _ - Represent INPUT fields and locations; would be displayed on Create screen.
```

1. **Create :** This field may be left blank or a "Y" may be entered. As soon as this screen is fully metricated, the cursor will start in the "Calc" field. Since this is a create transaction, update and delete are not available. Once a mix design has been used, it should never be deleted.

2. **Cal:** Calculation flag. Enter "Y" to have the screen calculate the design. Type "N" and press " Enter" in order to manually enter data into all fields. Once " Enter" has been pressed, the "Calc" field may not be changed in the create mode. This is a new field that is not currently displayed but will be after the screen conversion is complete.

3. *** PCC Mix #:** Mix design number Example: 82PCC1234. Any combination of letters and numbers may be used in the last four digits.

4. *** Material:** Material code for the concrete mix. This should always be **metric**. Example: 21601M or 21605M.

5. **Material code name:** Based on the input material code, MISTIC displays the associated material code name.

6. *** Effect:** Effective date of the mix design, "mmddyy." This represents the date the mix design was available for use.

7. **Ref Design #:** Reference mix design number. If the mix design that is being created is similar to another one, then the similar design number can be entered here. When the "Enter" key is pressed all the design, component and remarks data will be automatically pulled from the referenced design into the new design. The data can be adjusted after entering a "N" in the process field. This will be working in the near future.

8. **Class:** Class of concrete. Example: BD for bridge deck (see spec book, pages 678-681). This field has five occurrences

9. **Last Yr Used:** This is the last year the mix design was used. **This is not an input field**. In the future, the year will be inserted/updated automatically each time the 654 screen creates a new record.

10. **Term:** Termination date of the mix design, "mmddyy." If a 654 or 655 transaction uses a sample date greater than the termination date of a mix design, then a warning message will be displayed.

11. *** Resp:** Responsible location. Enter the digit "9" followed by the district number. Based on the number entered, MISTIC will generate the responsible location name.

12. **Resp Name:** Based on the input responsible location number, MISTIC will display the associated responsible location name.

13. **Lab:** Laboratory associated with the creation of the design. Based on the number entered, MISTIC will generate the laboratory name. Example: FP, for district paper designs; DI, for district laboratory; PP, for producer paper designs; PL, producer laboratory designs etc. This field is not required but it should be used.

14. **Lab Name:** Based on the input lab acronym, MISTIC displays the associated lab name.

15. **Reviewed by:** Name of the person that has reviewed the design.

16. **Dflag:** Delete flag. A "D" should be entered if the mix design is no longer valid or no longer being used.

17. **Mix Prod:** Concrete mix producer number, Example: 1945-01. Based on the number entered, MISTIC will display the concrete mix producer name when the screen is processed. Optional field.

18. **Mix Prod Name:** Based on the input mix producer number, MISTIC will display the associated mix producer name.

19. **Contract:** Contract number. This may be filled in for a contract specific mix design. Optional field.

20. *** Batch, CU m:** Batch size in cubic meters. This field should always be filled in with the number "1".

21. **Adx:** Admixture type. Enter as follows: "W" = water reducer, "S" = superplasticizer, "R" = Retarder

22. **H_2O% Red:** Percentage of water reducer used. Example: 2.5.

23. **Fine Mod:** Fineness modulus of the fine aggregate used in the mix design. Example: 2.36.Optional field.

24. *** % Air:** Percentage of air entraining. Example: 1.5.

25. *** Voids:** Percentage of voids in the coarse aggregate used in the mix design, entered as a decimal. Example: 0.42.

26. *** (Z) Cement:** Theoretical or original/target cement quantity in kilograms per cubic meter. This will not be the actual cement quantity if the mix contains any cement replacement products (fly ash, GGBF slag, microsilica, etc.) Conversion Example: 6.05 cwt/yd^3 * 59.327583 = 359 kg/m^3, 605 lbs./yd^3 * 0.593276 = 359 kg/m^3.

27. *** Mortar Factor:** Ratio of the volume of the mortar to the coarse aggregate volume. Example: .80

28. **Type, Ash:** Single letter designation for the type of fly ash used in the mix design. Use "C" or "F".

29. **Type, FA:** Single letter designation for the type of fine aggregate. Related to the relative angularity. Use "A", "B", or "C".

30. **<u>* H_2O L/kg, FA:</u>** Water requirement for fine aggregate in liters per kilogram of cement/cementitious materials. This value is based on what letter is used in the "Type, FA" field. “A”= .426 (5.1), “B” = .442 (5.3), “C” = .459 (5.5) Conversion: gallons/cwt * .0834541 = liters/kg

31. **<u>* H_2O L/kg, CA:</u>** Water requirement for coarse aggregate in liters per kilogram of cement/cementitious material. For gravel, “0” is commonly used; for crushed stone, “0.2” is commonly used. Use the same metric conversion as fine aggregate 0.2 gal/cwt * .0834541 = 0.017 liters/kg.

32. **<u>Abs. Vol, CA,B:</u>** Absolute volume of coarse aggregate per cubic meter of concrete. Calculated field. The letter “B” is also known as V_{CA} in 2.10 “Summary of Mix Design Equations”.

33. **<u>Abs. Vol, FA,A:</u>** Absolute volume of fine aggregate per cubic meter of concrete. Calculated field. The letter “A” is also known as V_{FA} in 2.10 “Summary of Mix Design Equations”.

34. **<u>* Material:</u>** Component material codes. There are six occurrences of this field. All material codes must be metric (“M” in the 6th position). All aggregate material codes should be “A” quality or superstructure quality. Fly ash, ground granulated blast furnace slag, or microsilica should be input in the 5th occurrence. The cement material code should always be in the 6th occurrence. MISTIC will check the component material for being an acceptable product under the producer

35. **<u>* Prod No:</u>** Component material producer number.. It is required for all aggregate and fly ash components but **it is not required for cement**.

36. **<u>Prod Name:</u>** Component material producer name. **This is not an input field**. Based on the producer number input, MISTIC will display the associated producer name.

37. **<u>* Sp G:</u>** Specific gravity of each component material. The specific gravity value should be entered to the nearest .001. Example: 2.675. The specific gravity to be used for cement is 3.150.

38. **<u>* %Blend/Z Ratio:</u>** This field has two uses: 1) %Blend for aggregate components - when using a blend of coarse aggregates or a blend of fine aggregates, the blend percentage must be entered for each component type that has a blend. Example: blending CA11 and CA16 @ 75%/25%--a 75 must be entered for the CA11 and a 25 for the CA16. The same would be true for fine aggregates. If there is not a blend, then the value should be “100”. **Each component must have a value or the weights will not be calculated!** 2) Z Ratio for Fly ash and Cement components - when using fly ash the percentage of cement being replaced should be entered in this field for the fly ash material code. The remaining percentage should be entered for the cement. Example: 15 for fly ash and 85 for cement. If there is not any fly ash in the mix, then the value for cement should be “100”.

39. *** %Moist/Repl:** This field has two uses: 1) %Moisture for aggregate components - the percentage moisture greater or less than saturated surface dry must be entered using a "+" or "-" sign. Example: +1.00. If the value is zero, it should be entered as "0" without a "+" or "-" sign. 2) Replacement for fly ash and cement - for fly ash enter the replacement ratio. Example: +1.5 or +1.25. A "+1", should always be entered for cement. The requirement for the "+" will be removed in the near future.

40. **kg/CU m, SSD:** The saturated surface dry weight in kilograms per cubic meter for each component. Conversion: lbs./yd^3 * .593276 = kg/m^3. Calculated field.

41. **kg/CU m, ADJ:** The moisture adjusted weight in kilograms per cubic meter for each component. Calculated field.

42. **lbs/CU YD:** The weight of each component in pounds per cubic yard. Calculated field.

43. **ADJ H_2O, kg:** Adjusted water content in kilograms per cubic meter. Conversion: lbs/yd^3 * .593276 = kg/m^3. Calculated field.

44. **ADJ H_2O, lbs:** Adjusted water content in pounds per cubic yard. Calculated field.

45. **Mix-H_2O:** Mix water in liters per kilogram of cement. This is the sum of the water requirements for fine (FA,A) and coarse (CA,B) aggregate. Calculated field.

46. **Ash/Cmt Wt:** Ratio of the weight of fly ash (kg) to the weight of cement (kg) per cubic meter. Calculated field.

47. **Total Batch Wt, kg:** Total weight of the components (including water) in kilograms per cubic meter. Calculated field.

48. **Total Batch Wt, lbs:** Total weight of the components (including water) in pounds per cubic yard. Calculated field.

49. **Red Mix H_2O:** Reduced mix water. This is the mix water reduced by the amount of water reducer that has been added to the mix. Calculated field.

50. **Total Cementitious Matl:** This is the weight of the cement and the fly ash per cubic meter. This value is the sum of the cement and fly ash from the adjusted weight column. If only cement is used, then this value will be the same as the "Z Factor". If both cement and fly ash are used , then this value will be larger than the "Z Factor". Calculated field.

51. **Theo. Water, kg:** Theoretical water in kilograms per cubic meter. Calculated field.

52. **Theo. Water, lbs:** Theoretical water in pounds per cubic yard. Calculated field.

53. **Remarks:** First remarks line. When required to mitigate against alkali-silica reaction (ASR), indicate the mixture option selected for reducing the risk of deleterious reaction. Additionally, if applicable, indicate if synthetic fibers will be used in the mixture.

54. **Theo H_2O (Gal):** Theoretical water in gallons per hundredweight of cement. Calculated field.

55. **Remarks:** Second remarks line.

56. **Adj H_2O (Gal):** Adjusted water in gallons per hundredweight of cement. Calculated field.

Footnotes:

***** - Denotes a required input field

Additional Note:

Any fields labeled "calculated" are currently input fields but will become calculated fields after the enhancement of this screen is completed (in the very near future).

APPENDIX B-A

PCC MIX DESIGN SOFTWARE TUTORIAL

Version 2.4

For help, comments, and/or suggestions, please contact:

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!!! IMPORTANT !!! This spreadsheet utilizes macros. Depending on Excel's security settings, the macros may not be enabled. To change the macros settings for Excel, refer to the steps found at the end of this tutorial.

General

This spreadsheet is designed to calculate and report PCC mix designs for submittal to IDOT. The spreadsheet is comprised of data inputs based on the mix design methodology provided in the PCC Level III Technician course manual.

Buttons are provided for ease of navigation, and their use is recommended as they ensure proper operation throughout the design process. Using the worksheet tabs, found at the bottom of the Excel screen, will also work.

The blue-shaded areas are cells which require data input, green-shaded areas are optional (unless required by your District), and white cells are calculation fields, which are password protected from accidental overwriting.

Throughout the spreadsheet, comments have been interspersed to offer hints on where to find relevant information. To view comments, hold the cursor over the red tags found in the upper right hand corner of commented cells, as shown below. These comments generally refer to sections of the Course Manual; however, it should be noted that the Department's Standard Specifications and Special Provisions take precedence.

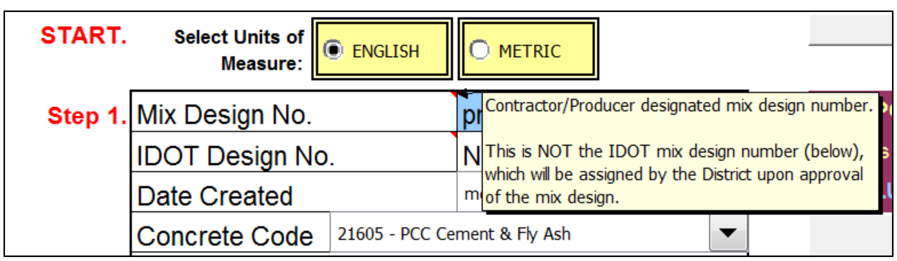


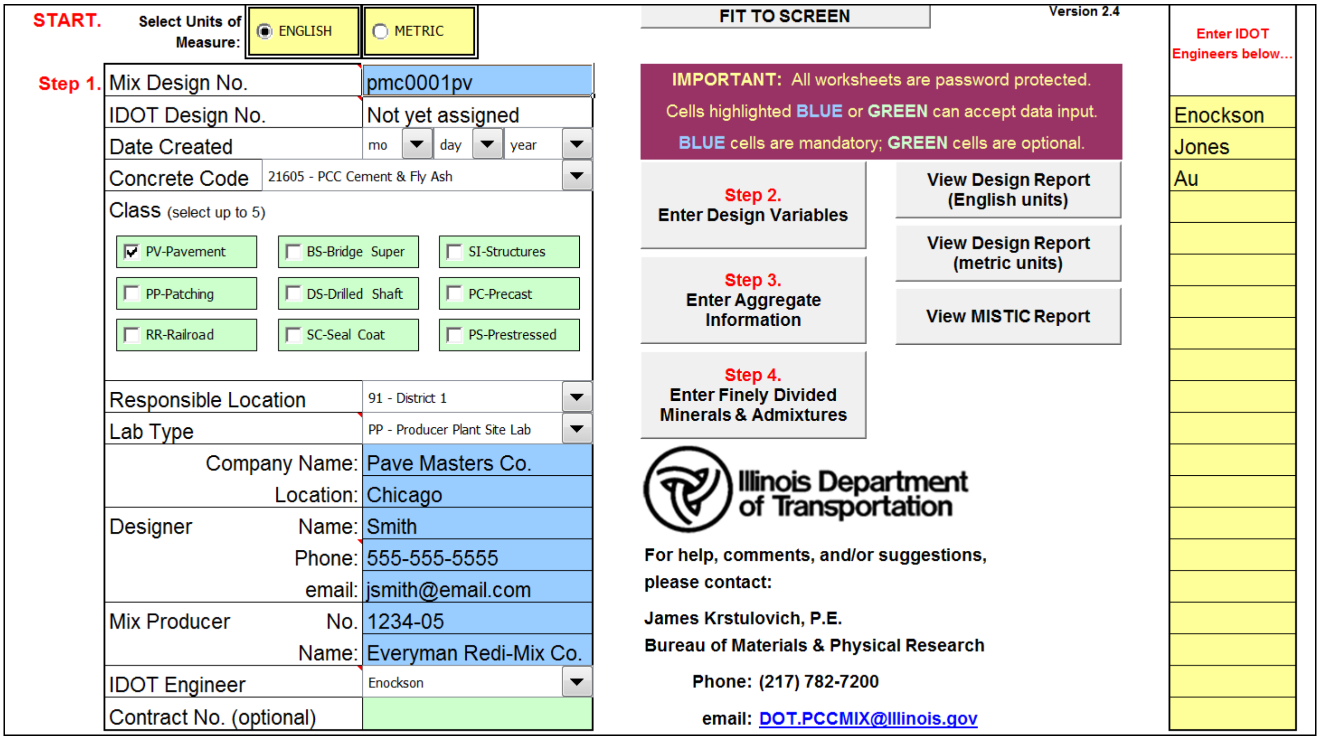
Figure 1. Example of a comment; note red flag, which indicates the cell has a comment.

Tutorial Mix Design

This tutorial also includes notes for how to input the example mix design discussed in Section 2.9 of the Course Manual. If you follow the notes in order as they are presented herein, you should successfully create a basic PCC paving mix design while also being introduced to all of the spreadsheet's functions and capabilities.

Step 1. Design Information

The Design Information page is important to establish the who-what-where of the mix design. This is where the designer decides in which units of measure the mix will be designed, what type of concrete it is, for what Classes of concrete it is valid, and those responsible for the mix design.



Fit to Screen [button]: Click this button to optimize each page of the mix design spreadsheet for viewing on your screen.

English/Metric [toggle]: Toggle button for selecting the units of measure for the mix design's inputs. All data inputs will have to be entered in the chosen units of measure. However, the design will be reported in **both** units of measure on the different final mix design reports generated.

EXAMPLE PROBLEM	Assuming most of us are more comfortable using English units of measure (lbs, yd^3, etc.), the example mix design will be designed using English units. Click on the **ENGLISH** toggle button.

Mix Design No.: Alphanumeric designation (up to nine characters in length). This is the Producer's or Contractor's self-designated mix design number; this is not the mix design number assigned by IDOT, see "IDOT Mix Design No." below.

EXAMPLE PROBLEM	Because this is the Producer's or Contractor's mix design number, any reasonably succinct and unique identifier can be used here, as long as it is no more than nine characters long. For this example, we will use **PMC0001PV** (i.e., Pave Masters Co. paving mix #1).

IDOT Mix Design No.: Nine character alphanumeric mix design number reported to the Department's MISTIC database. This number will be assigned by your District to an approved mix design.

EXAMPLE PROBLEM	Because this mix design number is assigned by the District upon approval, this cell reads **Not yet assigned**.

Date Created: The date the mix design was created.

Step 1. Design Information (continued)

Concrete Code: Select the appropriate material code. This code is used by the Department's MISTIC database to designate the type of concrete.

EXAMPLE PROBLEM	Because this mix will utilize Type I portland cement and Class C fly ash, the appropriate Concrete Code to select from the drop-down list is **21605**.

Class: Select up to five Classes of concrete.

EXAMPLE PROBLEM	Because this mix will be used for a continuously reinforced portland cement concrete pavement, the appropriate Class to select is **PV**.

Responsible Location: District responsible for mix design's use; for example, "91" for District 1.

EXAMPLE PROBLEM	Select one of the nine IDOT Districts with which you typically work; for example, select **91** if you often work with District 1 in the Chicago area.

Lab: Laboratory associated with the creation and/or testing of the design. For example: DI for district mix designs, or PP for producer mix designs. Contractors and Producers are to use "Producer" Lab codes. Consultants are to use "Independent" Lab codes.

Company Name: Name of laboratory responsible for creation and/or testing of mix design.

Location: Nearest municipality to Lab/Company.

Designer: Name, phone number, and email of person that created the design.

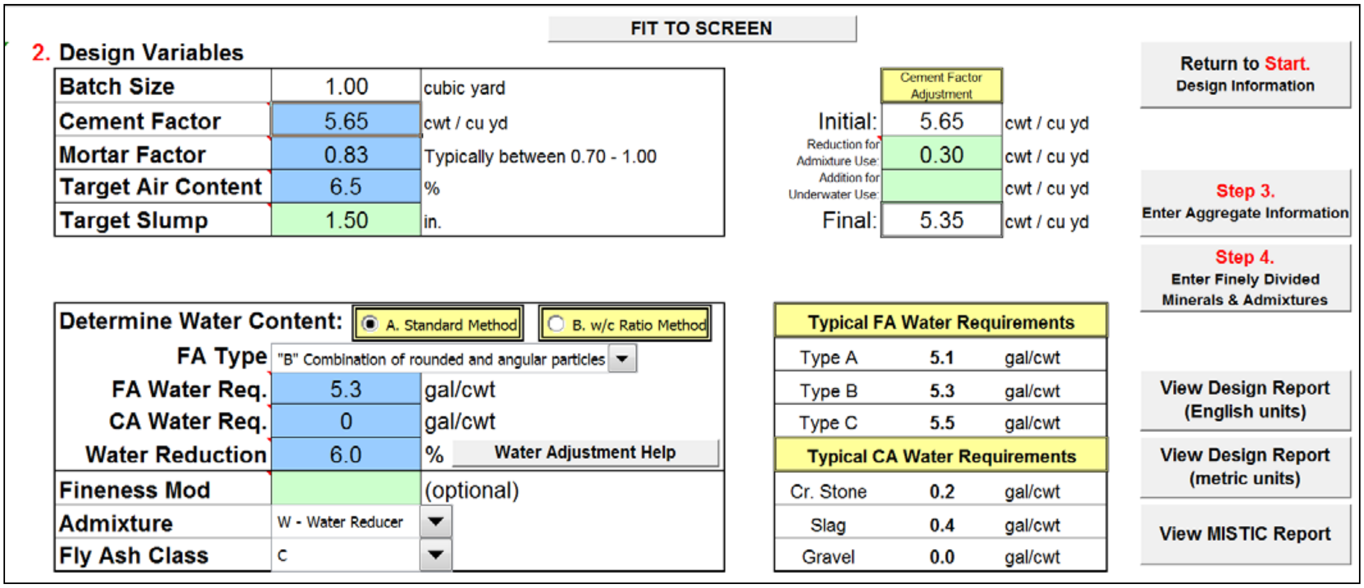
Mix Design Producer: MISTIC producer number and name of producer.

IDOT Engineer: This is the IDOT District representative to whom this mix design should be submitted for approval. Consult your District's Mixtures Control Engineer for more information. Use the yellow table to the right of the main input area to add names to the drop-down list.

Contract No.: (Optional) Either the five digit contract number, or if it is a local agency contract without a five digit number, then enter the MFT (Motor Fuel Tax) contract number.

Step 2. Design Variables

The Design Variables page is where the designer first begins to determine the mix design's parameters that factor into the mix design calculations.



Batch Size: Batch size in cubic yards (cubic meters). All mix designs are created per 1 yd^3 (1 m^3).

Cement Factor: Cement quantity in hundredweight per cubic yard (kilograms per cubic meter). Adjustments based on admixture use or underwater placement can be applied using the *Cement Factor Adjustment* table.

EXAMPLE PROBLEM	From Table 2.2.1 in the Course Manual, the cement factor for Class PV concrete from a central mixed plant is **5.65 cwt/yd³**. Also, from Section 2.2.2, a cement factor reduction of **0.30 cwt/yd³** can be applied because a water-reducing admixture will be used. Enter **0.30** in the appropriate box of the *Cement Factor Adjustment* table. Thus, the final, adjusted cement factor is reduced to **5.35 cwt/yd³**.

Mortar Factor: Refer to Table 2.8.2.3 *Design Mortar Factor* in the Course Manual.

EXAMPLE PROBLEM	From Table 2.8.2.3 in the Course Manual, a mortar factor can be selected for Class PV concrete. Enter **0.83** as a reasonable starting point.

Target Air Content: Percentage of entrained air in the concrete to improve durability. Refer to Table 2.7.1 *Air Content* in the Course Manual.

EXAMPLE PROBLEM	From Table 2.7.1 in the Course Manual, the midpoint of the air content range for Class PV concrete is **6.5%**.

Target Slump: Enter the target slump in inches (mm). Refer to Table 6.1 *Slump* in the Course Manual.

EXAMPLE PROBLEM	From Table 6.1 in the Course Manual, the slump range for Class PV concrete is 2 to 4 inches, except when slipformed, it is 1/2 to 2 1/2 inches (Table 6.1, Note 1). As noted in Section 6.1, experience has shown that a slump of 1/2 to 1-1/2 inches at the paver is typical for slipformed pavement construction, but many Contractors desire 1-1/2 inches to obtain a smooth pavement. Enter **1.5 inches**.

Step 2. Design Variables (continued)

Determine Water Content

First, using the toggle switch, select either the *Standard Method* or the *w/c Ratio Method*.

The *Standard* method requires the designer to enter fine and coarse aggregate water requirements, as well as percent water reduction. Refer to Section 2.5.1 *Water Requirement* in the Course Manual for more information.

Alternatively, the *w/c Ratio Method* will determine mix water based on the water/cement ratio (w/c) entered and the total content of cement and finely divided minerals. No water adjustment needs to be entered as it will be back-calculated based on the w/c ratio and aggregate water requirement inputs.

If the* Standard Method *has been selected, refer to the following inputs:

Determine Water Content:	A. Standard Method (selected)	B. w/c Ratio Method
FA Type	"B" Combination of rounded and angular particles	
FA Water Req.	5.3	gal/cwt
CA Water Req.	0	gal/cwt
Water Reduction	6.0	% Water Adjustment Help
Fineness Mod		(optional)
Admixture	W - Water Reducer	
Fly Ash Class	C	

Typical FA Water Requirements		
Type A	5.1	gal/cwt
Type B	5.3	gal/cwt
Type C	5.5	gal/cwt
Typical CA Water Requirements		
Cr. Stone	0.2	gal/cwt
Slag	0.4	gal/cwt
Gravel	0.0	gal/cwt

FA Type: Select fine aggregate type.

EXAMPLE PROBLEM	Because this mix will utilize a Type "B" fine aggregate, select **B** from the drop-down list.

FA Water Req.: Water requirement for fine aggregate in gallons per hundredweight (liters per kilogram) of cement and finely divided minerals. This value is based on the type of fine aggregate. For example, 5.1 gal/cwt (0.426 L/kg) is typical for Type "A" fine aggregate, as shown in the table, *Typical FA Water Requirements*.

EXAMPLE PROBLEM	Because this mix will utilize a Type "B" fine aggregate, the typical water requirement is **5.3 gal/cwt**.

CA Water Req.: Water requirement for coarse aggregate in gallons per hundredweight (liters per kilogram) of cement and finely divided minerals material. This value is based on the type of coarse aggregate. Typical values are provided in the table, *Typical CA Water Requirements*.

EXAMPLE PROBLEM	Because this mix will utilize a non-crushed gravel coarse aggregate, the typical water requirement is **0.0 gal/cwt**.

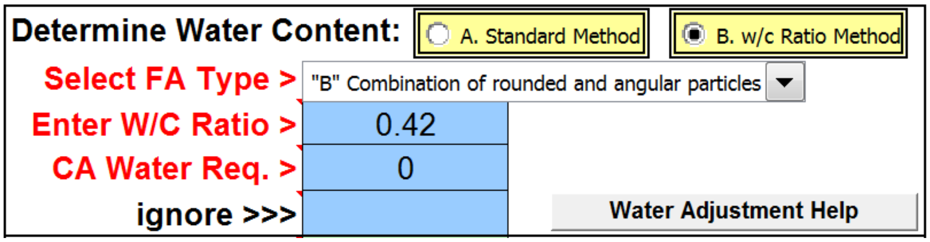
Water Reduction: Percentage of water adjustment (typically a reduction) taking into account various factors, such as admixture use, cement and finely divided mineral content, air content, etc. Note that because this input is referred to as a "reduction," the value entered may seem counter-intuitive; that is, a water reduction should be entered as a positive value, while a water addition should be entered as a negative value. For example, enter "10.0" for a 10 percent water reduction, and enter "-10.0" for a 10 percent water addition.

For help determining a reasonable water adjustment, click on the button, **Water Adjustment Help**. The Water Adjustment Help tab is modeled after Table 2.5.2 *Adjustment to Basic Water Requirement* in the Course Manual.

EXAMPLE PROBLEM	Because this mix will utilize a water-reducing admixture to provide a target water reduction of 6%, enter **6.0**. Note: If for some reason this mix needed a 6 percent water addition, you would have entered -6.0.

Step 2. <u>Design Variables</u> (continued)

If the* W/C Ratio Method *has been selected:



Enter W/C Ratio: When *w/c Ratio Method* is toggled, this field appears. Enter the target water/cement ratio that the design water will be based on; for example, 0.42.

It is still important to select the appropriate FA Type, as well enter the CA Water Requirement, so as to allow the spreadsheet to back-calculate the water reduction on the final mix design reports.

EXAMPLE PROBLEM	Another way to determine mix water is based on inputting a target water/cement ratio (w/c): In this example, per **Table 2.6.1** in the Course Manual, the maximum w/c for Class PV concrete is **0.42**. Also, by selecting the appropriate fine aggregate type ("B") and entering a reasonable water requirement for the coarse aggregate, the water reduction will be back-calculated on the final mix design reports.

Fineness Mod: (Optional) Fineness modulus of the fine aggregate used in the mix design; for example, 2.36. Fineness modulus is for informational purposes only; fineness modulus does not factor into proportioning calculations.

Admixture: Choose an admixture type: "W – water reducer", "S – superplasticizer", or "R – retarder".

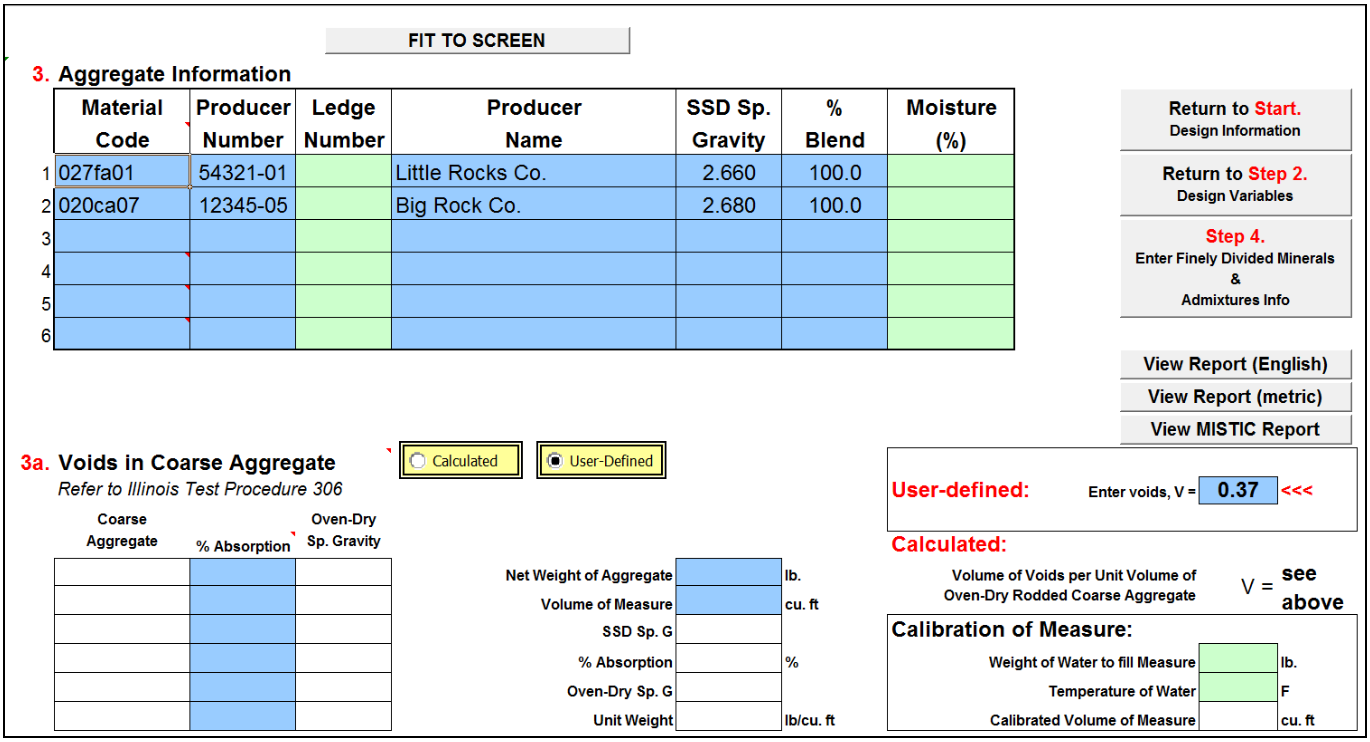
EXAMPLE PROBLEM	Because this mix will utilize a water-reducing admixture to meet the water/cement ratio requirement, select **W – Water Reducer** from the drop-down list.

Fly Ash Class: Choose the class of fly ash used in the mix design, if applicable.

EXAMPLE PROBLEM	Because this mix will utilize Class C fly ash, select **C** from the drop-down list. If this example did not utilize any fly ash, you would select "n/a".

Step 3. Aggregate Information

The Aggregate Information worksheet is where the designer enters all fine and coarse aggregate information. Note that although up to six aggregate materials can be accommodated by this spreadsheet, the Department's MISTIC database only allows a total of six materials, including cement and finely divided minerals. For example, four aggregates, one cement, and one finely divided mineral (e.g., fly ash); or three aggregates, one cement, and two finely divided minerals (e.g., fly ash and microsilica).



Material: Aggregate material codes. Coarse and fine aggregates may be entered in any order, except as required by your District. For more information regarding aggregate material codes, refer to form BMPR MI504 "Field/Lab Gradations".

EXAMPLE PROBLEM	• Fine aggregate: Enter **027FA01** as given in the Course Manual. This material code is for an "A" quality natural sand meeting the gradation criteria for FA 1 per Article 1003.01(c). • Coarse aggregate: Enter **020CA07** as given in the Course Manual. This material code is for an "A" quality non-crushed gravel meeting the gradation criteria for CA 7 per Article 1004.01(c).

Producer Number: Aggregate producer number. This field is required for all aggregate components.

Producer Name: Aggregate producer name.

Specific Gravity: Saturated Surface Dry (SSD) specific gravity of each aggregate.

EXAMPLE PROBLEM	The example problem as given in the Course Manual indicates that the saturated surface-dry specific gravities for the fine and coarse aggregate components are **2.66** and **2.68**, respectively.

Step 3. Aggregate Information (continued)

Agg. Moisture (%): Moisture of aggregates relative to SSD condition. If the percentage moisture is drier than SSD, it must be entered using a negative value (e.g., -1.00).

EXAMPLE PROBLEM	No aggregate moisture is indicated in the example problem as given in the Course Manual. Thus, it can be left blank.

% Blend: Percent blend for aggregate components. If only using one coarse aggregate and one fine aggregate material, enter "100" for each. On the other hand, if blending coarse aggregate materials, say, CA 11 and CA 16 at 75 and 25 percent, respectively, enter a "75" for the CA 11 and a "25" for the CA 16. Similarly, if blending fine aggregate materials. Do not blend coarse and fine aggregate, except as noted below for CAM II:

Note for CAM II designs *only*—Recommended % Blend of coarse-to-fine aggregate: 50-50 when using CA 7, CA 9, or CA 11; 75-25 when using CA 6; and 100-0 (i.e., no fine aggregate) when using CA 10. For example, when using CA 6 and FA 1, enter "75" for the CA 6 and "25" for the FA 1.

EXAMPLE PROBLEM	Because this mix is utilizing one coarse aggregate component and one fine aggregate component (and the mix is not CAM II), enter **100** for coarse aggregate and **100** for fine aggregate, as well.

Step 3a. Voids in Coarse Aggregate

The Designer has the option to either enter the Voids directly or calculate Voids by performing ITP 306, Voids Test of Coarse Aggregate for Concrete Mixtures, *which can be found in the* Manual of Test Procedures for Materials. *However, some Districts may provide a value for general aggregate types, such as* "0.36" *for gravels.*

If calculating the Voids, enter the "% Absorption", "Net Weight of Aggregate", *and* "Volume of Measure" *as determined while performing* ITP 306. *Consult your District for* "% Absorption" values. *(The* Calibration of Measure *is not required for every mix design, but is included for convenience.)*

3a. Voids in Coarse Aggregate (Calculated) (User-Defined)

Refer to Illinois Test Procedure 306

Coarse Aggregate	% Absorption	Oven-Dry Sp. Gravity
020CA07	-0.5	2.69

Net Weight of Aggregate	53.00	lb.
Volume of Measure	0.500	cu. ft
SSD Sp. G	2.68	
% Absorption	-0.5	%
Oven-Dry Sp. G	2.69	
Unit Weight	106.00	lb/cu. ft

< ignore

Calculated:

Volume of Voids per Unit Volume of Oven-Dry Rodded Coarse Aggregate V = **0.37**

Calibration of Measure:

Weight of Water to fill Measure	31	lb.
Temperature of Water	72	F
Calibrated Volume of Measure	0.5	cu. ft

If entering the Voids directly, toggle the "Enter Directly" button and input the appropriate value in the "User-defined" box. **Important:** *Enter* "1.00" *for any mix design that does not contain coarse aggregate.*

User-defined: Enter voids, V = **0.37** <<<

Calculated:

Volume of Voids per Unit Volume of Oven-Dry Rodded Coarse Aggregate V = **see above**

Calibration of Measure:

Weight of Water to fill Measure		lb.
Temperature of Water		F
Calibrated Volume of Measure		cu. ft

EXAMPLE PROBLEM	The example problem as given in the Course Manual notes that the Voids for the coarse aggregate is **0.37**.

Step 4. Finely Divided Minerals & Admixtures Information

This worksheet is where the designer enters all information pertaining to cement and finely divided minerals, as well as chemical admixtures (e.g., air-entraining water-reducing admixtures, etc.).

FIT TO SCREEN

4. Cement and Finely Divided Minerals Information

	Material Code	Producer Number	Producer Name	Specific Gravity	Percent Blend	Replacement Ratio
1	37601 Type I, Portland			3.150	75.0	
2	37801 Fly Ash Class C	555-05	City Electric Co.	2.610	25.0	
3	Select Slag...					
4	Select Other FDM...					
					100%	

Return to Start. Design Information

Return to Step 2. Design Variables

Return to Step 3. Aggregate Information

Report (English)

Report (metric)

MISTIC Report

5. Admixture Information

	Material Code	Admixture Type (ASTM C 494)	Product Name	Remarks (e.g. dosage rate)
1	42000	AEA - Air Entraining	Air Plus X	
2	43000	A - Water Reducer	Water Reducto 2000	
3		n/a		
4		n/a		

Latex Admixture Information

Batch Dosage		gal/cu yd
Specific Gravity		
% Solids		%

6. General Remarks

1 ASR Mix Option 2, 25% fly ash

2

Material: Cement and finely divided mineral (FDM) material codes. Each line is dedicated to a specific material: Line 1 for cement, Line 2 for fly ash, Line 3 for GGBF slag, and Line 4 for miscellaneous (e.g., microsilica, high-reactivity metakaolin, etc.).

EXAMPLE PROBLEM	Because this mix will utilize a Type I cement and Class C fly ash, Lines 1 and 2 will be used. • Cement: Because this mix is utilizing a Type I cement, select **37601 Type I, Portland** from the drop-down list. • Fly ash: Because this mix is utilizing a Class C fly ash, select **37801 Fly Ash Class C** from the drop-down list.

Producer Number: Material producer number. This field is required for all finely divided minerals.

Producer Name: Material producer name.

Specific Gravity: Specific gravity of each material. The specific gravity of cement is normally assumed to be 3.15. However, for a blended cement, this value should be verified with the District. Specific gravity values for finely divided minerals can be obtained from the Approved/Qualified Producer List of Finely Divided Minerals.

EXAMPLE PROBLEM	The example problem as given in the Course Manual notes that the specific gravity for the fly ash component is **2.61**. Although no specific gravity is given for the cement component, from Section 2.3 in the Course Manual, the specific gravity of cement is normally assumed to be **3.15**.

Step 4. Finely Divided Minerals & Admixtures Information (continued)

Percent Blend: The blend percentage must be entered for each material, totaling 100. For example, when blending fly ash and cement at 20 and 80 percent, respectively, enter "20" for the fly ash and "80" for the cement.

EXAMPLE PROBLEM	First, we have to determine if we need to mitigate for alkali-silica reaction (ASR): From Section 2.4.3 in the Course Manual, it is determined that the component aggregates are **Group II** (fine aggregate expansion in the **>0.16% - 0.27%** range and coarse aggregate expansion **≤0.16%**). Thus, we are required to use Mix Option 1, 2, 3, 4, or 5. Because the example problem as given notes that the mix will utilize a cement with alkali content >0.60% and a Class C fly ash, we will use **Mix Option 2**. Mix Option 2 requires a minimum 25.0 percent Class C fly ash. Furthermore, from Section 2.4.1.1 in the Course Manual, the Class C fly ash component can replace up to 30 percent of the cement. Thus, it is decided to use **30 percent** fly ash since fly ash is cheaper than cement, and will provide the most economical mix. Because the total Percent Blend must equal 100, enter **70.0** for the cement and **30.0** for the fly ash.

Replacement Ratio: (Optional) Enter the replacement ratio for each finely divided mineral, if applicable. If left blank, the default value of “1.00” will be used.

Step 5. Admixtures Information

Material Code: Enter admixture material codes here. The 5-digit material code for admixtures can be found on the Approved/Qualified Product List of Concrete Admixtures.

Admixture Type: Choose admixture type.

Admixture Name: Enter admixture product name here.

Remarks: Enter key information regarding proposed dosage rates, dosing procedures, etc.

Step 6. General Mixture Remarks

Remarks: Enter any pertinent information not already covered. When required to mitigate for alkali-silica reaction (ASR), indicate the mixture option selected.

EXAMPLE PROBLEM	Because we are required to mitigate for alkali-silica reaction, we must indicate the mixture option selected. Enter **ASR Mix Option 2, 30% fly ash**.

Latex Admixture Information (only required for mix designs using a latex admixture)

Batch Dosage: Enter latex admixture dosage in terms of gallons per cubic yard (liters per cubic meter).
Specific Gravity: Enter manufacturer’s specific gravity for the latex admixture.
% Solids: Enter manufacturer’s percent solids for the latex admixture.

Design Report

Given the inputs, the mix design proportions are calculated and reported. Three design reports are generated: one in English units of measure, one in metric (SI), and one formatted per the Department's MISTIC database requirements. Please consult your District for which report(s) to submit for approval.

ENGLISH UNITS DESIGN REPORT

DTT03110 PCC MIX DESIGN Version 2.4

Print English Report | View metric Report | View MISTIC Report | Design Information | Design Variables | Aggregate Information | Finely Divided Minerals & Admixtures

IDOT MIX #: **Not Assigned** MATERIAL: **21605** CONCRETE PC FLYASH EFFECTIVE: ____
CONTR MIX #: **PMC0001PV** CLASS: **PV**
RESP: **91** DISTRICT 1 LAB: **PP** Producer Plant Site REVIEWED BY: ____

BATCH CU YD	ADX	H2O% RED	FINE MOD	% AIR	VOIDS	(Z) CEMENT	MORTAR FACTOR	{TYPE} ASH	FA	{GAL/CWT} FA	CA	{ABS. VOL} CA,B	FA,A
1.00	**W**	**6.0**		**6.5**	**.37**	**5.35**	**0.83**	**C**	**B**	**5.30**	**0.00**	0.4315	0.2630

MATERIAL	PROD NO	PROD NAME	SP G	% BLEND	%MOIST / REPL	[LBS / CU YD] SSD	ADJ	[KG / CU M] ADJ
027FA01	**54321-01**	LITTLE ROCKS CO.	**2.660**	**100.0**	**0.00**	1178	1178	700
020CA07	**12345-05**	BIG ROCK CO.	**2.680**	**100.0**	**0.00**	1947	1947	1156
37601			**3.150**	**75.0**	**1.00**	405	405	240
37801	**555-05**	CITY ELECTRIC CO.	**2.610**	**25.0**	**1.00**	135	135	80
				ADJ. H2O (gal : lbs)		26.9	224	133
				TOTAL BATCH WT (lbs)			3889	2309

{FA + CA} MIX-H2O: 5.30 W/C RATIO: 0.42

TOTAL CEMENTITIOUS MATL: 5.40 THEO. H2O (gal : lbs) 26.9 224

PRODUCER: **1234-05** PROD NAME: **EVERYMAN REDI-MIX CO.**
REMARKS: ASR Mix Option 2, 25% fly ash CONTRACT
REMARKS:

ADDITIONAL INFORMATION: Lab: PAVE MASTERS CO. Location: CHICAGO Target
Designer: SMITH Created: Slump (in.) 1.5

Adx(s):

Matl Code	Type	Product	Remarks
42000	AEA	AIR PLUS X	
43000	A	WATER REDUCTO 2000	

Designer Phone: 555-555-5555
Designer email: jsmith@email.com
Cc: ENOCKSON Printed 12/6/2013

METRIC UNITS DESIGN REPORT

DTT03110 PCC MIX DESIGN Version 2.4

Print metric Report | View English Report | View MISTIC Report | Design Information | Design Variables | Aggregate Information | Finely Divided Minerals & Admixtures

IDOT MIX #: **Not Assigned** MATERIAL: **21605M** CONCRETE PC FLYASH EFFECTIVE: ____
CONTR MIX #: **PMC0001PV** CLASS: **PV**
RESP: **91** DISTRICT 1 LAB: **PP** Producer Plant Site REVIEWED BY: ____

BATCH CU M	ADX	H2O% RED	FINE MOD	% AIR	VOIDS	(Z) CEMENT	MORTAR FACTOR	{TYPE} ASH	FA	{L / KG} FA	CA	{ABS. VOL} CA,B	FA,A
1.00	**W**	**6.0**		**6.5**	**.37**	**320**	**0.83**	**C**	**B**	**0.4420**	**0.0000**	0.4315	0.2630

MATERIAL	PROD NO	PROD NAME	SP G	% BLEND	%MOIST / REPL	[KG / CU M] SSD	ADJ	[LBS / CU YD] ADJ
027FAM01	**54321-01**	LITTLE ROCKS CO.	**2.660**	**100.0**	**0.00**	700	700	1178
020CAM07	**12345-05**	BIG ROCK CO.	**2.680**	**100.0**	**0.00**	1156	1156	1947
37601M			**3.150**	**75.0**	**1.00**	240	240	405
37801M	**555-05**	CITY ELECTRIC CO.	**2.610**	**25.0**	**1.00**	80	80	135
				ADJ. H2O (L : kg)		133.0	133	224
				TOTAL BATCH WT (kg)			2309	3890

{FA + CA} MIX-H2O: 0.4420 W/C RATIO: 0.42

TOTAL CEMENTITIOUS MATL: 320 THEO. H2O (kg : lbs) 133.0 224

PRODUCER: **1234-05** PROD NAME: **EVERYMAN REDI-MIX CO.**
REMARKS: ASR Mix Option 2, 25% fly ash CONTRACT
REMARKS:

ADDITIONAL INFORMATION: Lab: PAVE MASTERS CO. Location: CHICAGO Target
Designer: SMITH Created: Slump (mm) 38.1

Adx(s):

Matl Code	Type	Product	Remarks
42000	AEA	AIR PLUS X	
43000	A	WATER REDUCTO 2000	

Designer Phone: 555-555-5555
Designer email: jsmith@email.com
Cc: ENOCKSON Printed 12/6/2013

MISTIC DESIGN REPORT

Print MISTIC Report	View English Report	View metric Report	Design Information	Design Variables	Aggregate Information	Finely Divided Minerals & Admixtures

PCC DESIGN MIX

PCC MIX #: [ ] MATERIAL: 21605M DATE EFFECT: [ ] (mmddyy)
REF DESIGN #: PMC0001PV CLASS: PV LAST YR USED: TERM:
RESP: 91 DISTRICT 1 LAB: PP REVIEWED BY: [ ] DFLAG:
MIX PROD: 1234-05 EVERYMAN REDI-MIX CO. CONTRACT:

BATCH CU m	ADX	H2O% RED	FINE MOD	% AIR	VOIDS	(Z) CEMENT	MORTAR FACTOR	{TYPE} ASH	{TYPE} FA	{H2O L/kg} FA	{H2O L/kg} CA	{ABS. VOL} CA,B	{ABS. VOL} FA,B
1.0	W	6.0		6.5	.37	320	0.83	C	B	0.4420	0.0000	0.4315	0.2630

MATERIAL	PROD NO	PROD NAME	SP G	%BLEND/ Z RATIO	%MOIST REPL	{kg / CU m} SSD	{kg / CU m} ADJ	LBS/ CU YD
027FAM01	54321-01	LITTLE ROCKS CO.	2.660	100.0	0.00	700	700	1178
020CAM07	12345-05	BIG ROCK CO.	2.680	100.0	0.00	1156	1156	1947
37801M	555-05	CITY ELECTRIC CO.	2.610	25.0	1.00	80	80	135
37601M			3.150	75.0	1.00	240	240	405

{CA + FA} {RATIOS} ADJ H2O (kg:LBS) 133 224
MIX-H2O: 0.4420 ASH/CMT WT: 33.3 TOTAL BATCH WT (kg:LBS) 2309 3890
RED MIX H2O: 0.4155
TOTAL CEMENTITIOUS MATL: 320 THEO. WATER (kg:LBS) 133 224
REMARKS: ASR Mix Option 2, 25% fly ash THEO H2O (GAL) 26.9
REMARKS: ADJ H2O (GAL) 26.9
Cc: ENOCKSON Designed By: SMITH Phone: 555-555-5555 W/C Ratio: 0.42
email: jsmith@email.com

Note: The MISTIC Report has three input fields ***to be completed upon receiving approval from the District***.

Additionally, there is a tab for help determining the percent water adjustment taking into account various factors. However, this table is for informational purposes only. The water adjustment calculated using this table is not referenced by any of the spreadsheet's mix design calculations. To use the water adjustment calculated using this table, **the value *must be entered* on the *Design Variable* tab**.

FIT TO SCREEN

Return to Design Variables

There are many factors that can be taken into account when determining a mix's water requirement. The table below allows you to estimate the percentage of water adjustment (typically a reduction) based on the mix's constituent materials. **IMPORTANT:** This table is for informational purposes only. The water adjustment calculated here is not referenced by any mix design calculations. To use the water adjustment calculated here, it must be entered on the **Design Variables** tab.

Water Adjustment	Suggested Range	Adjustment Percentage
Aggregate shape and texture: (Note 1)		
Baseline (cubical crushed stone)	(0%)	
Rounded, smooth	(-5 to 0%)	
Flat, elongated, rough	(0 to +5%)	
Combined aggregate grading:		
Well-graded	(-10 to 0%)	
Gap-graded	(0 to +10%)	
Admixture(s):		
Air entraining admixture — 1 to 3% air content	(0%)	
Minimum air content specified: 4 to 5% air content	(-5%)	
6 to 10% air content	(-10%)	
Normal water-reducing admixture	(-10 to -5%)	
Mid-range water-reducing admixture	(-15 to -8%)	
High range water-reducing admixture (Note 2)	(-30 to -12%)	
Finely Divided Minerals:		
Fly Ash (Note 3)	(-10 to 0%)	
Microsilica	(0 to +15%)	
High-Reactivity Metakaolin (HRM)	(-5 to +5%)	
Ground Granulated Blast Furnace (GGBF) Slag	(0%)	
Other factors:		
Coarse cement, water/cement ratio > 0.45, and concrete temperature < 60 °F (27 °C)	(-10 to 0%)	
Fine cement, water/cement ratio < 0.40, and concrete temperature > 80 °F (27 °C)	(0 to +10%)	
Cumulative Adjustment (%)		0
		0 %

Reference: Table 2.5.2 "Adjustment to Basic Water Requirement"
* PCC Level III Technician Course Manual

Note 1: It is recommended to adjust for aggregate shape and texture as described in Section 2.5.1.2* "Coarse Aggregate Water Requirement" and Section 2.5.1.3* "Basic Water Requirement."

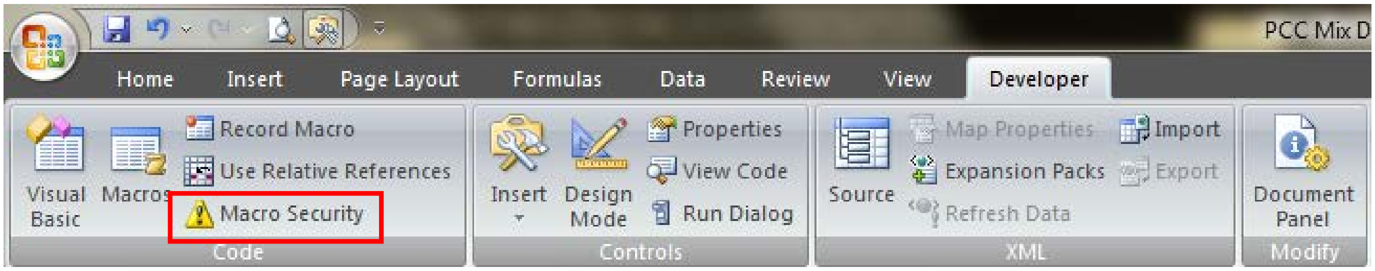
Note 2: A polycarboxylate superplasticizer may reduce the water content up to 40%.

Note 3: For each 10% of fly ash, it is recommended to allow a water reduction of at least 3%.

Changing Macro Security Settings in Microsoft Excel

Note: Any macro settings changes you make in Excel apply only to Excel and do not affect any other Office program.

To change the macro security settings in Excel 2007/2010/2013/2016:

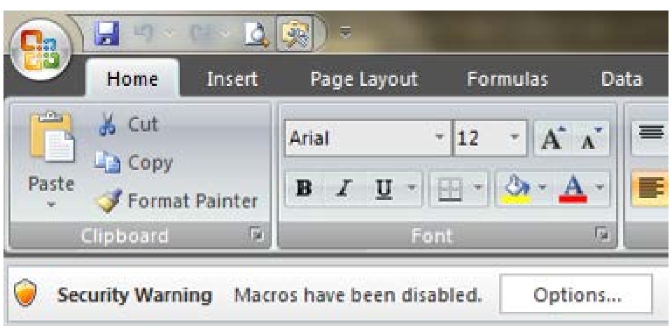


1. On the **Developer** tab*, in the **Code** group, click **Macro Security**.
2. In the **Macro Settings** category, under **Macro Settings**, click the 2nd option to **Disable all macros with notification**.

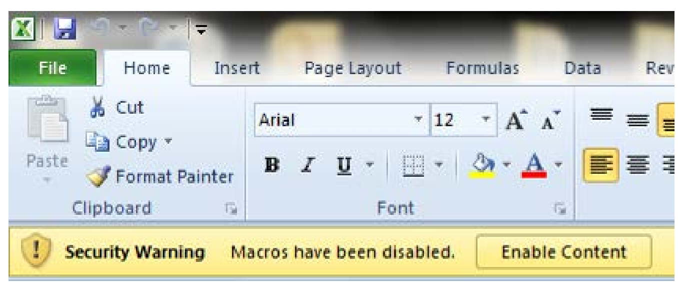
   This option initially disables macros, but alerts you if macros are present. This way, you can choose when to enable the macros on a case by case basis.
3. Now, close Excel, and re-open the PCC Mix Design spreadsheet.

   You should now get a **Security Warning** (below), click the **Options** button, then click to **Enable this content**, and finally click **OK** to close the window.

Office 2007



Office 2010



*** If the Developer tab is not displayed, follow these instruction:**

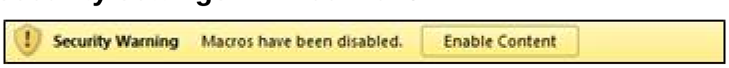
For Excel 2007:

1. Click the **Microsoft Office Button** 
2. Click **Excel Options** (bottom right corner)
3. In the **Popular** category, under **Top options for working with Excel**, click **Show Developer tab in the Ribbon**.

For Excel 2010:

1. Click the **File** tab, click **Options**, and then click the **Customize Ribbon** category.
2. In the **Main Tabs** list, check the **Developer**, and then click **OK**.
3. Click any other tab to return to your file.

To change the macro security settings in Excel 2013:

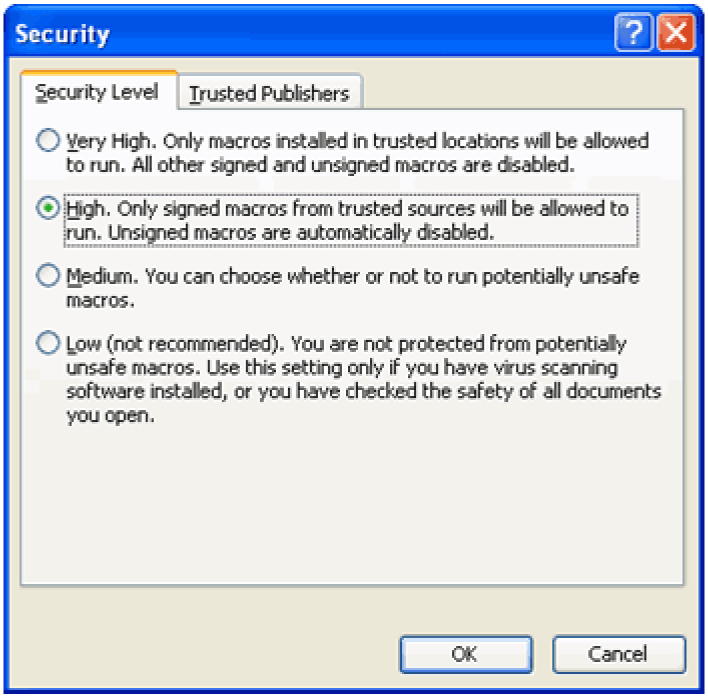


When you open a file that has macros, a yellow **Security Warning** (above) appears with a shield icon and an **Enable Content** button: click **Enable Content**. The file opens and is a trusted document.

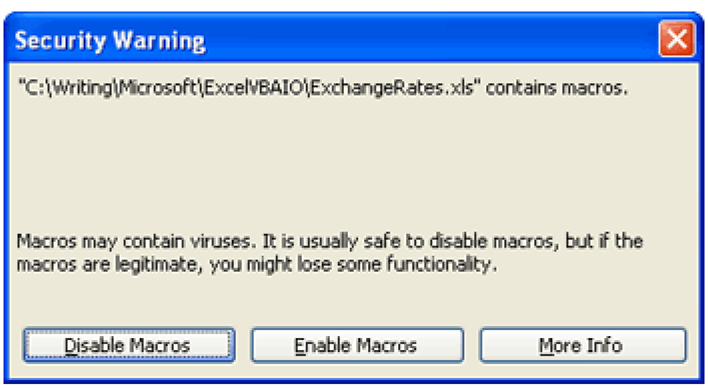
Changing Macro Security Settings in Microsoft Excel
(continued)

Older versions of Excel:

1. To access the macro security settings in older version of Excel, go to the **Tools** menu, **Options**, **Security** tab, and click on the **Macro Security** button. The **Security** window will open as shown:



2. Click on **Medium**, then click **OK**, and close Excel.
3. Re-open the PCC Mix Design spreadsheet. At **Medium**, whenever you open a file that has macros, a **Security Warning** (below) appears: click **Enable Macros**. The file opens and is a trusted document.



APPENDIX C

Illinois Test Procedure 306
Effective Date: April 1, 2008

VOIDS TEST OF COARSE AGGREGATE FOR CONCRETE MIXTURES

Reference Test Procedure(s):

1. Illinois Specification 101, Minimum Requirements for Electronic Balances

2. AASHTO M 231, Weighing Devices Used in the Testing of Materials

3. AASHTO T 255 (Illinois Modified), Total Moisture Content of Aggregate by Drying

4. ASTM E 29 (Illinois Modified), Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

To maintain brevity in the text, the following will apply:
Example: AASHTO T 255 (Illinois Modified) will be designated as "T 255."
ASTM E 29 (Illinois Modified) will be designated as "ASTM E 29."

1. GENERAL

The volume of voids per unit volume of dry rodded coarse aggregate relates experimental data to the theory of proportioning, which produces the amount of coarse aggregate needed in a concrete mixture. Voids may also be defined as the ratio of the volume of empty spaces in a unit volume of dry rodded coarse aggregate to the unit volume of dry rodded coarse aggregate.

All rounding shall be according to ASTM E 29.

2. EQUIPMENT

a. The measure shall be metal, cylindrical, watertight, and of sufficient rigidity to retain its form under rough usage. The top and bottom of the measure shall be true and even, and its sides should be provided with handles. The measure shall have a capacity of 0.014 or 0.028 m^3 (0.5 or 1.0 ft^3).

b. Tamping Rod—A round, straight steel rod 16 mm (5/8 in.) in diameter and at least 584 mm (23 in.) in length, having the tamping end or both ends rounded to a hemispherical tip the diameter of which is 16 mm (5/8 in.).

c. The balance or scale shall conform to M 231 and Illinois Specification 101. Refer to the requirements for unit weight.

3. PROCEDURE

a. Fill the measure with water at room temperature and cover with a piece of plate glass in such a way as to eliminate bubbles and excess water. The measure shall be calibrated by accurately determining the mass (weight) of water, to the nearest 0.05 kg (0.1 lb.), required to fill it. Calculate the Measure Volume according to Section 5.0.

b. The sample of aggregate shall be obtained and dried according to T 255, and shall be thoroughly mixed. When more than one size coarse aggregate is to be used in a mixture, the test shall be performed on the combination.

c. The measure shall be filled in three equal lifts. Level each lift with the fingers. Each layer shall be rodded 25 times when the measure's capacity is 0.014 m^3 (0.5 ft^3) or 50 times when the measure's capacity is 0.028 m^3 (1.0 ft^3).

Rodding shall be evenly distributed over the surface of the aggregate. The rodding should knead the layers together by the tamping rod extending slightly into the previous layer. Care shall be taken to rod immediately above the bottom of the measure without striking it.

d. With the final layer, the measure shall be filled to overflowing, rodded, and the surplus aggregate struck off, using the tamping rod as a straightedge.

e. The Net Mass (Weight) of the aggregate in the measure shall then be determined to the nearest 0.05 kg (0.1 lb.).

4. CALCULATIONS

a. The Unit Weight of the coarse aggregate is the Net Mass (Weight) of the coarse aggregate in the measure divided by the Measure Volume. Determine the Unit Weight to the nearest 0.01 kg/m^3 (0.01 lb/ft^3).

b. The volume of voids per unit volume of oven-dry rodded coarse aggregate is calculated to the nearest 0.01 as follows:

Metric:

$$\text{Voids, } V = \frac{(G_a \times 1000.00) - \text{Unit Wt.}}{G_a \times 1000.00}$$

English:

$$\text{Voids, } V = \frac{(G_a \times 62.37) - \text{Unit Wt.}}{G_a \times 62.37}$$

$$G_a = \frac{G_s}{\left(1 + \frac{A}{100}\right)}$$

Where: *Unit Wt.* is the unit weight of the coarse aggregate

G_a is the oven-dry specific gravity calculated to the nearest 0.01

G_s is the saturated surface-dry specific gravity of the coarse aggregate to the nearest 0.01, which is obtained from the Department's District office.

A is the percent absorption of the coarse aggregate to the nearest 0.1, which is obtained from the Department's District office.

When more than one size coarse aggregate is used in a mixture, calculate the oven-dry specific gravity for each aggregate. Then obtain a weighted average of the oven-dry specific gravity using the following formula.

$$WAG_a = \left(\frac{a}{100} \times A\right) + \left(\frac{b}{100} \times B\right) + \left(\frac{c}{100} \times C\right) + \ldots$$

Where: WAG_a = Weighted Average of Oven-dry Specific Gravity

a,b,c… = Percent of Total Coarse Aggregate

A,B,C…= Oven-dry Specific Gravity

The weighted average of the oven-dry specific gravity shall then be used in the Voids formula.

c. The test shall be performed at least twice. Test results with the same measure should check within 0.01.

5. CALIBRATION OF MEASURE

The Measure Volume is calculated to the nearest 0.01 m^3 (0.001 ft^3) as follows:

$$\text{Measure Volume} = \frac{M}{W}$$

Where: *M* = mass (weight) of water required to fill measure, kg (lb.)

W = unit weight of water (refer to Table 1), kg/m^3 (lb/ft^3)

Table 1. Unit Weight of Water

Temperature of Water		kg / m³	lb / ft³
°C	°F		
15.6	60	999.01	62.366
18.3	65	998.54	62.336
21.1	70	997.97	62.301
23.0	73.4	997.54	62.274
23.9	75	997.32	62.261
26.7	80	996.59	62.216
29.4	85	995.83	62.166

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APPENDIX D

WORKABILITY

1.0 PRINCIPLE FACTORS OF WORKABILITY

Workability is related to the ease of motion of one coarse aggregate particle relative to adjacent particles. The lubricating ability of the mortar depends on the thickness of the mortar layer and the viscosity of the mortar. Refer Figure 1.0.

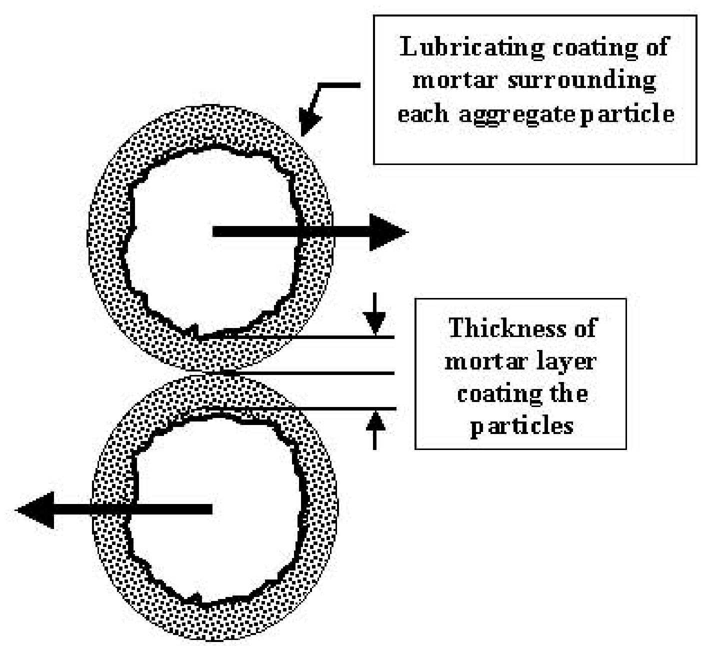


Figure 1.0 Mortar Layer Around Coarse Aggregate Particles

The thickness of the mortar layer depends on:
- Volume of coarse aggregate.
- Size and surface area of coarse aggregate.
- Shape and surface texture of aggregate particles.
- Volume of mortar.

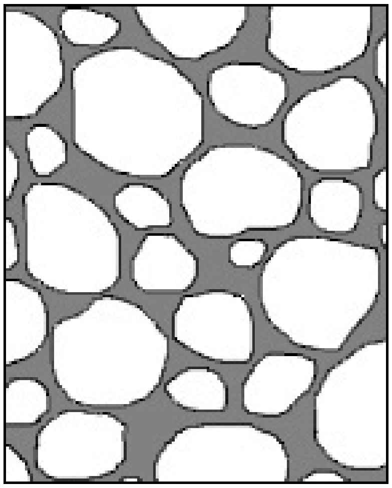
The mortar volume depends on:
- Water content.
- Volume of cement and finely divided minerals.
- Volume of air.
- Volume of fine aggregate.

The viscosity of the mortar depends on:
- Water content.
- Volume of cement and finely divided minerals.
- Particle shape and fineness of cement and finely divided minerals.
- Shape and fineness of fine aggregate.
- Air content.
- Water-reducing admixtures.
- Rate of hydration (accelerating and retarding admixtures, concrete temperature, cement type and type of finely divided minerals).

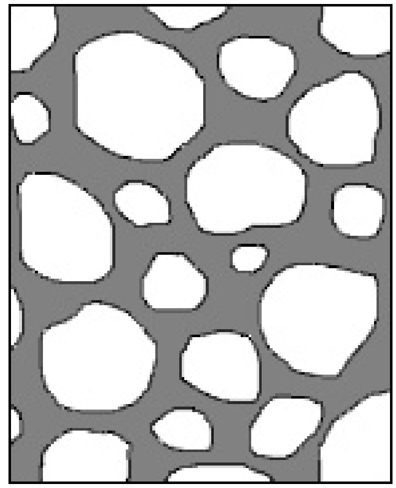
2.0 MORTAR AND WORKABILITY

The following sections illustrate the role of mortar and its influence on workability.

2.1 Mortar Illustration



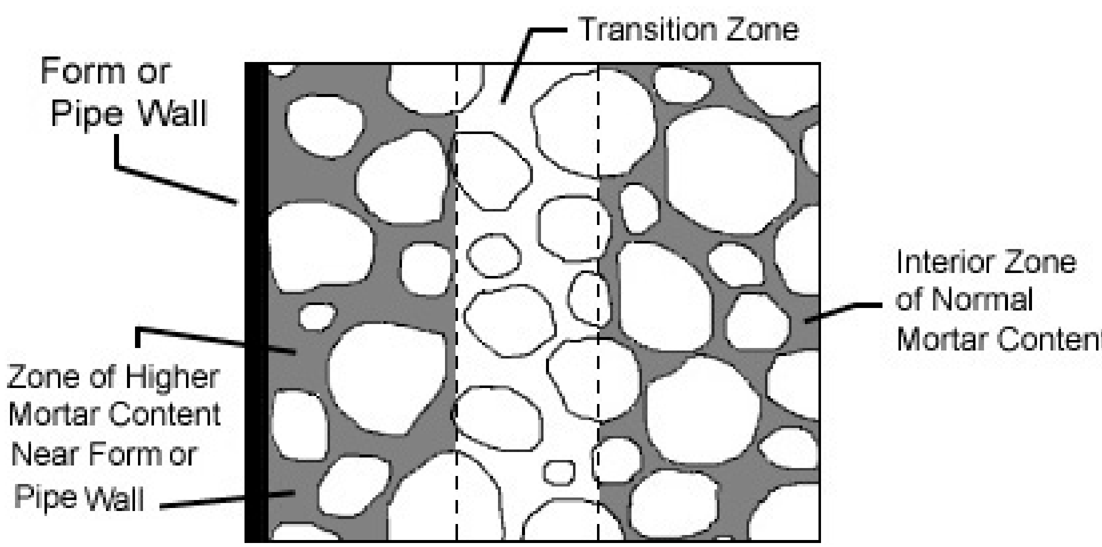
Concrete with low mortar content. This results in increased contact between coarse aggregate particles and decreases workability.



Concrete with high mortar content. This results in decreased contact between coarse aggregate particles and increases workability.

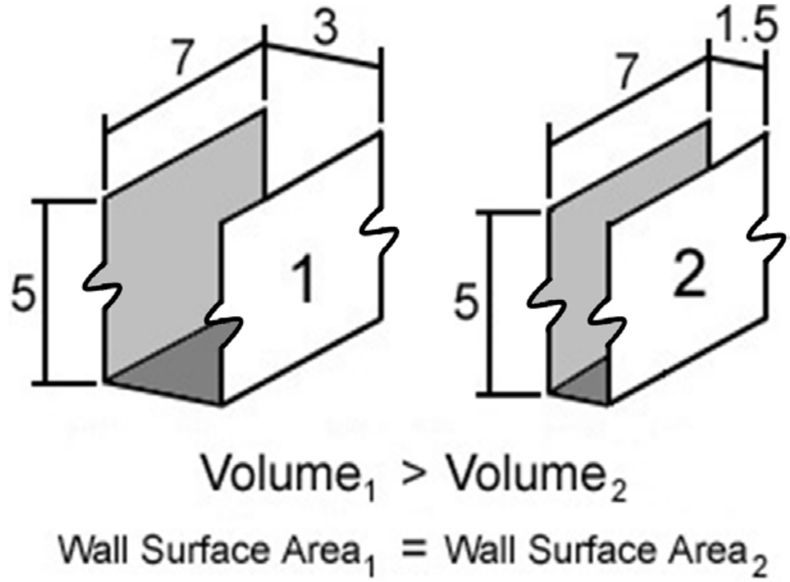
2.2 Mortar and Wall Effect

A higher mortar content is required at rigid boundaries, where the “wall effect” occurs. Examples of boundaries include structural members and pipe walls for pumping.

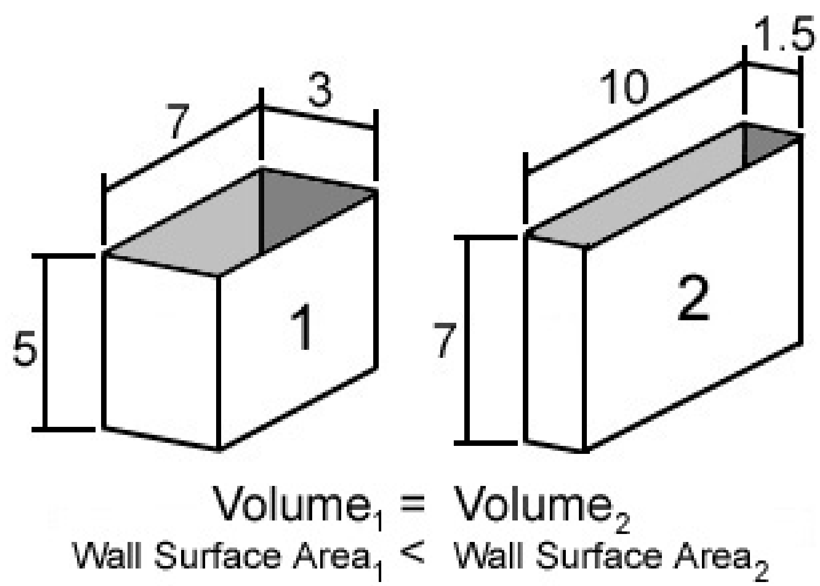


2.2.1 Mortar and Structural Member

The volume of mortar required for a smooth finish against formed surfaces (i.e., without honeycombing or "bug" holes) depends on the surface area to concrete volume ratio. For example, the volume of concrete decreases as the width of the structural member decreases (assuming all other dimensions are unchanged). However, the wall surface area remains the same. Thus, the reduced concrete volume has less mortar available to ensure a smooth finish. Therefore, a thinner structural member will require a higher mortar content.



As another example, two different structural members may have different dimensions, but require the same volume of concrete. A higher mortar content is required for the structural member with the higher surface area.



2.2.2 Mortar and Pipe Wall

A higher mortar content is required for smaller diameter concrete pump pipelines. For example, a 4 inch (102 mm) diameter pipe has a higher surface area to concrete volume ratio than a 5 in. (127 mm) diameter pipe.

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APPENDIX E

AGGREGATE BLENDING

1.0 AGGREGATE BLENDING

The grading, or particle size distribution, of an aggregate can have a significant influence on a concrete mixture. The two types of grading are as follows:

- Uniformly Graded – Aggregates which do not have a large deficiency or excess of any particle size. Also known as Well Graded or Continuously Graded.
- Gap Graded – Aggregates which have specific particle sizes omitted or are minimal.

Many Illinois coarse aggregates are gap graded, typically having a small amount of material passing the 1/2 in. (12.5 mm) sieve. Experience has shown that when the percent finer than 1/2 in. (12.5 mm) is below 40 percent, placement problems (such as when pumping) may occur. In order to improve workability and minimize potential problems, a second coarse aggregate is blended in to fill the gap.

Furthermore, the combined gradation of the coarse and fine aggregate has a significant impact on several mix characteristics: ease of placing, pumping, consolidating, and finishing, as well as water demand of the mix.

Blending aggregates may be specified as per Article 1004.02(d), or alternate combinations of gradation sizes may be used with the approval of the Engineer according to Article 1020.04, Table 1, Note 14.

1.1 Aggregate Blending Characterization

Over the years, a number of analytical methods have been developed to characterize the combined aggregate gradation, or blend. Three such methods will be discussed further in this section: the “8-18” Rule, the “Tarantula” Curve, and the 0.45 Power Curve.

First, it is necessary to know how to calculate the aggregate blend when combining aggregates. The formula for determining the total blend on a particular sieve is as follows:

$$TB = (\frac{a}{100} \times A) + (\frac{b}{100} \times B) + (\frac{c}{100} \times C) + \ldots$$

Where: TB = Total Blend of Aggregate either Passing or Retained on the Sieve,
a, b, c… = Percent of Total Aggregate, and
A, B, C… = Percent of Aggregate either Passing or Retained on the Sieve

For example, the percent passing the 3/8 in. (9.5 mm) sieve of the aggregate blend described in Table 1.1.1 is calculated as follows:

$$TB = (\frac{60}{100} \times 11\%) + (\frac{40}{100} \times 100\%)$$

$$TB = 6.6 + 40$$

TB = 46.6, or 47 percent after rounding

Table 1.1.1 is an illustration of a single coarse aggregate (gap graded) with a single fine aggregate. As described in Table 1.1.2, a second coarse aggregate (in this case, CA 16) is used to improve the aggregate blend. This data will be used to illustrate the "8-18" Rule, the "Tarantula" Curve, and 0.45 Power Curve.

Table 1.1.1 Gap Graded Aggregate Mix Design

Sieve Size (English)	Sieve Size (metric)	CA 07, a = 60%		FA 01, b = 40%		Aggregate Blend	
		% Passing A	% Retained A	% Passing B	% Retained B	%Passing TB	%Retained TB
1	25 mm	100	0	100	0	100	0
3/4	19 mm	86	14	100	0	92	8
1/2	12.5 mm	37	49	100	0	62	30
3/8	9.5 mm	11	26	100	0	47	15
No. 4	4.75 mm	2	9	97	3	40	7
No. 8	2.36 mm	2	0	89	8	37	3
No. 16	1.18 mm	2	0	77	12	32	5
No. 30	600 μm	2	0	53	24	22	10
No. 50	300 μm	2	0	12	41	6	16
No. 100	150 μm	2	0	2	10	2	4
No. 200	75 μm	1.4	0.6	0.5	1.5	1.0	1

Table 1.1.2 Blended Aggregate Mix Design

Sieve Size (English)	Sieve Size (metric)	CA 07, a = 45%		CA 16, b = 15%		FA 01, c = 40%		Aggregate Blend	
		% Pass. A	% Ret. A	% Pass. B	% Ret. B	% Pass. C	% Ret. C	% Passing TB	% Retained TB
1	25 mm	100	0	100	0	100	0	100	0
3/4	19 mm	86	14	100	0	100	0	94	6
1/2	12.5 mm	37	49	100	0	100	0	72	22
3/8	9.5 mm	11	26	96	4	100	0	59	13
No. 4	4.75 mm	2	9	28	68	97	3	44	15
No. 8	2.36 mm	2	0	5	23	89	8	37	7
No. 16	1.18 mm	2	0	3	2	77	12	32	5
No. 30	600 μm	2	0	3	0	53	24	23	9
No. 50	300 μm	2	0	2	1	12	41	6	17
No. 100	150 μm	2	0	2	0	2	10	2	4
No. 200	75 μm	1.4	0.6	1.9	0.1	0.5	1.5	1.1	0.9

1.1.1 The "8-18" Rule

The "8-18" Rule is one method to characterize an aggregate blend. In this rule, the percent retained on every sieve (except the top two and bottom two sieves) should be between 8 and 18 percent. This ensures that the peaks and valleys are not too severe. Figure 1.1.1.2 illustrates a typical gap graded aggregate mix design based on the data in Table 1.1.1. On the other hand, using the improved aggregate blend in Table 1.1.2, Figure 1.1.1.3 illustrates the benefits of blending another aggregate to normalize the peaks and valleys.

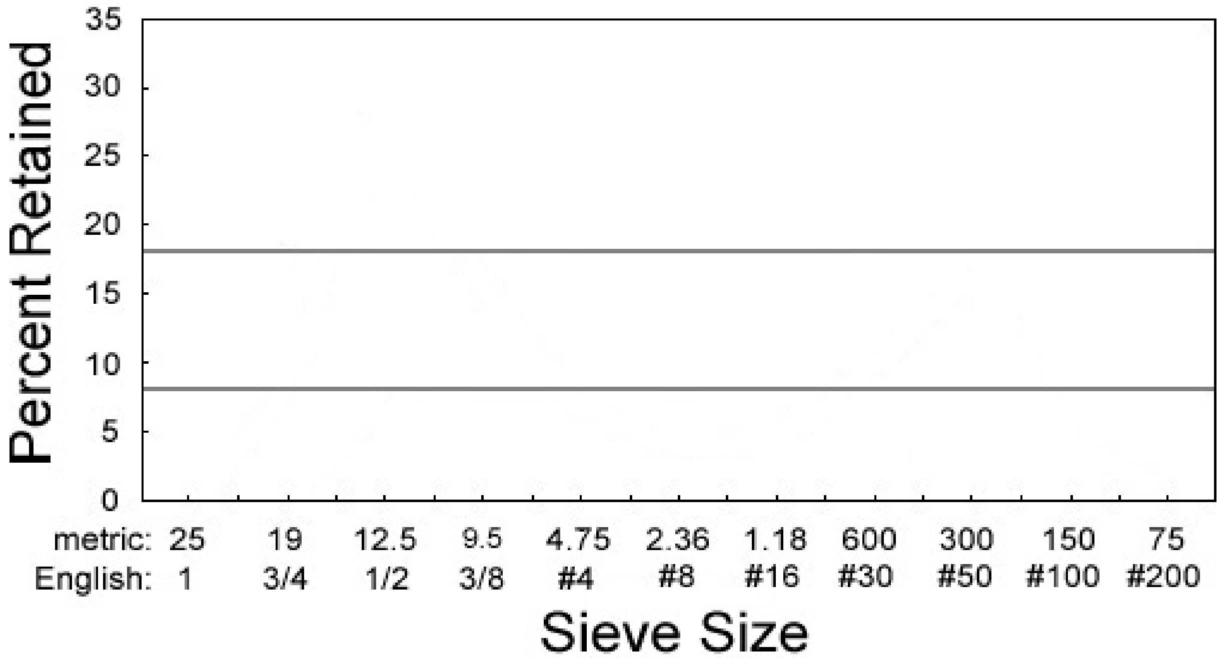


Figure 1.1.1.1 The "8-18" Rule

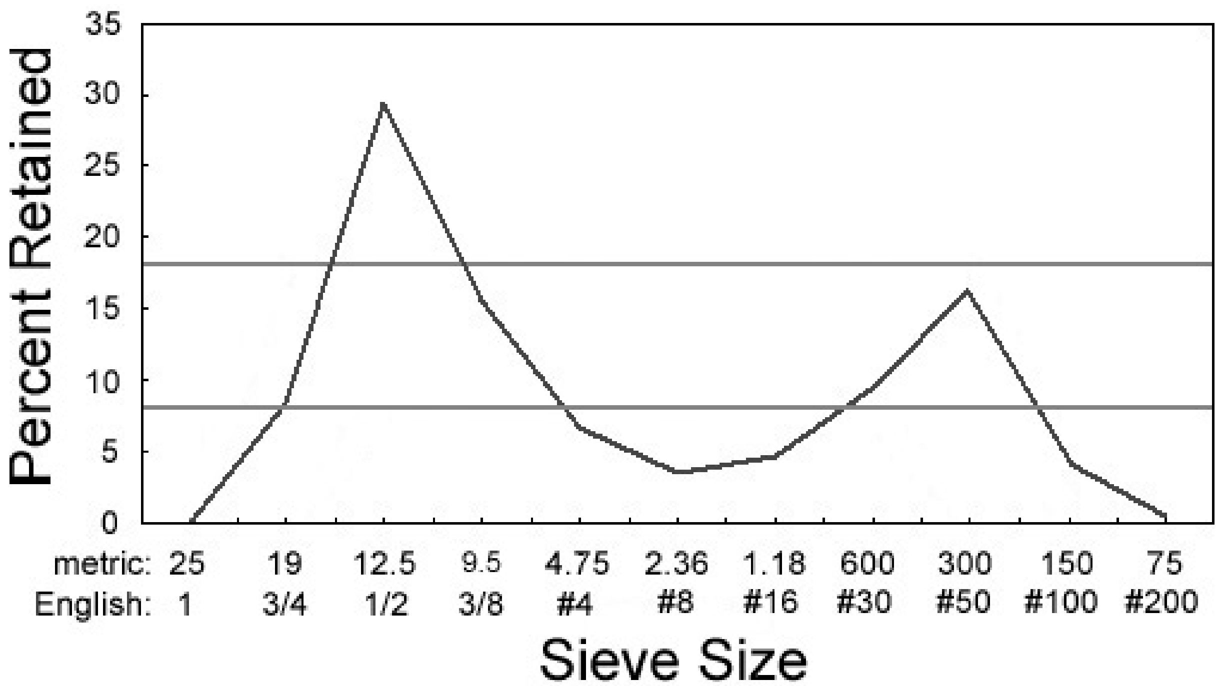


Figure 1.1.1.2 Gap Graded Aggregate Mix Design (referencing Table 1.1.1)

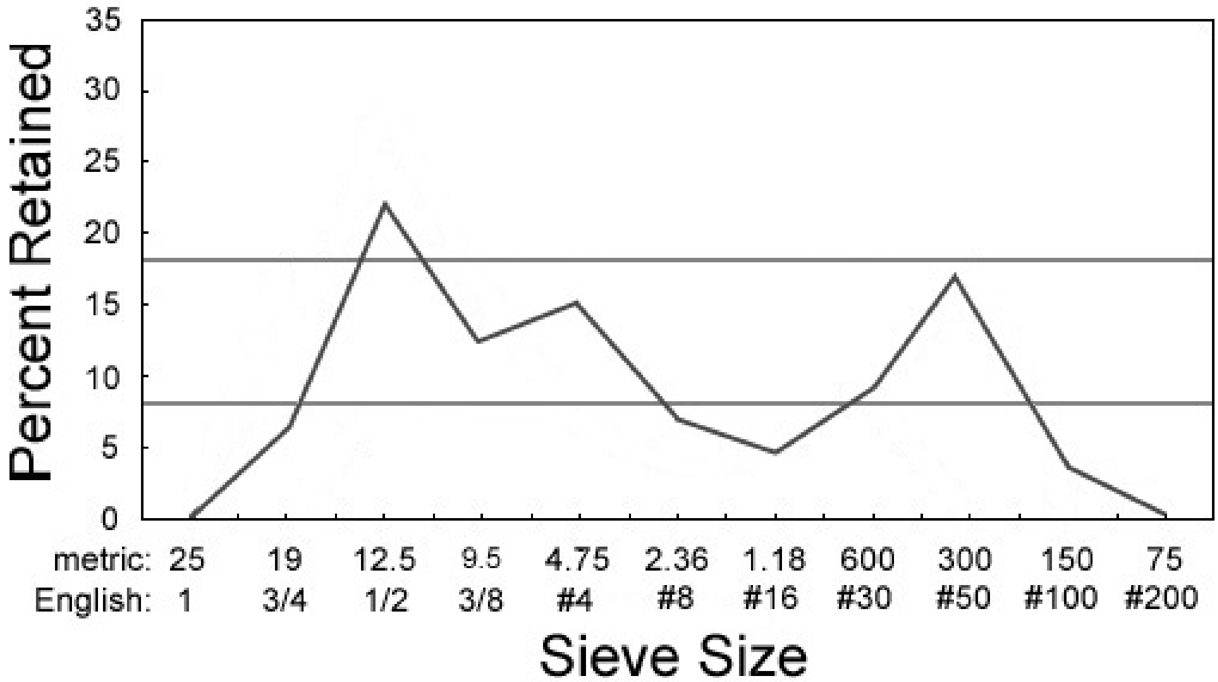


Figure 1.1.1.3 Blended Aggregate Mix Design (referencing Table 1.1.2)

Illinois aggregates cannot normally be combined to stay within the "8-18" rule, but they can be blended to lower the peak typically present on the 1/2 in. (12.5 mm) sieve. For example, as demonstrated in the figures, a CA 16 aggregate can be blended with a gap graded CA 07 or CA 11 to reduce the amount of material retained on the 1/2 in. (12.5 mm) sieve. As a rule of thumb, it is recommended to keep the difference between two sieves at 13 percent or less.

With most FA 01 and FA 02 aggregates, there will be a peak at the No. 50 (300 μm) sieve and a valley just before this peak, between the No. 8 (2.36 mm) and No. 16 (1.18 mm) sieves. Knowing this, it is important to remember that the amount of material passing the No. 30 (0.6 mm) sieve, but retained on the No. 50 (0.3 mm) sieve, is critical for holding entrained air bubbles in the mix. In addition, material between the No. 30 (0.6 mm) and No. 100 (0.15 mm) sieves is the most effective for entraining air.

As a final comment on the "8-18" rule, the 8 percent and 18 percent limits should be used only as a guide. Aggregate angularity (round vs. angular) and aggregate particle shape (flat and elongated) are not reflected in the "8-18" rule. For example, if the 3/8 in. (9.5 mm) to No. 16 (1.18 mm) sieve range contains 18 percent angular material, the concrete mixture would be gritty and difficult to finish. If the aggregate is flat and elongated, it may be more appropriate to have 4 to 8 percent retained on a given sieve.

1.1.2 The "Tarantula" Curve

Similar in concept to the "8-18" Rule, the "Tarantula" Curve is the result of research at Oklahoma State University for the Oklahoma DOT, and has been corroborated by data provided by the Iowa and Minnesota DOTs. Essentially, it provides a series of limits on percent retained for a combined gradation suited specifically to slipform construction.

The research suggests a minimum 15 percent cumulatively retained on the No. 8 (2.36 mm), No. 16 (1.18 mm), and No. 30 (0.6 mm) sieves; however, the amount retained on the No. 8 (2.36 mm) and No. 16 (1.18 mm) sieves individually should not exceed 12 percent.

Furthermore, it is recommended to have 24 to 34 percent of the total aggregate volume between the No. 30 (0.6 mm) and No. 200 (0.3 mm) sieves. Refer to Figure 1.1.2.

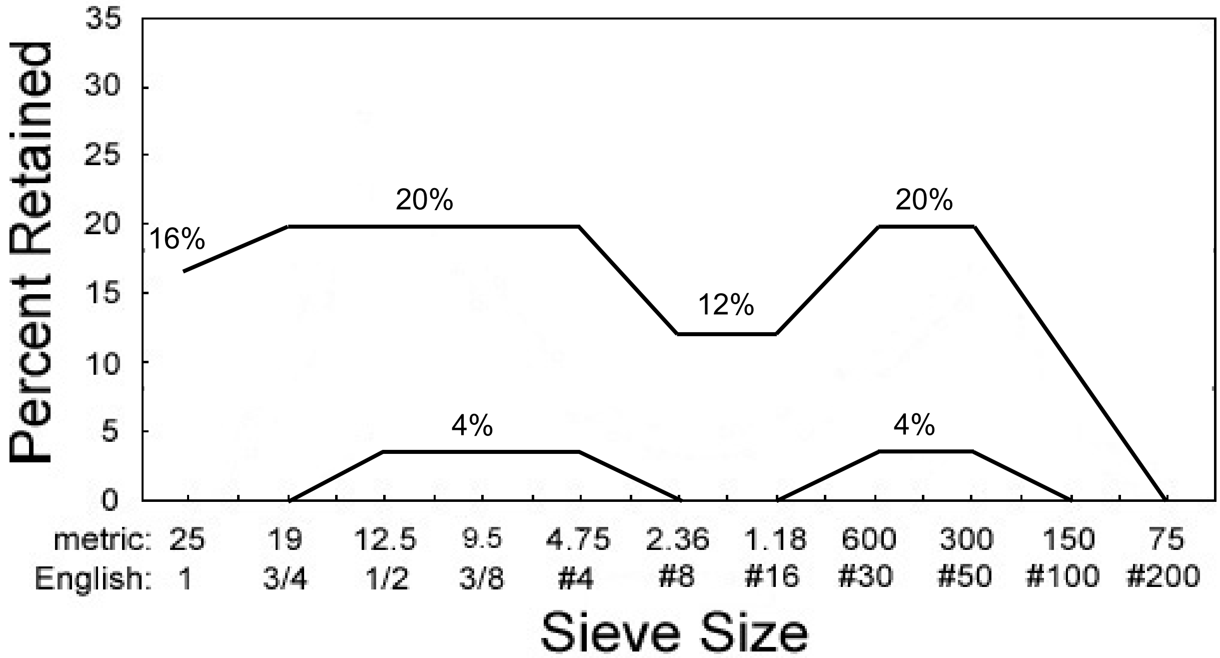


Figure 1.1.2 The "Tarantula" Curve (Oklahoma State University)

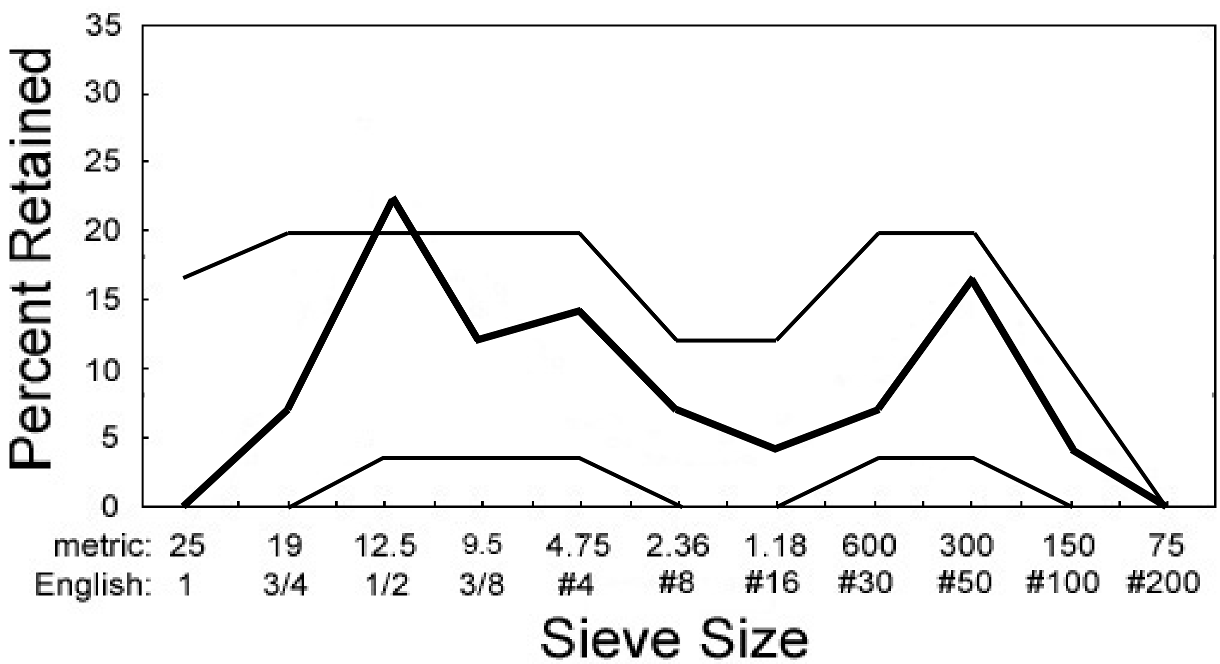


Figure 1.1.3 Blended Aggregate Mix Design (referencing Table 1.1.2)

1.1.3 The 0.45 Power Curve

The 0.45 Power Curve is another method to characterize an aggregate blend. Gap graded aggregate and blended aggregate gradation mix designs are plotted together on the 0.45 power curve in Figure 1.1.2, using Tables 1.1.1 and 1.1.2. When a second coarse aggregate material

(CA 16) is blended with the gap graded aggregate, the plotted line shifts closer to the theoretical optimum, indicating a more uniform combined gradation. The theoretical optimum gradation line originates at the bottom left corner and extends upward to the nominal maximum size. If the plotted line is located to the left of the theoretical optimum gradation line, this indicates a finer gradation. If the plotted line is located to the right of the theoretical optimum gradation line, this indicates a coarser gradation.

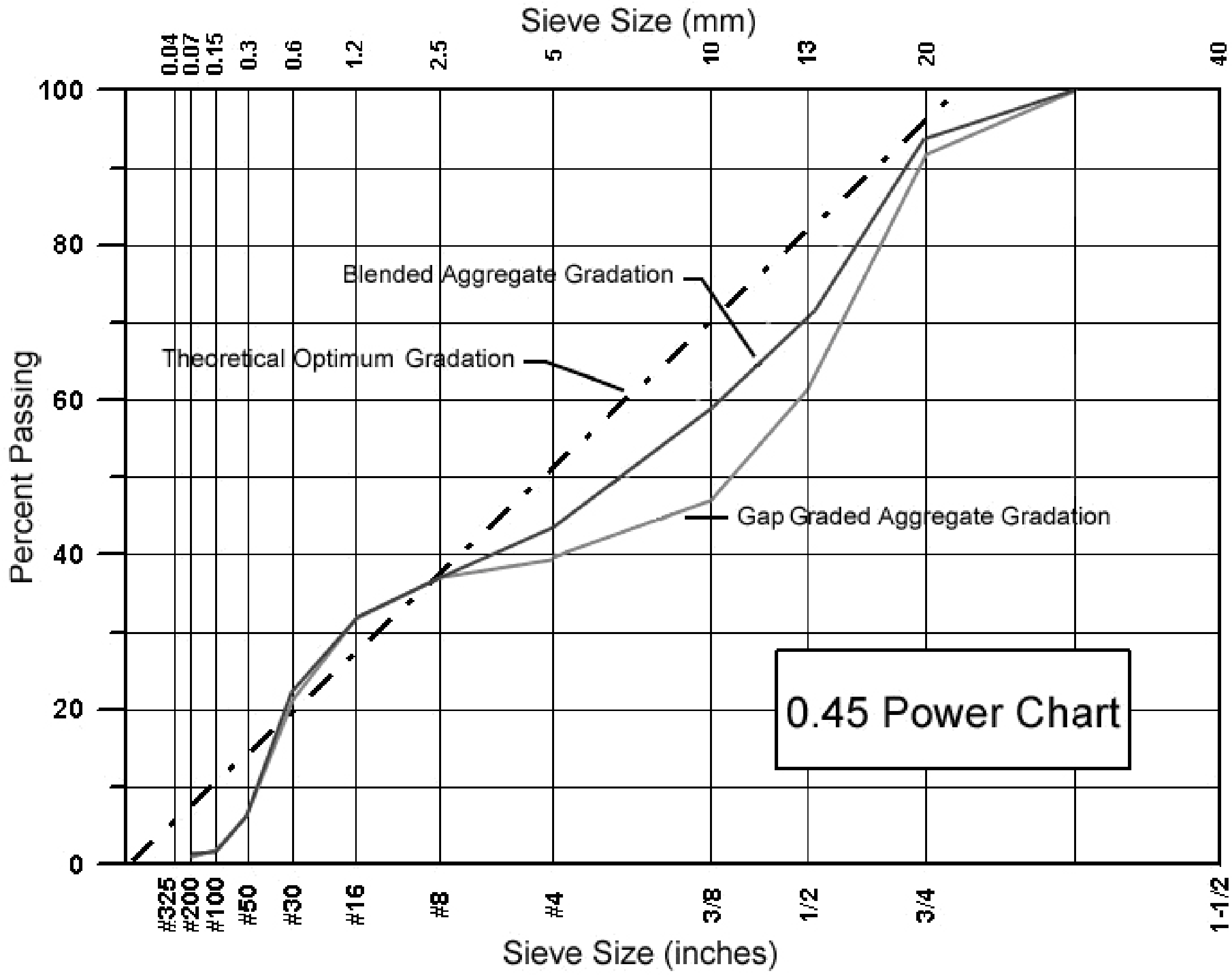


Figure 1.1.3 Gap Graded Aggregate Mix Design (Table 1.1.1) and Blended Aggregate Mix Design (Table 1.1.2) Example on 0.45 Power Curve

1.2 Fineness Modulus

Though not strictly related to aggregate blending, fineness modulus is a potentially useful method for characterizing aggregate gradation, particularly for fine aggregate. Fineness modulus is defined in ASTM C 125 as "a factor obtained by adding the percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: No. 100 (0.15 mm), No. 50 (0.3 mm), No. 30 (0.6 mm), No. 16 (1.18 mm), No. 8 (2.36 mm), No. 4 (4.75 mm), 3/8 in. (9.5 mm), 3/4 in. (19.0 mm), 1 1/2 in. (37.5 mm), 3 in. (75 mm), 6 in. (150 mm)" (see also ASTM C 136). Thus, for fine aggregate, the fineness modulus is calculated by dividing by 100 the sum of the cumulative percents retained on the sieves listed in Table 1.2.1 (refer also to Table 1.2.2 for an example calculation).

The fineness modulus is typically used in conjunction with the nominal maximum coarse aggregate size to determine the volume of dry rodded coarse aggregate per unit volume of concrete according to the ACI method for mix design (ACI 211.1). That is, it can be used to determine the initial aggregate proportions of a concrete mixture.

Table 1.2.1 Sieves Required to Calculate Fineness Modulus for Fine Aggregate

Sieve Size (English)	Sieve Size (metric)
3/8 inch	9.5 mm
No. 4	4.75 mm
No. 8*	2.36 mm*
No. 16	1.18 mm
No. 30*	600 μm*
No. 50	300 μm
No. 100	150 μm

* The sieve is not required by the "Required Sampling and Testing Equipment for Concrete" document, and would have to be acquired.

Table 1.2.2 Calculating Fineness Modulus for Fine Aggregate

Sieve Size (English)	Sieve Size (metric)	Percent Passing	Percent Retained	Cumulative Percent Retained
3/8 inch	9.5 mm	100	0	0
No. 4	4.75 mm	98	2	2
No. 8	2.36 mm	85	13	15
No. 16	1.18 mm	65	20	35
No. 30	600 μm	45	20	55
No. 50	300 μm	21	24	79
No. 100	150 μm	3	18	97
			Sum =	283
			Calculation	283/100
			FM =	2.83

The fineness modulus allows an individual to quickly identify a change in fine aggregate gradation, such as when it increases, the gradation becomes coarser. In addition, a fine aggregate with a high fineness modulus may result in a tendency for the concrete mixture to lose air. If the fine aggregate fineness modulus changes more than 0.2, changes in the mix proportions are probably needed to provide the same workability.

A good application for monitoring fineness modulus occurs when concrete is pumped. For example, ACI Committee 304 recommends the fine aggregate fineness modulus to be between 2.40 and 3.00 with at least 15 to 30 percent passing the No. 50 (300 μm) sieve and 5 to 10 percent passing the No. 100 (150μm).

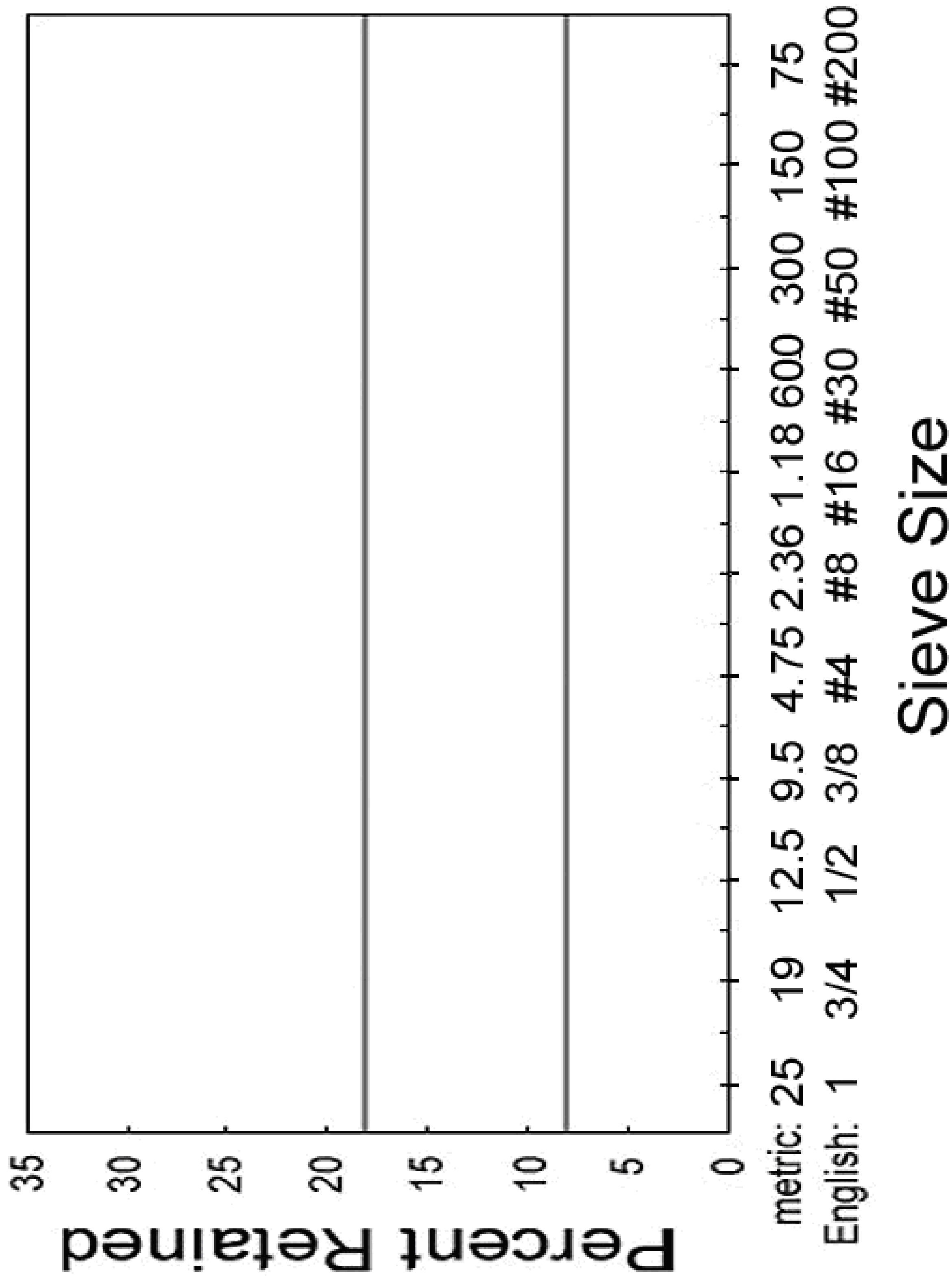
1.3 Aggregate Blending Worksheet

AGGREGATE BLENDING WORKSHEET

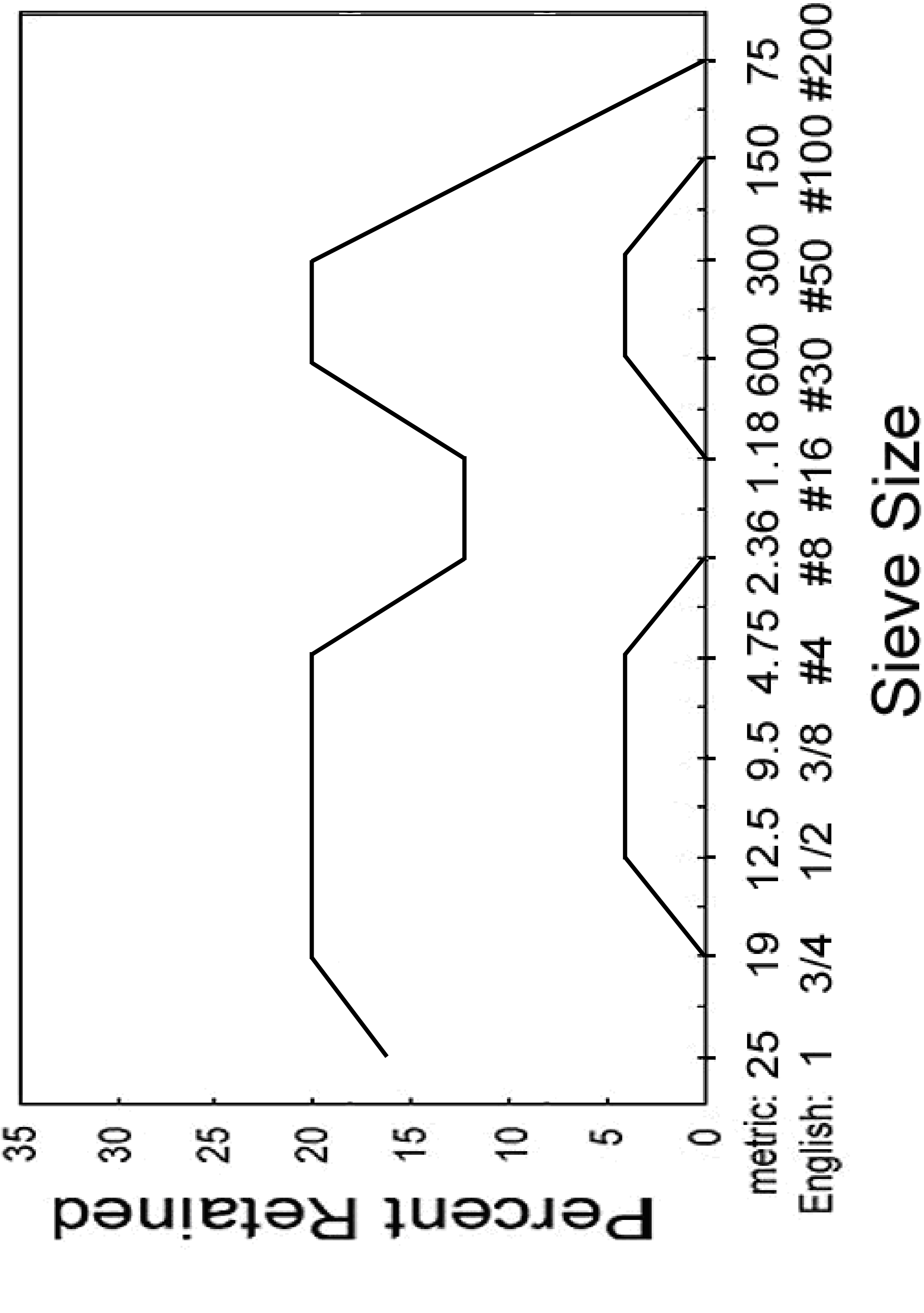
Sieves		Coarse Aggregate				Intermediate Aggregate				Fine Aggregate				Aggregate Blend	
English	metric	% Pass, A	% Pass, B	% of Total (a = %)		% Pass, A	% Pass, B	% of Total (b = %)		% Pass, A	% Pass, B	% of Total (c = %)		% Pass, TB*	% Ret., TB*
				Pass	Ret.			Pass	Ret.			Pass	Ret.		
2 1/2 in.	63 mm														
2 in.	50 mm														
1 3/4 in.	45 mm														
1 1/2 in.	37.5 mm														
1 in.	25 mm														
3/4 in.	19 mm														
5/8 in.	16 mm														
1/2 in.	12.5 mm														
3/8 in.	9.5 mm														
1/4 in.	6.3 mm														
No. 4	4.75 mm														
No. 8	2.36 mm														
No. 16	1.18 mm														
No. 30	600 µm														
No. 40	425 µm														
No. 50	300 µm														
No. 100	150 µm														
No. 200	75 µm														
PAN															

$$*TB = \left(\frac{a}{100} \times A\right) + \left(\frac{b}{100} \times B\right) + \left(\frac{c}{100} \times C\right) + \ldots$$

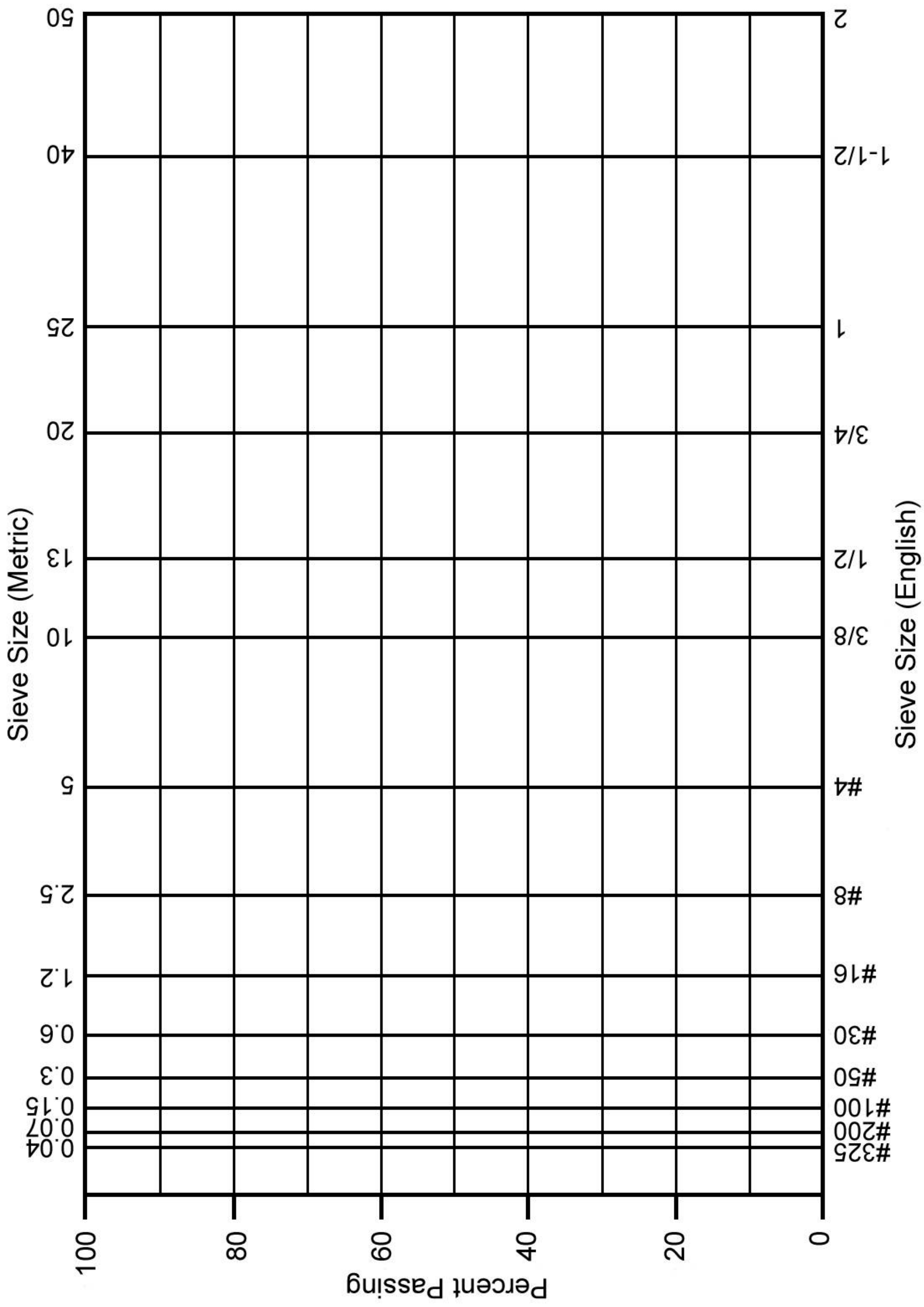
1.4 "8-18" Rule Worksheet



1.5 "Tarantula" Curve Worksheet



1.6 0.45 Power Curve Worksheet



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APPENDIX F

CEMENT AGGREGATE MIXTURE (CAM) II

1.0 CEMENT AGGREGATE MIXTURE (CAM) II MIX DESIGN DEVELOPMENT

The development of a CAM II mix design is similar to that of the Department's conventional concrete mix design. However, a fine aggregate water requirement, a coarse aggregate water requirement, and a mortar factor are not used.

Per Article 312.09, the Engineer will determine the proportions of materials for the mixture, or the Contractor may propose their own mix design. The Department recommends developing three mix designs for a cement-only mixture, or three mix designs for a cement and fly ash mixture, as follows:

Mixture Type	Mix Design Option	English Units, lb/yd^3	Metric Units, kg/m^3	W/C Ratio	
				CA 6, 9, 10	CA 7, 11
Cement Only Mixture	1	200	120	1.2	1.1
	2	250	150	1.1	1.0
	3	300	180	1.0	0.9
Cement and Fly Ash Mixture	1	170, 60	101, 36	1.2	1.1
	2	205, 70	122, 42	1.1	1.0
	3	245, 85	145, 50	1.0	0.9

The procedure for developing a CAM II mix design is as follows:

1. *Calculate the absolute volume of the cement and fly ash* (V_{Cement} *and* V_{Ash}*).* The mixture shall have a portland cement content minimum of 200 lb/yd^3 (120 kg/m^3), except a maximum 25 percent Class F ash or 30 percent Class C ash may replace the portland cement. However, per Article 312.09, the replacement shall not result in a mixture with a cement content less than 170 lb/yd^3 (101 kg/m^3). Furthermore, based on laboratory experience, the Department recommends a maximum cement content of 300 lb/yd^3 (136 kg/m^3), or maximum 330 lb/yd^3 (195 kg/m^3) of cement and fly ash combined.

2. *Calculate the absolute volume of water* (V_{Water}*).* The water/cement ratio indicated in the table in step 1 is only a starting point. Department experience has shown the water/cement ratio to range from 0.60 to 1.60. No matter what water/cement ratio is selected, a water-reducing admixture shall be used.

3. *Calculate the absolute volume of air* (V_{Air}*).* An air-entraining admixture shall be used to produce an air content of 7.0 to 10.0 percent. Design using the midpoint of this range (i.e., 8.5 percent).

4. *Calculate the absolute volume of combined aggregate* (V_{Agg}). Article 312.09 indicates the volume of fine aggregate shall not exceed the volume of coarse aggregate.

$$V_{Agg} = 1 - [V_{Cement} + V_{Ash} + V_{Water} + V_{Air}]$$

5. *Calculate the absolute volume of the constituent aggregates* (V_{CA} and V_{FA}). The *absolute volume of combined aggregate* is multiplied by the percentage of each aggregate to obtain their respective absolute volumes.

$$\textit{Absolute volume of coarse aggregate}: \quad V_{CA} = V_{Agg} \times \frac{\%CA}{100}$$

$$\textit{Absolute volume of fine aggregate}: \quad V_{FA} = V_{Agg} \times \frac{\%FA}{100}$$

   Department lab experience has shown a 50-50 percent blend of coarse aggregate to fine aggregate is a reasonable starting point when the coarse aggregate is CA 7, CA 9, or CA 11. For CA 6, the Department recommends 75 percent coarse aggregate and 25 percent fine aggregate. For CA 10, the Department recommends starting with 100 percent coarse aggregate and no fine aggregate. As an alternative to these starting points, refer to Appendix E for developing a uniformly graded mixture.

   As a word of caution, the coarse aggregate may be Class D quality or better. The risk is more clay material in Class B, C, or D quality aggregate as compared to Class A quality aggregate. Clay can make it more difficult to entrain air, which is why Class A quality aggregate is normally specified for concrete.

6. *Convert the absolute volumes of fine aggregate and coarse aggregate to pounds (kilograms).*

   Weight of Aggregate (lb/yd^3) = $V \times G_{SSD} \times 1{,}683.99$ (English)
   Mass of Aggregate (kg/m^3) = $V \times G_{SSD} \times 1{,}000.00$ (Metric)

   Where V = Absolute volume of coarse aggregate (V_{CA}) or fine aggregate (V_{FA})
   G_{SSD} = Specific gravity of coarse aggregate or fine aggregate

7. A trial batch should be performed for each mix design. The slump shall range from 1 in. (25 mm) to 3 in. (75 mm), and the air content shall range from 7.0 to 10.0 percent. If the slump and air content cannot be batched within the specified range, revise the mix design. It should also be noted that CAM II has no strength requirements. However, it is recommended to make three 4 in. x 8 in. (100 mm x 200 mm) cylinders for strength testing at 14 days. A value from 750-1500 psi (5,170-10,340 kPa) is desired, but a mix outside this range is perfectly acceptable.

8. Submit the mix design to the Department for freeze/thaw testing according ITP 161.

1.1 EXAMPLE PROBLEM FOR CEMENT AGGREGATE MIXTURE (CAM) II MIX DESIGN

Given:

- Type I portland cement with > 0.60 alkalies will be used.
- Class C fly ash with calcium oxide of 26.0 percent and specific gravity of 2.70 will be used.
- A fine aggregate (FA 1) with a saturated surface-dry specific gravity of 2.65 will be used. The alkali-silica reaction expansion for the fine aggregate is in the >0.16% – 0.27% range.
- A crushed stone coarse aggregate (CA 6) with a saturated surface-dry specific gravity of 2.69 will be used. The alkali-silica reaction expansion for the coarse aggregate limestone is an assigned value of 0.05 percent per Article 1004.02(g)(1).

1.1.1 Example for English Units

Step 1 Determine the absolute volume of cement and finely divided minerals.

- The minimum required cement is 170 lb/yd^3 if the portland cement is replaced with fly ash.
- The Class C fly ash can replace up to 30 percent of the cement.
- From 2.4.3 “Mitigation of Alkali-Silica Reaction with Finely Divided Minerals,” it is determined that the aggregate is in Group II. Thus, a minimum 25.0 percent Class C fly ash is required to reduce the risk of a deleterious alkali-silica reaction.

Thus, the Department’s default cement and fly ash mix design option 1 is selected. This mix design has 170 lb/yd^3 of cement and 60 lb/yd^3 of fly ash, and satisfies the minimum fly ash needed for the reactive aggregate without exceeding the maximum replacement as follows.

The calculation to determine the percent replacement
$= 60\ lb/yd^3 \div (170\ lb/yd^3 + 60\ lb/yd^3) = 26\%$ Class C fly ash.

The absolute volume of cement per cubic yard
$= 170\ lb/yd^3 \div (3.15 \times 1{,}683.99\ lb/yd^3) = 0.032$

The absolute volume of fly ash per cubic yard
$= 60\ lb/yd^3 \div (2.70 \times 1{,}683.99\ lb/yd^3) = 0.013$

Step 2 Determine the absolute volume of water.

Assume a water/cement ratio of 1.10 which takes into account that a water-reducing admixture will be used.

The calculation is $1.10 \times (170\ lb/yd^3 + 60\ lb/yd^3) = 253\ lb/yd^3$

The absolute volume of water per cubic yard
$= 253\ lb/yd^3 \div (1.0 \times 1{,}683.99\ lb/yd^3) = 0.150$

Step 3 Determine the absolute volume of air.

The midpoint of the air content range for CAM II is 8.5 percent.

The absolute volume of air per cubic yard = 8.5 percent $\div$ 100 = 0.085

Step 4 Determine the absolute volume of the combined fine and coarse aggregates.

The absolute volume of combined fine and coarse aggregates per cubic yard
$= 1 - (0.032 + 0.013 + 0.150 + 0.085) = 0.720$

Step 5 Determine the absolute volumes of the constituent aggregates.

For a CA 6, use the Department’s recommendation of a 75-25 percent blend of coarse aggregate to fine aggregate.

The absolute volume of coarse aggregate per cubic yard
$= 0.720 \times (75$ percent $\div 100) = 0.540$

The absolute volume of fine aggregate per cubic yard
$= 0.720 \times (25$ percent $\div 100) = 0.180$

Step 6 Convert the absolute volumes of the coarse and fine aggregate to pounds.

Coarse aggregate = 0.540 $yd^3 \times 2.69 \times 1{,}683.99\ lb/yd^3 = 2{,}446\ lb/yd^3$

Fine aggregate = 0.180 $yd^3 \times 2.65 \times 1{,}683.99\ lb/yd^3 = 803\ lb/yd^3$

Step 7 Summarize the mix design.

Cement (3.15*)	= 170 lb/yd^3
Fly Ash (2.70*)	= 60 lb/yd^3
Water	= 253 lb/yd^3
	or
	= 253 $lb/yd^3 \div 8.33$ lb/gallon = 30 $gallons/yd^3$
Air Content (Target)	= 8.5 percent
Coarse Aggregate (2.69*)	= 2,446 lb/yd^3
Fine Aggregate (2.65*)	= 803 lb/yd^3
Admixture	= water-reducing admixture
Slump (Target)	= 2 inches
Water/Cement Ratio	= 1.10

*Specific Gravity

1.1.2 Example for Metric Units

Step 1 Determine the absolute volume of cement.

- The minimum required cement is 101 kg/m^3 if the portland cement is replaced with fly ash.
- The Class C fly ash can replace up to 30 percent of the cement.
- From 2.4.3 "Mitigation of Alkali-Silica Reaction with Finely Divided Minerals," it is determined that the aggregate is in Group II. Thus, a minimum 25.0 percent Class C fly ash is required to reduce the risk of a deleterious alkali-silica reaction.

Thus, the Department's default cement and fly ash mix design option 1 is selected. This mix design has 101 kg/m^3 of cement and 36 kg/m^3 of fly ash, and satisfies the minimum fly ash needed for the reactive aggregate without exceeding the maximum replacement as follows.

The calculation to determine the percent replacement
$= 36\ kg/m^3 \div (101\ kg/m^3 + 36\ kg/m^3) = 26\%$ Class C fly ash.

The absolute volume of cement per cubic meter
$= 101\ kg/m^3 \div (3.15 \times 1000.00\ kg/m^3) = 0.032$

The absolute volume of fly ash per cubic meter
$= 36\ kg/m^3 \div (2.70 \times 1000.00\ kg/m^3) = 0.013$

Step 2 Determine the absolute volume of water.

Assume a water/cement ratio of 1.10, which takes into account that a water-reducing admixture will be used.

The calculation is $1.10 \times (101\ kg/m^3 + 36\ kg/m^3) = 151\ kg/m^3$

The absolute volume of water per cubic meter
$= 151\ kg/m^3 \div (1.00 \times 1{,}000.00\ kg/m^3) = 0.151$

Step 3 Determine the absolute volume of air.

The midpoint of the air content range for CAM II is 8.5 percent.

The absolute volume of air per cubic meter = 8.5 percent $\div$ 100 = 0.085.

Step 4 Determine the absolute volume of the combined fine and coarse aggregates.

The absolute volume of combined fine and coarse aggregates per cubic meter
= 1 – (0.032 + 0.013 + 0.151 + 0.085) = 0.719

Step 5 Determine the absolute volumes of the constituent aggregates.

For a CA 6, use the Department's recommendation of a 75-25 percent blend of coarse aggregate to fine aggregate.

The absolute volume of coarse aggregate per cubic meter
= 0.719 $\times$ (75 percent $\div$ 100) = 0.539

The absolute volume of fine aggregate per cubic yard
= 0.719 $\times$ (25 percent $\div$ 100) = 0.180

Step 6 Convert the absolute volumes of the fine and coarse aggregates to kilograms.

Coarse aggregate = 0.539 m^3 $\times$ 2.69 $\times$ 1000.00 kg/m^3 = 1,450 kg/m^3

Fine aggregate = 0.180 m^3 $\times$ 2.65 $\times$ 1000.00 kg/m^3 = 477 kg/m^3

Step 7 Summarize the mix design.

Cement (3.15*)	= 101 kg/m^3
Fly Ash (2.70*)	= 36 kg/m^3
Water	= 151 kg/m^3
	or
	= 151 kg/m^3 $\div$ 1 liter/m^3 = 151 liters/m^3
Air Content (Target)	= 8.5 percent
Coarse Aggregate (2.69*)	= 1,450 kg/m^3
Fine Aggregate (2.65*)	= 477 kg/m^3
Admixture	= water-reducing admixture
Slump (Target)	= 50 mm
Water/Cement Ratio	= 1.10

*Specific Gravity

2.0 DEPARTMENT CEMENT AGGREGATE MIXTURE (CAM) II MIX DESIGN VERIFICATION

2.1 Verification by the Engineer

A new cement aggregate mixture (CAM) II mix design will be verified by the Engineer from test information provided by the Contractor (optional), testing performed by the Engineer, applicable Department historical test data, and previous Department experience.

For a CAM II mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department's historical test data shows compliance with specification requirements.

2.2 Testing Performed by the Engineer

Per Article 312.09, constituent materials for CAM II mixtures are submitted to the Department for testing. The Department will verify all materials meet specification requirements.

Additionally, because CA 6, CA 9, and CA 10 gravel aggregates are not normally screened by the Department for alkali reaction per Article 1004.02(g), CA 6, CA 9, and CA 10 gravel aggregates submitted will need to be tested according to ASTM C 1260, and the mixture will be evaluated to meet the requirements of Article 1020.05(d).

The CAM II mixture shall meet the test requirements in Article 312.09 for relative durability (freeze/thaw resistance), air-entrainment, and slump. The mix design with the lowest cement content or cement and fly ash contents that meets the requirements will be reported to the District. Once one mix design is approved for a contract, no additional mixtures will be tested for that contract.

2.2.1 Testing Proportions Determined by the Engineer

The Engineer will test either a cement only mixture or a cement and fly ash mixture. For the selected mixture type, the Engineer will develop proportions for three mix design options. Refer to 1.0 “Cement Aggregate Mixture (CAM) II Mix Design Development.” In the event all three mix designs fail to meet specification requirements, one additional round of testing may be performed by the Engineer.

2.2.2 Testing Proportions Determined by the Contractor

The Engineer will test either a cement only mixture or a cement and fly ash mixture. For the selected mixture type, the Contractor can develop the proportions for up to three mix design options. The mix designs may be different from those suggested in 1.0 “Cement Aggregate Mixture (CAM) II Mix Design Development.” In the event all three mix designs fail to meet specification requirements, one additional round of testing (comprised of three mix design options) may be performed by the Engineer using proportions determined by the Engineer.

2.2.3 Unacceptable Materials

In some cases, all three mix design options fail due to material deficiencies that can be identified after the first round of testing. For example, high fines in an aggregate can make it impossible to properly entrain air, or very poor freeze/thaw durable aggregate can make it impossible to meet relative durability requirements. The Engineer may discontinue further testing of some or all materials determined to be of questionable quality after evaluating a minimum of three mix design options (one round of testing).

APPENDIX G

CONTROLLED LOW-STRENGTH MATERIAL (CLSM)

1.0 CONTROLLED LOW-STRENGTH MATERIAL (CLSM) MIX DESIGN DEVELOPMENT

For CLSM, there is no formal mix design procedure. However, the principle of volumetric mix design, designing in terms of a standard unit volume, still applies. The absolute volumes of cement, fly ash, water, air, and aggregate shall equal one. In addition, the mix shall comply with the mix design criteria. For more details concerning the mix design criteria and submittal of the mix design, refer to Section 1019 of the Standard Specifications.

The Contractor is advised that CLSM does not normally pump well.

2.0 DEPARTMENT CONTROLLED LOW-STRENGTH MATERIAL (CLSM) MIX DESIGN VERIFICATION

2.1 Verification by the Engineer

A new controlled low-strength material (CLSM) mix design will be verified by the Engineer according to Article 1019.06 of the Standard Specifications.

For a CLSM mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department's historical test data shows compliance with specification requirements.

This Page Reserved

APPENDIX H

STAMPED OR INTEGRALLY COLORED CONCRETE

Stamped or integrally colored concrete shall be done according to contract specifications. The following is for informational purposes when stamped or integrally colored concrete is used.

Stamped Concrete

A minimum cement factor of 6.05 cwt/yd^3 (360 kg/m^3) for central-mixed, truck-mixed or shrink-mixed concrete is recommended.

A slump range of 3 in. (75 mm) to 5 in. (125 mm) is recommended.

A coarse aggregate gradation of CA 11, CA 13, CA 14, or CA 16 is recommended.

A mortar factor of 0.88 to 0.90 is recommended.

Integrally Colored Concrete

The pigment for colored concrete has no influence on the mix design.

The following guidance may help prevent color variations.

- Maintaining a water/cement ratio within ± 0.02 of the target value is recommended.
- A calcium chloride accelerating admixture shall not be used.

This Page Reserved

Appendix I

CONCRETE REVETMENT MATS

1.0 CONCRETE REVETMENT MAT MIX DESIGN DEVELOPMENT

For concrete revetment mats, there is no formal mix design procedure, and Section 285 of the Standard Specifications provides very few mix design parameters. However, the principle of volumetric mix design, designing in terms of a standard unit volume, still applies. The absolute volumes of cement, fly ash, water, air, and fine aggregate (there is no coarse aggregate) shall equal one.

For an air content between 6.0 and 9.0 percent, the following mix design parameters should be used to meet the required 28-day compressive strength of 2500 psi (17,000 kPa).

Cement Only Mix Design

- Cement — 650 – 800 lb/yd^3 (385 – 475 kg/m^3)
- Water/Cement Ratio — Maximum 0.60
- Fine Aggregate (saturated surface dry condition) — Adjust for V_{Cement}, V_{Water}, and V_{Air}
- Air Content (Target) — 7.5 percent
- Water-Reducing or HRWR Admixture — Optional

Cement and Fly Ash Mix Design

- Cement — 470 – 610 lb/yd^3 (279 – 362 kg/m^3)
- Total Cement Plus Fly Ash* — 725 – 825 lb/yd^3 (430 – 489 kg/m^3)
- Water/Cement Ratio — Maximum 0.60
- Fine Aggregate (saturated surface dry condition) — Adjust for V_{Cement}, V_{Water}, and V_{Air}
- Air Content (Target) — 7.5 percent
- Water-Reducing or HRWR Admixture — Optional

*It is recommended to keep the fly ash at a maximum 35 percent of the total cement plus fly ash.

Section 285 states the mixture shall be proportioned to provide a pumpable slurry. A flow cone test according to ASTM D 6449 is a good method to determine pumpability. It is recommended the efflux time range from 9 to 12 seconds.

2.0 DEPARTMENT CONCRETE REVETMENT MAT MIX DESIGN VERIFICATION

2.1 Verification by the Engineer

A new concrete revetment mat mix design will be verified by the Engineer from test information provided by the Contractor (optional), testing performed by the Engineer, applicable Department historical test data, target strength calculations, and previous Department experience.

For a concrete revetment mat mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department's historical test data shows compliance with specification requirements.

2.2 Testing Performed by the Engineer

The Engineer may require the Contractor to provide a batch of concrete revetment mat mixture at no cost to the Department.

2.2.1 Procedure for Trial Batch

The procedure that follows shall be used to perform a trial batch unless specified otherwise in the contract plans.

The trial batch shall be performed in the presence of the Engineer, and the Engineer will perform all tests. The Contractor has the option to perform their own tests. The volume of the trial batch shall be a minimum of 2.0 yd^3 (1.5 m^3), but 4.0 yd^3 (3.0 m^3) is strongly recommended to more accurately evaluate the influence of mixing. Batch at or near the maximum water/cement ratio as requested by the Engineer. The air content should be within 0.5 percent of the maximum allowable specification value or as requested by the Engineer. Strength will be determined for the test of record, or at other ages as determined by the Engineer. The test of record shall be the day indicated in Section 285. In all cases, strength will be based on the average of a minimum two 6- by 12-in. (150- by 300-mm) cylinder breaks or three 4- by 8-in. (100- by 200-mm) cylinder breaks. In addition to air and strength testing, concrete temperature will be determined by the Engineer. Testing will be performed according to Illinois Modified AASHTO R 60, T 22, T 23, T 152 or T 196, and Illinois Modified ASTM C 1064. As an option for additional information, Illinois Modified AASHTO T 121 and ASTM D 6449 may be performed.

2.2.2.1 Verification of Trial Batch

The trial batch will be verified by the Engineer if Department test results meet specification requirements and the mixture is pumpable.

APPENDIX J

INSERTION LINING OF PIPE CULVERTS (GROUT)

1.0 GROUT MIXTURE MIX DESIGN DEVELOPMENT FOR INSERTION LINING OF PIPE CULVERTS

For the grout mixture used in insertion lining of pipe culverts, there is no formal mix design procedure. However, the principle of volumetric mix design, designing in terms of a standard unit volume, still applies. The absolute volumes of cement, fly ash, water, air, and fine aggregate (there is no coarse aggregate) shall equal one. According to Section 543 of the Standard Specifications, the mix design parameters are as follows:

> The grout mixture shall be 6.50 cwt/yd^3 (385 kg/m^3) of portland cement plus fine aggregate and water. Fly ash may replace a maximum of 5.25 cwt/yd^3 (310 kg/m^3) of the portland cement. The water/cement ratio, according to Article 1020.06, shall not exceed 0.60. An air-entraining admixture shall be used to produce an air content, according to Article 1020.08, of not less than 6.0 percent nor more than 9.0 percent of the volume of the grout. The Contractor shall have the option to use a water-reducing or high range water-reducing admixture.

As indicated by the mix design parameters, there are few variables for developing the mix design. The Contractor shall use a target air content of 7.5 percent, and vary the cement, fly ash, and water proportions to obtain a flowable mix. In addition, the grout mixture shall have a minimum 28 day compressive strength of 150 psi (1035 kPa).

2.0 DEPARTMENT GROUT MIXTURE FOR INSERTION LINING OF PIPE CULVERTS MIX DESIGN VERIFICATION

The mix design is normally be done by the Department, but the Contractor has the option to submit a mix design for a Quality Control/Quality Assurance project.

2.1 Verification by the Engineer

A new insertion lining of pipe culverts mix design will be verified by the Engineer from test information provided by the Contractor (optional), testing performed by the Engineer, applicable Department historical test data, target strength calculations, and previous Department experience.

For a insertion lining of pipe culverts mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department’s historical test data shows compliance with specification requirements.

2.2 Testing Performed by the Engineer

The Engineer may require the Contractor to provide a batch of insertion lining of pipe culverts mixture at no cost to the Department.

2.2.1 Procedure for Trial Batch

The procedure that follows shall be used to perform a trial batch unless specified otherwise in the contract plans.

The trial batch shall be performed in the presence of the Engineer, and the Engineer will perform all tests. The Contractor has the option to perform their own tests. The volume of the trial batch shall be a minimum of 2.0 yd^3 (1.5 m^3), but 4.0 yd^3 (3.0 m^3) is strongly recommended to more accurately evaluate the influence of mixing. Batch at or near the maximum water/cement ratio as requested by the Engineer. The air content should be within 0.5 percent of the maximum allowable specification value or as requested by the Engineer. Strength will be determined for the test of record, or at other ages as determined by the Engineer. The test of record shall be the day indicated in Section 543. In all cases, strength will be based on the average of a minimum of two breaks. In addition to air and strength testing, concrete temperature will be determined by the Engineer. Air and concrete temperature testing will be performed according to Illinois Modified AASHTO R 60, T 152 or T 196, and Illinois Modified ASTM C1064. Strength testing will be performed according to ASTM C 1107 and C 109. As an option for additional information, Illinois Modified AASHTO T 121 may be performed.

2.2.2.1 Verification of Trial Batch

The trial batch will be verified by the Engineer if Department test results meet specification requirements and the mixture is flowable.

Appendix K

INSERTION LINING OF PIPE CULVERTS (CELLULAR CONCRETE)

1.0 CELLULAR CONCRETE MIX DESIGN DEVELOPMENT FOR INSERTION LINING OF PIPE CULVERTS

Cellular concrete (sometimes called engineered fill) is a special mix which relies on foam to make the concrete low strength or light weight.

The mix designs are proprietary in nature, and therefore, their development will not be discussed within this manual. However, the principle of volumetric design, designing in terms of a standard unit volume, still applies. The absolute volume of materials shall equal one.

Cement Only Mix Design for Strength Range of 30 – 350 psi (207 – 2,413 kPa)

• Cement	400 – 650 lb/yd^3 (237 – 386 kg/m^3)
• Water/Cement Ratio	0.50 – 0.60
• Foam Admixture	Consult Manufacturer for Dosage
• Homogenous Void or Air Cell Structure	20 – 70 percent

Comments:

- Cement replacement with fly ash may reach as high as 65 percent.
- The use of fine aggregate is optional, but is not normally utilized when low strength or light weight is desired.

2.0 DEPARTMENT CELLULAR CONCRETE FOR INSERTION LINING OF PIPE CULVERTS MIX DESIGN VERIFICATION

2.1 Verification by the Engineer

The mix design will be verified by the Engineer from test information provided by the Contractor showing that the mix is flowable and meets compressive strength requirements.

This Page Reserved

APPENDIX L

CLASS SI CONCRETE BETWEEN PRECAST CONCRETE BOX CULVERTS

1.0 CLASS SI CONCRETE MIX DESIGN DEVELOPMENT (WHEN MIXTURE IS USED BETWEEN PRECAST CONCRETE BOX CULVERT SECTIONS)

For the Class SI concrete used between precast concrete box culvert sections, Article 540.06 states "The Class SI concrete shall be according to Section 1020, except the maximum size coarse aggregate shall be ⅜ in. (10 mm)." This requirement is also in the Bridge Guide Special Provision " Three Sided Precast Concrete Structure." Thus, the principle of volumetric mix design discussed in this manual applies. The key point is that the specification essentially states to use a fine aggregate only. According to Article 1003.01, fine aggregate has a maximum size of ⅜ in. (10 mm). To develop the mix design, the absolute volumes of cement, finely divided minerals, water, and air are calculated and added together. The resultant value is subtracted from one to get the volume of aggregate. Since the coarse aggregate proportion has been replaced with fine aggregate, the water demand will be higher. It is suggested to use a coarse aggregate basic water requirement of 0.4 gal/cwt (0.33 L/kg) as a starting point in developing the mix design.

2.0 DEPARTMENT CLASS SI CONCRETE MIX DESIGN VERIFICATION (WHEN MIXTURE IS USED BETWEEN PRECAST CONCRETE BOX CULVERT SECTIONS)

2.1 Verification by the Engineer

A new Class SI concrete (used between precast concrete sections) mix design will be verified by the Engineer from test information provided by the Contractor (optional), testing performed by the Engineer, applicable Department historical test data, target strength calculations, and previous Department experience.

For a Class SI concrete (used between precast concrete sections) mix design previously developed by the Engineer or Contractor, the Engineer will verify the mix design if the Department's historical test data shows compliance with specification requirements.

2.2 Testing Performed by the Engineer

The Engineer may require the Contractor to provide a batch of Class SI concrete (used between precast concrete sections) mixture at no cost to the Department.

2.2.1 Procedure for Trial Batch

The procedure that follows shall be used to perform a trial batch unless specified otherwise in the contract plans.

The trial batch shall be performed in the presence of the Engineer, and the Engineer will perform all tests. The Contractor has the option to perform their own tests. The volume of the trial batch shall be a minimum of 2 yd^3 (1.5 m^3), but 4 yd^3 (3.0 m^3) is strongly recommended to more accurately evaluate the influence of mixing. Batch at or near the maximum water/cement ratio or as requested by the Engineer. The air content should be within 0.5 percent of the maximum allowable specification value or as requested by the Engineer. The slump should be within the allowable specification range. Strength will be determined for the test of record, or at other ages determined by the Engineer. The test of record shall be the day indicated in Article 1020.04 or as specified. In all cases, strength will be based on the average of a minimum two 6- by 12-in. (150- by 300-mm) cylinder breaks, three 4- by 8-in. (100- by 200-mm) cylinder breaks, or two beam breaks. In addition to slump, air, and strength testing, concrete temperature will be determined by the Engineer. Testing will be performed according to Illinois Modified AASHTO R60, T 23, T 119, T 152 or T 196, T 22 or T 177, and Illinois Modified ASTM C 1064. As an option for additional information, Illinois Modified AASHTO T 121 may be performed.

2.2.1.1 Verification of Trial Batch, Voids Test, and Durability Test Data

The trial batch will be verified by the Engineer if Department test results meet specification requirements.

APPENDIX M

PERVIOUS CONCRETE

Pervious concrete shall be done according to contract specifications, and there is no formal mix design procedure. However, the principle of volumetric mix design, designing in terms of a standard unit volume, still applies. The absolute volumes of cement, finely divided minerals, water, air, and aggregate shall equal one.

When the contract specifications specify freeze/thaw durability, improved durability may be achieved by entraining air in the cement paste.

This Page Reserved

APPENDIX N

AVERAGE AND STANDARD DEVIATION

1.0 AVERAGE STRENGTH

"Average" strength implies that half of the samples tested are ***stronger than average*** and half are ***weaker than average***. Thus, the average strength of a concrete mix must be ***greater*** than the minimum required strength.

The quantitative difference between the average, or mix design target strength and the minimum required strength, depends on the accuracy and precision of the test results. The accuracy and precision of the test results must be calculated before the mix design target strength can be determined.

1.1 Accuracy and Precision

Accuracy refers to the average of the performance with reference to the target: a measure of how near the results are to the target.

Precision refers to the consistency of the performance itself: a measure of how near the results are to each other regardless of the target. That is, though the results may not be near the target, amongst themselves they are tightly grouped.

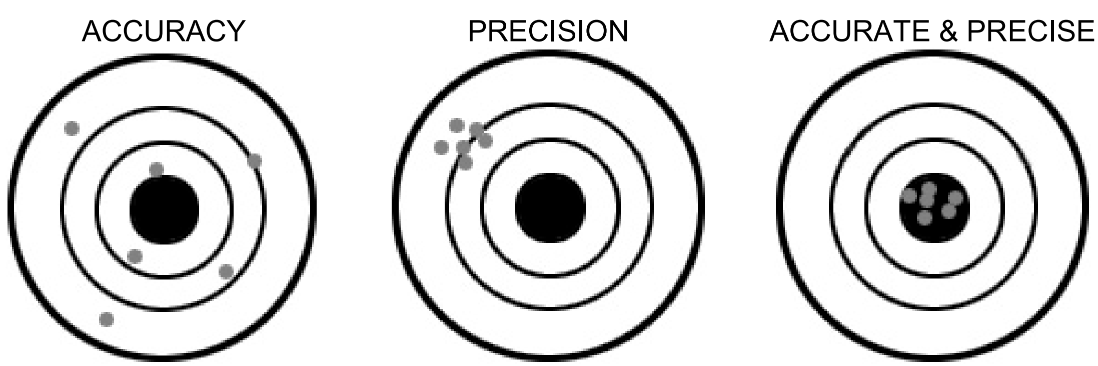


Figure 1. Illustration of Accuracy and Precision

Accuracy is typically measured by the mean, or average, of the test results as follows:

$$\text{Average, } \overline{X} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$$

Where x_i is an individual test result, and
n is the total number of test results

Precision, or "measure of dispersion," is measured by the standard deviation, which indicates width, spread, clustering, and consistency, and is defined as follows:

$$\text{Standard Deviation, } S = \sqrt{\frac{\sum(\overline{X} - x_i)^2}{(n-1)}}$$

Example Using English Units:

Test Record (psi)		Deviation $\overline{X} - x_i$	Square of Deviation $(\overline{X} - x_i)^2$
1	3000	4058 – 3000 = 1058	1,119,364
2	3450	4058 – 3450 = 608	369,664
3	3600	4058 – 3600 = 458	209,764
4	4650	4058 – 4650 = -592	350,464
5	4750	4058 – 4750 = -692	478,864
6	4900	4058 – 4900 = -842	708,964

sum = $\sum_{i \to n}^{n=6} x_i$ =	24,350	sum = $\sum_{i \to n}^{n=6} (\overline{X} - x_i)^2$ =	3,237,084
average, $\overline{X} = \frac{sum}{n}$ =	4058 psi	standard deviation, $S = \sqrt{\frac{sum}{(n-1)}}$ =	805 psi

Example Using Metric Units:

Test Record (kPa)		Deviation $\overline{X} - x_i$	Square of Deviation $(\overline{X} - x_i)^2$
1	20,690	27,980 – 20,690 = 7290	53,144,100
2	23,790	27,980 – 23,790 = 4190	17,556,100
3	24,820	27,980 – 24,820 = 3160	9,985,600
4	32,060	27,980 – 32,060 = -4080	16,646,400
5	32,750	27,980 – 32,750 = -4770	22,752,900
6	33,790	27,980 – 33,790 = -5810	33,756,100

sum = $\sum_{i \to n}^{n=6} x_i$ =	167,900	sum = $\sum_{i \to n}^{n=6} (\overline{X} - x_i)^2$ =	153,841,200
average, $\overline{X} = \frac{sum}{n}$ =	27,980 kPa	standard deviation, $S = \sqrt{\frac{sum}{(n-1)}}$ =	5547 kPa

2.0 THE NORMAL DISTRIBUTION—The Bell Curve

Characteristics in any statistical sample population, such as compressive strength test results, can be grouped around some central tendency, or average, as illustrated in Figure 2.

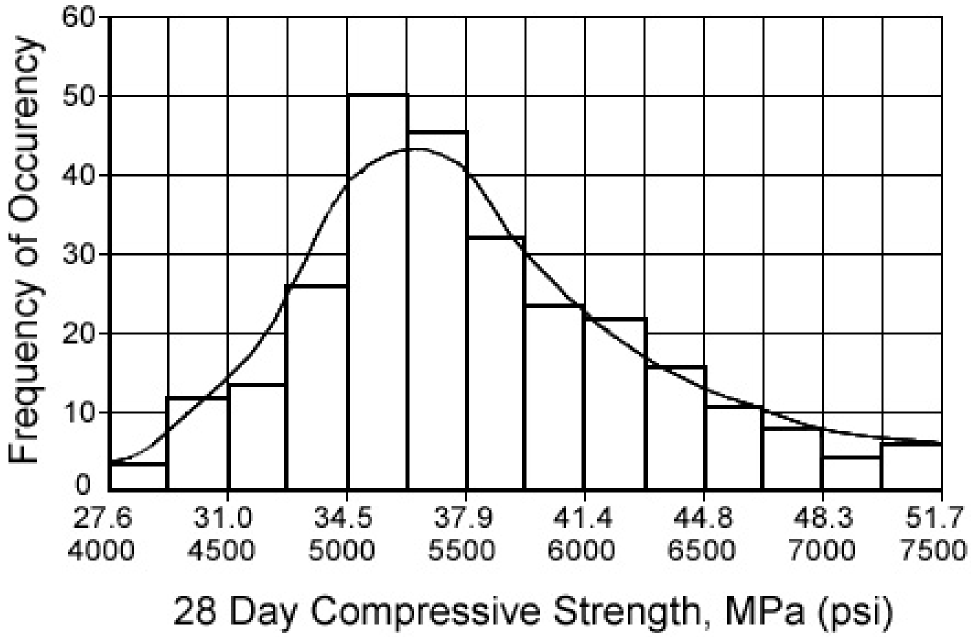


Figure 2. Example of Normal Distribution Histogram

Figure 2. is an example of a histogram, a graph of the frequency of occurrences per subdivision of the complete range of test results. For example, there were 50 occurrences of test results within 5000 and 5250 psi (34.5 and 36.2 MPa).

Now, a smooth bell-shaped curve can be drawn through the histogram. This "Bell Curve" is known as the Normal Distribution, characterized by a distinct central tendency toward the center, which is the average. The Bell Curve quantitatively illustrates how test results have an equal chance to be above or below the average.

The characteristics of the Normal Distribution are as follows:

- 68 percent of all results fall within 1 standard deviation from either side of the average
- 95 per cent of all results fall within 2 standard deviations from either side of the average
- 99.7 percent of all results fall within 3 standard deviations from either side of the average
- 99 percent of all results fall above the value that is 2.33 standard deviations below the average

The figures on the next page illustrate an example of how greater precision can help production. Figure 3 shows three mixes with the same target strength but different standard deviations (i.e., precision). Even with the different levels of precision, all three mixes can be expected to meet the minimum specified strength of 4000 psi (27.6 MPa). However, as illustrated in Figure 4, increased precision allows the target strengths for two of the mixes to be reduced (e.g., via reduced total cement) without fear of violating the minimum specified strength.

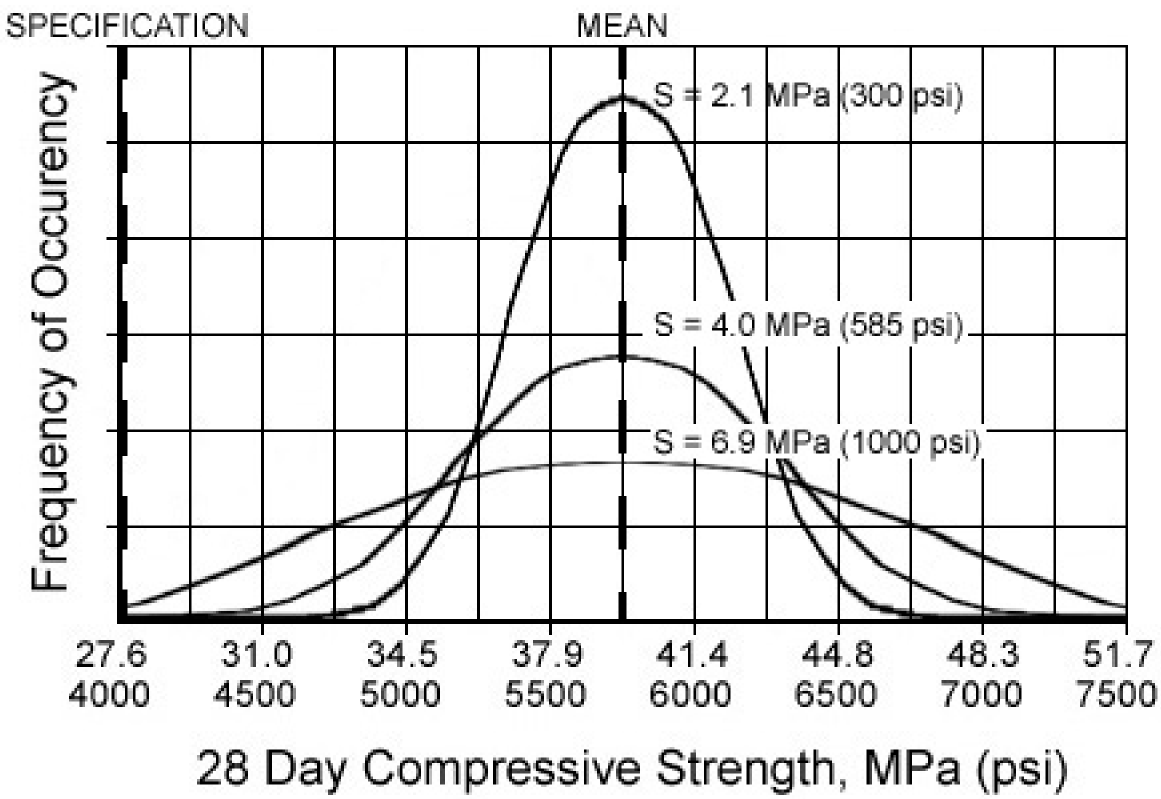


Figure 3 Example of Normal Distribution Plots for Mixes with the Same Target Strength but Differing Standard Deviations

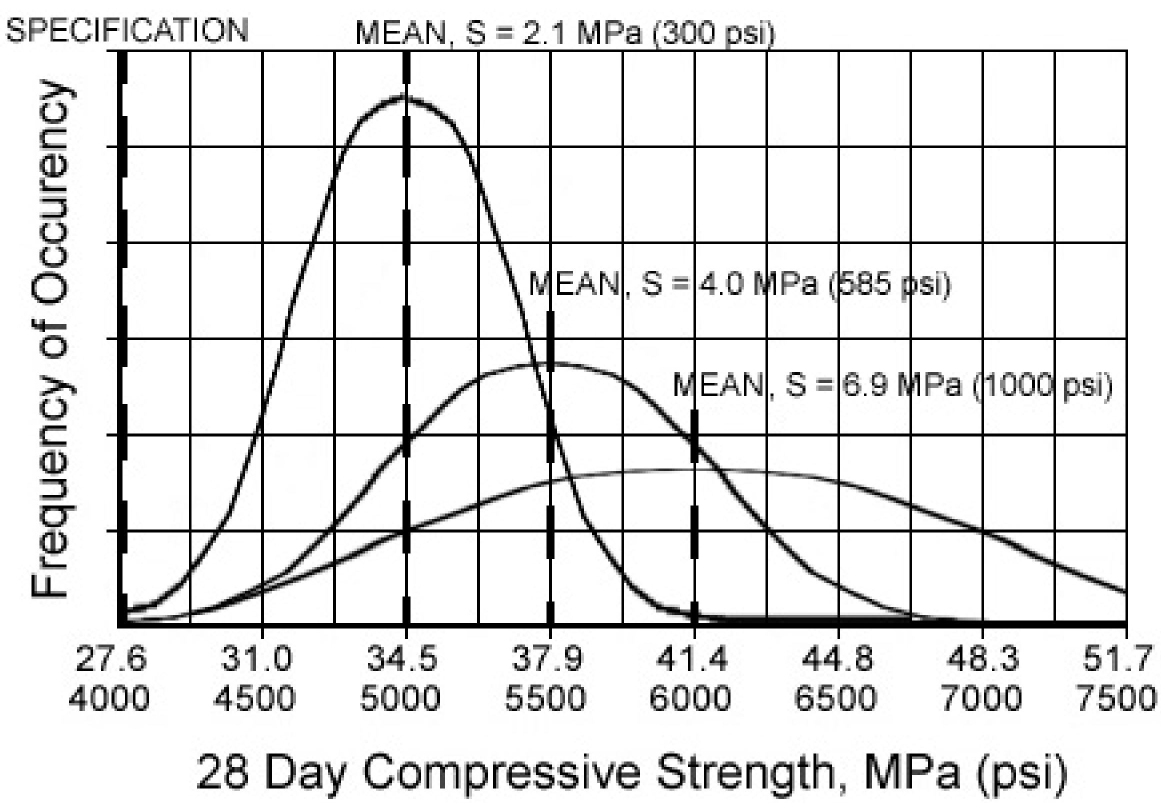
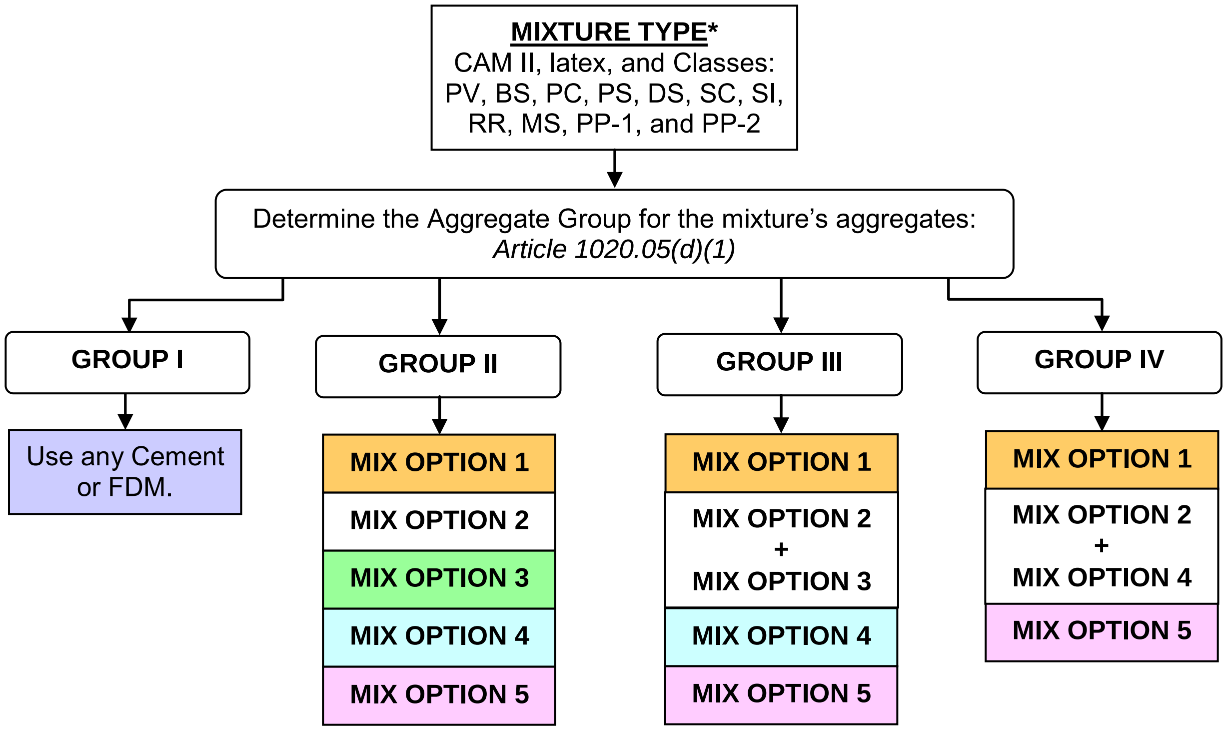
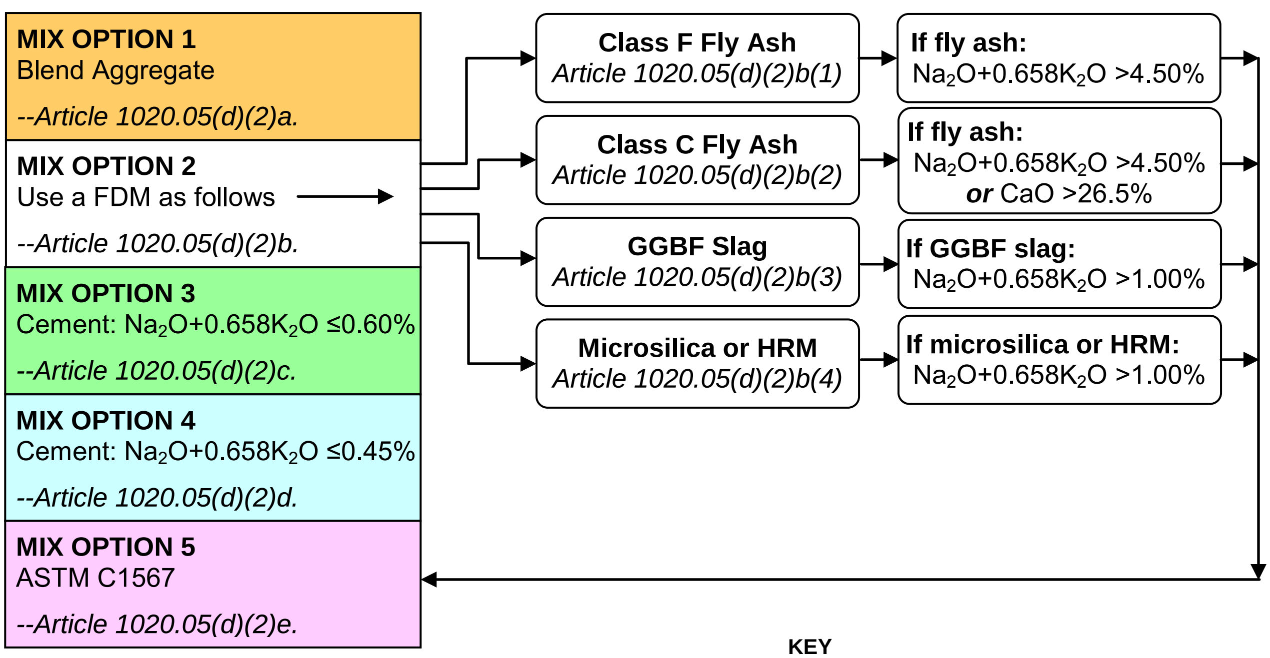


Figure 4 Example of Normal Distribution Plots for Mixes with Adjusted Target Strengths to Account for the Differing Standard Deviations

APPENDIX O

ALKALI-SILICA REACTION MITIGATION FLOW CHART





* Not applicable: concrete revetment mat, insertion lining of pipe culvert, portland cement mortar fairing course, CLSM, miscellaneous grouts that are not prepackaged, and Classes PP-3, PP-4, PP-5.

KEY
CAM: Cement Aggregate Mixture (e.g., CAM II)
CLSM: Controlled Low Strength Material
FDM: Finely Divided Mineral
GGBF: Ground Granulated Blast Furnace (slag)
HRM: High Reactivity Metakaolin

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APPENDIX P

BRIDGE DECK LATEX CONCRETE OVERLAY MIX DESIGN

Latex concrete shall be done according to the Guide Bridge Special Provision for Bridge Deck Latex Concrete Overlay, which provides approximate mix design criteria. The principle of volumetric mix design, designing in terms of a standard unit volume, still applies. Thus, it is important to note that the solids and nonsolids contained in the latex admixture may contribute significantly to the volume of the mix design. To account for the volumetric contribution made by the latex admixture, the absolute volumes of coarse aggregate and water can be reduced to accommodate the volumes of solids and nonsolids, respectively, of the latex admixture.

First, the mix design is calculated as though there is no latex admixture included; this will help ensure the intended 42 to 50 per cent coarse aggregate content (by weight) is established. Then, the volume of solids in the latex admixture is calculated and subtracted from the volume of coarse aggregate. Similarly, the volume of nonsolids in the latex admixture is subtracted from the volume of water in the mix. Finally, the weights of all components can be re-calculated based on their specific gravities as usual.

For example, calculate the adjusted batch weights for a latex concrete mixture using a latex admixture with specific gravity 1.01 and percent solids 46%:

Given: Latex Admixture Dosage – 24.5 gal/cu yd
Fine and Coarse Aggregate Specific Gravities – 2.65

	Initial Batch (without latex admixture)		Adjusted Batch (with latex admixture)	
	Absolute Volume (yd^3)	Batch Weight, SSD (lb/yd^3)	Absolute Volume (yd^3)	Batch Weight, SSD (lb/yd^3)
Fine Aggregate	0.346	1544	0.346	1544
Coarse Aggregate	0.339	1513	0.283	1263
Cement	0.124	658	0.124	658
Air (5%)	0.050	0	0.050	0
Water	0.143	240	0.078	131
Latex	---	---	0.121	206
Total	1.00		1.00	

Adjustment Calculations:

Batch Weight of Latex Admixture = 24.5 gal/yd^3 × (1.01 × 8.33 lb/gal) = 206 lb/yd^3
Absolute Volume of Latex Admixture = 206 ÷ (1.01 × 1683.99) = 0.121 yd^3
Absolute Volume of Latex Solids = 0.121 × (46/100) = 0.056 yd^3
Absolute Volume of Latex Nonsolids = 0.121 - 0.056 = 0.065 yd^3

Adjusted CA Absolute Volume = 0.339 - 0.056 = 0.283 yd^3
Adjusted CA Batch Weight = 0.283 × 2.65 × 1683.99 = 1263 lb/yd^3

Adjusted Water Absolute Volume = 0.143 - 0.065 = 0.078 yd^3
Adjusted Water Batch Weight = 0.078 × 1.00 × 1683.99 = 131 lb/yd^3

The Department's Excel PCC Mix Design program accounts for the latex admixture contribution in this way based on the following required design inputs:

- Batch Dosage: latex admixture dosage in terms of gallons per cubic yard (L/m^3).
- Specific Gravity: manufacturer's specific gravity for the latex admixture.
- % Solids: manufacturer's percent solids for the latex admixture.

This Page Reserved

PCC Level III
PowerPoint
Handout
Main Presentation

2017-2018

CONCRETE MIX DESIGN
CET 039

2018

1

INSTRUCTORS

- Greg Rohlf
- Joe Pitlik
- Derek White

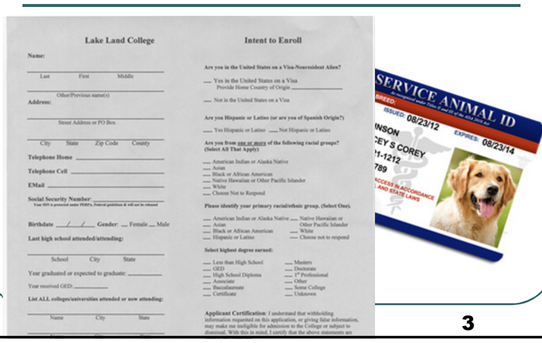
S.T.A.T.E. TESTING
DUNDEE CHICAGO

Illinois Department of Transportation

Lake Land College I.D.O.T. QC/QA

2

LLC Enrollment Form and Photo i.d.



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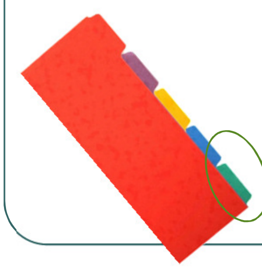
Follow the PowerPoint Notes

Last tabbed divider Course Manual



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OBJECTIVES

- Be able to perform mix design per IDOT Mortar Factor method
- Identify and understand IDOT PCC specifications
- Improve understanding of how ingredient materials affect PCC mix design and performance
- Introduce IDOT mix design spreadsheet

5

Administration

- Two Day Class
- Test – 2 ½ hours, open book
- You will be notified of results by mail
- Re-test by August 31
- 12 Professional Development Hours (PDH)

6

COURSE MANUAL PREVIEW

7

Table of Contents – Reference

- Course Evaluation Forms – Please fill out before you leave.
- Definitions
- Applicable Specifications
- Classes of Concrete
- Units of Measure
- Significant Digits and Rounding

8

Table of Contents (Page vii) Main Content (Page 1 of 46)

1.0 Mix Design Overview

2.0 Mix Design
- Walk thru specifications and design steps
- Example problems

3.0 Specialty Mixes (2nd day)

4.0 Ternary Mix Designs

5.0 Mass Concrete

6.0 Trial Mix

7.0 Target Strength

9

Table of Contents (more)

8.0 Durability Testing

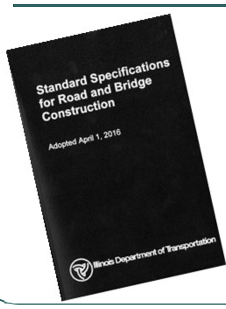
9.0 Verification – Trial Batch

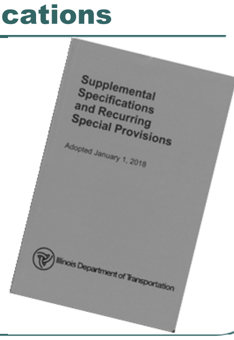
Appendices TOC (Page ix)

<u>Last tabs</u>
- Worksheets for Homework and Problems
- PowerPoint Handout

10

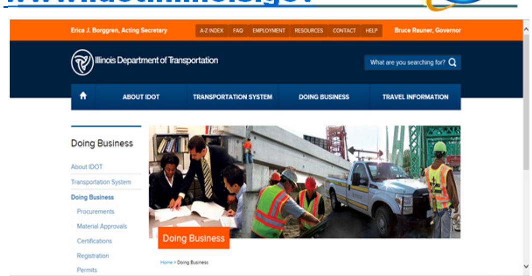
Applicable Specifications





11

Resources: www.idot.illinois.gov



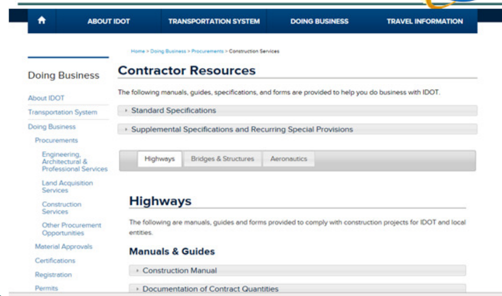
12

www.idot.illinois.gov
"Contractor Resources"

- Standard Specifications for Road and Bridge Construction - Every 5 years
- Supplemental Specifications and Recurring Special Provisions - Annually
- BDE (Bureau of Design & Environment) Special Provisions – Per letting
  - Remember Errata
- GBSP – Guide Bridge Special Provisions

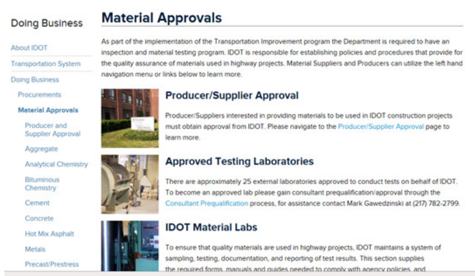
13

www.idot.illinois.gov
"Contractor Resources"



14

www.idot.illinois.gov
"Material Approvals"



15

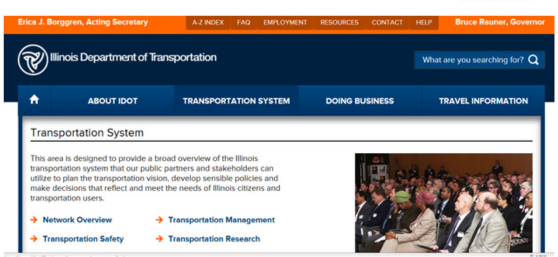
www.idot.illinois.gov
"Material Approvals"

- Cement
- Finely Divided Minerals (Fly ash, etc.)
- Admixtures
- Aggregate ASR and Freeze Thaw Rating
- Proprietary repair and specialty mixes

Updated weekly – Subscribe to Email Updates!

16

www.idot.illinois.gov
Search function



17

Hierarchy of Contract Documents (Article 105.05)

1. Special Provisions:
   - Project-Specific
   - Inserted BDE/GBSP
2. Plans (Detail Plans over Hwy. Standards)
3. Recurring Special Provisions (Check Sheet)
4. Supplemental Specifications
5. Standard Specifications


Supplemental Specifications and Recurring Special Provisions

Adopted January 1, 2017

Illinois Department of Transportation

18

Hierarchy of Contract Documents Art. 105.05

Art. 105.06 Control of Work

Hierarchy of the Contract Documents		
Special Provisions	Hold over:	Plans, Recurring Special Provisions, Supplemental Specifications, and Standard Specifications
Plans [1/, 2/, 3/]	Hold over:	Recurring Special Provisions, Supplemental Specifications, and Standard Specifications
Recurring Special Provisions	Hold over:	Supplemental Specifications, and Standard Specifications
Supplemental Specifications	Hold over:	Standard Specifications

1/ Detail plans hold over Highway Standards.

2/ Calculated dimensions hold over scaled dimensions.

3/ The Highway Standards indicated by the revision number listed in the Index of Highway Standards on the plans shall hold over Highway Standards listed anywhere else.

19

GBSP
Guide Bridge Special Provisions

Issued by the Bureau of Bridges and Structures
Inserted into Project Manual

- Deck Slab Repair
- Bridge Deck Overlays - Microsilica, Latex, High-Reactivity Metakaolin, Fly Ash, GGBF Slag
- Concrete Wearing Surface
- Structural Repair of Concrete

20

BDE Special Provisions
(Bureau of Design and Environment)

- Dept. Mix Design BDE Special Provision 80277 (Appendix A)
- QC/QA BDE (4x8 cylinders allowed)
- Placing and Consolidating 80316 (Moved to Standard Specs, Article 503.07)

Inserted in Project Manual.
Look for Updates on IDOT website
Revised alternate lettings.

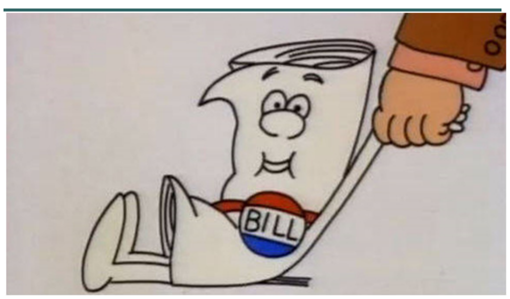
21

Concrete Mix Design – Department Provided (BDE 80277) Appendix A

- Contractor has the option to request the Engineer determine mix design material proportions for all classes of concrete (except PS)
- A single mix design for each class of concrete will be provided.
- Contractor must still meet specification requirements.
- District Option to include in contracts

22

Standard Specs vs. Special Provisions



23

PCC in SSRBC – Article 1020 (2016)

- Classes of concrete & mix design criteria
- Rules for Fly Ash/GGBFS replacement & ternary mixes
- Use of concrete admixtures (Also Article 1021)
- Alkali-Silica (ASR) mitigation (See Appendix O)
- Mix time, use of multiple plants, curing, temperature restrictions
- Curing and protection
- Heat of hydration control for mass structures

24

Supplemental Specification for PCC

Supplemental Specification amends Section 1020 of *Standard Specifications for Road & Bridge Construction* (Except when *Standard Specifications* are newly issued)

- Most now in Article 1020 of SSRBC
- Clarification of class DS concrete
- Temperature control for placement (85 F max for bridge decks)

25

Recurring Special Provisions (Check Sheets)

Included in *Supplemental Specifications* book

District option to include - Must be "checked" in project manual to apply.

#23 Calcium Chloride Accelerator for PP-2

#24 QC/QA for PCC at the plant

#25 QC/QA Special Provision (QC Plan, required tests & frequencies, procedures)

26

Illinois Department of Transportation

Memorandum

New!

To: Regional Engineers

From: Maureen M. Addis *mA*

Subject: Special Provision for Portland Cement Concrete

Date: August 4, 2017

This special provision was developed by the Central Bureau of Materials to improve uniformity of slump when using a high-range water-reducing admixture.

This special provision should be inserted into all projects involving cast-in-place concrete, precast concrete, and precast prestressed concrete.

The districts should include the BDE Check Sheet marked with the applicable special provisions for the November 17, 2017 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 August 4, 2017.

80389m

27

PORTLAND CEMENT CONCRETE (BDE)

Effective: November 1, 2017

Revise the Air Content % of Class PP Concrete in Table 1 Classes of Concrete and Mix Design Criteria in Article 1020.04 of the Standard Specifications to read:

"TABLE 1. CLASSES OF CONCRETE AND MIX DESIGN CRITERIA

Class of Conc.	Use	Air Content %
PP	Pavement Patching Bridge Deck Patching (10)	
	PP-1	4.0 - 8.0"
	PP-2	
	PP-3	
	PP-4	
	PP-5	

New!

Revise Note (4) at the end of Table 1 Classes of Concrete and Mix Design Criteria in Article 1020.04 of the Standard Specifications to read:

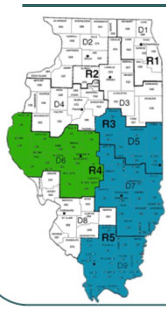
"(4) For all classes of concrete, the maximum slump may be increased to 7 in (175 mm) when a high range water-reducing admixture is used. For Class SC, the maximum slump may be increased to 8 in. (200 mm). For Class PS, the maximum slump may be increased to 8 1/2 in. (215 mm) if the high range water-reducing admixture is the polycarboxylate type."

80389

28

IDOT District QC/QA and Mix Design Status

OUTDATED

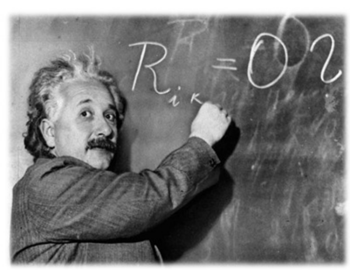


SUBJECT TO CHANGE

- Districts 1, 2, 3, 4, 8 - QC/QA; Contractor Mix Design.
- District 6 - Moving from QC at Plant to QC/QA.
- Districts 5, 7, 9 - Not QC/QA, District will provide mix designs.

29

DEFINITIONS and MATH REVIEW



30

p. xviii

Abbreviations

BDE…….Bureau of Design and Environment
FDM…….Finely Divided Mineral
GBSP…..Guide Bridge Special Provision
MF………Mortar Factor
CWT……Hundredweight
SSD…….Saturated Surface Dry
SG………Specific Gravity
GGBFS…Ground Granulated Blast Furnace Slag
HRM…….High-Reactivity Metakaolin
CBM…….Central Bureau of Materials

31

Abbreviations, continued

ASR……Alkali Silica Reaction
FCA…….Fraction of Coarse Aggregate
FM………Fineness Modulus
SCC…….Self Consolidating Concrete
CAM II….Cement Aggregate Mixture II
CLSM…..Controlled Low-Strength Material
VCA……Voids in Coarse Aggregate
ITP……..IDOT Test Procedure
MISTIC…Materials Integrated System for Test Information and Communication

32

p. xvii

Significant Digits / Rounding

Retain 0.XXX until end.

Whole Number

- Cement, Finely Divided Minerals **(550 LB) (round up to next 5 LB)**
- Coarse and Fine Aggregate **(1,986 LB)**

One Digit to Right of Decimal

- Water, Air Content, Basic Water **(5.3 gal/cwt 44.1 lbs. 6.5%) >>>**

33

Significant Digits / Rounding

Two Digits to Right of Decimal

- Specific Gravity, Unit Weight **(2.68, 146.35 pcf)**
- Water/Cement Ratio, Mortar Factor, VCA **(0.44, 0.80, 0.41)**

Three Digits to Right of Decimal:

- Absolute Volume **(0.116)**

34

Water/Cement Ratio

W/C ratio =

$$\frac{\text{All liquids, including water in admixtures}}{\text{All cement and cementitious materials}}$$

35

Yield

Volume of concrete batch expressed in volume (FT^3)

$$\frac{\text{Sum of Batched Material Weight (LB)}}{\text{Unit Weight of Concrete Mix } (LB/FT^3)}$$

36

Shrink Mix

- PCC is mixed in plant mixer before discharge into truck mixer
- Short mixing period in the plant reduces the bulk volume Typically, 1.3 yd^3 fully mixed PCC requires about 2.07 yd^3 of individual (ACPA)
- Thus, more PCC can be loaded into each truck mixer
- The amount of mixing should be determined via mixer uniformity tests

37

Concrete Math

- Concrete is batched by weight, sold by volume (Level II)
- Designed by volume, batched by weight (Level III)

38

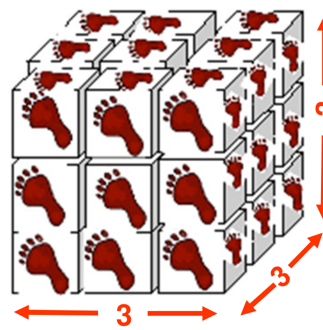
IMPORTANT CONCEPT #1

IDOT DESIGN VOLUME

The sum of volume of all ingredients is ONE CUBIC YARD!

1 Cubic Yard "box"

39



Remember?

1 YD^3

3 x 3 x 3 = 27 FT^3

40

IDOT Design Volume = 1 Cubic Yard

+ Aggregate
+ Cement
+ Other cementitious materials (FDM's)
+ Water
+ Air
+ Admixtures

1 Cubic Yard

41

Volume vs. Weight Typical PCC Mix

	VOLUME	WEIGHT
AIR	6%	0%
WATER	13%	6%
CEMENTITIOUS	11%	14%
AGGREGATE	70%	80%
	100%	100%

42

Unit Weight (Density): Requires 2 Measurements

$$\frac{\text{Mass (or Weight)}}{\text{Volume}}$$

e.g.

$$\frac{\text{Pounds}}{\text{Cubic Foot}}$$

43

Volumetric Testing – Weight and Volume

Weigh it (mass)

Wet it (volume)

Volume of Displaced Water

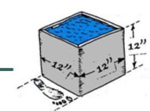
44

Unit Weight Formula 3 Configurations

	examples
Unit Wt. = $\frac{\text{Weight}}{\text{Volume}}$	PCF = $\frac{\text{Pounds}}{\text{Cu. Ft.}}$
Volume = $\frac{\text{Weight}}{\text{Unit Wt.}}$	Cu. Ft. = $\frac{\text{Pounds}}{\text{PCF}}$
Weight = Vol. x Unit Wt.	Pounds = CF x PCF

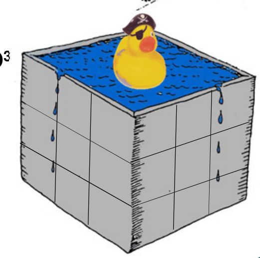
45

Unit Weight of Water



Unit Weight = 62.37 LB/FT^3
(1000 kg per cubic meter)

62.37 LB/FT^3 X 27 FT^3/YD^3
= 1,683.99 LB/YD^3



For this class
= 1,684 LB/YD^3

46

Specific Gravity "The Other Unit Weight"

Unit weight relative to the unit weight of water:

$$\frac{\text{Weight of Material}}{\text{Wt. of Equal Vol. of Water}}$$

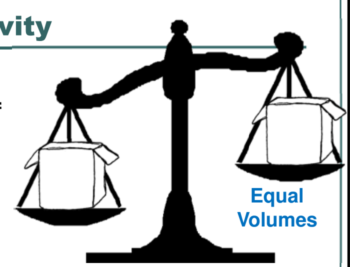
47

Specific Gravity

Example:
Unit Wt. = 1,000 pcf

Specific Gravity =
1,000 / 62.4 = 16

(SG has no "units")



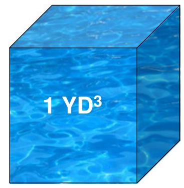
48

Specific Gravity Example

- Depleted uranium: 1192.4 pcf / 62.4 = S.G. 19.1

49

Specific Gravity of Water



1,684 LB/YD³

$$SG = \frac{1{,}684\ LB/YD^3}{1{,}684\ LB/YD^3}$$

= 1.000

50

Bulk vs. Solid

- Bulk includes air
- Solid means solid.

51

Aggregate – Bulk and Solid

Bulk

Solid

52

Specific Gravity of Solid Rock

4,500 LB

e.g.
Wt of 1 YD³ solid rock
= 4,500 LB/YD³

$$SG = \frac{4{,}500\ LB/YD^3}{1{,}684\ LB/YD^3} = 2.67$$

53

Specific Gravity of Bulk Cement

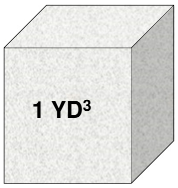
94 Pound Sacks
1 cubic foot each

$$\text{Unit Wt.} \quad \frac{\text{Weight}}{\text{Volume}} \quad \frac{94\ LB}{1\ FT^3} = 94\ pcf$$

$$\text{Bulk SG} \quad \frac{\text{Unit Wt}}{\text{Unit Wt Water}} \quad \frac{94\ pcf}{62.4\ pcf} = 1.52$$

54

Specific Gravity of Solid Cement



5,305 LB/YD³

SG = $\frac{5{,}305 \text{ LB/YD}^3}{1{,}684 \text{ LB/YD}^3}$

= 3.15
Given for Type 1 Cement

55

Cement Factor – History

Bagged cement
94 LBS

e.g. "Six Bag Mix"
= 94 X 6
= 564 LB/YD³
IDOT PV spec = 5.65 cwt

56

Cement Factor: Weight of Cement per Cubic Yard

Expressed as **cwt per cubic yard** or **cwt**

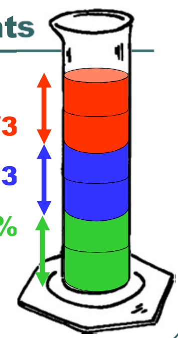
cwt = 100 pounds of cement
e.g. **5.65 cwt/yd³**
or (shortcut) **5.65 cwt**

x 100 to get "Cement Content" of mix
cwt x 100 = 565 LB/YD³.

57

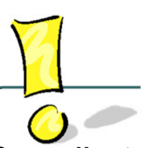
Numerical Equivalents

Fraction 1/3
= Decimal Fraction 0.333
= Percentage 33.3%



58

Important Concept #2



Absolute Volume (2.1)
- The **solid** volume of each ingredient material in the design volume
- Calculated based on mass & S.G.
- Percent expressed as a decimal fraction (0.XXX)
- Total of all ingredients = 1.000

59

Absolute Volume example

$\frac{22 \text{ FT}^3 \text{ Material}}{27 \text{ FT}^3 \text{ Box}}$

= 0.815
Absolute Volume

60

Absolute Volume = Another way to express percentage

Typical PCC Mix	Percent	Absolute
AIR	6.5%	.065
WATER	12.5%	.125
CEMENTITIOUS	11.0%	.110
AGGREGATE	70.0%	.700
	100%	1.000

61

Absolute volume concept works for any container

As long as you know the proportions of the contents.

62

Absolute Volume of Liquid

- Container 40% Full
- Absolute Volume Liquid = 0.400
- Absolute Volume Air = 0.600

63

Bulk candy absolute volume

Bulk Volume 50%
Half is air.

64

Solid candy absolute volume

Absolute Volume Candy = 0.250 (25%)

Absolute Volume of Air = 0.750.

65

Absolute Volume Formula

$$\frac{\textbf{Weight of Material}}{\textbf{(s.g. of Material) x (Unit Wt. Of Water)}}$$

$$\frac{\textbf{(Weight) LB}}{\textbf{(Specific Gravity) x 1,684 LB/YD}^3}$$

$= 0.XXX\ YD^3$

66

Concrete Materials

- Aggregate
  - Coarse
  - Fine
- Cement
- Finely Divided Minerals (FDM's)
- Admixtures
- Fibers
- Water

67

Properties of Concrete Aggregates

- Quality
- Nominal size
- Gradation
- Specific gravity
- Absorption
- Voids in coarse aggregate (VCA)

68

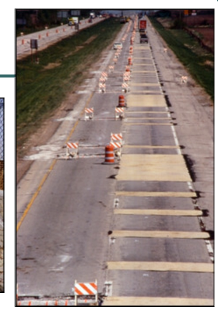
Concrete Aggregate

- Quality – "A"
- Gradation
- Durability - Resistant to:
  - D-Cracking
  - Alkali-Silica Reaction

69

PCC AGGREGATE DURABILITY

ASR



"D" Cracking

70

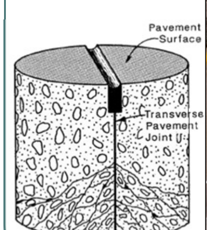
D Cracking – "Destructive"

3 Conditions:

1. Moisture
2. Susceptible Coarse Aggregate
3. Freeze-Thaw Cycling

71

Bottom-up D Cracking



72

Freeze-Thaw Rated Coarse Aggregate – On Grade

- Pavement
- Base course
- Base course widening
- Shoulders
- & repair
- Driveway
- Sidewalk
- Curb, Gutter,
- Combination curb and gutter
- Median
- Paved ditch

73

"D" Cracking Mitigation

Use Coarse Aggregate per IDOT Freeze-Thaw Rating Approved list:

- 20-Year – All on-grade PCC
- 30-Year – Extended Life Pavement*
- 40-Year – Extended Life Pavement*

*via Special Provision

74

Fine Aggregate Quality SSRBC (1003.01)

FINE AGGREGATE QUALITY

QUALITY TEST	CLASS A	CLASS B	CLASS 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	---

75

Coarse Aggregate Quality SSRBC - (1004.01)

(b) Quality. The coarse aggregate shall be according to the quality standards listed in the following table.

COARSE AGGREGATE QUALITY

QUALITY TEST	CLASS A	CLASS B	CLASS C	CLASS D
Na_2SO_4 Soundness 5 Cycle, Illinois Modified AASHTO T 104 1/, % Loss max.	15	15	20	25 2/
Los Angeles Abrasion, Illinois Modified AASHTO T 96, % Loss max.	40 3/	40 4/	40 5/	45
Minus No. 200 (75 µm) Sieve Material, Illinois Modified AASHTO T 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.

76

Particle size

77

PCC Aggregate Nomenclature

Maximum Aggregate Size

1st sieve w/ 100% passing

Nominal Maximum Aggregate Size

Next Sieve - 1st to retain any aggregate.

78

NMAS for PCC and HMA may not be the same.

Nominal Maximum Agg Size CA11

Sieve	Spec % Pass	Blend A	Blend B
1"	100%	100%	100%
¾"	84-100%	100%	**89%**
½"	30-60%	**45%**	30%

NMAS

	Blend A	Blend B
HMA	¾"	1"
PCC	**½"**	**¾"**

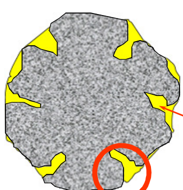
79

Aggregate Specific Gravity

1. Oven Dry (G_a)
   - Specific Gravity of Dry Aggregate
   - Used to determine Voids in Coarse Aggregate (coming up later)
2. Saturated Surface Dry (G_{SSD})
   - Specific gravity, including absorbed and damp-surface water
   - Used in PCC design and production

80

Oven-Dry Bulk Specific Gravity



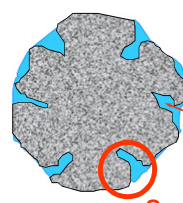
$$G_a = \frac{\text{Mass (Dry Agg)}}{\text{Vol (Agg + Surf Voids)}}$$

Vol. of water-perm. voids

Surface Voids (empty)

81

SSD Bulk Specific Gravity



$$G_{SSD} = \frac{\text{Mass (Dry Agg + } H_2O\text{)}}{\text{Vol (Agg + Surf Voids)}}$$

Vol. of water-perm. voids

Surface Voids (filled)

82

Aggregate Specific Gravity Calculations – 3 Measurements

3 Measurements

A = Oven Dried Wt.

B = SSD Weight

C = Submerged Wt.

3 Calculations

$$G_a = \frac{A}{B-C}$$

$$G_{SSD} = \frac{B}{B-C}$$

$$\text{Absorption} = \frac{B-A}{A}$$

83

Cement (2.2)

84

Types of Cements

- Type I – Normal
- Type II – Sulfate Resistant
- Type III – High Early Strength
- Type IV – Low Heat
- Type V – High Sulfate Resistant
- Type IA – Air Entraining

85

Blended Cements

- Type IP (Portland-Pozzolan)
- Type IS (Portland blast-furnace slag cement)
- Type IT –Ternary blended cement
  - e.g. Type IT(S25)(P15) contains 25% slag and 15% pozzolans (fly ash)
- Type IL (Limestone cement)

86

Approved Cements

Page 1

Illinois Department of Transportation
Bureau of Materials and Physical Research
APPROVED LIST OF QUALIFIED CEMENT PLANTS
October 25, 2013
This list supersedes the March 15, 2013 list.
Standard Specifications for Road and Bridge Construction, Section 1001 (Adopted January 1, 2012)
Current Policy Memorandum, "Portland or Blended Cement Acceptance Procedure for Qualified and Non-Qualified Plants"

Material Code No.
Type I 37601, Type II 37603, Type III 37605, Type IP 37703, Type IS 37701, Type V 37608, Type II (MH) 37609

For information regarding new product submittal, click the "New Submittal" bookmark to the left.

Producer	Location	Producer Number	Ty I	Ty II	Ty I / Ty II Alkalies			Ty III	Ty III Alkalies			Other Types and their Alkalies (Na_2O + 0.658 K_2O)
					≤.45	≤.60	>.60		≤.45	≤.60	>.60	
Buzzi Unicem	Greencastle, IN^	6097-02	x				x	x			x	
	Cape Girardeau, MO ^	6097-03	x	x		x						Ty II (MH) ≤.60

⇑ Alkalis

87

Finely Divided Minerals (2.4)

GROUND GRANULATED BLAST-FURNACE SLAG

FLY ASH

HIGH REACTIVITY METAKAOLIN (HRM)

MICROSILICA

88

Finely Divided Minerals "FDMs"

"Cementitious Material"

- Fly Ash
- Ground Granulated Blast Furnace Slag
- Microsilica
- High-Reactivity Metakaolin

Used for cement replacement and mix enhancement

89

Supplementary Cementitious Materials

Another term for FDM

IDOT uses "FDM"

90

Fly Ash

Coal plant by-product

- Increases workability
- Lowers heat of hydration
- Delays set
- Reduces permeability
- Decreases air content
- Lower early strength – Higher long term strength

91

Fly Ash Classes

Class C - From Lignite/Subbituminous (brown) coal – Cementitious and Pozzolanic properties

- More commonly used in IL
- Usually allowed

Class F – From Anthracite/Bituminous (black) coal - Pozzolanic properties

- Burned from harder, older coal
- More restrictions on use

92

Illinois Department of Transportation
Bureau of Materials and Physical Research
APPROVED LIST OF SUPPLIERS FOR FINELY DIVIDED MINERALS
October 14, 2011

Source	Unit No.	Producer/ Supplier No.
Alliant Power [A] Columbia Station Portage, WI	1, 2	52403-03

Class	Material Code No.	R Factor [C]	Average Specific Gravity
C	37801	3.61	2.68

93

Source	Unit No.	Producer/ Supplier No.
Alliant Utilities [B] Burlington Station Burlington, IA	1	52203-05

A/ … the average calcium oxide (CaO) of the Class C fly ash from this source is ≥18% to < 26.5%, and the loss on ignition (LOI) is less than 2.0%.

B/ …the average calcium oxide (CaO) of the Class C fly ash from this source is ≥26.5%, and the loss on ignition (LOI) is less than 2.0%.

94

Fly Ash as Cement Replacement Supplemental Spec (Section 1020)

Fly Ash	Concrete Class	Max. Cement Replacement by weight (mass)
Class F	PV, BS, PC, PS, DS, SC, SI	25 percent
Class C	PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, SI	30 percent

95

Ground Granulated Blast Furnace Slag (GGBFS)

- Increases workability
- Lowers heat of hydration
- Delays set
- Reduces permeability
- Lower early strength – Higher long term strength.

96

GGBFS as Cement Replacement

	Concrete Class	Max. Cement Replacement by weight (mass)
GGBFS	PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC and SI	35 percent

97

Microsilica (Silica Fume)

Electric arc furnace by-product

- Reduces Permeability of bridge decks
- Decreases air content
- Reduces workability
  - Requires Super
- Higher early and long term strength
- Dense, Brittle
- Required for PP-3 and microsilica overlay

98

High-Reactivity Metakaolin (HRM)

Processed by calcining (heating) purified kaolinite (a clay).

- Increases PCC strength, durability
- Reduces permeability, mitigates ASR
- Enhances workability and finishing
- Reduces shrinkage, due to "particle packing" making concrete denser
- Can be used in HPC and lightweight concrete
- Finer than cement, not as fine as microsilica

99

Microsilica and HRM as Cement Replacement

	Concrete Class	Max. Cement Replacement by weight
Microsilica	All *	5.0 percent
	* Class PP-3 concrete	Per Art. 1020.04
HRM	All	5.0 percent

100

TERNARY CONCRETE MIXTURES

A mix that includes Portland cement and two FDM's.

Chicago's Wacker Drive

101

Ternary concrete mixtures can be designed for:

- Higher strength
- Lowered permeability
- Corrosion resistance
- Sulfate resistance
- ASR mitigation
- Elimination/reduction of thermal cracking

102

Use of FDMs in Ternary Mixes Supplemental Spec (Section 1020)

Class PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, and SI	
	Maximum Cement Replacement
Combined FDMs [1/]	35% of total cementitious
Class C Fly Ash	30%
Class F Fly Ash	25%
Class C + F Fly Ash	30%
GGBF Slag	35%
Microsilica or HRM	10% individual or combined
[1/] FDM in Blended cements count toward 35% total.	

103

Ternary Mix Example

- Portland cement: 400#
- Fly ash: 100#
- GGBFS: 75#

104

Ternary Mix Example

Mix Design	3*	4*
Cement	445 (264)	445 (264)
GGBF Slag***	90 (53)	90 (53)
Microsilica Solids	25 (15)	--
HRM	--	27 (16)

105

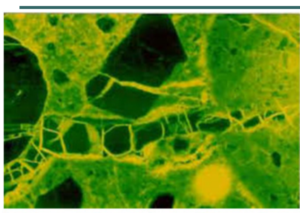
Options: IDOT Cement / FDM Selection

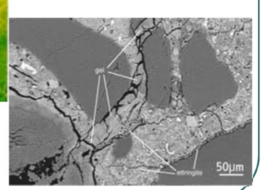
1. Straight cement, per Table 2.2.1
2. Use 1 FDM
3. Use Ternary Mix

NOTE: Mix Design must comply with ASR mitigation requirements (Article1020).

106

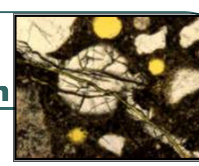
Alkali-Silica Reaction





107

Alkali Silica Reaction



- Reaction of alkalies in cement with siliceous material in some aggregate
- Requires water
- Gel forms – expands and cracks concrete
- Affects strength, stiffness, serviceability, safety, and stability
- Difficult to recognize, identify and monitor
- Not universal or completely predictable

108

Alkali-Silica Reaction

- First discovered by Thomas Stanton in 1930's
- Cases documented in 1950's
- 1957 – 1st case in Canada reported

109

Alkali-Silica Reaction

110

Alkali-Silica Reaction Mitigation (Article 1020/Appendix O)

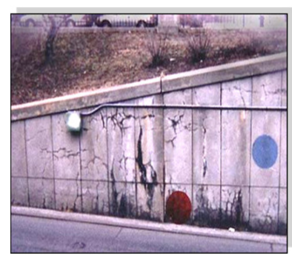
Applies to all projects

- Department tests coarse and fine aggregates for "Aggregate Expansion Value" ASTM C 1260, ASTM C 1293
- Ranges posted on IDOT web page
- Fine aggregate: Limestone and Dolomite = 0.03
- Coarse aggregate: Limestone and Dolomite = 0.05
- Combined values determines "Group"
- ~~May~~ Will shape material selection

111

ASR Mitigation (Standard Specs Section 1020)

1. Identify Aggregate Groups
2. Evaluate Mitigation Options
3. Apply Options



112

IDOT ASR Rating List Gives Ranges

Illinois Department of Transportation
Bureau of Materials and Physical Research
ALKALI-SILICA POTENTIAL REACTIVITY RATING LIST
October 11, 2013
This list supersedes the August 9, 2013 list. Note: Changes are not high-lighted on this list.

P/S No.	*Ledge Description*	*Material Code*	*ASR Rating**
52600-07	ABOVE WATER	027FA02	B

A = < 0.16   B = 0.17 - 0.27   C = > 0.28

Contact individual sources for ASR Expansion Value

113

ASR Rating List

Illinois Department of Transportation
Bureau of Materials and Physical Research
ALKALI-SILICA POTENTIAL REACTIVITY RATING LIST
May 22, 2015

Page 18 of 23

This list supersedes the April 10, 2015 list. Note: Changes are not high-lighted on this list.

The following values are based on Illinois Modified ASTM C 1260 test results.

Please Note: Each coarse aggregate limestone or dolomite shall have an assigned expansion value of 0.05% and each fine aggregate limestone or dolomite (manufactured stone sand) shall have an assigned expansion value of 0.03%, unless otherwise noted below.

Dist.	Producer Name	Location	P/S No.	Ledge Description	Material Code	ASR Rating*	Testing** Frequency	Number of Tests	C 1293 Test***
94	RIVERSIDE MATERIALS	CHILLICOTHE, IL	51430-09	BELOW WATER - ROUNDED	027FA01	B	3	3	
94	SAND HILL MATERIALS	ELLISVILLE, IL	50570-10	ABOVE & BELOW WATER - ROUNDED	027FA01	B	2	5	
94	SPOON RIVER S & G	SEVILLE, IL	50570-07	ABOVE WATER - ROUNDED	027FA01	B	1	2	
94	SPOON RIVER S & G	SEVILLE, IL	50570-07	ABOVE & BELOW WATER - ROUNDED	027FA01	B	1	2	

114

Illinois Department of Transportation
Bureau of Materials and Physical Research

ALKALI-SILICA POTENTIAL REACTIVITY RATING LIST
July 15, 2016

This list supersedes the May 22, 2015 list. Note: Changes are not high-lighted on this list

The following values are based on Illinois Modified ASTM C 1260 test results

Please Note: Each coarse aggregate limestone or dolomite shall have an assigned expansion value of 0.05% and each fine aggregate limestone or dolomite (manufactured stone sand) shall have an assigned expansion value of 0.03%, unless otherwise noted below

Dist.	Producer Name	Location	P/S No.	Ledge Description	Material Code	ASR Rating*	Testing** Frequency	Number of Tests	C 1293 Test***
91	ELMHURST CHICAGO ST.	KANEVILLE, IL	50890-29	BELOW WATER - PARTIAL 2 (JAW, CONE, VSI)	020CA16	A	2	5	
91	ELMHURST CHICAGO ST.	KANEVILLE, IL	50890-29	ABOVE WATER - PARTIAL 1 (JAW, CONE)	027FA02	B	1	1	
91	ELMHURST CHICAGO ST.	ROMEOVILLE, IL	51970-06	ABOVE WATER - ROUNDED	027FA01	A	1	1	
91	HANSON MATERIAL SVC	ALGONQUIN, IL	51110-12	ABOVE & BELOW WATER - PARTIAL (JAW)	020CA11	A	3	7	
91	HANSON MATERIAL SVC	ALGONQUIN, IL	51110-12	ABOVE & BELOW WATER - PARTIAL (JAW)	020CA16	A	3	8	
91	HANSON MATERIAL SVC	ALGONQUIN, IL	51110-12	ABOVE & BELOW WATER - PARTIAL (JAW)	027FA02	B	3	8	2017
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE WATER - CRUSHED (JAW, CONE, HSI)	029FA20	A	3	3	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	BELOW WATER - CRUSHED 2 (JAW, CONE, HSI, VSI)	029FA20	A	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - PARTIAL 2 (JAW, CONE)	020CA11	A	2	5	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - CRUSHED 2 (JAW, CONE, HSI, VSI)	027FA01	A	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - CRUSHED 2 (JAW, CONE, HSI, VSI)	027FA02	A	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	BELOW WATER - CRUSHED (JAW, CONE, HSI)	029FA20	A	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - PARTIAL 2 (JAW, CONE)	020CA16	A	2	6	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - PARTIAL 2 (JAW, CONE)	027FA01	C	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - PARTIAL (JAW)	027FA02	B	1	1	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - CRUSHED 2 (JAW, CONE, HSI, VSI)	029FA20	A	3	5	
91	LAFARGE ELBURN	ELBURN, IL	50890-27	ABOVE & BELOW WATER - CRUSHED (JAW, CONE, HSI)	029FA20	A	3	4	

**ASR Rating - Indicates ASR Expansion Value Range; A = < 0.16, B = 0.17 - 0.27, C = > 0.28; Please contact individual sources for ASR Expansion Value, when needed*

*** Testing Frequency: 1's, sample as needed until 3 tests are completed; 2's, sample in 2017; 3's, sample in 2016; Note: only 1 sample required per year indicated*

****Where applicable, ASTM C 1293 results used; Replace ASTM C 1260 results with 0.08; Resample required during year indicated*

115

ASR
Evaluate Mitigation Options

1. Blend Aggregates to improve "group"
2. Mitigate with FDM's
3. Use low alkali cement (≤ 0.60%)
4. Use Lower alkali cement (≤ 0.45%)
5. Verify mitigation: Test highest expansive aggregate with ASTM C 1567

116

ASTM C 1260 / 16 Day Test

117

ASTM C 1293 / 1 Year Test

118

ASR
Identify Aggregate Groups

COARSE AGGREGATE or Blend ASTM C 1260 Expansion	Fine Aggregate Or Fine Aggregate Blend ASTM C 1260 Expansion		
	≤0.16%	>0.16% - 0.27%	>0.27%
≤0.16%	Group I	Group II	Group III
>0.16% - 0.27%	Group II	Group II	Group III
>0.27%	Group III	Group III	Group IV

119

ASR
Valid Options (X)

AGG GROUP	Mitigation Option 1	2	3	4	5
I	Use any cement or finely divided mineral.				
II	Y	Y	Y	Y	Y
III	Y	Combine Option 2 plus Option 3		Y	Y
IV	Y	Option 2 plus Option 4	Invalid Option	Option 2 plus Option 4	Y

120

ASR Option 1
Blend Aggregates

Weighted Expansion Value = (a/100 x A) + (b/100 x B) + (c/100 x C) + …

Where:

a, b, c… = percentage of aggregate in the blend;

A, B, C… = expansion value for that aggregate

Look at CA and FA separately.

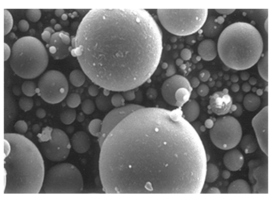
121

ASR Expansion Value Blending

Gradation	CA 07	CA 16	Total
% total mix	45%	15%	60%
(a) % of CA	75%	25%	100%
(A) Exp Value	0.05	0.19	
(a/100) x (A) =	0.04	0.05	0.09

122

ASR Option 2
Mitigate with FDM



123

Mitigation with Class C Fly Ash
Low Alkali

	CAM II, Class PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, SI
Class C Fly Ash	Replace 25% Cement

Class Fly Ash maximum total equivalent available alkali content ($Na_2O + 0.658K_2O$) $\leq$ 4.50% and the calcium oxide $\leq$ 26.50%.

124

Mitigation with Class F Fly Ash

	CAM II, Class PV, BS, PC, PS, MS, DS, SC, SI
Class F Fly Ash	Replace 25% Cement

Class F Fly Ash maximum total equivalent available alkali content ($Na_2O + 0.658K_2O$) $\leq$ 4.50%

125

Mitigation with GGBF Slag

	PV, PP-1, PP-2, RR, BS, PC, PS, DS, SC, and SI
GGBF Slag	Replace 25% Cement

GGBF Class F Fly Ash maximum total equivalent available alkali content ($Na_2O + 0.658K_2O$) $\leq$ 1.00%

126

Mitigation with Microsilica or High Reactivity Metakaolin

	All Concrete Classes
Microsilica or High Reactivity Metakaolin	Replace 5% Cement

Maximum total equivalent available alkali content ($Na_2O + 0.658K_2O$) $\leq$ 1.00%

127

ASR Option 3 and 4 FDM + Low Alkali Cement

The cement used shall have a maximum total equivalent alkali content of

Option 3: 0.60%

Option 4: 0.45%

FDM alkali content per Option 2.

128

ASR Option 5 Test the Combination of Materials

The proposed cement or FDM may be used if the ASTM C 1567 expansion value is ≤0.16 percent when performed on the aggregate in the concrete mixture with the highest ASTM C 1260 test result.

129

ASR - Don't ignore this!

- Know your material:
  - Aggregate - Expansion values
  - Cement - Alkali %
  - FDM - Alkali %

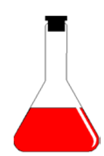
130

Concrete Admixtures (2.5.3 - Pg. 12)

131

Admixtures - Function

- Reduce cost
- Modify concrete properties
- Maintain quality during mixing, transporting, placing, and curing
- Mitigate some production emergencies



132

2.5.3 Required/Optional Use of Admixtures (Section 1020.05)

- Air-Entrainer
- Water reducer
- Retarder
- Superplasticizer
- Accelerator

133

Specialty Admixtures

- Corrosion inhibitor
- Shrinkage reducer
- Viscosity modifier
- Latex
- Workability enhancers
- Bonding
- Damp Proofing
- Coloring

134

Approved Admixture List

Illinois Department of Transportation
Bureau of Materials and Physical Research
APPROVED LIST OF CONCRETE ADMIXTURES
October 4, 2013
This list supersedes the July 12, 2013 list.
Standard Specifications for Road and Bridge Construction, Section 1021 (Adopted January 1, 2012)

AIR ENTRAINING ADMIXTURES
TYPE A: WATER REDUCING ADMIXTURES
TYPE B: RETARDING ADMIXTURES
TYPE C: ACCELERATING ADMIXTURES
TYPE D: WATER REDUCING AND RETARDING ADMIXTURES
TYPE E: WATER REDUCING AND ACCELERATING ADMIXTURES
TYPE F: HIGH RANGE WR ADMIXTURES (SUPERPLASTICIZERS)
TYPE G: HIGH RANGE WR & RETARDING ADMIXTURES (SUPER)
TYPE F: ONE COMPONENT SELF-CONSOLIDATING (FOR SCC)
TYPE S: RHEOLOGY-CONTROLLING ADMIXTURE

135

Admixture Approval and Use

- Admixtures approved based on manufacturer's certified tests
- The admixture technical representative shall be consulted when determining an admixture dosage from this list
- The dosage shall be within the range indicated on the approved list (unless other circumstances warrant otherwise)

136

DOSAGE RATE – (Approved List)

AIR ENTRAINING ADMIXTURES

Producer / Supplier Number	Brand Name	Admixture Dosage Range Based on Cementitious mL/100 kg (oz/cwt.) **
4695-01	Catexol AE 260	6.5-391 (0.1-6)
4695-01	Catexol AE 360	32.6-391.2 (0.5-6.0)
4179-04	MB AE 90	16.3-260.8 (0.25-4.0)
4179-04	MBVR Concentrate*	16.3-260.8 (0.25-4.0)
4179-04	MBVR Standard *	16.3-260.8 (0.25-4.0)

137

Air Entrainment

All PCC shall contain entrained air

- Except SC, Seal coat (optional) and Latex-Modified

138

Cement Reduction with Water-Reducing Admixtures

For class PV, PP-1, RR, SC, SI concrete:

Cement factor may be reduced by a maximum of 0.30 cwt (except under water)

PCC III Manual, Pg. 3

(This is Step 1 in Mix Design)

139

Class BS Concrete Admixtures

Class BS and bridge deck overlays

1. Retarder at ≥ 65°F (air or concrete)
2. Water-reducer (Optional)

140

Accelerating Admixtures

- Non-chloride accelerator <u>required</u> for PP-2, PP-3, and PP-5
- <u>Optional</u> for PP-1 or RR concrete.
- PP-1, PP-2, RR – calcium nitrite when air <55°F
- PP-3 - calcium nitrite only.
- Calcium chloride allowed only by special provision in the contract; normally for PP-2.

141

Water Content of Admixtures

When determining water in admixtures for water/cement ratio, the Contractor shall calculate 70 percent of the admixture dosage as water, except a value of 50 percent shall be used for a latex admixture used in bridge deck latex concrete overlays. (Section 1020.05)

<u>See: Appendix P – Check with manufacturer</u>

142

Fibers (Page 33)

- Req'd for whitetopping
- Optional for slipformed curb, paved ditch, etc. (per Special Provision)
- IDOT Approved List
- Not a mix design component
- Report in "comments" in mix design submittal

143

Materials Economics

144

Typical Unit Costs

Type I Cement	$ 85-100 / Ton
Type III Cement	$ 95-120 / Ton
C Fly Ash:	$ 65-85 / Ton
GGBF Slag	$ 75-85 / Ton
Microsilica	$ 0.50-0.60 / lb ($1,000/ton)
CA:	$ 15 / Ton
FA:	$ 12 / Ton

145

FDM Replacement Calculation

	$/T	$/lb	lb/cy	$/cy
100% Cement	$90	$0.045 x	575 =	$25.88

30% Fly Ash Ty C Replacement				
70% Cement	$90	$0.045 x	405 =	$18.23
30% Fly Ash	$75	$0.038 x	175 =	$6.65
			580	$24.88

($/lb = $/T ÷ 2000 lb/T)

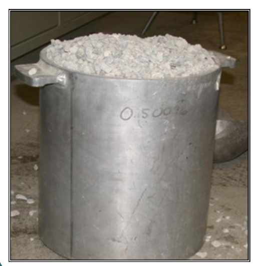
146

Conversion Example

- If cattle feed is $290 per ton…
- $290 / 2000 # per ton = $0.145 per pound

147

Voids in Coarse Aggregate VCA



Percent Voids in a compacted sample of Coarse Aggregate.

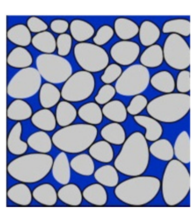
Expressed as a decimal (0.XX)

Determined via test

148

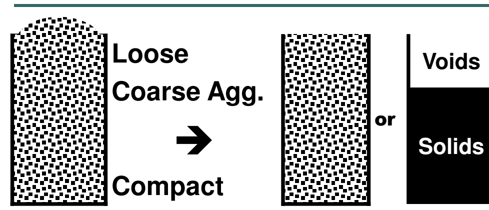
Voids in Coarse Aggregate

- **VCA is an AGGREGATE PROPERTY!**
- **Same for all users of same aggregate**
- **District Option to provide VCA for design**



149

Voids in Coarse Aggregate



VCA = Vol. Voids / Vol. Bucket

150

Voids in Coarse Aggregate

- AASHTO T 19
- ASTM C 29
- ITP 306 (Appendix C)

151

Procedure

STEP 1:
START WITH
ONE BUCKET
OF ROCKS

152

1st - Check your gradations!!!

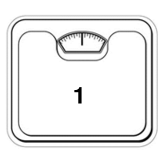
153

Equipment Needed

- Bucket (½ ft^3 min.)
- Scale
- Tamping Rod
- Scoop

154

Calibrate bucket
(See temperature chart, Table 1, Appendix C)



155

2 weights needed

Weigh and Record:
1. Bucket
2. Bucket + coarse aggregate

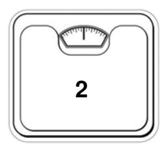
156

Dry aggregate to constant weight

Fill 1/3 with aggregate
Level and rod 25 times (3 layers)

Bucket should be overflowing
Strike off & level surface

Weigh bucket and coarse aggregate



Repeat

- Perform test twice
- Results should be within 0.01

Calibration of Measure (Bucket)

V (Volume of Measure) = $\frac{\text{M (Mass Water)}}{\text{W (Water Unit WT)}}$

V = (X.XXX FT^3)
M = Mass (Wt.) of water to fill (X.XXX LB)
W = Unit weight of water- (X.XXX LB/FT^3).

Bucket Calibration

Weight of Bucket + Glass + Water	48.763 LB
(-) Weight of Bucket + Glass	- 17.613 LB
= Weight of Water	31.150 LB

$$\text{Volume of Bucket} = \frac{\text{Weight of water}}{\text{Unit wt. of water}} = \frac{31.150}{62.301}$$

$= 0.500\ FT^3$

163

Calculate Voids in Coarse Aggregate

Three Calculations

1) Coarse aggregate bulk unit weight
2) Conversion between G_a and G_{SSD}
3) Voids in coarse aggregate

164

Coarse Aggregate Bulk Unit Weight

Weight of Full Bucket	68.200 LB
(-) Weight of Empty Bucket	- 15.550
Weight of Bulk Aggregate	52.650 LB

$$\frac{\text{Weight of Bulk Aggregate}}{\text{Volume of Bucket}} = \frac{52.650\ LB}{0.500\ FT^3}$$

$= 105.3\ LB/FT^3$

165

Oven Dry Specific Gravity (G_a)

A = Oven Dry Wt.

B = SSD Weight

C = Submerged Wt.

$$G_a = \frac{A}{B - C}$$

$$G_{SSD} = \frac{B}{B - C}$$

$$\text{Absorption} = \frac{B - A}{A}$$

166

Oven Dry to SSD Conversion

$$G_a = \frac{G_{SSD}}{1 + \frac{\text{Abs.}}{100}} = \frac{2.66}{1 + \frac{2.0}{100}} = 2.61$$

167

Specific Gravity – IDOT website

Illinois Department of Transportation
Bureau of Materials and Physical Research
Specific Gravity (Gsb) List
December 20, 2013

Page 8 of 34

This list supercedes the December 6, 2013 list. Note: Changes are not high-lighted on this list.
Standard Specifications for Road and Bridge Construction, Articles 1020 and 1030 (Adopted January 1, 2012)

Dist	Producer Name	Location	P/S No.	Material	Remarks	HMA Use Bulk	PCC Use SSD	Absorp.
91	PAYNE & DOLAN	EAST TROY, WI	52400-50	039FM21	ABOVE WATER, CRUSHED GRAVEL	2.697	2.72	0.7
91	PAYNE & DOLAN	FOX LAKE, IL	51110-58	020CM16	ABOVE WATER, ROUNDED GRAVEL	2.623	2.68	2.1
91	PAYNE & DOLAN	FOX LAKE, IL	51110-58	021CM1101	ABOVE WATER, CRUSHED GRAVEL	2.695	2.73	1.4
91	PAYNE & DOLAN	FOX LAKE, IL	51110-58	021CM1601	ABOVE WATER, CRUSHED GRAVEL	2.688	2.73	1.6
91	PAYNE & DOLAN	FOX LAKE, IL	51110-58	027FM02	ABOVE WATER	2.629	2.66	1.3
91	PAYNE & DOLAN	FOX LAKE, IL	51110-58	039FM20	ABOVE WATER	2.676	2.71	1.5
91	PAYNE & DOLAN	RACINE, WI	52402-01	028FM20	ALL LEDGES	2.657	2.70	1.8
91	PAYNE & DOLAN	RACINE, WI	52402-01	032CM16	ALL LEDGES	2.696	2.74	1.7
91	PAYNE & DOLAN	RACINE, WI	52402-01	042CM11	ALL LEDGES	2.713	2.75	1.3

168

Voids in Coarse Aggregate

$$V_{CA} = \frac{(G_a \times 62.37) - \text{Bulk Unit Weight}}{G_a \times 62.37}$$

or

$$\frac{\text{Solid Unit Wt.} - \text{Bulk Unit Weight}}{\text{Solid Unit Weight}}$$

e.g.

$$\frac{(2.68 \times 62.37) - 105.3}{(2.68 \times 62.37)}$$

$= 0.37$

0.370

0.630

169

Run Test Carefully

Change of ± 0.02 in coarse aggregate voids requires new mix design

170

Coarse Aggregate Voids Affected by:

- Crushing
- Shape
- Gradation
- Texture

171

CA Voids – Typical Values

- Crushed: 0.39 – 0.45
- Uncrushed: 0.36 - 0.41
- Rodding consolidates 4 to 8%
- NMAS is not a big factor
- Similar for CM-07, -11, -13, -16

District may provide CA voids 2.8.1 (p. 17)

172

Summary Voids in Coarse Aggregate

Department provides:

1. Absorption
2. G_A & G_{SSD} (Specific gravities)

Mix Designer Calculates:

1. Bulk Unit Weight
2. Coarse Aggregate Voids

173

Fraction Coarse Aggregate (F_{CA})

$F_{CA} + V_{CA} = 1.000$

$V_{CA} = 0.37$

$F_{CA} = 1.00 - 0.37 = 0.63$

0.37 ← V_{CA}

0.63 ← F_{CA}

174

Mortar Factor

IDOT specification to assure minimum mortar for:

- Workability/consistency
- Durability
- Finished surface

Method unique to IDOT

175

What is paste?

+ Cement
+ Finely Divided Minerals (Fly ash, GGBFS, etc.)
+ Water
+ Air

Ø Fine Aggregate
Ø Coarse Aggregate

176

What is mortar?

+ Paste
+ Fine Aggregate

Everything except coarse aggregate!

177

Consistency

Ability to flow

Usually measured by the slump test

178

Workability

Appendix D

Characteristic that describes ability to:

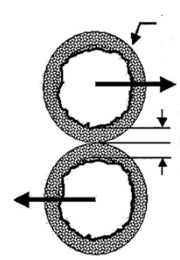
- Place
- Consolidate
- Finish

179

Workability
Lubrication of Mortar Layer

Appendix D

FACTORS
- Thickness of mortar
- Volume of mortar
- Viscosity of mortar



180

Thickness of Mortar
Appendix D

Factors:
- Volume of coarse aggregate
- Size & surface area of coarse aggregate
- Shape & texture of aggregate
- Volume of mortar

181

Volume of Mortar
Appendix D

Factors:
- Water content
- Volume of cement & FDM's
- Volume of air
- Volume of fine aggregate

182

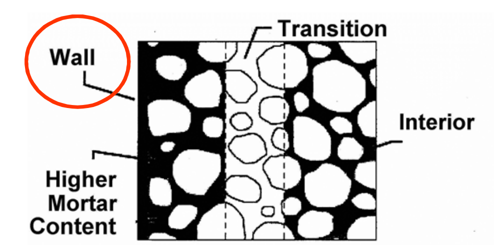
Viscosity of Mortar
Appendix D

Factors:
- Water content
- Air + admixtures
- Volume & shape of cement + FDM's
- Shape & fineness of fine aggregate
- Air content and admixtures
- Rate of hydration

183

Appendix D

Workability - Wall Effect

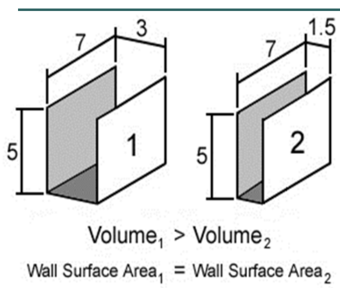


Walls, Pipes, Forms

184

Appendix D

Wall Effect - Volume

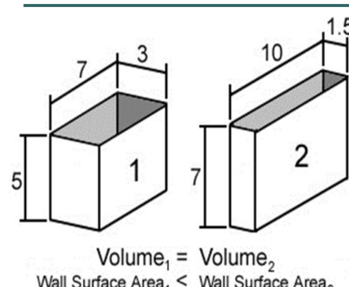


- Higher volume, less mortar available
- Thinner member needs higher mortar content

185

Appendix D

Wall Effect – Surface Area



- Higher surface area needs higher mortar content

186

"Initial and Final Set"

INITIAL SET – The point of time where the concrete begins to become firm. This will typically occur 2 to 4 hours after batching the concrete.

FINAL SET – The point of time where the concrete is no longer plastic and finishing no longer can take place. This will typically occur 5 to 8 hours after batching the concrete.

187

Penetrometer – Initial Set

188

Mortar Factor Defined

"Volume of mortar per volume of dry rodded coarse aggregate"

189

Mortar Factor Defined

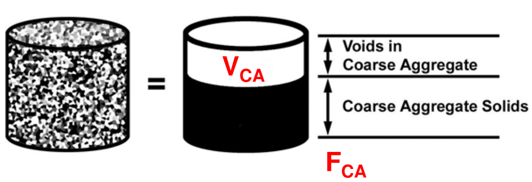
Or,

"Mortar added to VCA bucket of Coarse Aggregate"

Bucket volume = 1.00

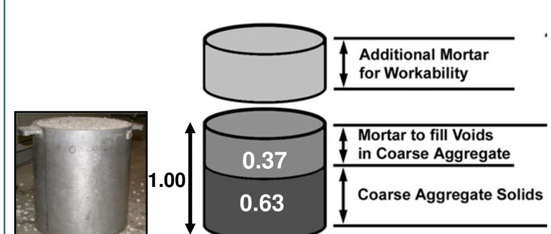
190

Mortar Factor Illustrated



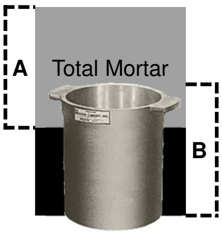
191

Mortar Factor Illustrated



192

Mortar Factor Illustrated

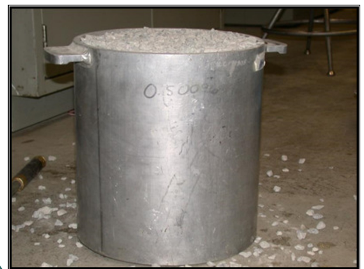


$$\frac{\text{A (Volume Mortar)}}{\text{B (Volume Bucket - 1.00)}}$$

"Volume of mortar per volume of dry-rodded coarse aggregate"

193

Mortar Factor Illustrated



1 - Bucket of Rodded Aggregate

194

Mortar Factor Illustrated

2 – Fill the Coarse Aggregate Voids with Mortar

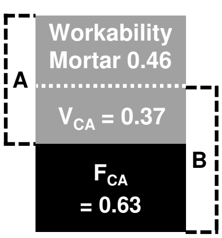
195

Mortar Factor Illustrated

3 - Add "Workability" Mortar

196

Mortar Factor (M_O) Back-Calculated for Illustration, only



M_O = A/B = Mortar/1.00

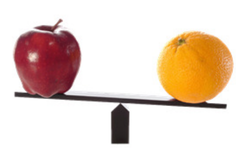
$= \frac{0.37 + \text{Workability Mortar}}{1.00}$

$= \frac{0.37 + 0.46}{1.00}$

= 0.83

197

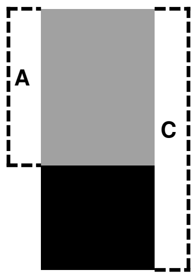
Mortar Factor vs. Percent Mortar



- **Mortar Factor is a design criteria (Specification)**
- **Percent Mortar (or Mortar Fraction) is a volumetric property**

198

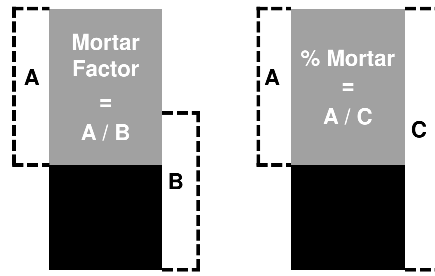
Percent Mortar



$$\frac{\text{A (Volume Mortar)}}{\text{C (Total Volume)}}$$

199

Mortar Factor vs. Percent Mortar



200

Volume Fraction of Mortar (p. 20)

$$\text{Mortar Fraction} = \frac{M_O}{M_O + F_{CA}}$$

M_O = Mortar Factor
F_{CA} = CA Solids

Given:
$M_O = 0.83$
$V_{CA} = 0.39$

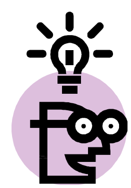
$F_{CA} = 1 - V_{CA} = 1.00 - 0.39 = 0.61$

Post-it

$$\text{Mortar} = \frac{0.83}{0.83 + 0.61} = 0.576$$

201

Volume Fraction (Percent) Coarse Aggregate



+ Mortar Fraction
+ Coarse Aggregate Fraction
= 100% Total Volume

1.000 Total Volume
- 0.568 Mortar Fraction
= 0.432 Coarse Aggregate.

202

Mortar Factor is a Design Criteria

Table 2.8.2.2 Design Mortar Factor		
Class of Concrete	Coarse Agg. Gradation	Mortar Factor Range
BS[2,3,7]	CA 7,11,or 14	0.70 - 0.865[5,6]
PV	CA 5 & 7; CA 5 & 11; CA 7,11, or 14	0.70 - 0.90[5]

Not in Spec Book

203

Table 2.8.2.2 Typical Mortar Factor values

CLASS	Spec	Typical
BS	0.70-0.86*	0.83
PV	0.70-0.90	0.86 Formed
		0.88 Slipformed
PP (CA11)	0.70-0.93	0.83
PP (CA13)	0.79-0.99	0.90
SI	0.70-0.90	0.85-0.90

*except for structural lightweight

204

Placement method affects Mortar Factor

Paving Machine	0.83
Chute	0.85
5 inch pump	0.86
4 inch pump	0.90

205

MIX DESIGN

206

PAGE 1

1.0 VOLUMETRIC MIX DESIGN

- IDOT Mortar Factor method
- Volumetric method more accurate than design by weight
- Based on:
  - Decades of IDOT experience
  - Established material properties

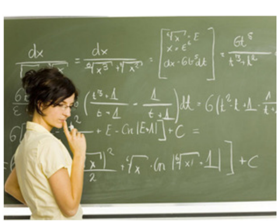
207

Mix Design Steps

1. PCC III Manual and course
2. "PCC Mix Design" EXCEL spreadsheet
3. Mix design on paper, calculations
4. Trial mix, submittals
5. Verification, Trial batch

208

Mix Design and Submittals



209

Understanding the Mix Specification – Job #1

- Class of concrete
- Type of cement
- Component material specs
- Cement factor
- Water/Cement ratio
- ASR mitigation
- Mortar factor
- Air content
- Slump
- Required admixtures
- Aggregate allowed
- Minimum strength

210

PAGE 3

Concrete Mix Design (2.0)

+ Aggregate
+ Cement
+ FDM's
+ Water
+ Air
+ Admixtures.

211

Section 2.0 of Manual

- Combines PCC material specifications from Section 1020 and the GBSP's
- In effect January 2018
- ~~May~~ Will be modified by future Special Provisions and course manuals.

212

Absolute Volume Concept

- Solid volume, excluding voids between the particles
- Serves as the basis of concrete proportioning
- ALWAYS expressed as a decimal; e.g., 14.1% = absolute volume 0.141

$$\frac{\text{Weight of Material}}{\text{S.G. of Material x Unit Wt. Of Water}}$$

213

Absolute Volume Concept

- Absolute volume is percent expressed as a decimal
- X.XXX format – always carry decimal 3 places
- Example: 56.1% = 0.561 absolute volume

214

Mix Design - Order of Operations

1) Cement factor from Table 2.2.1
2) Cement reduction with water-reducing admixtures
3) Cement replacement with FDM's
4) Water requirement and W/C ratio
5) Air content
6) Aggregate proportions

215

2.2 Cement Factor

Step 1 – Check the Spec!

Specification ~~usually~~ always governs:

- Minimum – Strength and durability
- Maximum – Minimize shrinkage cracking

216

Important note: Minimum Portland Cement (p. 6)

"…the Portland Cement content in the mixture shall be a minimum of 400 lbs/cu yd."

Unless the mix is freeze-thaw durable according to AASHTO T 161 (14 day test) – minimum is 375 lbs/cu yd. - 1020.05(a)

Or to control heat of hydration for structures per Article 1020.15

217

Table 2.2.1

Class or Type of Concrete	Minimum Cement Factor (cwt/yd^3)	Maximum Cement Factor (cwt/yd^3)
BS	6.05	7.05
PV	5.65 /2 6.05 /3	7.05

/2 Central-mixed /3 Truck mixed or shrink-mixed

218

Note re: Manual Tables

Similar toTable 1 in Section 1020 (Standard Specs) and Special Provisions with more detail

- GBSP mixes added to Manual
- Contains information not in Supplemental Specs
- Always read the fine print and footnotes!

219

Allowable Cement Factor Reduction with W-R Admixture 2.2.2 (Pg. 3)

Available for most mixes – PV, PP-1, RR, SC, SI:

- Using water reducing or high-range WR admixture may reduce minimum cement factor by 0.30 cwt/yd^3
- Since most mixes contain water reducer…usually take the reduction when offered
- Not available for BS mixes

220

Cement Factor Reduction

e.g.

- Cement Factor for PV = 6.05
- 0.30 Reduction for Water-Reducer

Revised Cement Factor:

= 6.05 – 0.30 = 5.75

221

2.3 Cement Absolute Volume

$$\frac{\text{Weight of Material}}{\text{S.G. of Material x Unit Wt. Of Water}}$$

$$\frac{5.75 \text{ (Cement Factor) x } 100 \text{ (LB/cwt)}}{3.15 \text{ (S.G.) x } 1{,}684 \text{ (LB/YD}^3\text{)}}$$

= 0.108 (YD^3)

222

Cement Replacement with FDM 2.4.1 (Page 6)

223

Cement Replacement with FDMs

Replacement Rate;

- Varies by mix class
- Varies for different FDM's

Replacement Factors:

1. Cement replacement percentage
2. FDM Replacement ratio is always 1:1 (since 2012)

224

2.4.1 Type C Fly Ash

Max. 30% Cement Replacement

- For Class PV and most other classes

225

e.g. FDM Replacement

- Revised Cement Factor = 5.75
  - S.G. = 2.61
- 30% allowable replacement
- 5.75 cwt/YD^3 x 30% = 1.71 cwt/YD^3
- Round UP to next 5 LB ---- 175 LB/YD^3

226

Fly Ash Absolute Volume

$$\frac{\text{Weight of FDM}}{\text{s.g. of FDM} \times \text{Unit Wt. Of Water}}$$

e.g. $\frac{175 \text{ LB}}{2.61 \times 1{,}684 \text{ LB/YD}^3}$

= 0.040 YD^3.

227

2.3 Cement Absolute Volume, revisited

- Using our example:
- Cement factor = 5.75
- 30% replaced with fly ash
- 70% x 5.75 = 4.03 (Round up to 4.05)

$$\frac{4.05 \text{ (Cement Factor)} \times 100 \text{ (LB/cwt)}}{3.15 \text{ (S.G.)} \times 1{,}684 \text{ (LB/YD}^3)}$$

Absolute volume = 0.076 (YD^3)

228

2.5 Water

Since cement content is generally controlled by the specifications, the amount of water is the most important variable of the design. Includes:

- Batch water
- Free moisture
- Admixture water

229

2.5 Water

Fine aggregate H_2O demand
+ Coarse aggregate H_2O demand
= Total concrete water demand

230

Fine Aggregate Water Demand 2.5.1 (Pg. 8)

Fine Aggregate Type	Shape	Basic Water
Type A	Round – natural sand	5.1 gal/cwt
Type B	Mixed	5.3 gal/cwt
Type C	Angular – manufactured sand	5.5 gal/cwt

231

Coarse Aggregate Water Demand (Pg. 9)

Coarse Agg. Shape	Additional Water
Rounded Gravel (Uncrushed)	None
Crushed Stone or Crushed Gravel	+0.2 gal/cwt
Lightweight Slag	+0.4 gal/cwt

232

Calculation – Basic Water

Example: FA is Type B
CA is Uncrushed gravel

Basic Water Requirement:
5.3 gal/cwt (Fine aggregate)
+ 0.0 gal/cwt (Coarse aggregate)
5.3 gal per cwt of *Total Cementitious*

233

PAGE 11 - NOT A SPEC!

Table 2.5.2 Water Adjustment

Aggregate	*Range*
Shape & texture: Baseline = cubical crushed stone	(0%)
Rounded, smooth	(-5 to 0%)
Flat, elongated, rough	(0 to +5%)
Combined grading: Well-graded	(-10 to 0%)
Gap-graded	(0 to +10%) more>

234

Table 2.5.2 Water Adjustment

ADMIXTURES	Range
Air-entraining 1 to 3% air	(0%)
4 to 5% air	(-5%)
6 to 10% air	(-10%)
Water-reducing Normal range	(-10 to -5%)
Mid-range	(-15 to -8%)
High range (superplasticizer), minimum of 14% when used to reduce cement factor	(-30 to -12%) Note 2

more>

235

Table 2.5.2 Water Adjustment

Finely Divided Minerals	Range
Fly Ash	(-10 to 0%) 3% for each 10% Fly Ash
Microsilica	(0 to +15%)
HRM	(-5 to +5)
GGBF Slag	(0%)

more>

236

Table 2.5.2 Water Adjustment

Other factors	Range
•Coarse cement •Water/Cement ratio > 0.45 •Concrete temperature < 60° F	(-10 to 0%)
•Fine cement •water/Cement ratio < 0.40 •Concrete temperature > 80° F	(0 to +10%)

more>

237

Table 2.5.2 Water Adjustment Notes:

- Suggested max water reduction recognizing overlapping effects is -30%.
- Minimum water/cement ratio applies.
- A high range W-R admixture may be able to reduce the water content up to 40%.
- For each 10% of fly ash, it is recommended to allow a water reduction of at least 3%.

238

2.6 Water/Cement Ratio

$$\frac{\text{Weight of Water}}{\text{Weight of Cementitious Material}}$$

- Water includes ALL FREE water
- "Cementitious" includes FDM's

See Table 2.6 (Pg. 15)

239

2.6 Water/Cement Ratio

Post-it

Minimum

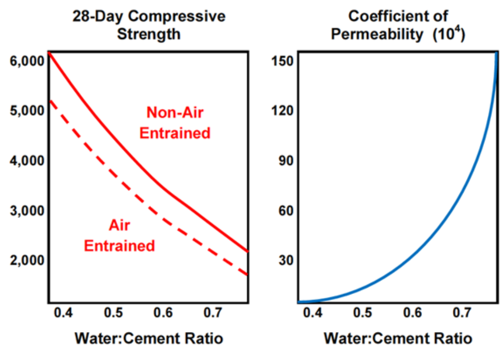
- Need adequate water to hydrate cement (≈0.32)
- Extra water is needed for workability
- Excess water creates pore space, reducing strength and durability

Maximum

- Normal maximum spec: 0.40 - 0.44
- If not specified, min. = 0.32; max. = 0.45

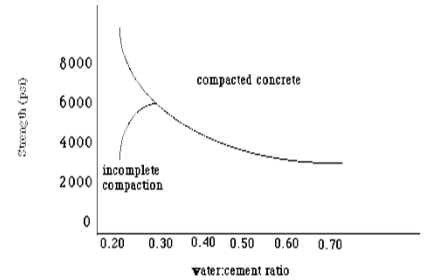
240

W/C and Performance



241

W/C and Performance



242

Water Adjustment example:

Basic Water:	5.3 gal/cwt	
Reduction for W-R	-6%	(Option)
Revised Water	5.0 gal/cwt	

<u>Cementitious</u>

Cement = 405 lbs.	4.05 cwt
Fly Ash = 175 lbs.	1.75 cwt
	5.80 cwt

Water = 5.0 x 5.80 x 8.33 (lbs/gal) = 242 lbs. of water

243

Water Absolute Volume

$$\frac{\text{Weight of Water}}{\text{S.G. of Water x Unit Wt. Of Water}}$$

e.g. $\frac{242 \text{ LB}}{1.00 \times 1{,}684 \text{ LB/YD}^3}$

= 0.144 (YD^3)

244

2.6 Water/Cement Ratio Calculation (Method #1)

e.g. Adjusted Basic Water = 5.0 gal/cwt

W/C = $\frac{\text{Water (gal/cwt) x 8.33 (LB/gal)}}{\text{100 LB/cwt}}$

= $\frac{\text{5.0 gal/cwt x 8.33 LB/gal}}{\text{100 LB/cwt}}$

= 0.42

245

2.6 Water/Cement Ratio Calculation (Method #2)

W/C = $\frac{\text{Weight of water}}{\text{Weight of cement + FDM's}}$

= $\frac{\text{242 \# water}}{\text{405 \# cement + 175 \# fly ash}}$

= 0.42

246

2.6 W/C Ratio Verification

Verify Minimum Spec:
(Table 2.6 – Pg. 15)
Class PV
Range: 0.32 – 0.42
Our result = 0.42

OK ✓

247

Where are we?

We know:
1. Cement Factor
2. W-R Reduction
3. FDM Replacement
4. Water
5. W/C Verification

Next: Entrained Air

248

PAGE 16

2.7 Air Content

Class or Type of Concrete	Air Content Percent
BS /1	5.0-8.0
PV /1	5.0-8.0
SI /1	5.0-8.0
PP	4.0-8.0

Design to midpoint of spec range

[1] For slipform construction, the minimum air content is 5.5 percent. (Still design @ 6.5% air)

249

2.7 Air Content Absolute Volume

Absolute Volume of Air
= Percent Air ÷ 100
e.g. 6.5% Air
Absolute Volume = 6.5 ÷ 100
= 0.065 YD^3

250

2.7.1 Minimum Air Content

Page 16

Necessary for freeze-thaw resistance

If not otherwise specified,
Design to minimum 18% (volume) of:
H_2O + Cement + FDM

251

Minimum Air Content example

$Air_{MIN} = [0.18 \times (V_{H2O} + V_{cement} + V_{FDM})] \times 100$

e.g. V_{H2O} = 0.134
V_{cement} = 0.071
V_{FDM} = 0.038

Air%= [0.18 x (0.134+0.071+0.038)] x 100
= 4.3%.

252

Adjustment of Air (Art. 503.07) ~~BDE 80316 Concrete Placement~~

- Maximum air loss caused by pumping operation shall be 3.0%
- Minimum air at the point of discharge shall be per Article 1020.04.

253

Where are we?

<u>We know all about the Paste:</u>

1. Cement Factor
2. Water
3. FDM
4. W/C Verification

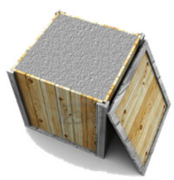
Next:

- Add the Paste to the aggregate
- Using V_{CA} and Mortar Factor

254

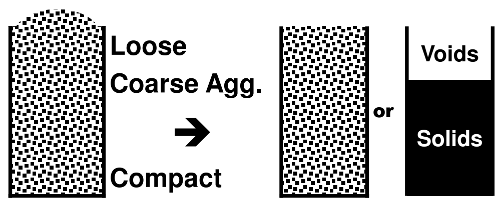
Refresher

- **Mortar Factor** is related to the VCA bucket
- **Mortar Fraction** is related to the Design Box



255

V_{CA}



V_{CA} = Vol. Voids / Vol. Bucket

256

V_{CA} - Voids in Coarse Aggregate (ITP 306)

<u>From Department, obtain:</u>

- Absorption
- G_A (Oven Dry Specific Gravity) &
- G_S (SSD Specific Gravity)

<u>Calculate</u>

1. Unit Weight
2. V_{CA} - Coarse Aggregate Voids

257

Design Mortar Factor

Select Mortar Factor based on Table 2.8.2 and experience with local materials and construction applications.

A new mix design is required if MF changes by ±0.05 from original value.

258

Page 21

2.8.2.2 Design Mortar Factor

Class or Type of Concrete	Coarse Aggregate Gradation	Mortar Factor Range
BS[2,3,7]	CA-7, CA-11, or CA-14	0.70 - 0.865[5,6]
PV	CA-5 & CA-7, CA-5 & CA 11, CA-7, CA-11, or CA-14	0.70 - 0.90[5]

[3] CA minimum 45% passing ½" when pumped
[5] Max = 0.85 if FA is Stone Sand

259

Exceptions to the Rule

- MF >1.00 for structural lightweight (90-115 lb/ft^3) using lightweight coarse aggregate (2.8.2.2)
- MF >1.00 for SCC or latex
- MF >0.86 for BS concrete using lightweight coarse aggregate (Pg. 43)

260

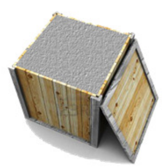
Volume Fraction (%) of Mortar

We know:

- Mortar Factor M_O (0.83 given)
- V_{CA} (0.37 from VCA test)

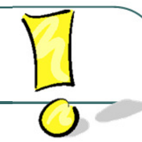
Calculate:

1. Mortar Fraction (% Mortar)
2. Coarse Aggregate Fraction.



261

Mortar Volume Fraction



$$\% \text{ Mortar} = \frac{M_O}{M_O + F_{CA}}$$

Example: M_O Mortar Factor = 0.83
V_{CA} = 0.37 (F_{CA} = 0.63)

$$\% \text{ Mortar} = \frac{0.83}{0.83 + 0.63}$$

$$= 0.568 \ (56.8\%)$$

262

Mortar Absolute Volume

Mortar Fraction = 0.568

This is also the Absolute Volume of the mortar.

Mortar is everything but coarse aggregate.: Cementitious + Water + Air + Fine Aggregate

263

Absolute Volume of Aggregate

264

Coarse Aggregate Absolute Volume (2.8.3)

PAGE 22

Mortar + Coarse Aggregate = Concrete

For our example:

0.568 + Coarse Aggregate = 1.000

Coarse Aggregate = 1.000 – 0.568

= 0.432 = Absolute Volume of Coarse Aggregate

265

Coarse Aggregate Absolute Vol.

Cement	0.CEM	0.568 Mortar
Fly Ash	0.FLY	
Water	0.H2O	
Air	0.AIR	
Fine Aggregate	0.FA2	
Coarse Aggregate	0.CA7	0.432
		= 1.000

266

Fine Aggregate Absolute Volume (2.8.4)

PAGE 22

This is the last unknown:

Subtract everything else from 1.000

= 1.000- (Cement + FDM + H_2O + Air + CA)

e.g.

= 1.000- (0.076 + 0.040 + 0.144 + 0.065+0.432)

= 0.243 (Fine aggregate absolute volume)

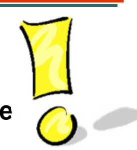
267

Converting Aggregate Volume to Weight (2.8.5)

PAGE 23

Given:

- G_{SSD}
- Absolute volume of aggregate



Calculate Weight:

Wt. = Absolute Vol. x SG_{SSD} x Unit Wt_{H2O}

268

Converting Coarse Aggregate Volume to Weight (2.8.5)

Weight = Abs. Vol. x SG_{SSD} x Unit Wt_{H2O}

e.g.

- CA Absolute Volume = 0.432
- SG_{SSD} = 2.68

Wt. = 0.432 (YD^3) x 2.68 x 1,684 (LB/YD^3)

= 1,950 LB

269

Converting Fine Aggregate Volume to Weight (2.8.5)

Weight = Abs. Vol. x SG_{SSD} x Unit Wt_{H2O}

e.g.

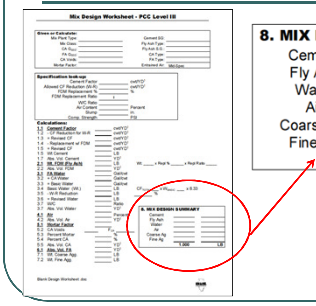
- FA Absolute Volume = 0.243
- SG_{SSD} = 2.65

Wt. = 0.243 (YD^3) x 2.65 x 1,684 (LB/YD^3)

= 1,084 LB

270

Design Worksheet (see Appendix)



8. MIX DESIGN SUMMARY	Volume	Batch weight
Cement		
Fly Ash		
Water		
Air		
Coarse Ag		
Fine Ag		
	1.000	LB

271

Workbook and Class Illustration Problem

8. MIX DESIGN SUMMARY

	Absolute Vol.	WEIGHT
Cement	0.076	405
FDM1	0.031	135
FDM2		
Water	0.134	225
Air	0.065	0
Coarse Ag	0.424	1,914
Fine Ag	0.270	1,209
	1.000	3,888

MF= 0.83 VCA= 0.39

272

PV Example Problem 2.9 Page 23 (Solution App. HW-1)

Example Problem Solution - PCC Level III

Given or Calculate:

Mix Plant Type:	Central						
Mix Class:	PV (Slip)					ASR INFO	
Coarse Agg:	022CM11	G_{SSD}:	2.68	CA Type:	Gravel	Exp. Value:	0.05
Fine Agg:	027FA01	G_{SSD}:	2.66	FA Type:	B	Exp. Value:	0.20
Cement	Ty 1	SG:	3.15	Use 6% water adjustment		Alkali:	>0.60
FDM1	Fly C	SG:	2.61			Alkali:	
FDM2		SG:				Alkali:	
CA Voids:	0.39					Aggr. Group:	II
Mortar Factor:	0.83						

Specification look-up:

Cement Factor	5.65	cwt/YD^3
Allowed CF Reduction (W-R)	0.30	cwt/YD^3
FDM Replacement %	25	%
FDM Replacement Ratio	1.0 (1:1)	
W/C Ratio	0.42	Max

25% FDM replacement required for ASR

Mitigation Option	2	
Target Air Content	6.5	%
Target Slump	0.5-2.5	in.
Min. Comp. Strength	3,500 @ 14	PSI @ days

273

2.9 EXAMPLE PROBLEM (Pg. 23)

Given:

- Continuous reinforced slipformed concrete pavement (CRCP)
- Central mix plant using dumps
- Type I cement with >0.60 alkalies (S.G. 3.15)

274

Example – Aggregates

- Fine aggregate - Type B
- 027FA01 SG_{SSD} = 2.66
- ASR expansion value 0.20% (>0.16%-0.27%)
- Coarse aggregate – 022CM11 (crushed stone)
- ASR value = 0.05%
- SG_{SSD} = 2.68
- V_{CA} Coarse Aggregate Voids = 0.39
- Target water reduction = -10%

275

Example Problem – Fly Ash

- Class C
- S.G. = 2.61
- CaO = 25.1%
- Ignition loss = 1.0%

276

ASR
Identify Aggregate Groups

COARSE AGGREGATE or Blend ASTM C 1260 Expansion	Fine Aggregate Or Fine Aggregate Blend ASTM C 1260 Expansion		
	≤0.16%	>0.16% - 0.27%	>0.27%
≤0.16%	Group I	Group II	Group III
>0.16% - 0.27%	Group II	Group II	Group III
>0.27%	Group III	Group III	Group IV

277

ASR Group II - Valid Options (Will mitigate with FDM's)

AGG GROUP	Mitigation Option 1	2	3	4	5
I	Use any cement or finely divided mineral.				
II	X	X	X	X	X
III	X	Combine Option 2 plus Option 3		X	X
IV	X	Option 2 plus Option 4	Invalid Option	Option 2 plus Option 4	X

278

Step 1.1 – Choose Cement Factor

Standard Cement Factor

(Table 2.2.1 – Pg. 4)

- PV (paving) mix
- Cement Factor = 5.65[2]

Footnote: [2] Central-mixed

279

Step 1.2 Reduce Cement Factor

Allowable reduction for W-R admixture

(from 2.2.2 0 Pg. 3)

0.30 cwt./YD^3 reduction allowed

The use of water reducer is a designer option, based on spec, guidelines, and experience

Revised cement factor:

5.65 – 0.30 = 5.35 cwt/YD^3

280

Step 1.3 – Cement Replacement 2.4.1 (Pg. 6)

Allowable Cement Replacement with Fly Ash

Up to 30% replacement allowed for Class C fly ash, 400 cwt cement per yard minimum

5.35 x 0.25 = 1.34 cwt/YD^3

Revised Cement:

5.35 – 1.34 = 4.01 cwt/YD_3

Rounds <u>up</u> to 4.05 cwt/YD_3 (405 lbs)

281

Step 1.4 – Cement Absolute Volume

Absolute Volume =

Weight ÷ (SG x 1,684)

Weight = 405 pounds

SG = 3.15

$$= \frac{405 \text{ LB}}{3.15 \times 1,684}$$

= 0.076

282

Step 2.0 – Fly Ash

Absolute Volume

1.34 cwt/YD^3 or 134 lbs (Rounds up to 135)

SG = 2.61

= Weight / S.G. x 1,684

$$= \frac{135}{2.61 \times 1{,}684}$$

= 0.031

283

Step 3.0 – Basic Water Requirement

Basic Water for Aggregate

From 2.5.1.1
Water for Type B fine agg. = 5.3 gal/cwt.

From 2.5.1.2
Additional crushed stone = 0.2 gal/cwt

Basic Water = 5.3 + 0.2 = 5.5 gal/cwt

284

Step 3.1 – Adjustment to Water Requirement

From 2.5.2 (Pg. 11)
10% Target reduction (Given)
Basic Water = 5.5 gal/cwt
10% Water reduction = 0.55 gal/cwt
Revised Water = 5.5 – 0.55
= 5.0 gal/cwt

285

Step 3.2 – Water Calculation

Revised Water

Revised Water = 5.0 gal/cwt
5.0 gal/cwt x 8.33 LB/gal = 41.65 LB/cwt
41.65 x (4.05 + 1.35) = 225 LB

Order of calculations makes slight difference

286

Step 3.4 – Verify Water/Cement Ratio

Water/Cement Ratio

Water = 41.65 LB/cwt
(From 2.6)
W/C = Weight of Water / Weight of Cement
= 41.65 / 100
= 0.4165 (Rounds up to 0.42)
Max. W/C = 0.42 OK (Table 2.6)

287

Step 3.4 - Water/Cement Ratio

Alternate calculation:

Total Water = 225 lbs.
Total Cementitious = 405 + 135 = 540
W/C = 225 ÷ 540 = 41.66

Max. W/C = 0.42

Still OK

288

Step 3.3 – Water Absolute Volume

Absolute Volume

$$= \frac{\text{Weight}}{\text{SG} \times 1{,}684}$$

$$= \frac{225 \text{ LB}}{1.00 \times 1{,}684 \text{ LB/YD}^3}$$

= 0.134

289

Step 4.0 – Air

(From Table 2.7 - Pg. 16)

Spec = 5.0-8.0%

Midpoint = 6.5%

Absolute Volume = % air / 100

= 0.065

290

Step 5.0 – Percent Mortar

M_O: Mortar Factor = 0.83

VCA = 0.39

F_{CA} = 1.00 – 0.39 = 0.61

$$\% \text{ Mortar} = \frac{100 \times M_O}{M_O + F_{CA}}$$

$$= \frac{100 \times 0.83}{0.83 + 0.61}$$

= 57.6 % (Absolute Volume = 0.576 YD^3)

291

Step 5.1 – Coarse Aggregate Absolute Volume

CA Absolute Volume

= 1- (Mortar Absolute Volume)

= 1- 0.576

= 0.424 YD^3 Absolute Volume

292

Step 6.0 – Fine Aggregate Absolute Volume

= 1

- V_{Cement} (0.076)
- V_{FDM} (0.031)
- V_{Water} (0.134)
- V_{Air} (0.065)
- V_{CA} (0.424)

= 0.270 YD^3

293

Step 7.0 – Determine Aggregate Weights

Weight = Abs Vol x S.G. x 1,684

Coarse Aggregate

= 0.424 YD^3 x 2.68 x 1,684 LB/YD^3

= 1,914 LB

Fine Aggregate

= 0.270 YD^3 x 2.66 x 1,684 LB/YD^3

= 1,209 LB

294

Step 8.0 – Mix Design Summary

- Cement – 405 lbs.
- Fly Ash – 135 lbs.
- Water – 225 lbs.
- Air – 6.5%
- CA – 1,914 lbs.
- FA – 1,209 lbs.
- Mortar Factor – 0.83
- CA Voids – 0.39
- W/C Ratio – 0.42
- Later - Slump & Strength

295

Where are we?

- VCA test ☑
- Mix Design Proportions ☑
- Trial Mix ☐
- Trial Batch ☐

296

6.0 Trial Mixture (Pg. 36)

<u>Contractor's</u> pre-verification of:

- Slump (6.1 – Pg. 36)
- Air (2.7 – Pg. 15)
- Minimum strength (6.2 – Pg. 38)

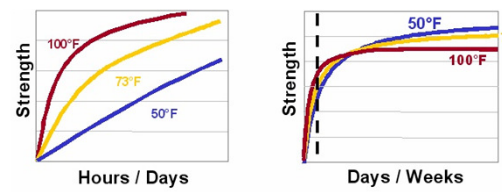
Minimum 2 cubic yards (4 recommended)

Recommended near-max. W/C ratio for trial

Recommended strength curves at 3, 7, 14, 28, and 56 days.

297

Strength Curves Recommended (Pg. 41)

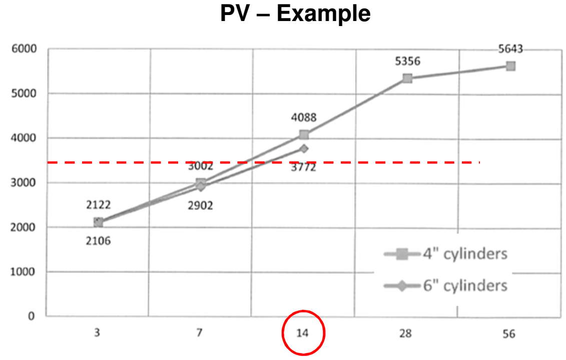


Learn about your mixes

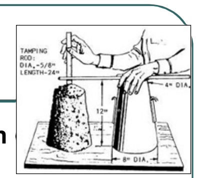
- Set time/strength gain
- Temperature

298

PV – Example



Trial Mix Slump



Slump measures batch-to-batch

Read the Footnotes:

- Slipform PV slump spec: 0.5 – 2.5 inches*
- Others may be modified with water reducer
- *D1 Special Provision! 0.5-1.5"
- For trial mix, near max slump recommended

300

Slipform Slump Specification

SLIPFORM PAVING (D-1)
Effective: November 1, 2014

Revise Article 1020.04 Table 1, Note (5) of Standard Specifications to read:

"The slump range for slipform construction shall be 1/2 to 1 1/2 in."

Revise Article 1020.04 Table 1 (metric), Note (5) of Standard Specifications to read:

"The slump range for slipform construction shall be 13 to 40 mm."

301

Trial Mix Air

Trial results within 0.5% of spec max (except for slipformed mixes)

302

Trial Mix Strength

Must meet minimum strength on day of record for trial mix

However, in the field, IDOT has discretion to wait for strength

303

6.3 Laboratory p. 39

- **Approved for QC per Bureau of Materials Policy Memorandum on minumum lab requirements**
- **(AASHTO accreditation is not required)**
- **QC/QA Trained Technicians**

304

Design Lab Steps

1. **Batch**
2. **Evaluate / Adjust for air, slump**
3. **Evaluate for consistency, plasticity, and workability**
4. **Evaluate for yield**
5. **Make strength specimens – beams or cylinders**
6. **Document test of record.**

305

8.0 Durability Testing (Pg. 43)

Not required for most mixes because IDOT policy provides:

- **Specified Procedures**
- **Specified Mix Parameters**
  - **Cement, FDM, W/C, Air content**
- **Specified Material Quality**
  - **Aggregate**

306

Durability Testing

Required for unique mix designs if Mortar Factor is not within spec limits. Only spec change that will be considered.

- For Class BS concrete, MF ≤ 0.86
- FA portion ≤ 50% of total aggregate

Employ Accredited Lab; Perform:

- 300 Cycle Freeze-Thaw – IL Method
- Salt Scaling – IL Method.

307

Where are we?

- VCA test ☑
- Mix Design Proportions ☑
- Trial Mix ☑
- Department Verification/Trial Batch ☐

308

9.0 Department Verification (Pg. 44)

Considerations:

- Proportions / calculations
- Strength test results
- Historical test data for similar mixes
- Target strength calculations
- Department experience
- Trial batch

309

Trial Batch (Pg. 45)

Department Option

- If concerns with strength, workability, history
- MF outside limits
- Contractor's mix expense
- Department testing expense

310

Trial Batch Procedure

- 2 yd^3 Minimum (4 yd^3 Preferred)
- Air within 0.5% of upper spec limit
- Air for slipform trial batch TBA
- For SCC, w/c at or near max
- Temperature per IDOT specs
- Strength on specified day (Usu. 14 days)
- All Tests per Manual of Test Procedures

311

IDOT Verification Tests

- Air
- Slump
- Strength (cylinders or beams)
- Temperature
- Yield (optional)
- Durability (TBA)
- CA voids
- Extra testing for SCC (Flow, J-ring,etc.)

312

Trial Batch Verification

Batch verified if test results meet specification requirements.

CA voids (VCA) verified if Department test results are within 0.02 of Contractor's value.

313

Materials Control

New mix design required when…

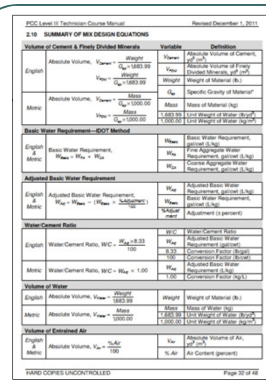
- Cement s.g. change > 0.04 (Pg. 5)
- FDM s.g. change > 0.04 (Pg. 6)

314

Source	Unit No.	Producer/ Supplier No.	Class	Material Code No.	R Factor [A]	Average Specific Gravity
Alliant Power [B,D] Columbia Station Portage, WI	1, 2	52403-03	C	37801	3.17	2.63
Alliant Power [B,D] Edgewater Station Sheboygan, WI	5	52403-05	C	37801	2.99	2.67
EME Midwest Generation [B,D] Joliet Station Joliet, IL	7, 8	51973-64	C	37801	4.03	2.76
Muscatine Power & Water [B,E] Muscatine Station Muscatine, IA	9	52203-04	C	37801	3.93	2.76
NRG Energy, Inc. [B,E] Will County Generating Station Romeoville, IL	4	51973-18	C	37801	4.63	2.81

315

2.10 Summary Mix Design Equations


PCC Level III Technician Course Manual Revised December 1, 2011

2.10 SUMMARY OF MIX DESIGN EQUATIONS

Volume of Cement & Finely Divided Minerals		Variable	Definition
English	Absolute Volume, $V_{Cement} = \frac{Weight}{G_{sp} \times 1{,}683.99}$; $V_{FDM} = \frac{Weight}{G_{sp} \times 1{,}683.99}$	V_{Cement}	Absolute Volume of Cement, yd³ (m³)
		V_{FDM}	Absolute Volume of Finely Divided Minerals, yd³ (m³)
		Weight	Weight of Material (lb.)
Metric	Absolute Volume, $V_{Cement} = \frac{Mass}{G_{sp} \times 1{,}000.00}$; $V_{FDM} = \frac{Mass}{G_{sp} \times 1{,}000.00}$	G_{sp}	Specific Gravity of Material*
		Mass	Mass of Material (kg)
		1,683.99	Unit Weight of Water (lb/yd³)
		1,000.00	Unit Weight of Water (kg/m³)
Basic Water Requirement—IDOT Method			
English & Metric	Basic Water Requirement, $W_{Basic} = W_{FA} + W_{CA}$	W_{Basic}	Basic Water Requirement, gal/cwt (L/kg)
		W_{FA}	Fine Aggregate Water Requirement, gal/cwt (L/kg)
		W_{CA}	Coarse Aggregate Water Requirement, gal/cwt (L/kg)
Adjusted Basic Water Requirement			
English & Metric	Adjusted Basic Water Requirement, $W_{Adj} = W_{Basic} - (W_{Basic} \times \frac{\%Adjustment}{100})$	W_{Adj}	Adjusted Basic Water Requirement, gal/cwt (L/kg)
		W_{Basic}	Basic Water Requirement, gal/cwt (L/kg)
		%Adjustment	Adjustment (± percent)
Water/Cement Ratio			
English	Water/Cement Ratio, $W/C = \frac{W_{Adj} \times 8.33}{100}$	W/C	Water/Cement Ratio
		W_{Adj}	Adjusted Basic Water Requirement (gal/cwt)
		8.33	Conversion Factor (lb/gal)
		100	Conversion Factor (lb/cwt)
Metric	Water/Cement Ratio, $W/C = W_{Adj} \times 1.00$	W_{Adj}	Adjusted Basic Water Requirement (L/kg)
		1.00	Conversion Factor (kg/L)
Volume of Water			
English	Absolute Volume, $V_{Water} = \frac{Weight}{1{,}683.99}$	Weight	Weight of Material (lb.)
Metric	Absolute Volume, $V_{Water} = \frac{Mass}{1{,}000.00}$	Mass	Mass of Water (kg)
		1,683.99	Unit Weight of Water (lb/yd³)
		1,000.00	Unit Weight of Water (kg/m³)
Volume of Entrained Air			
English & Metric	Absolute Volume, $V_{Air} = \frac{\%Air}{100}$	V_{Air}	Absolute Volume of Air, yd³ (m³)
		% Air	Air Content (percent)

HARD COPIES UNCONTROLLED Page 32 of 48

Page 30

316

Basic Water – IDOT Method

Basic Water Requirement—IDOT Method	
English & Metric	Basic Water Requirement, $W_{Basic} = W_{FA} + W_{CA}$

Unit = X.X gal/cwt

317

Adjusted Basic Water

Adjusted Basic Water Requirement	
English & Metric	Adjusted Basic Water Requirement, $W_{Adj} = W_{Basic} - (W_{Basic} \times \frac{\%Adjustment}{100})$

Unit = X.X gal/cwt

318

Water/Cement Ratio

Water/Cement Ratio	
English	Water/Cement Ratio, $W/C = \frac{W_{Adj} \times 8.33}{100}$

Unit = 0.XX

319

Water/Cement Ratio Alternate Method

$$= \frac{\text{Total Weight Water}}{\text{Total Weight Cementitious}}$$

Unit = 0.XX

320

Absolute Volume

Volume of Cement & Finely Divided Minerals	
English	Absolute Volume, $V_{Cement} = \frac{Weight}{G_{sp} \times 1{,}683.99}$ $V_{FDM} = \frac{Weight}{G_{sp} \times 1{,}683.99}$

Unit = 0.XXX

321

Water Absolute Volume

Volume of Water	
English	Absolute Volume, $V_{Water} = \frac{Weight}{1{,}683.99}$

Unit = 0.XXX YD^3

322

Entrained Air Absolute Volume

Volume of Entrained Air	
English & Metric	Absolute Volume, $V_{Air} = \frac{\%Air}{100}$

Unit = 0.XXX YD^3

323

Minimum % Air Content

Minimum Percent Air Content	
English & Metric	Minimum Percent Air $= [0.18 \times (V_{Water} + V_{Cement} + \Sigma V_{FDM})] \times 100$

Unit = X.X %

324

Volume CA Solids and Mortar

Volume Fraction of Coarse Aggregate & Mortar	
English & Metric	Fraction of Coarse Aggregate Solids, $= 1 - V$
	Volume Fraction of Mortar $= \dfrac{M_O}{M_O + F_{CA}}$

V = VCA

Unit = 0.XXX

325

Coarse Aggregate Absolute Volume

Volume of Coarse Aggregate	
English & Metric	Absolute Volume, $V_{CA} = 1 -$ Volume Fraction of Mortar OR $V_{CA} = \dfrac{1}{1+\left(\dfrac{M_O}{1-V}\right)}$

Unit = 0.XXX YD3

326

Fine Aggregate Absolute Volume

Volume of Fine Aggregate	
English & Metric	Absolute Volume, $V_{FA} = 1 - (V_{Cement} + \Sigma V_{FDM} + V_{Water} + V_{Air} + V_{CA})$

Unit = 0.XXX YD3

327

Aggregate Weight

Aggregate Content	
English	Weight of Aggregate (lb./yd^3) $= V_{CA} \times G_{SSD} \times 1{,}683.99$ $= V_{FA} \times G_{SSD} \times 1{,}683.99$

X,XXX LB

328

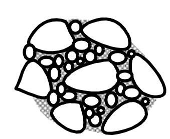
Aggregate Blending
Appendix E

- Aggregate grading
- Fineness Modulus of fine aggregate
- "8-18 Rule"
- 0.45 Power Curve

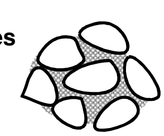
329

Types of Aggregate Grading

* Uniformly graded
- Balance of sieve sizes



* Gap graded
- Imbalance of sieve sizes



330

Aggregate grading (particle size distribution) affects:

- Ease of placing
- Pumping
- Consolidating
- Finishing
- Water demand

331

Illinois Coarse Aggregates

"Problems occur when % passing 12.5 mm is less than 40%."

Product	P 12.5 mm
CA-05	0-10%
CA-07	30-60%
CA-11	30-60%
CA-14	80-100%
CA-16	100%

332

Coarse Aggregate for Bridge Decks

(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.

When placing Class BS concrete with a pump, the discharge end of the pump shall have an "S" shaped flexible or rigid conduit, a 90 degree elbow with a minimum of 10 ft (3 m) of flexible conduit placed parallel to the deck, or a similar configuration approved by the Engineer.

333

Fine Aggregate Gradation

Affects:

- Air retention
- Workability
- Pumping capacity
- Finishing
- Bleeding

334

Fineness Modulus of Fine Aggregate

Cumulative Sum:

$$\frac{\text{Retained (3/8 through \#100 sieve)}}{100}$$

335

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	15	
#16	65	_____	_____	
#30	45	_____	_____	
#50	21	_____	_____	
#100	3	_____	______	
		Sum	______	_____

336

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	15	
#16	- 65	= 20		
#30	45	_____	_____	
#50	21	_____	_____	
#100	3	_____	______	
		Sum	______	_____

337

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	+ 15	
#16	65	+ 20	= 35	
#30	45	_____	_____	
#50	21	_____	_____	
#100	3	_____	______	
		Sum	______	_____

338

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	15	
#16	65	20	35	
#30	- 45	20	55	
#50	21	_____	_____	
#100	3	_____	______	
		Sum	______	_____

339

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	15	
#16	65	20	35	
#30	45	20	55	
#50	21	24	79	
#100	3	_____	______	
		Sum	______	_____

340

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	98	2	2	
# 8	85	13	15	
#16	65	**20**	35	
#30	45	**20**	**55**	
#50	21	**24**	**79**	
#100	3	**18**	**97**	
		Sum	**283**	**2.83**

341

Fineness Modulus

- **Larger number = coarser**
- **FM range typically 2.0 to 4.0**
- **ACI recommends 2.4 to 3.0**
- **ACI recommends 2.7 to 3.5 for slipform**
- **0.2 change is significant – workability may be affected**
- **Very high FM may result in lost air**
- **May need to change FA &/or raise MF**

342

Fineness Modulus Class Exercise

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	97			
# 8	89			
#16	77			
#30	53			
#50	12			
#100	2			
		Sum		

343

Fineness Modulus Class Exercise

Sieve	Passing	Retained	Σ Retained	FM
3/8	100	0	0	
# 4	97	3	3	
# 8	89	8	11	
#16	77	12	23	
#30	53	24	47	
#50	12	41	88	
#100	2	10	98	
		Sum	270	2.70

344

How to Blend Numbers (Appendix E)

For:

1. Gradation
2. Specific Gravity
3. ASR Expansion Value

345

Blending Aggregate Gradations

TB = (a /100) x A + (b/100) x B + ……

Where:

TB = Total blend on each sieve

a, b… = Percent of aggregate product

A, B … = Percent on that sieve

Valid for % Passing or Retained.

346

Gradation Blending
Calculate for each sieve:

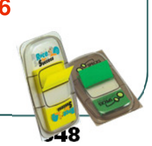
Gradation	CA 07	CA 16	FA 01	Total
(a) % mix	45%	15%	40%	100%
(A) P 3/8"	11%	96%	100%	
(a/100) x (A) =	5%	14%	40%	59%

Total P 3/8" in Aggregate Blend =
5% + 14% + 40%= 59%.

347

Specific Gravity Blending

Gradation	CA 07	CA 16	Total
% total mix	45%	15%	60%
(a) %CA	75%	25%	100%
(A) S.G.	2.60	2.45	
(a/100) x (A) =	1.95	0.61	2.56



348

ASR Expansion Value Blending

Gradation	CA 07	CA 16	Total
% total mix	45%	15%	60%
(a) % of CA	75%	25%	100%
(A) Exp Value	0.05	0.19	
(a/100) x (A) =	0.04	0.05	0.09

349

Aggregate Blend Gradation Characterization

1. "8-18" Rule
2. Tarantula Curve
3. 0.45 Power Curve

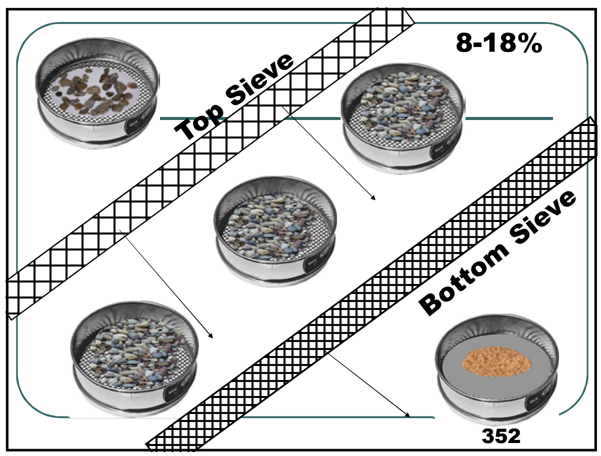
350

"8-18" Rule

"Percent retained on all sieves, except top and bottom two, should fall with between 8 and 18"

Rule of Thumb: Keep difference between sieves ≤ 13% (p. E-5).

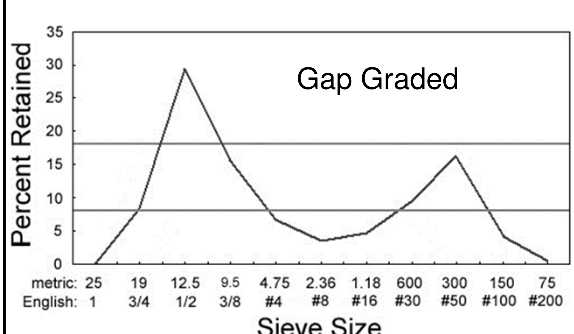
351



352

Table 1.2.1 GAP Graded			
Sieve	Pass	Retain	8-18?
1 inch	100%	0	N/A
3/4 inch	92%	8%	N/A
1/2 inch	62%	30%	N
3/8 inch	47%	15%	Y
No. 4	40%	7%	N
No. 8	37%	3%	N
No. 16	32%	5%	N
No. 30	22%	10%	Y
No. 50	6%	16%	Y
No. 100	2%	4%	N/A
No. 200	1.0%	1%	N/A

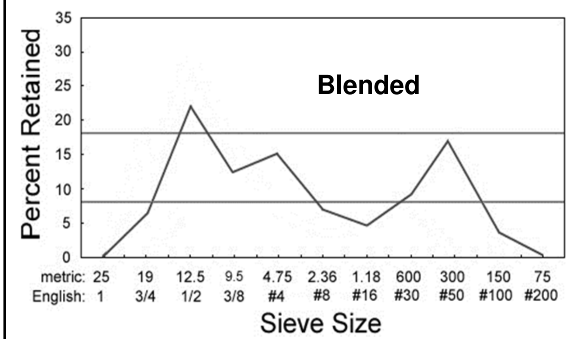
353



354

Table 1.2.2 Blended CA			
Sieve	**Pass**	**Retain**	**8-18?**
1 inch	100%	0	N/A
3/4 inch	94%	6%	N/A
1/2 inch	72%	22%	N
3/8 inch	59%	13%	Y
No. 4	44%	15%	Y
No. 8	37%	7%	N
No. 16	32%	5%	N
No. 30	23%	9%	Y
No. 50	6%	17%	Y
No. 100	2%	4%	N/A
No. 200	1.0%	0.9%	N/A

355



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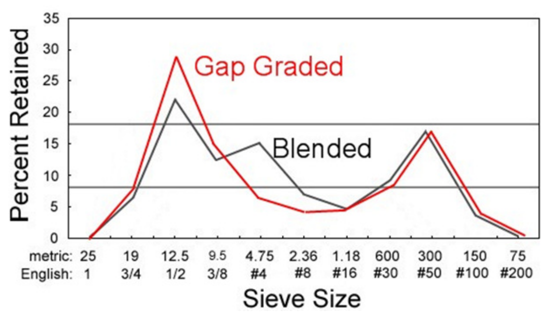


357

Fine Aggregate and Air

Amount passing #30 and retained on the #50 is critical for holding entrained air.

For this blend:

P#30 = 23%

P#50 = 6%

Retained on #50 = 17%

358

Tarantula Curve

- **Similar to "8-18" rule**
- **Developed by Tyler Ley at Oklahoma State University**

359

Tarantula Curve

- **For slipform, recommended that 15% total be retained on the #8, #16, and #30 sieves, and 24-34% between the #30 and #200**
- **For non-slipform, recommended that 20% total be retained on the #8, #16, and #30 sieves, and 25-40% between the #30 and #200**
- **For either, the amount individually retained on the #8 and #16 should not exceed 12%**

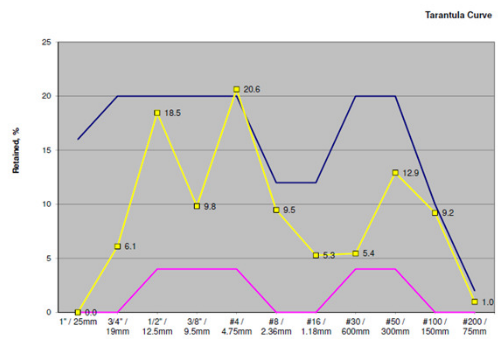
360

Tarantula Curve Gradation Limits

Sieve	Upper Limit	Lower Limit	% Retained
1" / 25mm	16	0	0.0
3/4" / 19mm	20	0	6.1
1/2" / 12.5mm	20	4	18.5
3/8" / 9.5mm	20	4	9.8
#4 / 4.75mm	20	4	20.6
#8 / 2.36mm	12	0	9.5
#16 / 1.18mm	12	0	5.3
#30 / 600µm	20	4	5.4
#50 / 300µm	20	4	12.9
#100 / 150µm	10	0	9.2
#200 / 75µm	2	0	1.0

%Retained on #8, #16, and #30?	20.2
%Retained between #30 and #200?	28.5

361



362

0.45 Power Curve

- Y = Percent Passing each Sieve
- X = Sieve Size raised to the 0.45 power
- Maximum density line plotted from origin to Nominal Maximum Aggregate Size (NMAS) for PCC.

363

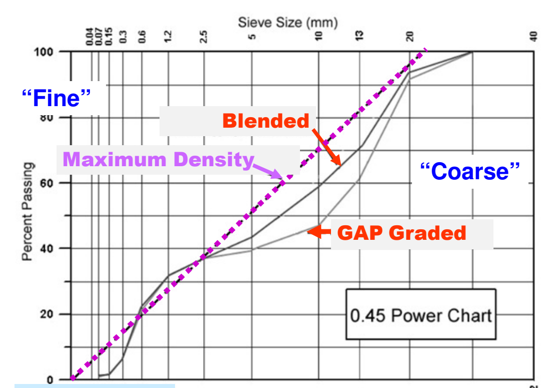


Figure 1.2.2

7.0 Design Strength

- Section 7 (Pg. 41)
- Appendix N

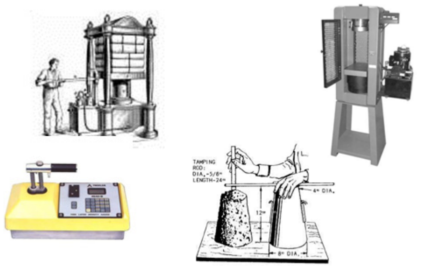
365

Statistics - Appendix N

- Accuracy
- Precision
- Standard deviation
- Averages (Median & Mean)
- Bell curves

366

What Do Test Results Mean?

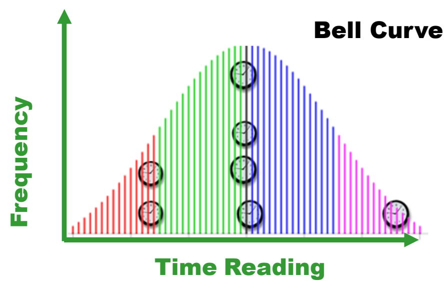


367

What Time is it?

368

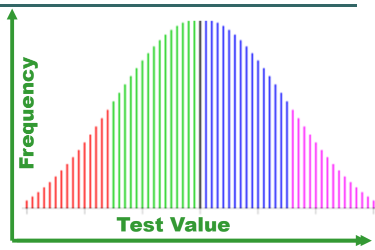
Normal Distribution



369

Language of Statistics

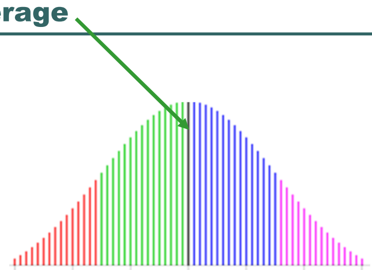
- Average
- Precision
- Accuracy
- Standard Deviation.



Normal Distribution

370

Average



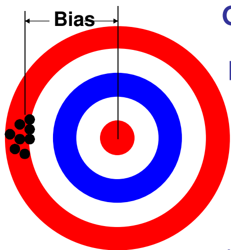
371

Precision and Accuracy

- Precision - Variability of repeating same measurement
- Accuracy - Conformity to the true value
- Bias - Deviation from the true value

372

Precise



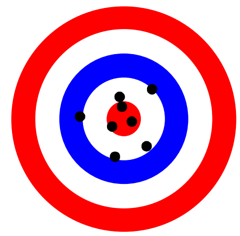
Good Precision

Poor Accuracy
(Biased)

(Average off Center)

373

Accurate



Good Accuracy
(Unbiased)

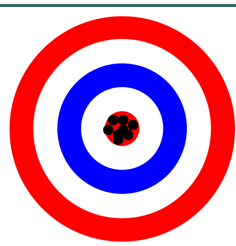
Poor Precision

(Average on Center)

374

Precise and Accurate

Good Precision
Good Accuracy
(Unbiased)



(Average on Center)

375

Standard Deviation
Appendix N-2

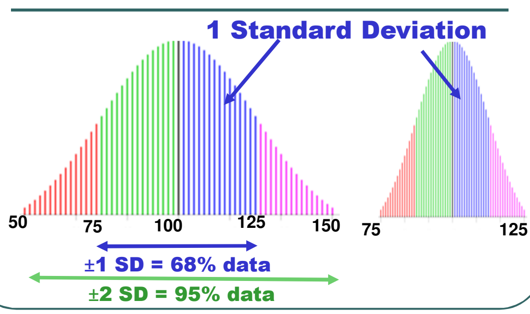
(f) spread of test results from the average.

$$\text{sum} = \sum_{i \to n}^{n=6} (\overline{X} - x_i)^2$$

$$\text{standard deviation} \quad S = \sqrt{\frac{\text{sum}}{(n-1)}}$$

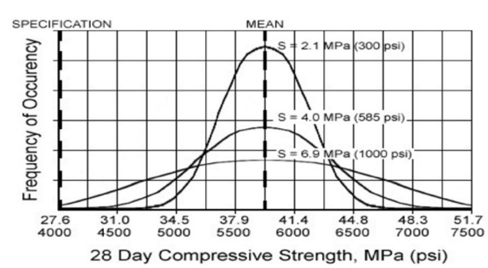
376

Standard Deviation



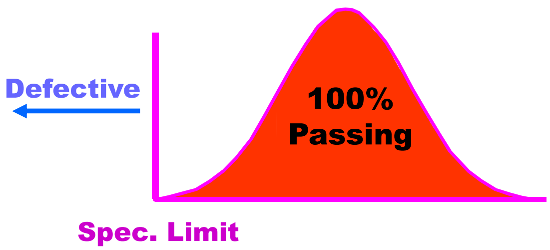
377

Average Strength and Standard Deviation of 3 mixes



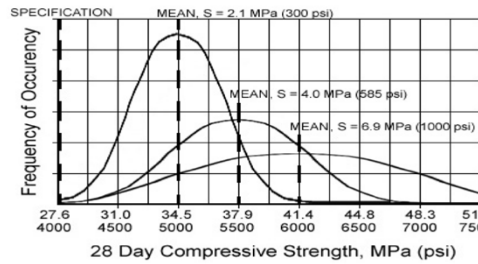
378

IDOT Strength Specification



379

Minimum Strength and Standard Deviation



380

7.0 Design Target Strength (Pg. 41)

ACI 301 (Required for Ternary mix designs)

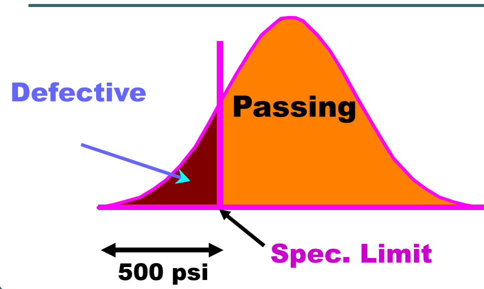
- Average of 3 tests may not be below minimum spec. (test = 2 cylinders)
- No single test can exceed 500 psi below minimum spec

@ 14 days for most IDOT mixes

@ 28 days for > 4,000 psi design

381

Statistical Approach – ACI 301 (Specifications for Structural Concrete)



382

Improving confidence in PCC Strength

1. Increase average strength, or
2. Decrease standard deviation

383

7.0 Statistical Analysis of Strength (ACI 301)

- A statistical analysis of strength is strongly recommended when developing a new mix design,

384

Target Strength (<15 Tests)

Less Than 15 Tests or No Test Data Available	Mix Design Target Strength
If $f'_c < 3{,}000$ psi	$f'_{cr} = f'_c + 1{,}000$ psi
If f'_c is 3,000 – 5,000 psi	$f'_{cr} = f'_c + 1{,}200$ psi
If $f'_c > 5{,}000$ psi	$f'_{cr} = 1.10\, f'_c + 700$ psi

f'_{cr} may be adjusted based on statistical analysis per ACI 301 (>15 batches; 30+ optimum)

385

The End Part 1

386

PCC Level III
PowerPoint
Handout
Specialty Mixes

2017-2018

3.0 Specialty Mixes (Pg. 32/Appendices)

1

Specialty Mixes

- High-Early Strength (Section 3.1)
- CAM II (Appendix F)
- CLSM (Appendix G)
- Stamped/Colored Concrete (Appendix H)
- Revetment Mats (Appendix I)
- Pipe Lining Grout (Appendix J)
- Cellular Concrete (Appendix K)
- Class SI Between Precast Boxes (Appendix L)

More >>>>

2

More……Specialty Mixes

- Pervious Concrete (Appendix M)
- Latex Concrete (Appendix P)
- Self-Consolidating Concrete (Section 1020)
- Mass Concrete
- Structural Concrete Mixes
- Patching Mixes
- White Topping
- Roller-Compacted Concrete

3

High-Early Strength Concrete (3.1 – Pg. 32)

Need 48-hr strength?

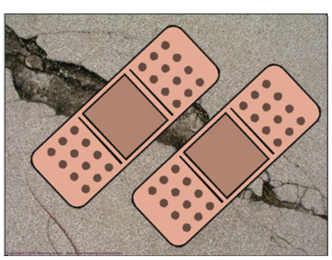
3 OPTIONS:

1. Use Type III high-early strength cement
2. Use a higher cement content Type I cement mix
   - 7-bag mix (658 Pounds)
   - Less FA Water 4.9 gal/cwt
   - WR admixture or superplasticizer, if permitted)
3. Use approved accelerator

4

Concrete Patches

- PP-1
- PP-2
- PP-3
- PP-4
- PP-5



5

Concrete Patches

PP-1 Standard patch - Type I cement (7.0 bag)
48 hr. strength.
Type C fly ash or GGBFS allowed. (w/HR)
Type III option w/lower cement content
Most economical

PP-2 "Hot patch" – Type I cement (7.8 bag)
24 hr. strength
Non-chloride accelerator w/HRWR
Chloride accelerator only via S.P.
Lower durability, seldom used

6

Concrete Patches

PP-3 Same-day Opening – 16 hr. strength
Type III cement
Slag & microsilica required
Non-chloride accelerator required
Higher durability, seldom used

PP-4 Rapid-hardening cement - 8 hr. strength
Mobile mixer only
Product from "Approved List of Packaged, Dry, Rapid-Hardening Cementitious Materials"

7

Illinois Department of Transportation
Bureau of Materials and Physical Research
QUALIFIED PRODUCT LIST OF PACKAGED, DRY, RAPID HARDENING CEMENTITIOUS MATERIALS FOR CONCRETE REPAIRS
December 9, 2016
This list supersedes the March 11, 2016 list.
Guide Bridge Special Provision "Structural Repair of Concrete" (Revised April 1, 2016) Recurring Special Provision for Subsealing of Concrete Pavements (Revised January 1, 2007) Standard Specifications for Road and Bridge Construction, Section 1018 (Adopted April 1, 2016) Standard Specifications for Road and Bridge Construction, Section 1001 (Adopted April 1, 2016) Current Policy Memorandum, "Quality Control/Quality Assurance Program for Precast Concrete Products" Manual for Fabrication of Precast Prestressed Concrete Products

RAPID HARDENING CEMENT (Section 1001)

For information regarding new product submittal, click the "New Submittal" bookmark to the left.

Material Code No. 37901
The rapid hardening cement is used for Class PP-4 concrete. The Material Code No. is 22106, "PATCHING MIXTURE, RAPID HARDENING CEMENT".

No materials approved at this time.

8

PP-5

- Calcium Aluminate Cement – High strength/ sensitive to admixtures
- 4-hour strength
- Mobile mixer required
- Suitable for low temperature placement
- Proprietary accelerator and superplasticizer

9

Patch Opening Strength Specs Section 701.17

TABLE 1. CLASSES OF CONCRETE AND MIX DESIGN CRITERIA

Class of Conc.	Use	Specification Section Reference	Cement Factor cwt/cu yd (3) Min.	Cement Factor cwt/cu yd (3) Max	Water / Cement Ratio lb/lb	Slump in. (4)	Mix Design Compressive Strength (Flexural Strength) psi, minimum Days 3	14	28	Air Content %	Coarse Aggregate Gradations (14)

PP	Pavement Patching Bridge Deck Patching (10)	22,100 (4150)	
	PP-1	at 48 hours	3,200 psi open
	PP-2	at 24 hours	1,600 psi open 3,200 psi @ time
	PP-3	at 16 hours	
	PP-4	at 8 hours	
	PP-5	at 4 hours	

10

Opening to Traffic (Section 701.17)

Strength Tests. For patches constructed with Class PP-1 concrete, the pavement may be opened to traffic when test specimens have obtained a minimum flexural strength of 600 psi (4,150 kPa) or a minimum compressive strength of 3200 psi (22,100 kPa) according to Article 1020.09.

For patches constructed with Class PP-2, PP-3, PP-4, or PP-5 concrete, the pavement may be opened to traffic when test specimens have obtained a minimum flexural strength of 250 psi (1725 kPa) or a minimum compressive strength of 1600 psi (11,000 kPa) according to Article 1020.09. However, the concrete mixture shall obtain a minimum flexural strength of 600 psi (4150 kPa) or a minimum compressive strength of 3200 psi (22,100 kPa) in the time specified in Table 1 of Article 1020.04.

11

CAM II – Cement Aggregate Mixture (Appendix F)

- Stabilized Subbase, Section 312.09
- No basic water, mortar factor, or strength requirement
- Minimum cement 170 lbs. per yard
- 3 trial mixes recommended – with and without fly ash
- Slump 1-3 inches
- Air 7-10%

12

CAM II

- Dept. will conduct freeze-thaw tests
- ASR applies
- Dept. will perform one set of mix designs with contractor's three cement ranges.

13

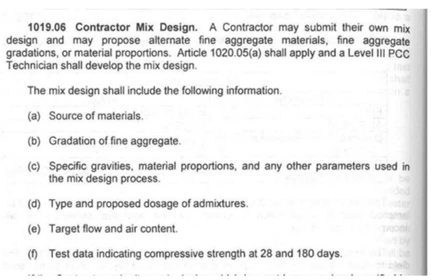
CLSM – Controlled Low Strength Material (Appendix G)

"Flowable Fill" - Section 1019

- No design procedure
- 3 proportion options offered
- Design criteria
  - ≥ 7 inch flow (IL Test Method)
  - 0-25% air
  - ≤ 1.5 in./blow dynamic cone penetrometer
  - 30-150 psi strength @ 28 and 180 days.

14

CLSM – Controlled Low Strength Material (Appendix G)



1019.06 Contractor Mix Design. A Contractor may submit their own mix design and may propose alternate fine aggregate materials, fine aggregate gradations, or material proportions. Article 1020.05(a) shall apply and a Level III PCC Technician shall develop the mix design.

The mix design shall include the following information.

(a) Source of materials.

(b) Gradation of fine aggregate.

(c) Specific gravities, material proportions, and any other parameters used in the mix design process.

(d) Type and proposed dosage of admixtures.

(e) Target flow and air content.

(f) Test data indicating compressive strength at 28 and 180 days.

15

CLSM Mix Properties

- Self-leveling
- Self-compacting
- Able to readily fill voids
- Minimum bleeding and shrinkage

16

CLSM Uses

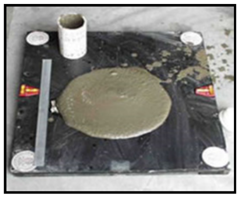
- Backfilling utility trenches.
- Backfilling abandoned vaults and pipes.
- Backfilling underground tanks.
- Structural backfill under/around over-excavated foundations.
- Backfilling washed out or undermined areas.

17

Workable/Diggable

18

CLSM Bonus Benefits



- Reduce traffic inconvenience
- Safer working environment
- Easily 'dig-able' or removable
- Fewer pavement failures, fewer future expenses, fewer delays

19

CLSM Mix Design Options

	Mix 1	Mix 2	Mix 3
Cement	50 lb.	125 lb.	40 lb.
Fly Ash	125 lb.		125 lb.
FA	2900 lb.	2500 lb.	2500 lb.
Water	50-65 gal.	35-50 gal.	35-50 gal.
Air	0	15-25 %	15-25 %

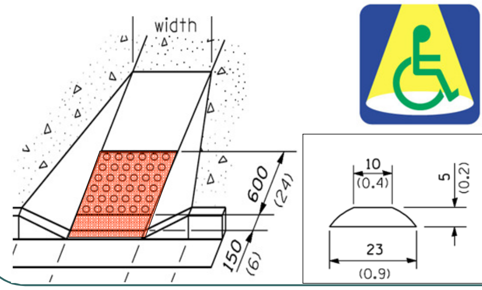
20

CLSM-Type Products

- Flowable Fill
- Flash Fill
- FlowFill
- Geofill
- Redi-Fill.

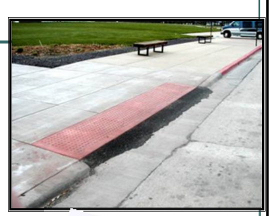
21

Stamped/Colored Concrete (Appendix H)



22

Stamped/ Colored Concrete



- Article 424.08 - concrete no longer required for domed ramps.
- Mix design guidelines Appendix H.
- See District for Special Provision

23

Stamped/Colored Concrete recommendations (Appendix H)

- 6.05 cwt/yd cement
- Slump range 3-5"
- CA11, CA13, CA14, or CA16
- MF 0.88 to 0.90
- For colored concrete, w/c ratio $\pm$0.02 of target
- No calcium chloride accelerators

24

Fabric Formed Revetment Mats (Appendix I)

- Section 285
- No formal mix design
- 2,500 psi, pumpable "mortar"
- Mix options:
  1. Cement only
  2. Cement + Fly Ash
- 6.0-9.0 % air
- 0.60 max. W/C ratio

25

Pipe Lining Options BDE 80315

"SECTION 543. INSERTION LINING OF CULVERTS

543.02 Materials

(g) Grout Mixture 1024.01
(h) Portland Cement Concrete 1020
(i) Controlled Low-Strength Material 1019
(j) Cellular Concrete 1029

26

Pipe Lining - Grout Mixture (Appendix J)

- Article 1024.1
- 150 psi @ 28 days min.
- 6.50 cwt/yd^3
- 80% fly ash replacement allowed
- 0.60 max. W/C ratio
- 6.0-9.0% air
- Trial Batch Required.

27

Cellular Concrete (Appendix K)

"Engineered Fill" Lightweight "foam" concrete

- Not Article 1029
- Proprietary mixes
- 4.0-6.5 cwt
- 65% Fly Ash replacement
- 0.50-0.60 W/C ratio
- 20-70% air voids structure
- Fine Aggregate is optional
- Proprietary foam admixture

28

Class SI PCC Between Precast Concrete Box Culverts (Appendix L)

- Article 540.06 – Multi-Cells (rows)
- "Maximum Agg. Size ⅜-inch"
- CM16 (finer) or 100% FA
- Higher H_2O demand
- Start with CA basic water 0.4 gal/cwt.

3-inch space between rows

29

Pervious Concrete (Appendix M)

No IDOT Spec.

30

Pervious Concrete

Green Alley

- No formal design procedure
- Project-specific Special Provision
- Single CA (usu. CM13)
- Typical: 450# Cement/100 # GGBFS + fibers
- Hydration stabilizer
- 2,000 – 3,000 psi
- 18-25% voids structure
- Can use transit mixer, mobile mixer, or dump

31

Pervious Examples

Center Strip

Full Width

NRMCA Certification Program

32

Self-Consolidating Concrete (SCC)

33

SCC

Can flow around reinforcement and consolidate without additional effort and without segregation

34

SCC for Cast-in-place Construction

Article 1020.04

Usage –BS, PC, PS, DS, & SI

Reduces:

- Equipment use
- Construction time
- Labor
- Construction noise, vibration
- Segregation, bug holes

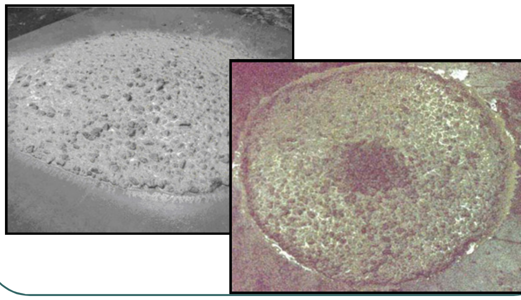
35

Materials & Design

- High range W-R, or
- High range W-R admixture + separate viscosity modifying admixture
- CA 100% <12.5 mm 95% <19 mm
- FA 50% Max. total aggregate
- Maximum cement factor 7.05 cwt/cu yd
- Maximum water/cement ratio 0.44
- Special design and QC tests

36

Visual Stability Index



37

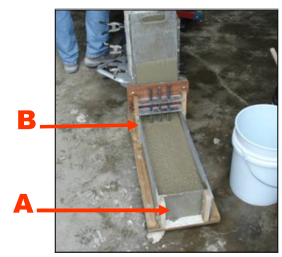
Slump Flow
Range 22 to 28 in.

38

J-Ring
(J-Ring Flow - Slump flow) ≤ 2”

39

L-Box
Blocking Ratio (A/B) min. 80%



40

Hardened Visual Stability Index

41

Column Segregation

- Optional Test
- Wash concrete from each section through #4 sieve
- Difference in retained weight of CA cannot exceed 15% Index

42

Mass Concrete (Pg. 35)

- Class MS concrete replaced with a spec for "massive" pours with least dimension >5 ft.
- Drilled shaft, foundation, footing, substructure, superstructure
- Temperature restrictions
- Pre-cooling & post-cooling measures
- Larger aggregate, uniformly graded
- More FDMs allowed, less total cementitious

43

Structural Concrete Mixes *Guide Bridge Special Provisions*

- Bridge Deck Microsilica Overlay
- Bridge Deck Latex Concrete Overlay
- Bridge Deck High-Reactivity Metakaolin Overlay
- Bridge Deck Thin Polymer Overlay
- High Performance Concrete Structures
- Deck Slab Repair

44

Bridge Deck Latex Concrete (Appendix P)

CM13	1,267 lbs. (42-50% by weight of total aggregate)
FM02	1,544 lbs. (≥ 50% of agg.)
Cement	658 lbs.
Water	15.7 gal
Latex	24.5 gal (c. 54% water)
Air	0

C.F. = 6.58

W/C = 0.37

CA weights adjusted for solids in latex

45

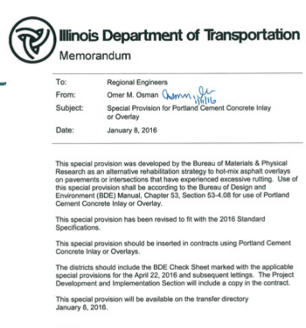
White Topping Special Provision 80353

PORTLAND CEMENT CONCRETE INLAY OR OVERLAY (BDE)

Effective: January 1, 2015
Revised: April 1, 2016

46

White Topping



Illinois Department of Transportation
Memorandum

To: Regional Engineers
From: Omer M. Osman
Subject: Special Provision for Portland Cement Concrete Inlay or Overlay
Date: January 8, 2016

This special provision was developed by the Bureau of Materials & Physical Research as an alternative rehabilitation strategy to hot-mix asphalt overlays on pavements or intersections that have experienced excessive rutting. Use of this special provision shall be according to the Bureau of Design and Environment (BDE) Manual, Chapter 53, Section 53-4.08 for use of Portland Cement Concrete Inlay or Overlay.

This special provision has been revised to fit with the 2016 Standard Specifications.

This special provision should be inserted in contracts using Portland Cement Concrete Inlay or Overlays.

The districts should include the BDE Check Sheet marked with the applicable special provisions for the April 22, 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 January 8, 2016.

80353m

47

Mix Characteristics

- Class PV
- Variable design thickness (≥ 4 inches)
- Cement factor 6.05 cwt (Central-mixed)
- Cement factor reduction < 0.30 cwt
- NMAS limited by thickness
- Minimum 3000 psi @ 14 days.
- Synthetic fibers < 5.0 lb/cu yd

48

RCC
Roller Compacted Concrete

- No slump
- Blended coarse aggregate
- Impermeable

49

RCC
Roller Compacted Concrete

ROLLER COMPACTED CONCRETE (BMPR)
Effective: January 17, 2014

Item	Criteria
Cement Factor, cwt/cu yd (kg/cu m)	5.35 (320) (Note 1)
Water/Cement Ratio, lb/lb (kg/kg)	0.25 – 0.40
Slump, in. (mm)	Not Applicable
Air Content, %	Not Applicable
Coarse Aggregate Gradations	CA11
Intermediate Aggregate Gradations	CA13, CA14, CA16
Fine Aggregate Gradations	FA01, FA02, FA20
Mix Design Compressive Strength, psi (kPa), minimum	3,500 (24,000) at 7 days; 4,500 (31,000) at 28 days

Notes: (1) The minimum portland cement content in the mixture shall be 400 lbs/cu yd (237 kg/cu m). A cement factor reduction for using a water-reducing admixture or a high range water-reducing admixture will not be allowed, and Articles 1020.05(c)(5)b. and 1020.05(c)(5)c. will not apply.

50

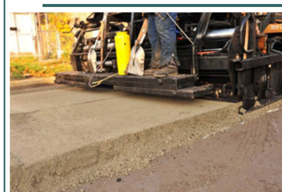
Roller Compacted Concrete (RCC)

Material	WT	Vol
CM11	830	0.183
CM13	850	0.187
FM20	1,820	0.406
Ty 1	400	0.075
Fly	125	0.029
Air	0	0.020
Water	168	0.100
	4,193	1.000

$M_O = 0.95$

51

Roller-Compacted Concrete



52

The End

53

PCC Level III
PowerPoint
Handout
Mix Design
Software

2017-2018

PCC MIX DESIGN Software V2.4.1 (2018)

1

Resources & Downloads

1. Tutorial - Appendix B-A
2. See Section 1.2.1 of Course Manual for downloading instructions

2

References

Below are reference materials to assist in getting materials approved and IDOT guidelines.

- Guides/Spreadsheets

The following documents are provided as a tool to assist with identifying materials and/or ensuring that correct data is supplied to IDOT.

- Model Quality Control Plan for Concrete Production BMPR PCC04 Template
- PCC Mix Design Spreadsheet
  - PCC Mix Design(V2.4)
  - Tutorial (V2.4)
  - PV Example Mix Design
  - Allowable H20 (V2.2.1)
  - Blending Aggregrates (V2.2)
- PCC Mixer Performance Spreadsheet

The following documents are provided as a tool to assist with identifying materials and/or ensuring that correct data is supplied to IDOT.

- QC/QA Package Downloads

Stay Connected and subscribe for updates:

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- Unsubscribe unsubscribe-dot-qcqaprogramupdates@lists.illinois.gov

3

PCC Level III Technician Course Manual Revised February 1, 2016

APPENDIX B-A

PCC MIX DESIGN SOFTWARE TUTORIAL (Version 2.4)	For help, comments, and/or suggestions, please contact: James M. Krstulovich, Jr. IDOT Bureau of Materials and Physical Research 126 East Ash Street Springfield, Illinois 62704 Phone: (217) 782-7200 email: DOT.PCCMIX@illinois.gov

!!! IMPORTANT !!! This spreadsheet utilizes macros. Depending on Excel's security settings, the macros may not be enabled. To change the macros settings for Excel, refer to the steps found at the end of this tutorial.

4

Guide for input for PV Example Problem

EXAMPLE PROBLEM	Because this is the Producer's or Contractor's mix design number, any reasonably succinct and unique identifier can be used here, as long as it is no more than nine characters long. For this example, we will use **PMC0001PV** (i.e., Pave Masters Co. paving mix #1).

5

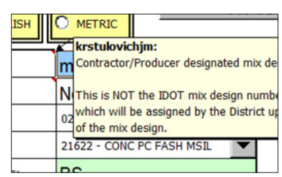
Cell Format / Input

Input

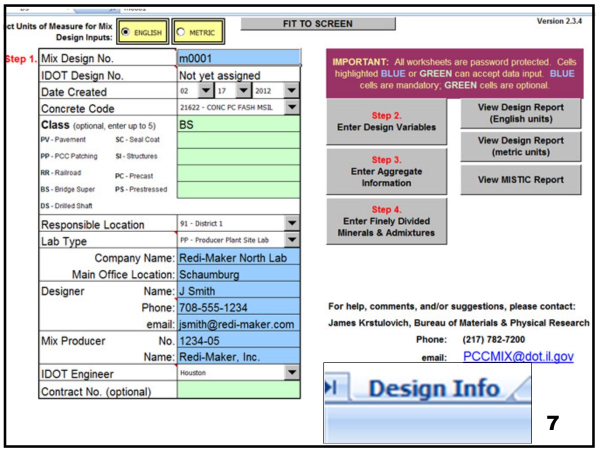
Optional

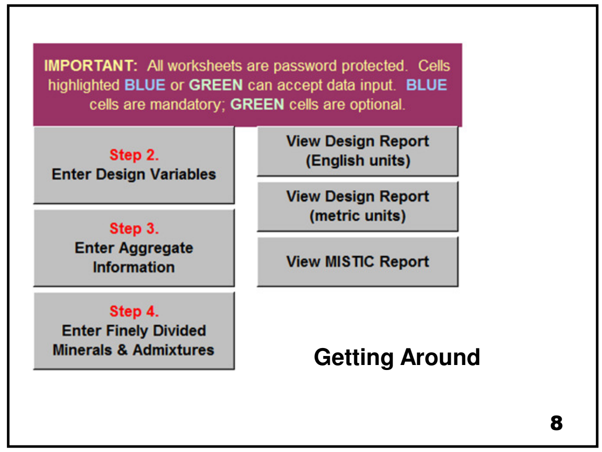
Calculated / Locked

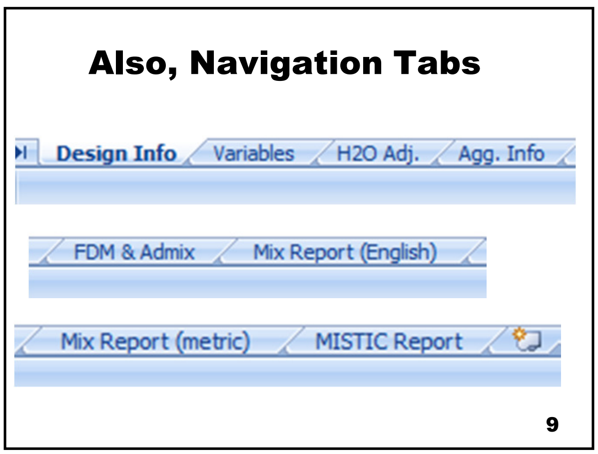
RED Tags have comments



6


ct Units of Measure for Mix Design Inputs:
ENGLISH
METRIC
FIT TO SCREEN
Version 2.3.4
Step 1.
Mix Design No. m0001
IDOT Design No. Not yet assigned
Date Created 02 17 2012
Concrete Code 21622 - CONC PC FASH MSIL
Class (optional, enter up to 5) BS
PV - Pavement SC - Seal Coat
PP - PCC Patching SI - Structures
RR - Railroad PC - Precast
BS - Bridge Super PS - Prestressed
DS - Drilled Shaft
Responsible Location 91 - District 1
Lab Type PP - Producer Plant Site Lab
Company Name: Redi-Maker North Lab
Main Office Location: Schaumburg
Designer Name: J Smith
Phone: 708-555-1234
email: jsmith@redi-maker.com
Mix Producer No. 1234-05
Name: Redi-Maker, Inc.
IDOT Engineer Houston
Contract No. (optional)
IMPORTANT: All worksheets are password protected. Cells highlighted BLUE or GREEN can accept data input. BLUE cells are mandatory; GREEN cells are optional.
Step 2. Enter Design Variables
Step 3. Enter Aggregate Information
Step 4. Enter Finely Divided Minerals & Admixtures
View Design Report (English units)
View Design Report (metric units)
View MISTIC Report
For help, comments, and/or suggestions, please contact:
James Krstulovich, Bureau of Materials & Physical Research
Phone: (217) 782-7200
email: PCCMIX@dot.il.gov
Design Info
7


IMPORTANT: All worksheets are password protected. Cells highlighted BLUE or GREEN can accept data input. BLUE cells are mandatory; GREEN cells are optional.
Step 2. Enter Design Variables
Step 3. Enter Aggregate Information
Step 4. Enter Finely Divided Minerals & Admixtures
View Design Report (English units)
View Design Report (metric units)
View MISTIC Report
Getting Around
8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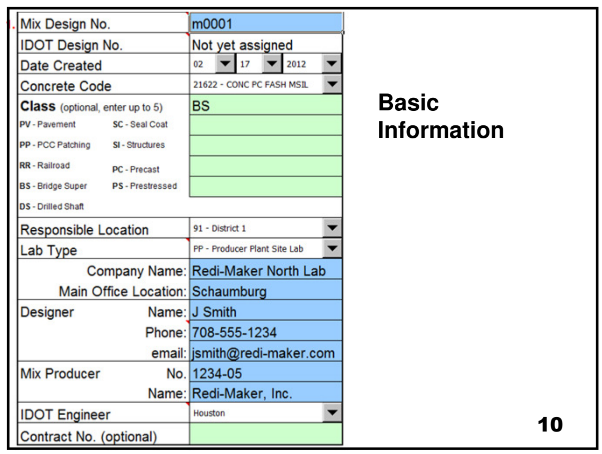
Variables
H2O Adj.
Agg. Info
FDM & Admix
Mix Report (English)
Mix Report (metric)
MISTIC Report
9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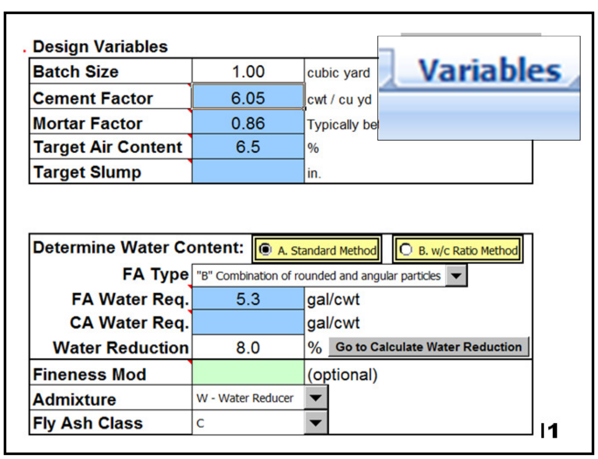
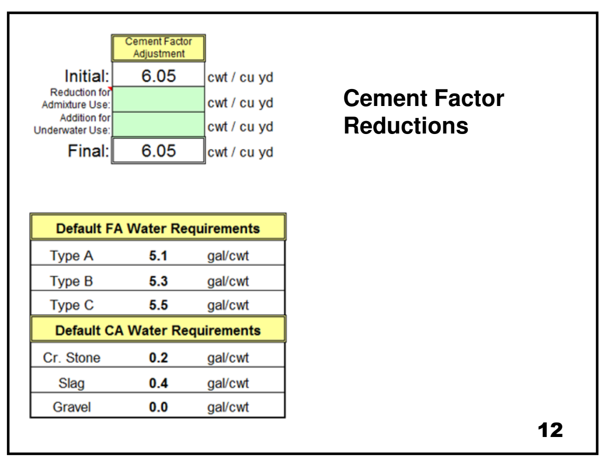
IDOT Design No. Not yet assigned
Date Created 02 17 2012
Concrete Code 21622 - CONC PC FASH MSIL
Class (optional, enter up to 5) BS
PV - Pavement SC - Seal Coat
PP - PCC Patching SI - Structures
RR - Railroad PC - Precast
BS - Bridge Super PS - Prestressed
DS - Drilled Shaft
Responsible Location 91 - District 1
Lab Type PP - Producer Plant Site Lab
Company Name: Redi-Maker North Lab
Main Office Location: Schaumburg
Designer Name: J Smith
Phone: 708-555-1234
email: jsmith@redi-maker.com
Mix Producer No. 1234-05
Name: Redi-Maker, Inc.
IDOT Engineer Houston
Contract No. (optional)
Basic Information
10


Design Variables
Batch Size 1.00 cubic yard
Cement Factor 6.05 cwt / cu yd
Mortar Factor 0.86 Typically be
Target Air Content 6.5 %
Target Slump in.
Variables
Determine Water Content: A. Standard Method B. w/c Ratio Method
FA Type "B" Combination of rounded and angular particles
FA Water Req. 5.3 gal/cwt
CA Water Req. gal/cwt
Water Reduction 8.0 % Go to Calculate Water Reduction
Fineness Mod (optional)
Admixture W - Water Reducer
Fly Ash Class C
11


Cement Factor Adjustment
Initial: 6.05 cwt / cu yd
Reduction for Admixture Use: cwt / cu yd
Addition for Underwater Use: cwt / cu yd
Final: 6.05 cwt / cu yd
Cement Factor Reductions
Default FA Water Requirements
Type A 5.1 gal/cwt
Type B 5.3 gal/cwt
Type C 5.5 gal/cwt
Default CA Water Requirements
Cr. Stone 0.2 gal/cwt
Slag 0.4 gal/cwt
Gravel 0.0 gal/cwt
12

Water Adjustment	Water Adjustment Range	*Adjustment Percentage Selected
Aggregate shape and texture:		
Baseline (cubical crushed stone)	(0%)	Note 1
Rounded, smooth	(-5 to 0%)	
Flat, elongated, rough	(0 to +5%)	
Combined aggregate grading:		
Well-graded	(-10 to 0%)	5
Gap-graded	(0 to +10%)	
Admixture(s):		
Air entraining admixture **Note:** Use allowable minimum specification air content		-5
1 to 3% air content	(0%)	
4 to 5% air content	(-5%)	
6 to 10% air content	(-10%)	
Normal water-reducing admixture	(-10 to -5%)	
Mid-range water-reducing admixture	(-15 to -8%)	-8
High range water-reducing admixture, minimum of 14% when used to reduce cement factor (Note 2)	(-30 to -12%)	

es | H2O Adj.

13

Finely Divided Minerals:		
Fly Ash (Note 3)	(-10 to 0%)	-5
Microsilica	(0 to +15%)	5
High-Reactivity Metakaolin (HRM)	(-5 to +5%)	
GGBF Slag	(0%)	
Other factors:		
Coarse cement, water/cement ratio > 0.45, concrete temperature < 60 °F (27 °C)	(-10 to 0%)	
Fine cement, water/cement ratio < 0.40, concrete temperature > 80 °F (27 °C)	(0 to +10%)	
Cumulative adjustment percentage = sum of all values		-8
The suggested maximum water reduction recognizing overlapping effects of individual factors is -30%.		**-8**

Maximum 30% Reduction.
Manually carry Reduction to mix design

14

dj. | Agg. Info

Aggregate Information

	Material Code	Producer Number	Ledge No.	Producer Name	SSD Sp. Gravity	% Blend	Moisture (%)
1	027fa01	5432-01		sandy sand co	2.600	100.0	3.60
2	022ca11	1234-05		big rocks inc	2.680	100.0	0.50
3							
4							
5							
6							

15

a. Voids in Coarse Aggregate ○ Calculate ◉ Enter Directly

Refer to Illinois Test Procedure 306

Coarse Aggregate	% Absorption	Oven-Dry Sp. Gravity

Net Weight of Aggregate		lb.
Volume of Measure		cu. ft
SSD Sp. G		
% Absorption		%
Oven-Dry Sp. G		
Unit Weight		lb/cu. ft

16

Info | FDM & Admix | Mix R

4. Finely Divided Minerals Information

	Material Code	Producer Number	Producer Name	Specific Gravity	Percent Blend	Replacement Ratio
1	37601 Type I, Portland			3.150	76.5	1.00
2	37801 Fly Ash Class C	666-06	general electrical	2.550	18.9	1.00
3	Select Slag...					
4	37852 Microsilica	777-07	specialty materials inc	2.200	4.6	1.00
					100.0 %	

5. Admixtures Information

	Material Code	Admixture Type (ASTM C 494)	Product Name	Remarks (e.g. dosage rate, charging sequence, etc.)
1		n/a		
2		n/a		
3		n/a		
4		n/a		

17

DTT03110 PCC MIX DESIGN Version 2.3.4

IDOT PCC MIX # Not Assigned MATERIAL: 21622 CONC PC FASH MSIL EFFECTIVE:
CONT REF MIX# M0001 CLASS: BS
RESP: 91 DISTRICT 1 LAB: PP Producer Plant Site REVIEWED BY:

BATCH CU YD	ADX	H2O% RED	FINE MOD	% AIR	VOIDS	(Z) CEMENT	MORTAR FACTOR	(TYPE) ASH	(TYPE) FA	(GAL/CWT) FA	(GAL/CWT) CA	(ABS. VOL) CA,B	(ABS. VOL) FA,A
1.00	W	8.0		6.5	0.41	6.05	0.86	C	B	5.30	0.00	0.4069	0.2580

MATERIAL	PROD NO	PROD NAME	SP G	% BLEND	%MOIST / REPL	[LBS / CU YD] SSD	[LBS / CU YD] ADJ	[KG / CU M] ADJ
027FA01	5432-01	SANDY SAND CO	2.600	100.0	3.60	1130	1170	698
022CA11	1234-05	BIG ROCKS INC	2.680	100.0	0.50	1836	1846	1096
37601			3.150	76.5	1.00	465	465	275
37801	666-06	GENERAL ELECTRICAL	2.550	18.9	1.00	115	115	70
37852	777-07	SPECIALTY MATERIALS INC	2.200	4.6	1.00	28	28	17
					ADJ. H2O (gal : lbs)	23.7	197	117
					TOTAL BATCH WT (lbs)		3821	2268

(FA + CA) MIX-H2O: 5.30 W/C RATIO: 0.41
TOTAL CEMENTITIOUS MATL: 6.08 THEO. H2O (gal : lbs) 29.6 247

PRODUCER: 1234-05 PROD NAME: REDI-MAKER, INC.
REMARKS:
REMARKS: CONTRACT

ADDITIONAL INFORMATION: Lab: REDI-MAKER NORTH L/ Location: SCHAUMBURG Target
Designer: J SMITH Created: 02/17/12 Slump (in.)

Adx(s): Matl Code	Type	Product	Remarks

Designer Phone: 708-555-1234
Designer email: jsmith@redi-maker.com
Cc: HOUSTON
Printed 3/15/2012

& Admix | Mix Report (English) | Mix Re

18

METRIC UNITS DESIGN REPORT (2)

PCC MIX DESIGN

Assigned — MATERIAL: 21622M CONC ASH MS
01 — CLASS: BS
RICT 1 — LAB: PP Producer Plant Site — REVIEWED

% D	FINE MOD	% AIR	VOIDS	(Z) CEMENT	MORTAR FACTOR	{TYPE} ASH	FA	{L / KG} FA	C

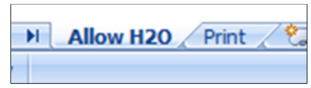
MISTIC DESIGN REPORT (3)

PCC DESIGN MIX

MATERIAL: 21622M
M0001 — CLASS: BS — LAST YR USED
DISTRICT 1 — LAB: PP — REVIEWED BY:
1234-05 — REDI-MAKER, INC. — CONTRACT:

19

Allowable Water Worksheet



20

Select Water Content Calculation Method

◉ Standard Method ○ w/c Ratio Method

FA Water Requirement	5.5	gal/cwt
CA Water Requirement	0.2	gal/cwt
Water Reduction	10.0	%
Maximum W/C Ratio	0.44	

Aggregate Moisture

Matl Code	SSD Weight lbs / cu yd	Moisture %	Water gal / cu yd
022ca11	2396	-2.07	-5.95
027fa01	749	-1.96	-1.76

Water in Admixtures

Total Cement+FDM 6.05 cwt/cu yd

Type	Product	Dosage Rate oz / cwt of cement+FDM	Water oz H2O / oz of admixture
AEA		6.0	0.7
A		8.0	0.7
			0.0
			0.0
Total Admixture Water:			59.29 oz per cu yd

ILLINOIS DEPARTMENT OF TRANSPORTATION
WATER/CEMENT RATIO WORKSHEET

Date: (mm/dd/yy)	01/01/06	Ticket No.:	
Producer No.:		Contract No.:	
Producer Name:	PCC Ready-Mixed Co.	Contractor Name:	
Mix Design No.:	50PCC1234	Resident Engineer:	J. Smith
PCC Level II:		Level II Employer:	
Department Inspector at Plant		Inspector Employer:	

1. Total Cement + Finely Divided Minerals		605	lb/cu yd
2. Maximum w/c ratio		0.44	
3. Maximum Allowable Total Water*	(per cubic yard)	32.0	gal/cu yd
4. Batch Size		1.00	cu yd
5. Water in FA per Batch		-1.8	gallons
6. Water in CA per Batch		-6.0	gallons
7. Water in Admixture(s) per Batch		0.5	gallons
8. Plant Water** per Batch		38.2	gallons
9. Wash Water in Truck per Batch		0.0	gallons
10. Total Water in Batch	(at Plant Site)	30.9	gallons
11. Maximum Water Allowed per Batch		32.0	gallons
12. Maximum Additional Water Allowed per Batch		1.1	gallons
13. Water Added to Batch at Jobsite		1.2	gallons
14. Water in Admixture(s) Added to Batch at Jobsite			gallons
15. Total Water in Batch	(at Jobsite)	32.1	gallons

21

Select Water Content Calculation Method

◉ Standard Method ○ w/c Ratio Method

FA Water Requirement	5.5	gal/cwt
CA Water Requirement	0.2	gal/cwt
Water Reduction	10.0	%
Maximum W/C Ratio	0.44	

Aggregate Moisture

Matl Code	SSD Weight lbs / cu yd	Moisture %	Water gal / cu yd
022ca11	2396	-2.07	-5.95
027fa01	749	-1.96	-1.76

22

Water in Admixtures

Total Cement+FDM 6.05 cwt/cu yd

Type	Product	Dosage Rate oz / cwt of cement+FDM	Water oz H2O / oz of admixture
AEA		6.0	0.7
A		8.0	0.7
			0.0
			0.0
Total Admixture Water:			59.29 oz per cu yd

23

1. Total Cement + Finely Divided Minerals		605	lb/cu yd
2. Maximum w/c ratio		0.44	
3. Maximum Allowable Total Water*	(per cubic yard)	32.0	gal/cu yd
4. Batch Size		1.00	cu yd
5. Water in FA per Batch		-1.8	gallons
6. Water in CA per Batch		-6.0	gallons
7. Water in Admixture(s) per Batch		0.5	gallons
8. Plant Water** per Batch		38.2	gallons
9. Wash Water in Truck per Batch		0.0	gallons
10. Total Water in Batch	(at Plant Site)	30.9	gallons
11. Maximum Water Allowed per Batch		32.0	gallons
12. Maximum Additional Water Allowed per Batch		1.1	gallons
13. Water Added to Batch at Jobsite		1.2	gallons
14. Water in Admixture(s) Added to Batch at Jobsite			gallons
15. Total Water in Batch	(at Jobsite)	32.1	gallons

24

Project Information

Date: (mm/dd/yy)	01/01/06
Producer No.:	
Producer Name:	PCC Ready-Mixed Co.
Mix Design No.:	50PCC1234
PCC Level II:	
Department Inspector at Plant	

Ticket No.:	
Contract No.:	
Contractor Name:	
Resident Engineer:	J. Smith
Level II Employer:	
Inspector Employer:	

25

Illinois Department of Transportation

Water/Cement Ratio Worksheet

Date: (mm/dd/yyyy)	1/1/2006	Ticket No.:	
Producer No.:		Contract No.:	
Producer Name:	PCC Ready-Mixed Co.	Contractor Name:	
Mix Design No.:	50PCC1234	Resident Engineer:	J. Smith
PCC Level II:		Level II Employer:	
Department Inspector at Plant:		Inspector Employer:	

1. Total Cement plus Finely Divided Minerals*, lb/yd³ (kg/m³)........ 605.0 lb/yd³ (kg/m³)
   * Fly Ash, Ground Granulated Blast-Furnace Slag, Microsilica, High Reactivity Metakaolin
2. Maximum water/cement ratio........ 0.44
3. Maximum Allowable Water, gal/yd³ (L/m³)........ 32.0 gal/yd³ (L/m³)
   English: (Line 1 × Line 2) ÷ 8.33
   Metric: Line 1 × Line 2
4. Batch Size, yd³ (m³)........ 1.00 yd³ (m³)
5. Water in Fine Aggregate per Batch, gal (L)........ -1.8 gal (L)
   English: [(%FA Moisture ÷ 100) × FA lb/yd³] × Line 4) ÷ 8.33

26

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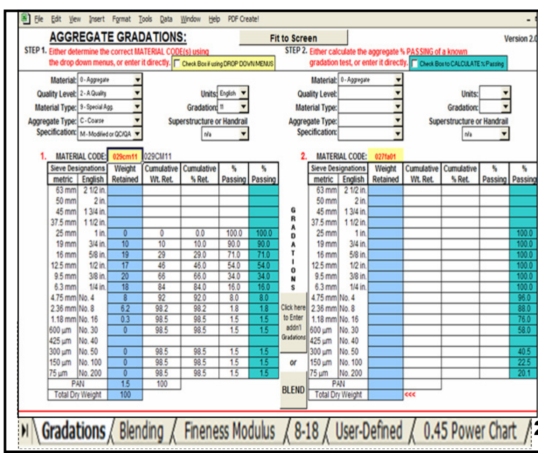
11. Maximum Water Allowed per Batch, gal (L)........
    Line 3 × Line 4
12. Maximum Additional Water Allowed per Batch, gal (L)........
    Line 11 - Line 10
13. Water Added to Batch at Job Site, gal (L)........
14. Water in Admixture(s) Added to Batch at Job Site, gal (L)......
    Refer to Line 7 for calculation.
15. Total Water in Batch at Job Site, gal (L)........
    Line 10 + Line 13 + Line 14

27

Blending Aggregates Worksheet

28



29

AGGREGATE GRADATIONS:

STEP 1. Either determine the correct MATERIAL CODE(s) using the drop down menus, or enter it directly.

☐ Check Box if using DROP DOWN MEN

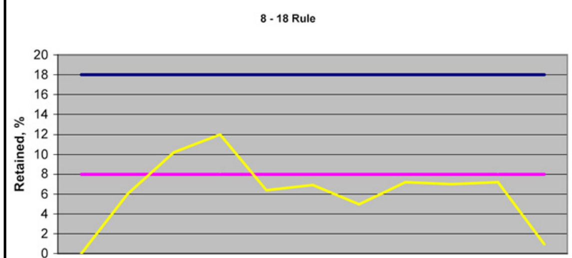
Material:	0 - Aggregate
Quality Level:	2 - A Quality
Material Type:	9 - Special Agg.
Aggregate Type:	C - Coarse
Specification:	M - Modified or QC/QA
Units:	English
Gradation:	11
Superstructure or Handrail	n/a

1. MATERIAL CODE: 029cm11 029CM11

Sieve Designations metric	English	Weight Retained	Cumulative Wt. Ret.	Cumulative % Ret.	% Passing	Pa
63 mm	2 1/2 in.					
50 mm	2 in.					
45 mm	1 3/4 in.					
37.5 mm	1 1/2 in.					
25 mm	1 in.	0	0	0.0	100.0	
19 mm	3/4 in.	10	10	10.0	90.0	

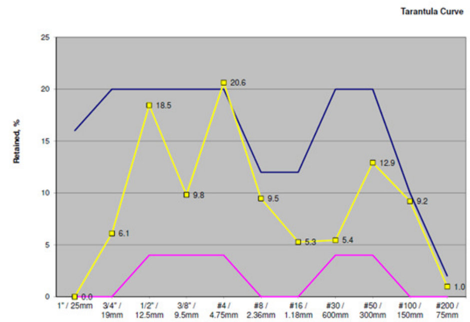
30

8-18 Rule



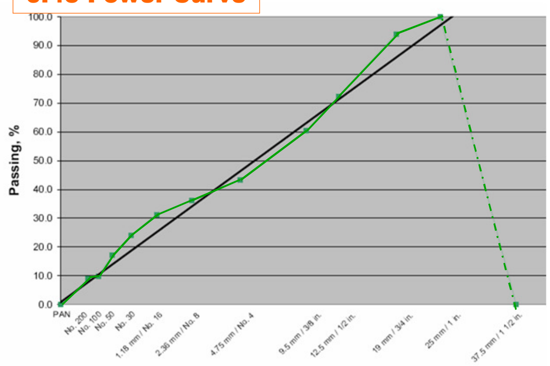
31

Tarantula Curve



32

0.45 Power Curve



33

Other Design Software & Information – (see Workbook 2.1)

- COST - FHWA and NIST
- COMPASS - The Transtec Group, Inc. through funding FHWA.
- ConcreteWorks - Concrete Durability Center at the Univ. of Texas

34

FINISH

35

Table of Contents

Homework and Forms

Example Problem Solution - PCC Level III

Given or Calculate:

Mix Plant Type:	Central						
Mix Class:	PV (Slip)					**ASR INFO**	
Coarse Agg:	022CM11	G_{SSD}:	2.68	CA Type:	Crushed	Exp. Value:	0.05
Fine Agg:	027FA01	G_{SSD}:	2.66	FA Type:	B	Exp. Value:	0.20
Cement	Ty 1	SG:	3.15	Use 10% water adjustment		Alkali:	>0.60
FDM1	Fly C	SG:	2.61			Alkali:	
FDM2		SG:				Alkali:	
CA Voids:	0.39					Aggr. Group:	II
Mortar Factor:	0.83						

Specification look-up:

Cement Factor	5.65	cwt/YD^3
Allowed CF Reduction (W-R)	0.30	cwt/YD^3
FDM Replacement %	25	%
FDM Replacement Ratio	1.0 (1:1)	
W/C Ratio	0.42	Max

25% FDM replacement required for ASR

Mitigation Option	2	
Target Air Content	6.5	%
Target Slump	0.5-2.5	in.
Min. Comp. Strength	3,500 @ 14	PSI @ days

Calculations:

1.0	**Cement**			
1.1	Starting CF	5.65	cwt/YD^3	
1.2	- Reduction for W-R	0.30	cwt/YD^3	
1.3	= Revised CF	5.35	cwt/YD^3	
1.4	- Replacement w/ FDM1	1.34	cwt/YD^3	(25 % x CF)
1.4	- Replacement w/ FDM2		cwt/YD^3	(% x CF)
1.5	= Final Cement cwt	4.01	cwt/YD^3	
1.5	Wt. Cement	405	LB (5#)	(100 x cwt)
1.7	Absolute Volume Cement	0.076	YD^3	(Wt ÷ (sg x 1,684)
2.0	**FDMs**			
2.1	Wt. FDM1	135	LB (5#)	(25 % x Wt Cement 535 x Repl. Ratio)
2.2	Abs. Vol. FDM1	0.031	YD^3	Wt.÷ (sg x 1,684)
2.3	Wt. FDM2		LB (5#)	(% x Wt Cement x Repl. Ratio)
2.4	Abs. Vol. FDM2		YD^3	Wt. ÷ (sg x 1,684)
3.0	**Water**			
3.1	Basic Water	5.5	Gal/cwt	(FA Water 5.3 + CA Water 0.2)
3.2	- Water adjustment	0.55	10 %	
3.3	= Basic Water $_{REV}$	5.0		
3.4	Final Water	225	LB	(CWT$_{TOTAL}$ 5.4 x W$_{REV}$ 5.0 x 8.33)
				ck/ H_2O/Cement Ratio (H_2O ÷ Σ $_{Cement+FDM}$) 0.42
3.5	Abs. Vol. Water	0.134	YD^3	
4.0	**Air**			
4.1	Percent 6.5 Abs. Vol.	0.065	YD^3	
5.0	**Mortar** Mortar Factor	0.83	M_O	
5.1	CA Voids 0.39 F_{CA}	0.61		
5.2	% Mortar (M_O ÷ (M_O + F_{CA})	57.6	%	
6.0	**% Coarse Aggregate**	42.4	%	
6.1	CA Abs. Vol.	0.424	YD^3	
6.2	CA Weight.	1,914	LB	
7.0	**FA Abs. Vol.**	0.270	YD^3	
7.1	FA Weight	1,209	LB	

8. MIX DESIGN SUMMARY

	Absolute Vol.	WEIGHT
Cement	0.076	405
FDM1	0.031	135
FDM2		
Water	0.134	225
Air	0.065	0
Coarse Ag	0.424	1,914
Fine Ag	0.270	1,209
	1.000	3,888

BS Homework Problem - PCC Level III

Given or Calculate:

Mix Plant Type:	Central						
Mix Class:	BS					**ASR INFO**	
Coarse Agg:	022CA11	G_{SSD}:	2.69	CA Type:	Crushed	Exp. Group:	0.05
Fine Agg:	027FA02	G_{SSD}:	2.65	FA Type:	B	Exp. Group:	<0.16
Cement	Ty 1	SG:	3.15	Use 8% water adjustment		Alkali:	>0.60
FDM1	Fly C	SG:	2.66			Alkali:	
FDM2		SG:				Alkali:	
CA Voids:	0.40					Aggr. Group:	I
Mortar Factor:	0.86						

Specification look-up:

Cement Factor		cwt/YD^3
Allowed CF Reduction (W-R)		cwt/YD^3
FDM Replacement %	30	%
FDM Replacement Ratio	1.0 (1:1)	
W/C Ratio		Max

25% FDM replacement required for ASR

Mitigation Option n/a

Target Air Content ____ %

Target Slump ____ in.

Min. Comp. Strength ____ PSI @ days

Calculations:

1.0	**Cement**			
1.1	Starting CF		cwt/YD^3	
1.2	- Reduction for W-R		cwt/YD^3	
1.3	= Revised CF		cwt/YD^3	
1.4	- Replacement w/ FDM1		cwt/YD^3	(30 % x CF)
1.4	- Replacement w/ FDM2		cwt/YD^3	(____ % x CF)
1.5	= Final Cement cwt		cwt/YD^3	
1.5	Wt. Cement		LB (5#)	(100 x cwt)
1.7	Absolute Volume Cement		YD^3	(Wt ÷ (sg x 1,684)
2.0	**FDMs**			
2.1	Wt. FDM1		LB (5#)	(30 % x Wt Cement ____ x Repl. Ratio)
2.2	Abs. Vol. FDM1		YD^3	Wt.÷ (sg x 1,684)
2.3	Wt. FDM2		LB (5#)	(____ % x Wt Cement ____ x Repl. Ratio)
2.4	Abs. Vol. FDM2		YD^3	Wt. ÷ (sg x 1,684)
3.0	**Water**			
3.1	Basic Water		Gal/cwt	(FA Water ____ + CA Water ____)
3.2	- Water adjustment		8 %	
3.3	= Basic Water $_{REV}$			
3.4	Final Water		LB	(CWT_{TOTAL} ____ x W_{REV} ____ x 8.33)
				ck/ H_2O/Cement Ratio (H_2O ÷ Σ $_{Cement+FDM}$) ____
3.5	Abs. Vol. Water		YD^3	
4.0	**Air**			
4.1	Percent ____ Abs. Vol.		YD^3	
5.0	**Mortar** Mortar Factor	0.86	M_O	
5.1	CA Voids 0.40 F_{CA}			
5.2	% Mortar (M_O ÷ (M_O + F_{CA})		%	
6.0	**% Coarse Aggregate**		%	
6.1	CA Abs. Vol.		YD^3	
6.2	CA Weight.		LB	
7.0	**FA Abs. Vol.**		YD^3	
7.1	FA Weight		LB	

8. MIX DESIGN SUMMARY

	Absolute Vol.	WEIGHT
Cement		
FDM1		
FDM2		
Water		
Air		
Coarse Ag		
Fine Ag		
	1.000	

SI Ternary Mix Problem - PCC Level III

Given or Calculate:

Mix Plant Type:	Truck-Mix						
Mix Class:	SI					**ASR INFO**	
Coarse Agg:	020CA11	G_{SSD}:	2.68	CA Type:	Gravel	Exp. Group:	≤0.16
Fine Agg:	027FA02	G_{SSD}:	2.64	FA Type:	B	Exp. Group:	≤0.16
Cement	Ty 1	SG:	3.15	Use 8% water adjustment		Alkali:	≤0.60
FDM1	Fly C	SG:	2.70			Alkali:	
FDM2	GGBFS	SG:	2.95			Alkali:	
CA Voids:	0.39					Aggr. Group:	I
Mortar Factor:	0.90						

Specification look-up:

Cement Factor		cwt/YD^3
Allowed CF Reduction (W-R)		cwt/YD^3
FDM Replacement %	30	%
FDM Replacement Ratio	1.0 (1:1)	
W/C Ratio		Max

25% FDM replacement required for ASR

Mitigation Option	2	
Target Air Content		%
Target Slump		in.
Min. Comp. Strength		PSI @ days

Calculations:

1.0	**Cement**			
1.1	Starting CF		cwt/YD^3	
1.2	- Reduction for W-R		cwt/YD^3	
1.3	= Revised CF		cwt/YD^3	
1.4	- Replacement w/ FDM1		cwt/YD^3	(20 % x CF)
1.4	- Replacement w/ FDM2		cwt/YD^3	(10 % x CF)
1.5	= Final Cement cwt		cwt/YD^3	
1.5	Wt. Cement		LB (5#)	(100 x cwt)
1.7	Absolute Volume Cement		YD^3	(Wt ÷ (sg x 1,684)
2.0	**FDMs**			
2.1	Wt. FDM1		LB (5#)	(20 % x Wt Cement ____ x Repl. Ratio)
2.2	Abs. Vol. FDM1		YD^3	Wt.÷ (sg x 1,684)
2.3	Wt. FDM2		LB (5#)	(10 % x Wt Cement ____ x Repl. Ratio)
2.4	Abs. Vol. FDM2		YD^3	Wt. ÷ (sg x 1,684)
3.0	**Water**			
3.1	Basic Water		Gal/cwt	(FA Water ____ + CA Water ____)
3.2	- Water adjustment		8 %	
3.3	= Basic Water $_{REV}$			
3.4	Final Water		LB	(CWT_{TOTAL} ____ x W_{REV} ____ x 8.33)
				ck/ H_2O/Cement Ratio (H_2O ÷ Σ $_{Cement+FDM}$) ____
3.5	Abs. Vol. Water		YD^3	
4.0	**Air**			
4.1	Percent ____ Abs. Vol.		YD^3	
5.0	**Mortar** Mortar Factor	0.90	M_O	
5.1	CA Voids 0.39 F_{CA}			
5.2	% Mortar (M_O ÷ (M_O + F_{CA})		%	
6.0	**% Coarse Aggregate**		%	
6.1	CA Abs. Vol.		YD^3	
6.2	CA Weight.		LB	
7.0	**FA Abs. Vol.**		YD^3	
7.1	FA Weight		LB	

8. MIX DESIGN SUMMARY

	Absolute Vol.	WEIGHT
Cement		
FDM1		
FDM2		
Water		
Air		
Coarse Ag		
Fine Ag		
	1.000	

Homework Problem 1 – Blending
PCC Level III

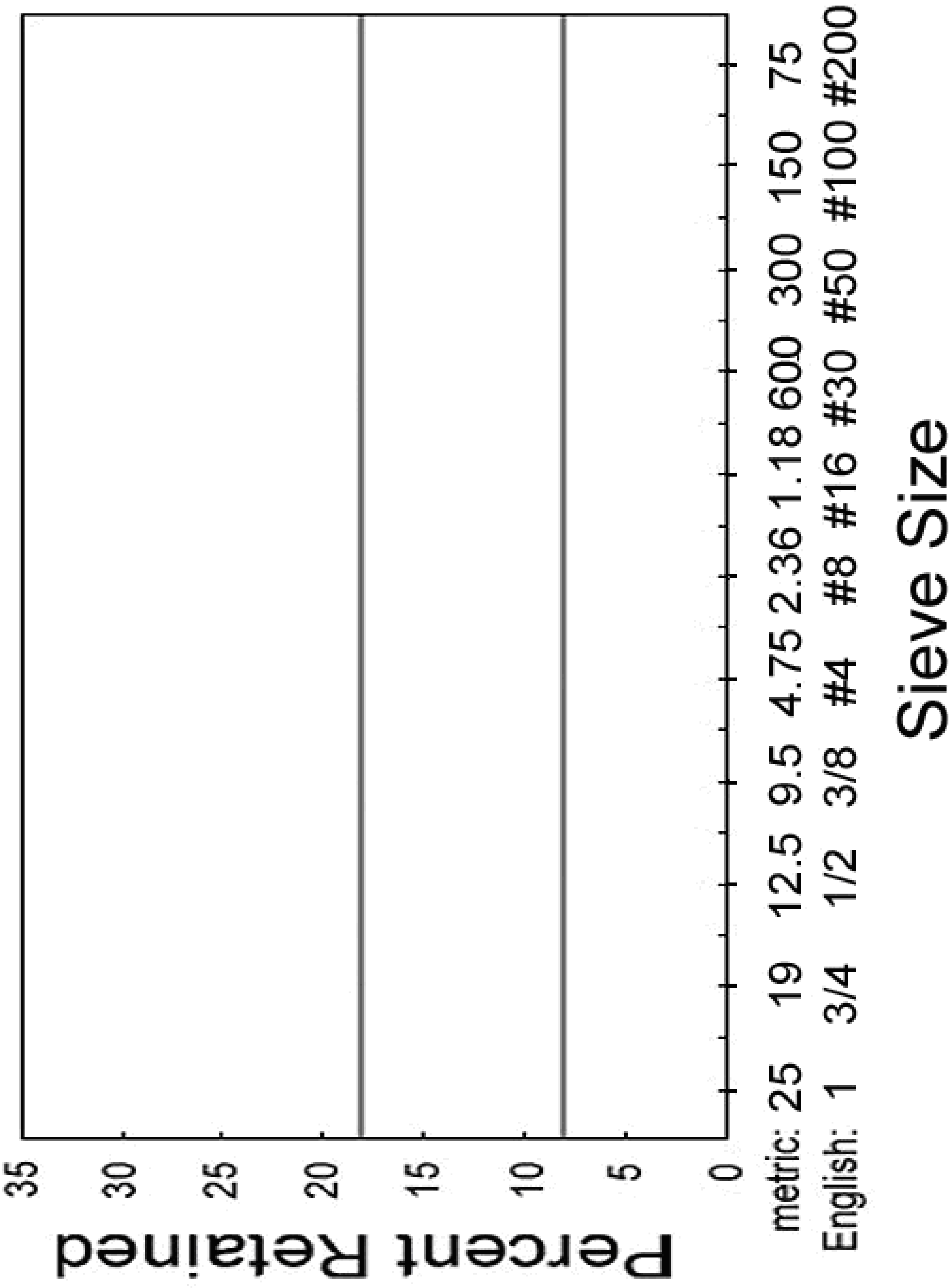
Instructions:
- Read Appendix E, "Aggregate Blending"
- Use the blank 8-18 and 0.45 Power Charts in Appendix E
- Plot the above product on the charts

The homework will be discussed on the morning of Day 2.

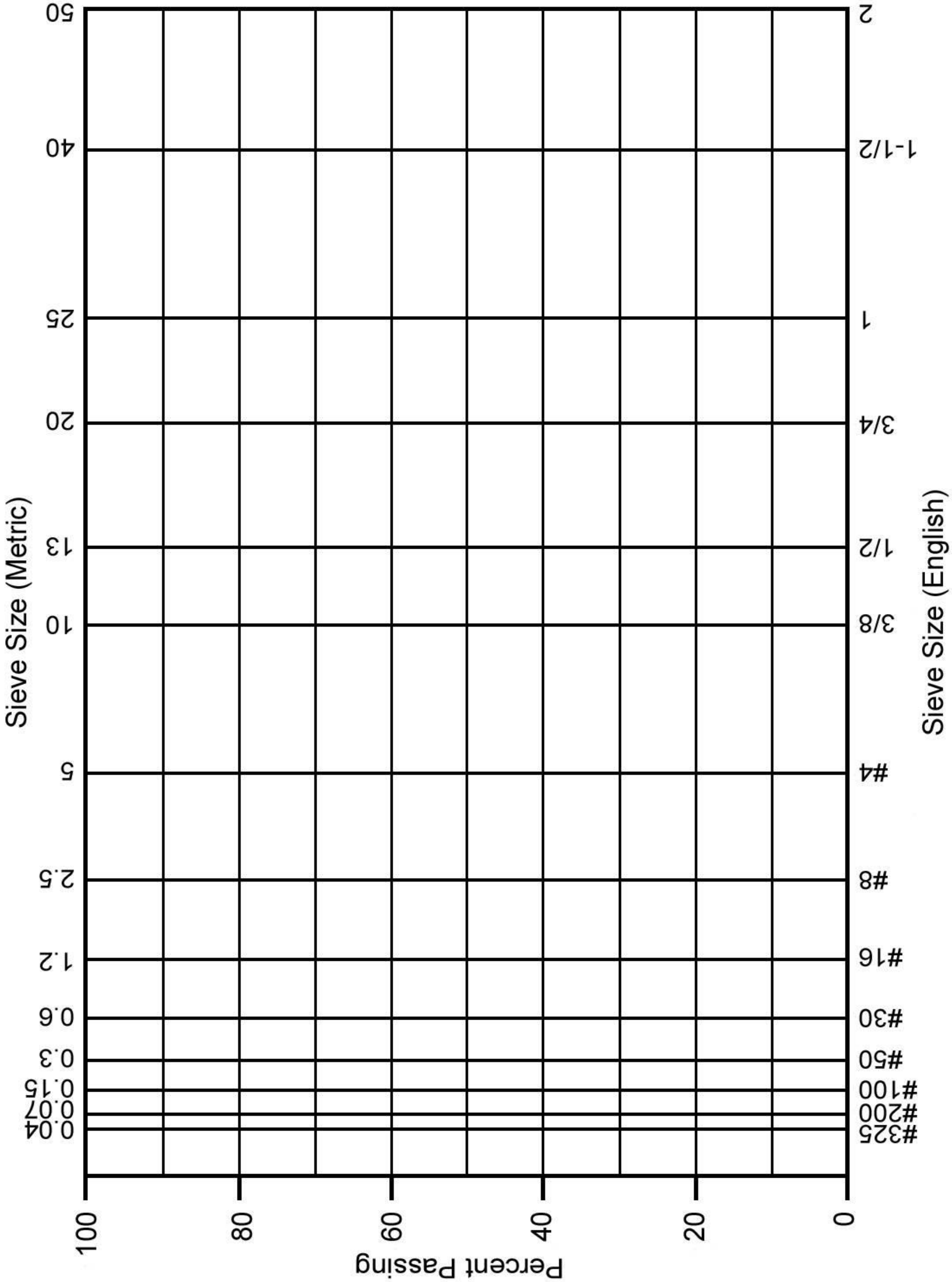
There may be questions about this exercise on the exam.

Blending Exercise "8-18" and "0.45"		
Sieve	**Pass**	**Retain**
1 inch	100%	0
3/4 inch	94%	6%
1/2 inch	78%	16%
3/8 inch	60%	18%
No. 4	44%	16%
No. 8	35%	9%
No. 16	27%	8%
No. 30	20%	7%
No. 50	6%	14%
No. 100	2%	4%
No. 200	1.0%	1.0%

Rule 8-18 Blank Form



0.45 Power Curve Blank



Mix Design Worksheet - PCC Level III

Given or Calculate:

						ASR INFO	
Mix Plant Type:	______						
Mix Class:	______						
Coarse Agg:	______	G_{SSD}:	______	Water Type:	______	Exp. Group:	______
Fine Agg:	______	G_{SSD}:	______	Water Type:	______	Exp. Group:	______
Cement	______	SG:	______			Alkali:	______
FDM1	______	SG:	______			Alkali:	______
FDM2	______	SG:	______			Alkali:	______
CA Voids:	______					Aggr. Group:	______
Mortar Factor:							

Specification look-up:

Cement Factor	______	cwt/YD^3			
Allowed CF Reduction (W-R)	______	cwt/YD^3			
FDM Replacement %	______	%	Mitigation Option	______	
FDM Replacement Ratio	**1.0 (1:1)**		Target Air Content	______	%
W/C Ratio	______	Max	Target Slump	______	in.
			Min. Comp. Strength		PSI @ days

Calculations:

1.0	**Cement**			
1.1	Starting CF	______	cwt/YD^3	
1.2	- Reduction for W-R	______	cwt/YD^3	
1.3	= Revised CF	______	cwt/YD^3	
1.4	- Replacement w/ FDM1	______	cwt/YD^3	**(______ % x CF)**
1.4	- Replacement w/ FDM1	______	cwt/YD^3	**(______ % x CF)**
1.5	= Final Cement cwt	______	cwt/YD^3	
1.5	Wt. Cement	______	LB (5#)	**(100 x cwt)**
1.7	Absolute Volume Cement	______	YD^3	**(Wt ÷ (sg x 1,684)**
2.0	**FMDs**			
2.1	Wt. FDM1	______	LB (5#)	**(______ % x Wt Cement ______ x Repl. Ratio)**
2.2	Abs. Vol. FDM1	______	YD^3	**Wt.÷ (sg x 1,684)**
2.3	Wt. FDM2	______	LB (5#)	**(______ % x Wt Cement ______ x Repl. Ratio)**
2.4	Abs. Vol. FDM2	______	YD^3	**Wt. ÷ (sg x 1,684)**
3.0	**Water**			
3.1	Basic Water	______	Gal/cwt	**(FA Water ______ + CA Water ______)**
3.2	- W-R Reduction	______	______ %	
3.3	= Basic Water $_{REV}$	______	______	
3.4	Final Water	______	LB	**(CWT_{TOTAL} ______ x W_{REV} ______ x 8.33)**
				ck/ H_2O/Cement Ratio **(H_2O ÷ Σ $_{Cement+FDM}$)** ______
3.5	Abs. Vol. Water	______	YD^3	
4.0	**Air**			
4.1	Percent ______ Abs. Vol.	______	YD^3	
5.0	**Mortar** Mortar Factor	______	M_O	
5.1	CA Voids ______ F_{CA}	______		
5.2	% Mortar **(M_O ÷ (M_O + F_{CA})**	______	%	
6.0	**% Coarse Aggregate**		%	
6.1	CA Abs. Vol.	______	YD^3	
6.2	CA Weight.	______	LB	
7.0	**FA Abs. Vol.**	______	YD^3	
7.1	FA Weight	______	LB	

8. MIX DESIGN SUMMARY

	Absolute Vol.	**WEIGHT**
Cement		
FDM1		
FDM2		
Water		
Air		
Coarse Ag		
Fine Ag		
	1.000	

Mix Design Worksheet - PCC Level III

Given or Calculate:

Mix Plant Type:	______						
Mix Class:	______					**ASR INFO**	
Coarse Agg:	______	G_{SSD}:	______	Water Type:	______	Exp. Group:	______
Fine Agg:	______	G_{SSD}:	______	Water Type:	______	Exp. Group:	______
Cement	______	SG:	______			Alkali:	______
FDM1	______	SG:	______			Alkali:	______
FDM2	______	SG:	______			Alkali:	______
CA Voids:	______					Aggr. Group:	______
Mortar Factor:							

Specification look-up:

Cement Factor	______	cwt/YD³			
Allowed CF Reduction (W-R)	______	cwt/YD³			
FDM Replacement %	______	%	Mitigation Option	______	
FDM Replacement Ratio	**1.0 (1:1)**		Target Air Content	______	%
W/C Ratio	______	Max	Target Slump	______	in.
			Min. Comp. Strength		PSI @ days

Calculations:

1.0	**Cement**			
1.1	Starting CF	______	cwt/YD³	
1.2	- Reduction for W-R	______	cwt/YD³	
1.3	= Revised CF	______	cwt/YD³	
1.4	- Replacement w/ FDM1	______	cwt/YD³	**(______ % x CF)**
1.4	- Replacement w/ FDM1	______	cwt/YD³	**(______ % x CF)**
1.5	= Final Cement cwt	______	cwt/YD³	
1.5	Wt. Cement	______	LB (5#)	**(100 x cwt)**
1.7	Absolute Volume Cement	______	YD³	**(Wt ÷ (sg x 1,684)**
2.0	**FMDs**			
2.1	Wt. FDM1	______	LB (5#)	**(______ % x Wt Cement ______ x Repl. Ratio)**
2.2	Abs. Vol. FDM1	______	YD³	**Wt.÷ (sg x 1,684)**
2.3	Wt. FDM2	______	LB (5#)	**(______ % x Wt Cement ______ x Repl. Ratio)**
2.4	Abs. Vol. FDM2	______	YD³	**Wt. ÷ (sg x 1,684)**
3.0	**Water**			
3.1	Basic Water	______	Gal/cwt	**(FA Water ______ + CA Water ______)**
3.2	- W-R Reduction	______	______ %	
3.3	= Basic Water $_{REV}$	______	______	
3.4	Final Water	______	LB	**(CWT_{TOTAL} ______ x W_{REV} ______ x 8.33)**
				ck/ H_2O/Cement Ratio **(H_2O ÷ Σ $_{Cement+FDM}$)** ______
3.5	Abs. Vol. Water	______	YD³	
4.0	**Air**			
4.1	Percent ______ Abs. Vol.	______	YD³	
5.0	**Mortar** Mortar Factor	______	M_O	
5.1	CA Voids ______ F_{CA}	______		
5.2	% Mortar **(M_O ÷ (M_O + F_{CA})**	______	%	
6.0	**% Coarse Aggregate**		%	
6.1	CA Abs. Vol.	______	YD³	
6.2	CA Weight.	______	LB	
7.0	**FA Abs. Vol.**	______	YD³	
7.1	FA Weight	______	LB	

8. MIX DESIGN SUMMARY

	Absolute Vol.	**WEIGHT**
Cement	______	______
FDM1	______	______
FDM2	______	______
Water	______	______
Air	______	______
Coarse Ag	______	______
Fine Ag	______	______
	1.000	