

Superstructure Concrete
Certified Technician
Program Manual

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Mix Design & Proportioning QC/QA Superstructure Concrete

CMD Linear Equation

Threshold Linear Equation

Trial Batch Demonstration

Superstructure Concrete Analysis for Quality Assurance

Random Sampling Locations for QC/QA Superstructure Concrete

**CERTIFIED CONCRETE TECHNICIAN
PROGRAM INSTRUCTORS**

Industry Representatives

Gary Brown	R. L. McCoy, Inc.	(317) 544-0000
Nick Fletcher	George's Concrete Pumping	(317) 787-6124
Tom Grisinger	Lehigh Portland Cement Co.	(317) 469-4660
Mike Kaelin	Gohmann Asphalt & Const.	(812) 246-7350
Toby Knott	Leigh Portland Cement Co.	(317) 469-4660
Don MacDonell	Wightman-Petrie Environmental, Inc.	(574) 232-4388
Mark MacKenzie	Erie - Haven, Inc.	(219) 478-1674
Marvin Obermeyer	Buzzi Unicem, USA	(317) 694-1552
Norm Thoeming	Irving Materials, Inc.	(317) 326-3101

University Representative

Dr. Jan Olek	Purdue University	(765) 494-5015
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INDOT Representatives (Materials & Tests Division -- (317) 610-7251)

Joe Braun	Cement/Steel Laboratory Supervisor	Ext. 250
Matt Doherty	Laboratory Program Director	Ext. 248
Ricky Harris	Concrete Laboratory Supervisor	Ext. 244
Gary Mithoefer	Field Support Coordinator	Ext. 236
Bob Rees	Field Support Geologist	Ext. 233
Steve Summers	Aggregate Laboratory Supervisor	Ext. 247
Todd Tracy	Senior Chemist	Ext. 240
Ron Walker	Quality Assurance Engineer	Ext. 202
Tony Zander	Asst. Quality Assurance Engineer	Ext. 234

CERTIFIED CONCRETE TECHNICIAN TRAINING COURSE AGENDA

<u>Title-Time</u>	<u>Subjects</u>	<u>Instructors</u>	<u>Reference</u>
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Monday Morning
Moderator: Ron Walker

Introduction

10:00 to 10:15	Opening Comments Agenda/Manual Update Technician Requirements QC/QA Concepts	Ron Walker	
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Math for Concrete

10:15 to 10:45	Round-Off Rules Basic Math	Ron Walker	Chp 1
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10:45 to 11:00	** BREAK **		
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Materials for Concrete

11:00 to 11:30	Cement	Tom Grisinger (Toby Knott)	Chp 2
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11:30 to 12:00	Mineral Admixtures	Tom Grisinger (Toby Knott)	Chp 2
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12:00 to 1:00	** LUNCH **		
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Monday Afternoon
Moderator: Ron Walker

Materials for Concrete (continued)

1:00 to 1:30	Chemical Admixtures	Marvin Obermeyer (Mark MacKenzie)	Chp 2
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1:30 to 2:15	Aggregates Steel Evaporative Retardants	Ron Walker Tony Zander	Chp 2
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2:15 to 2:30	**BREAK**		
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Mix Design of PCC

2:30 to 3:15	Specification Requirements CMD Targets Material Availability INDOT Approval	Tony Zander	Chp 3
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Proportioning

3:15 to 4:00	Weight/Volume Relationship	Tony Zander	Chp 3
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Tuesday Morning
Moderator: Ron Walker

Homework Review

8:00 to 8:15	Answers & Discussion	Tony Zander
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Linear Equation

8:15 to 9:30	Unit Wt. vs. Air Content for CMD	Tony Zander	Chp 3
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9:30 to 9:45	**BREAK**
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Linear Equation

9:45 to 11:00	Unit Wt. vs. Air Content at Max. Allowable $W/(C+P+SF)$ INDOT Approval	Tony Zander	Chp 3
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Field Testing Equipment

11:00 to 12:00	Unit Weight Air Content Compressive Strength Equipment Calibration	Gary Mithoefer	Appendix C
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12:00 to 1:00	**LUNCH**
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Tuesday Afternoon
Moderator: Ron Walker

Testing Procedures

1:00
to
2:30

Requirements
AASHTO Exceptions
Problem Areas

Gary Mithoefer

Appendix B

2:30 to 2:45

****BREAK****

Trial Batch Demonstration

2:45
to
3:30

Purpose
Preparation
Allowable Adjustments
Case Studies

Tony Zander

Chp 4

Wednesday Morning
Moderator: Ron Walker

Homework Review

8:00
to
8:30

Tony Zander

Trial Batch Demonstration (continued)

8:30
to
9:45

Tony Zander

Chp 4

9:45 to 10:00

****BREAK****

Quality Control -- Field Operations

10:00
to
11:00

Plant Production
Concrete Delivery

Mark MacKenzie

Chp 5

Quality Control -- Field Operations

11:00
to
12:00

Pumping Procedures

Gary Brown
(Nick Fletcher)

Chp 5

12:00 to 1:00

****LUNCH****

Wednesday Afternoon
Moderator: Ron Walker

Quality Control -- Field Operations

1:00 to 1:30	Finishing and Curing Form and Falsework Removal Load Application	Tony Zander	Chp 5
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Sublot and Lot Sizes

1:30 to 1:45	Terms and Definitions	Ron Walker	Chp 6
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Quality Control -- Minimum Specification Requirements

1:45 to 2:15	General Scope Specification Requirements Quality Control Plans	Ron Walker	Chp 7
2:15 to 2:30	**BREAK**		

Quality Control (continued)

2:30 to 3:00	Producer Perspective	Norm Thoeming	
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Quality Control (continued)

3:00 to 3:30	Contractor Perspective	Mike Kaelin	
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Quality Control (continued)

3:30 to 4:00	Consultant Perspective	Don MacDonell (Jim Sherer)	
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Computer Demonstration

4:00 to 4:15		Tony Zander Gary Mithoefer	
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Thursday
Moderator: Ron Walker

Lab Demonstration at INDOT Materials & Tests Division

8:00
to
11:30

12:00 to 1:00 ****LUNCH****

Homework Review

1:00
to
1:15

Tony Zander

Quality Assurance

1:15
to
2:30

Random Sampling
Specification Requirements
Pay Factors
Appeal Procedures

Ron Walker

Chp 6

2:30 to 2:45

****BREAK****

Failed Material Investigation

2:45
to
3:30

Specifications
INDOT Responsibility
Contractor Options
Case Studies

Tony Zander

Chp 6

Friday
Moderator: Ron Walker

8:00
to
12:00

Written Exam

**CERTIFIED CONCRETE
TECHNICIAN PROGRAM**

PROCEDURES and POLICIES

MANUAL

JANUARY, 2000

INDOT
CERTIFIED CONCRETE TECHNICIAN PROGRAM

Objectives

The Indiana Department of Transportation (INDOT) has established a Quality Control/Quality Assurance (QC/QA) program for Superstructure Concrete for the purpose of properly assigning responsibilities on the projects and overall improving the quality of bridges. The Superstructure QC/QA specifications require that a Certified Concrete Technician supervise all sampling and testing for process control.

The principal objective of the Certified Concrete Technician Program is to provide the necessary training to project personnel so that they may administer the Quality Control requirements of QC/QA specifications. Knowledge of mix design, plants, materials, and transportation and placement of the concrete are provided to enhance the technician's ability to interpret test results obtained during production.

Administration

The program is administered by INDOT and Purdue University. Specific duties of each agency include:

Purdue University

1. Registration of Students
2. Manual Printing
3. Distribution of Funds
4. Monitoring the Examination
5. Grading the Examination
6. Certificates
7. Continuing Education Units
8. Miscellaneous Administrative Tasks

INDOT

1. Course Announcement
2. Writing and Maintenance of the Training Manual
3. Notification to Students of Examination Results
4. Mailing Certificates
5. Maintenance of Certified Concrete Technician List
6. Retesting
7. Recertification

Program Committee

The Program Committee acts as the steering committee which establishes the needs for the certification program and provides technical assistance for course materials and examinations. The committee is composed of the following members:

- 4 Representatives of INDOT
- 1 Representative of Purdue University
- 1 Representative of Indiana Constructors Inc.
- 1 Representative of Consultanting Engineers of Indiana Inc.
- 1 Representative of Indiana Ready Mixed Concrete Association

Certification Committee

The Certification Committee is responsible for revocation or suspension of certifications for technicians. Their tasks will include reviewing the violations of standard policies, rendering judgement of the seriousness of the violation, and hearing any subsequent appeal. The committee is composed of the following members:

- Chief, INDOT Materials and Tests
- 1 Representative of Purdue University
- 1 Representative of Indiana Constructors Inc.

Prerequisite

Participants in the course will be required to be currently qualified as ACI certified concrete field testing technicians, grade I. Proof of this qualification shall be submitted with the course registration form.

Certification Requirements

A technician is required to pass a written examination to become certified. The examination will be given at the completion of the training course. The technician may take the examination without attending the training course; however, failure to pass both parts of the examination will require the technician to attend the training course and pass the examination to become certified. Technicians only taking the examination are required to be currently qualified as ACI certified concrete field testing technicians, grade I.

Examinations

The examination time is limited to a maximum duration of four hours and will be "open book and notes." There will be two parts to the examination. Part I will consist of true/false, multiple choice and fill in the blank questions, and Part II will consist of word problems. A minimum score of 70 percent is required on each part to pass the examination.

A technician that has attended the training course and failed the examination will be allowed one retake. Only the part(s) failed will be required to be retaken. A duration of 1 ½ hours for Part I and 2 ½ hours for Part II will be allowed. The examination will be "open book and notes" and consist of a format similar to the original examination. The retake will be given at the INDOT Materials and Tests Division within 30 days of notification of the technician's results of the original examination. A minimum score of 70 percent on each part of the retake is required to pass the examination. Technicians failing either part of the retake will be required to attend the training course and pass the examination to become certified.

The examinations will be retained by Purdue University for a period of one year after such time the examinations will be destroyed. Technicians may review their examinations in the presence of an INDOT representative within one year of the examination date.

Fees

The fee for attending the training course and taking the examination will be \$450. This cost will include a training manual, all course materials, refreshments, and four lunches. The cost of taking the examination only will be \$50.

The refund policy for course fees will consist of the following:

1. An administration fee of \$100 will be charged for cancellation by the technician within 7 days of the course.
2. No attendance of the course will result in no refund of fees.
3. Unforeseen emergencies during the course or certification examination will result in no refund of fees; however the technician will be allowed to retake the course or examination, whichever is applicable, at a later date.

Cancellation Policy

If a scheduled course is cancelled because of insufficient class size, the technicians will be notified 1 week prior to the start of the course. The technicians will be reimbursed the course cost or allowed to transfer the fee for the next available course, if a course is available within the same year. The technicians will be allowed to take the examination and have one retake, if required.

Continuing Education Units

Four continuing education units will be awarded to technicians who successfully complete the training course and pass the examination. Purdue University will maintain the necessary files for each technician who requests that the continuing education units be recorded.

Recertification

The certification will be valid for three years as determined from the date of initial issuance. If the technician does not renew the certification, the certification will expire. If the technician does not renew the certification the next year, attendance at the training course and subsequent passing of the examination is required to become certified.

The certified technician shall be responsible for applying for certification renewal and for maintaining a current address on file with Purdue University.

The technician will be required to pass a recertification examination to become recertified. The examination will be "open book and notes" and the examination time will be limited to a maximum duration of 2 ½ hours. The examination will consist of word problems and a minimum score of 70 percent will be required to pass the examination. One retake of the recertification examination will be allowed. A voluntary refresher course will be offered prior to the recertification examination.

Revocation or Suspension of Certification

Certifications awarded may be revoked or suspended at any time by the Certification Committee for just cause. Proposed revocations will be sent to the technician in writing along with an explanation of the technician's right to appeal the proposed revocation. The technician will be allowed 60 days from the date of the notification to respond by letter of explanation to the Certification Committee. The proposed revocation is effective upon receipt of notification and will be affirmed, modified, or vacated following any appeal. The reasons that technicians will be subject to revocation or suspension of their certification include:

1. Submittal of false information on certification applications
2. Cheating on recertification examinations
3. Falsification of quality control test results and/or records
4. Failure to pass the recertification examination
5. Failure to pay the recertification refresher course or examination fees

The Certification Committee may decide to suspend or revoke the certification depending upon the seriousness of the violation. Violations deemed as unintentional will result in a penalty of a letter of reprimand to the technician and the technician's employer. Subsequent violations will result in a period of suspension of certification for a designated period as determined by the Certification Committee. The certification will return to good standing again after the period of suspension expires.

Intentional deviations will result in a one year suspension of the certification. Subsequent violations will result in permanent revocation of the certification. If the technician wishes to become recertified after the period of suspension, the technician will be required to take the training course and pass the examination to become certified.

1 INTRODUCTION

Certified Technician Program

Symbols

Rounding

Volumetrics

CHAPTER ONE: INTRODUCTION

Quality Control/Quality Assurance (QC/QA) is often used synonymously with the term Quality Assurance (QA). AASHTO defines Quality Assurance as "All those planned and systematic actions necessary to provide confidence that a product will perform satisfactorily in service." This definition considers QA to be an all encompassing concept which includes quality control (QC), acceptance, and independent assurance (IA). The Indiana Department of Transportation (INDOT) further defines the QC/QA Program by differentiating the duties of the Contractor and INDOT; the Contractor is responsible for all QC (process control) activities and INDOT is responsible for acceptance of the material (QA).

A better understanding of the QC/QA concept can be made if the characteristics of the specifications are considered. These include:

1. QC/QA recognizes the variation in materials and test methods.
2. QC/QA uses a statistical basis that is applied and modified with experience and sound engineering judgement.
3. QC/QA places the primary responsibility on the Contractor for production control.
4. QC/QA makes a clear delineation between process control and acceptance testing.

The advantages of this type of specification include the proper allocation of responsibility for quality between the Contractor and INDOT, more complete records, and statistically based acceptance decisions. The Contractor has a greater choice of materials, and can design the most economical mixtures to meet specifications. Finally, there is a lot-by-lot acceptance so that the Contractor knows if his operations are producing an acceptable product.

The Quality Assurance Training Program is designed for both INDOT and Contractor's personnel. Although the responsibilities of the certified technician may or may not apply to both, the information presented in this training course is valuable in understanding the production of quality Superstructure Concrete.

CERTIFIED TECHNICIAN PROGRAM

The certified technician is the cornerstone of the Quality Assurance Program. Without the certified technician determining the quality and consistency of the concrete being produced, bridge deck performance problems are certain. This fundamental shift of quality control from INDOT to the Contractor is important because it places control of the material in the hands of the Contractor.

It is the responsibility of the certified technician to test the quality and consistency of the concrete being produced. This job however does not stop at this point. The certified technician must also ensure that the concrete maintains this consistency by monitoring the materials at the plant. Finally, and most important, the certified technician must know what action to take when the materials deviate from specifications.

SYMBOLS

For the purposes of QC/QA Superstructure Concrete we are specifically interested in the following units:

Slump -- in. (inches)

Unit Weight -- lb/ft^3 (pounds per cubic feet)

Compressive Strength -- $\text{lb}/\text{in.}^2$ (pounds per square inch)

Flexural Strength -- $\text{lb}/\text{in.}^2$ (pounds per square inch)

Portland Cement Content -- lb/yd^3 (pounds per cubic yard of concrete)

Temperature -- °F (degrees Fahrenheit)

Lot/Sublot Size -- yd^3 (cubic yards)

Lot/Sublot Length -- ft (feet)

Evaporation Rate -- $\text{lb}/\text{ft}^2/\text{h}$ (pounds per square feet per hour)

Wind Velocity -- mph (miles per hour)

ROUNDING

When calculations for quantities of material or test values are required, rounding in accordance with the standard "5" up procedure is used as follows:

1. When the first digit discarded is less than 5, the 1st digit retained should not be changed.

Examples: 2.4 becomes 2
 2.43 becomes 2.4
 2.434 becomes 2.43
 2.4341 becomes 2.434

2. When the first digit discarded is 5 or greater, the last digit retained should be increased by one unit.

Examples: 2.6 becomes 3
 2.56 becomes 2.6
 2.416 becomes 2.42
 2.4157 becomes 2.416

QC/QA Superstructure concrete specifications and procedures require test values to be calculated to the nearest figure as indicated in Figure 1.1

Property	Nearest 10 Units (00)	Nearest Whole Unit (0)	First Decimal Place (0.0)	Second Decimal Place (0.00)	Third Decimal Place (0.000)
Concrete					
Rapid CI Permeability	X				
Slump				X	
Unit Weight			X		
Air Content			X		
Compressive Strength	X				
Evaporation Rate				X	
W/(C+P+SF)					X
Aggregate					
Gradation			X		
Moisture			X		
Absorption				X	
Bulk Specific Gravity (SSD)					X

FIGURE 1.1

VOLUMETRICS

Proportioning concrete by the absolute volume method requires calculating the volume of each component necessary to make a single unit (ft³) of concrete. Volumes are subsequently converted to design weights, which then become the basis for actual production of concrete from the plant. Specific gravity is the means to convert from units of volume to weight. The definition of specific gravity and equations relating specific gravity to unit weight and volume are as follows:

Specific Gravity -- the ratio of the weight in air of a unit volume of a material to the weight of the same volume of water at stated temperatures.

Weight to Volume

$$V = \frac{W}{G \times 62.27}$$

where:

V = Volume in ft³

W = Weight in lb

G = Specific Gravity

62.27 = Density of Water in lb/ft³ at 73.4°F

Example:

Weight of Cement = 658 lb

Specific Gravity of Cement = 3.150

$$V = \frac{658}{3.150 \times 62.27}$$

$$= 3.35 \text{ ft}^3$$

Volume to Weight

$$W = V \times G \times 62.27$$

Example:

Volume of Coarse Aggregate = 10.32 ft³

Bulk Specific Gravity (SSD) of Coarse Aggregate = 2.658

(Bulk Sp. Gr. (SSD) is used for Aggregates)

$$W = 10.32 \times 2.658 \times 62.27$$
$$= 1708 \text{ lb}$$

RATE OF EVAPORATION

The rate of water evaporation determination is one procedure used to decide if protective measures are required to prevent the early loss of moisture from the concrete. The equation used for the evaporation rate contains several calculations that may be difficult. Included below is the equation and further mathematical explanation of some of the values.

$$E = [T_c^{2.5} - (r \times T_a^{2.5})] [1 + 0.4V] \times 10^{-6}$$

where:

E = evaporation rate, lb/ft²/h

T_c = concrete temperature, °F

T_a = air temperature, °F

r = (relative humidity %) / 100

V = wind velocity, mph

$$T^{2.5} = T \times T \times \sqrt{T}$$

$$10^{-6} = 0.000001$$

2 MATERIALS

Aggregates

Requirements

Certified Aggregate Producer Program (CAPP)

Fine Aggregate Gradation

Fineness Modulus

Coarse Aggregate Gradation

Mixture Gradation

Particle Shape and Surface Texture

Specific Gravity

Absorption and Surface Moisture

Portland Cements

Requirements

Portland Cement Types

Admixtures

Mineral Admixtures

Chemical Admixtures

CHAPTER TWO: MATERIALS

AGGREGATES

Aggregates generally occupy approximately 75 percent of the concrete volume and strongly influence the concrete's hardened and freshly mixed properties. The properties of the aggregate have a major effect on the durability, strength, shrinkage, unit weight, and frictional properties of hardened concrete, as well as the mix proportions, slump, workability, pumpability, bleeding, finishing characteristics and air content of freshly mixed concrete. The selection of the proper aggregates and control of the use of those aggregates is essential in producing quality concrete mixtures.

Requirements

The QC/QA superstructure concrete specifications have several restrictions on the use of aggregates in concrete. They include:

1. The class of the fine and coarse aggregates shall be Class A or higher.
2. If the contract requires stay-in-place metal forms for the bridge deck or if the Contractor elects to use such forms, the bridge deck concrete shall incorporate class AP coarse aggregate.
3. Fine aggregate shall be natural sand.
4. Coarse aggregates shall be crushed limestone or dolomite, crushed or uncrushed gravel, or air cooled blast furnace slag.
5. The gradation of the fine and coarse aggregates shall be in accordance with size No. 23 and size No. 8, respectively, or a proposed alternate gradation for each.
6. If alternate gradations are proposed the tolerances for each sieve shall be as stated in the Quality Control Plan.
7. For coarse aggregates, 100 percent shall pass the 1 in. sieve.
8. The combined amount of fine and coarse aggregate passing the No. 200 sieve shall be from 0.0 to 2.0 percent for sand and gravel, and from 0.0 to 2.5 percent for sand and stone or slag.

9. The fine aggregate shall be no less than 35 percent or more than 50 percent of the total volume of the aggregate in each cubic yard, based upon saturated surface dry aggregates.

Fine aggregates and coarse aggregates are defined as follows:

Fine Aggregate -- Material that is 100 percent passing the 3/8 in. sieve and a minimum of 80 percent passing the No. 4 sieve

Coarse Aggregate -- Material that has a minimum of 20 percent retained on the No. 4 sieve.

Certified Aggregate Producer Program (CAPP)

The Certified Aggregate Producer Program is a program in which a qualified mineral aggregate Producer or Redistribution Terminal desiring to supply material to INDOT does so by assuming all of the Plant site controls and a portion of the testing responsibility that had been previously assumed by INDOT. The program focuses on production testing by the Producer and a site specific Quality Control Plan (QCP) that indicates how the Producer proposes to control the materials at the plant. Benefits of the program to the Producer include improved customer service, more plant control, and better documentation of test results and events at the plant. For INDOT the obvious benefit is that the Producer is providing material that has a consistent gradation.

The CAPP requires the source to conduct numerous tests on the aggregate as it is being produced and when it is shipped out. As a minimum, the gradation, decantation, crushed particle content, and deleterious tests are required, if applicable. Gradation, crushed particle content, and deleterious content are determined during production of the aggregate, and the gradation and decantation tests are conducted when material is loaded out.

Gradation tests are required to be plotted on a control chart by the Certified Aggregate Producer. A control chart is merely a graphic representation of the test data shown in conjunction with prescribed limits. Figure 2.1 illustrates an example of a control chart for the "critical sieve" (1/2 in.) of a No. 8 aggregate. The CAPP defines what the critical sieve is for each Standard Specification coarse aggregate material and this is the only sieve required to be plotted for coarse aggregates; however, all sieves having a gradation limit designated in the specification are required to be tested. Coarse aggregates not meeting the established limits of the Standard Specifications are classified as QA products and the Producer is required to designate the critical sieve and all the gradation limits in the QCP. Fine aggregate gradations are required to be plotted on control charts for all applicable sieves designated either in the Standard Specifications or in the QCP if the material is a QA sand.

SOURCE #2001 - #8 STANDARD SPEC. 1/2 in. CRITICAL SIEVE

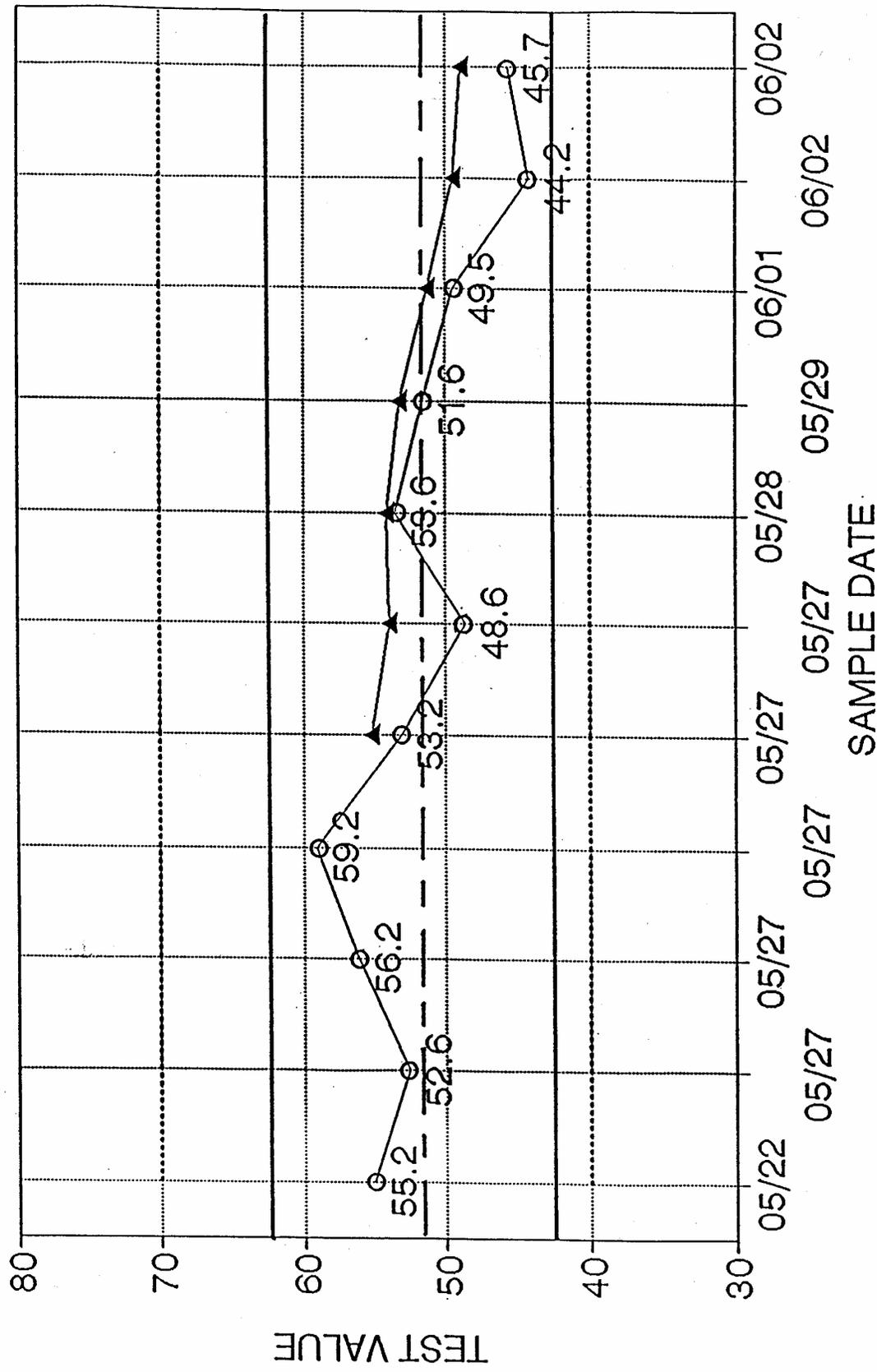


FIGURE 2.1

Fine Aggregate Gradation

Fine aggregate shall be natural sand and meet the gradation requirements of No. 23 sand or a QA sand with a designated gradation from the Certified Aggregate Producer. No. 23 sand is the most common size of fine aggregate used. Figure 2.2 lists the gradation requirements for this material. The table requires that the sand be well graded and not have an excessive amount of particles on any sieve by limiting the amount retained on two consecutive sieves to no more than 45 percent.

Sieve Size	Min. % Passing	Max % Passing
3/8 in.	100	---
No. 4	95	100
No. 8	80	100
No. 16	50	85
No. 30	25	60
No. 50	5	30
No. 100	0	10
No. 200	0	3

Note: The fine aggregate shall have not more than 45% retained between any 2 consecutive sieves

FIGURE 2.2

Concrete mixtures lacking the proper amount of fine sand will be harsh and difficult to finish. In particular, the amounts passing the No. 50 and No. 100 sieves affect workability, surface texture and bleeding of concrete the most.

In general, if the water/cementitious ratio is kept constant and the ratio of fine-to-coarse ratio is chosen correctly, a wide range in fine aggregate gradations can be used without a measurable effect on compressive strength.

Fineness Modulus

The fineness modulus is an indicator of the fineness of an aggregate and is most used for evaluating fine aggregates. The higher the number, the coarser the aggregate. The fineness modulus is computed by adding the cumulative percentages retained on the 6 in., 3 in., 1 1/2 in., 3/4 in., 3/8 in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100 sieves, and then dividing by 100. The fineness modulus of a fine aggregate is useful in estimating the proportions of fine and coarse aggregates in concrete mixtures. An example of determining the fineness modulus of a fine aggregate is as follows:

Example:

Sieve Size	100	-	% Passing	=	% Retained
3/8 in.	100	-	100	=	0.0
No. 4	100	-	100	=	0.0
No. 8	100	-	89.2	=	10.8
No. 16	100	-	68.3	=	31.7
No. 30	100	-	45.1	=	54.9
No. 50	100	-	13.8	=	86.2
No. 100	100	-	2.6	=	97.4
					<u>281.0</u>

$$\frac{281.0}{100} = 2.81 = \text{Fineness Modulus}$$

Coarse Aggregate Gradation

Coarse aggregate shall be limestone, dolomite, gravel or air cooled blast furnace slag and meet the gradation requirements of a No. 8 coarse aggregate or a QA coarse aggregate with a designated gradation from the Certified Aggregate Producer. Also, the coarse aggregate is required to have 100 percent passing the 1 in. sieve. No. 8 coarse aggregate is the most common size used in superstructure concrete. Figure 2.3 lists the gradation requirements for this material. The specification requires that when the material is stone or slag the decant shall be 0 to 2.5 and when the material is gravel the decant shall be 0 to 2.0.

Sieve Size	Min. % Passing	Max % Passing
1 in.	100	---
3/4 in.	75	95
1/2 in.	40	70
3/8 in.	20	50
No. 4	0	15
No. 8	0	10
Decant *	0	1.5

* When the material is stone or slag, the decant may be 0 to 2.5

FIGURE 2.3

A coarse gradation is one having a percent passing each required sieve that is close to the bottom limit for that sieve (i.e., 75% passing the 3/4 in. sieve). Coarse aggregates with a coarse gradation, in general, require less water and cement than aggregate that are finer. The reason for this is that there is less surface area and therefore less cementitious requirement to adequately coat and bind the aggregate to other particles.

Mixture Gradation

The combined mixture gradation affects relative aggregate proportions as well as cement and water requirements, workability, pumpability, economy, porosity, shrinkage, and durability of concrete. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

Particle Shape and Surface Texture

Particle shape and surface texture of an aggregate predominately influence the properties of freshly mixed concrete. Rough-textured, angular, elongated particles require more water to produce workable concrete than do smooth, rounded, cubical-shaped particles. Concrete with an excess of angular particles may cause problems with workability and finishing. Irregular and angular particles that tend to interlock when consolidated will increase the strength of the mixture. Rough-textured particles give the cementing material something to grip, producing a stronger bond, and therefore also increase the strength of the mixture. Flat and elongated particles require an increase in mixing water and thus may affect the strength of concrete if the water/cementitious ratio is not maintained.

Specific Gravity

The specific gravity of an aggregate is the ratio of its weight to the weight of an equal volume of water. The value is used in computations for mixture proportioning and control, such as the absolute volume occupied by an aggregate. The specific gravity of an aggregate may be determined on an oven-dry basis or a saturated surface dry (SSD) basis. Oven-dry aggregates do not contain any absorbed or free water. Saturated surface dry aggregates are aggregates in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface.

The bulk specific gravity is determined by first drying the test sample to a constant weight in accordance with AASHTO T 84 and T 85. Both test methods allow the elimination of this initial drying if the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition. However, it should be noted that the absorption and bulk specific gravity (SSD) values may be significantly higher for aggregates that are not oven dried initially before soaking. This is especially true of particles with a high porosity since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

Mixture design and proportioning of QC/QA superstructure concrete are determined using bulk specific gravity (SSD) of each aggregate component. The bulk specific gravity determined on a dry basis is a common test conducted by the aggregate industry. However, using the absorption value of the aggregate, the bulk specific gravity (SSD) may be calculated in accordance with AASHTO T 84 and T 85 as follows:

$$S_s = (1 + A/100) S_d$$

where:

S_s = bulk specific gravity (SSD)

S_d = bulk specific gravity (dry)

A = absorption in percent

Example: BSG_(dry) = 2.615
 Absorption = 3.21%

$$\begin{aligned} S_s &= (1 + 3.21/100) 2.615 \\ &= 1.0321 \times 2.615 \\ &= 2.699 \end{aligned}$$

The calculated bulk specific gravity (SSD) value is an estimate. QC/QA Superstructure Concrete specifications require that the actual bulk specific gravity (SSD) test value be used for mixture design and proportioning of concrete.

Absorption and Surface Moisture

The absorption and surface moisture (free moisture) of aggregates are required to be determined so that the net water content of the concrete can be controlled and the correct batch weights determined. Internally, aggregate particles are made up of solid mater and voids that may or may not contain water. Definitions of absorption and surface moisture, derived from AASHTO T 85 and AASHTO T 255, respectively, are as follows:

Absorption -- the increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles.

Surface Moisture (Free Moisture) -- the water adhering to the outside surface of the particles.

AASHTO T 255 designates the procedure for determining the total moisture content of the aggregate by drying that is required by QC/QA superstructure concrete specifications. The surface or free moisture content of a fine or coarse aggregate can be determined by deducting the absorption from the total moisture content.

The moisture conditions of aggregates at the jobsite and their contribution to the water in the concrete include:

1. Oven-dry -- no contribution to the water content.
2. Air Dry -- dry at the particle surface but containing some interior moisture. Particles have not reached full absorption and will absorb some water from the concrete mixture.
3. Saturated Surface Dry (SSD) -- particles have obtained the full absorption that is available and will neither absorb water from nor contribute water to the concrete mixture.
4. Damp or Wet -- particles have more moisture than the quantity needed for full absorption and will contribute water (free moisture) to the concrete mixture.

The amount of water used for the concrete mixture must be adjusted for the moisture content of the aggregates in order to meet the designated water requirement. The compressive strength, workability and other properties will be effected if the water content of the concrete mixture is not kept constant.

PORTLAND CEMENTS

Portland cements are finely ground powders that set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a solid mass. When the paste (cement and water) is added to aggregates, it acts as an adhesive and binds the aggregates together to form concrete.

Hydration of the cement begins as soon as there is contact with water. Each cement particle forms a growth on its surface that spreads until it connects with the growth of other particles or adheres to adjacent substances. This reaction results in progressive stiffening, hardening, and strength development. As the concrete stiffens there is a loss of workability that usually occurs within three hours of mixing; however, the composition and fineness of the cement, the mixture proportions, and temperature conditions all may have an affect on the loss of workability.

Hydration will continue as long as there is available space for the hydration products and the moisture and temperature conditions are favorable. The concrete will become stronger as the hydration continues. Most of the hydration and strength development will take place within the first month after mixing, and will continue slowly for a long time.

Requirements

QC/QA superstructure concrete allows the use of only Portland Cement (Types I, II or III), Portland Blast-Furnace Slag Cement (Type IS), or Portland-Pozzolan Cement (Type IP). Further restrictions on the use of portland cement include:

1. Cements shall be accepted by certification from qualified manufacturers or manufacturer/distributors. INDOT will maintain the approved list.
2. A means for storing and protecting the cement against dampness shall be provided. Cement which has become partially set, contains lumps or caked cement, or is salvaged from discarded or used sacks shall not be used.
3. Different kinds or brands, or cement of the same brand from different mills, shall not be mixed during use or used alternately in any one pour.
4. Type IS or type IP portland pozzolon cements may only be incorporated into concrete placed between April 1 and October 15 of the same calendar year. This time period restriction will not apply if traffic is not anticipated on the concrete or if silica fume is used as a portion of the total cementitious material.
5. If Type IP is used, the minimum portland cement content shall be increased to 600 lb/yd³.

Portland Cement Types

Type I

Type I portland cement is a general-purpose cement suitable for all uses where special properties, such as sulfate resistance, high early strength, or low heat of hydration, are not required. It is used in concrete that is not subject to aggressive exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration.

Type II

Type II portland cement is used where it is important to protect the concrete from moderate sulfur attack. Also, Type II portland cement will usually generate less heat at a slower rate than Type I, which is important when concrete is placed in warm weather or in large structural elements where differential in thermal gradient is of concern.

Type III

Type III portland cement provides a high strength at a period of usually a week or less. It is used when forms need to be removed as soon as possible or when the structure is required to be put in service quickly. In cold weather, the curing period may be reduced.

Type IS

Type IS portland blast-furnace slag cement is used for general concrete construction applications. It is a blend of portland cement and granulated blast-furnace slag with the slag content between 25% and 70% by weight. These cements are produced by intergrinding the slag with the portland cement, separately grinding the slag and blending with the cement, or combining the grinding and blending of the two products.

Type IP

Type IP portland-pozzolon cement is used for general concrete construction applications. It is a blend of portland cement and a pozzolon with the pozzolon content a maximum of 20% by weight. These cements are produced by intergrinding portland cement clinker with the pozzolon, by blending portland cement and a pozzolon, or by a combination of intergrinding and blending.

ADMIXTURES

Admixtures are those ingredients added to concrete immediately before or during mixing other than portland cement, water, and aggregates. The major reasons for using admixtures include:

1. To reduce the cost of concrete construction
2. To achieve certain properties in concrete more effectively than by other means
3. To insure the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather condition

The effectiveness of any admixture is dependent on such factors as:

1. Type, brand, and amount of cement
2. Water content
3. Aggregate shape, gradation, and proportions
4. Mixing time
5. Slump
6. Temperatures of the concrete and air

Trial batches of the project materials and the admixtures should be made to verify the compatibility of the materials as well as the effects on the properties of the concrete. The amount of admixture recommended by the manufacturer should be used.

Mineral Admixtures

Mineral admixtures are powdered or pulverized materials added to concrete before or during mixing to improve or change some of the plastic or hardened concrete properties. The mineral admixtures allowed in QC/QA superstructure concrete are classified as cementitious materials (ground granulated blast-furnace slag) and pozzolons (fly ash and silica fume).

Ground Granulated Blast Furnace Slag

Ground granulated blast-furnace slag is a nonmetallic material that is developed in a molten condition simultaneously with iron in a blast furnace. A glassy granular material is formed when molten blast-furnace slag is rapidly chilled by immersion in water. This glassy granular material is then ground to cement fineness resulting in ground granulated blast-furnace slag. The rough and angular-shaped ground slag hydrates and sets in a manner similar to portland cement when exposed to water and portland cement.

Fly Ash

Fly ash is a finely divided residue that results from the combustion of pulverized coal in electric power generating plants. In general, class F fly ash is produced from burning anthracite or bituminous coal and class C fly ash is produced from burning lignite or subbituminous coal. During combustion, the coal's mineral impurities (such as clay, feldspar, gravity, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gas. In the process, the fused material cools and solidifies into spherical particles called fly ash, which is collected by electrostatic precipitators or bag filters.

Silica Fume

Silica Fume is a powdery product that is the result from reducing high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrsilicon alloy. In the process, silica fume rises as an oxidized vapor from a 3630°F furnace, cools, condenses, and is collected in cloth bags. The condensed silica fume is then processed to remove impurities.

Mineral Admixture Effect on Concrete

The effects of the ground granulated blast-furnace slag, fly ash, and silica fume on the concrete are as follows:

Fly Ash

1. Enhances workability
2. Lowers permeability
3. Lowers water demand
4. Slightly enhances long term strength
5. Reduces the heat of hydration
6. Retards setting time
7. Delays strength gain

Ground Granulated Blast-Furnace Slag

1. Increases strength
2. Lowers permeability
3. Improves sulfate resistance
4. Lowers heat of hydration
5. Reduces potential alkali-silica reaction
6. Improves workability and pumpability

Silica Fume

1. Increases unit weight
2. Increases durability
3. Decreases permeability
4. Enhances strength
5. Increases mixing time
6. Reduces workability
7. Enhances pumpability

Requirements

QC/QA superstructure concrete has the following restrictions on the use of mineral admixtures:

1. Fly ash and ground granulated blast-furnace slag may only be incorporated into the concrete between April 1 and October 15 of the same calendar year. These dates will not apply if traffic is not anticipated on the concrete.
2. Fly ash will not be permitted in conjunction with the use of type IS or IP cements, or with ground granulated blast-furnace slag.
3. When silica fume is used the following criteria shall be used:
 - a. The minimum portland cement content shall be 530 lb/yd³ with a tolerance not to exceed one percent as directed by 702.06

- b. The minimum and maximum cementitious content with silica fume shall be 650 - 715 lbs/yd²
- c. Silica fume shall constitute 7.0-7.5 percent of the total cementitious content in the mix design
- d. Class F or C fly ash may be used as part of the total cementitious content. The maximum Portland cement/fly ash ratio shall be 6.4 by weight
- e. The water/cementitious ratio shall be no less than 0.370 and shall not exceed the maximum of 0.420
- f. The minimum compressive strength at 28-days shall be 5800 psi.

Chemical Admixtures

Chemical admixtures are materials added to concrete before or during mixing, that affect the concrete as follows:

Air-Entraining Admixtures -- used to entrain microscopic air bubbles in concrete.

Water-Reducing Admixtures -- used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water/cementitious ratio, or increase slump.

Retarding Admixtures -- used to retard the rate of setting of concrete.

Accelerating Admixtures -- used to accelerate strength development at an early age.

High-Range Water Reducers (Superplasticizers) -- added to concrete with low-to-normal slump and water-cement ratio to make high-slump flowing concrete.

Requirements

QC/QA superstructure concrete is required to contain an air entraining agent and either a water reducing, high range, admixture (Type F), or water-reducing, high range, and retarding admixture (Type G) as identified in the INDOT list of approved PCC Admixtures and Admixture Systems.. The following restrictions apply:

- 1. The type of admixture used shall not be changed during any individual contiguous pour.

2. When either the air or concrete temperature is expected to be 65°F or above and dead load deflection is of concern, a Type G admixture or HRWRR Admixture System shall be used.
3. If a fly ash or ground granulated blast-furnace slag admixture is used, the dosage of Type F or Type G may be lowered to an amount as recommended in writing by the manufacturer of the admixture.
4. A Type F admixture or HRWR Admixture System shall be used when both air and concrete temperatures are expected to be below 65°F or dead load deflection is not of concern.

3 MIX DESIGN & PROPORTIONING

Mix Design

Mixing Proportioning

Instructions for Page 1 Of Worksheets

Linear Equation of Unit Weight vs. Air Content

Instructions for Page 2 of Worksheets

Threshold for Max. Allowable Water/Cementitious Ratio

Instructions for Page 3 of Worksheets

Department Concurrence of Mix Design

CHAPTER THREE:

MIX DESIGN

MIX DESIGN

The concrete mix design (CMD) for QC/QA superstructure concrete must produce a workable concrete mixture having properties that will not exceed the maximum and/or minimum values defined in the special provision. Workability in concrete defines its capacity to be placed, consolidated, and finished without harmful segregation or bleeding. Workability is affected by aggregate gradation, particle shape, proportioning of aggregate, amount and qualities of cementitious materials, presence of entrained air, amount and quality of high range water reducer, and consistency of mixture.

Consistency of the concrete mixture is its relative mobility and is measured in terms of slump. The higher the slump the more mobile the concrete, affecting the ease with which the concrete will flow during placement. Consistency is not synonymous with workability. Two different mix designs may have the same slump; however, their workability may be different.

Selection of target parameters by the contractor for any mix design must consider the influence of the following:

1. material availability and economics
2. variability of each material throughout period of usage
3. control capability of production plant
4. ambient conditions expected at the time(s) of concrete placement
5. logistics of concrete production, delivery, and placement
6. variability in testing concrete properties
7. generation of heat in large structural elements and differential in thermal gradient (i.e. 2 - 3 ft thick and cement content above 600 lb/yd³)

The qualities of the cementitious paste provide a primary influence on the properties of concrete. Proper selection of the cementitious content and water/cementitious ratio is dependent on the experience of the concrete producer and becomes a very important first step in preparing a design. For workable concrete, a higher water cementitious ratio is typically required when aggregate becomes more angular and rough textured. The presence of air, certain pozzolans, and aggregate proportioning will work to lower the water cementitious ratio; however the most significant reduction in water demand comes through the use of a high range water reducing chemical admixture.

Water/cementitious ratio is determined from the net, per unit, quantity of water and total cementitious materials (by weight). The net water content excludes water that is absorbed by the aggregates. For a given set of materials and conditions, as water/cementitious ratio increases, strength and unit weight will decrease. Compressive strength is a concrete parameter used in combination with unit weight and air content to evaluate the durability of the superstructure concrete's exposure to freeze / thaw action, and exposure to deicing salts. It is important to note that the designer of the bridge structure does not recognize the benefit of increased compressive strength. The slab still relies on a minimum design compressive strength (f'_c) of 4000 psi at 28-days.

Proportioning of aggregates is defined by the volume of fine aggregate to the volume of coarse aggregate, as a percent. The lower percentage of fine to total aggregate provides an increase in compressive strength at the expense of workability. The gradation, particle shape and texture of the coarse aggregate along with fineness modulus of the fine aggregate will determine how low the fine to total aggregate percentage can be for a given workability requirement.

MIXING PROPORTIONING

Once the cement content, pozzolan content, water/cementitious ratio, and fine to total aggregate percentage are defined for the concrete's intended use in the superstructure, proportioning of the mix in terms of design batch weights can begin. Specific gravities must be accurately defined for each material being utilized in order to proportion the mix properly by the absolute volume method. Cement is typically accepted as having a specific gravity of 3.15. Pozzolans will typically vary between 2.22 and 2.77 depending on the type of pozzolan (fly ash, GGBFS, silica fume) and its source. Pozzolan suppliers should readily be able to provide current values for their material. Approximate specific gravities are identified for each source on the Department's Approved/Prequalified Materials list; however, they should not be considered the most current.

Bulk specific gravity, in the saturated surface dry condition, must be used to proportion the fine and coarse aggregate. Accurate testing of one or more samples of fine and coarse aggregate must be accomplished by the

Contractor as part of any proportioning for a mix design. It is of great benefit to identify the geologic ledges from which a crushed stone coarse aggregate is produced. Subsequent shifts in benching at the aggregate source may cause significant shifts in bulk specific gravity and absorption. These are important aggregate properties to monitor as part of concrete quality control.

Proportioning concrete by the absolute volume method involves calculating the volume of each ingredient and its contribution to making one yd³ or 27 ft³ of concrete. Volumes are subsequently converted to design weights, which then become the basis for actual production of concrete from the plant. For cementitious materials and water, the weight to volume conversion is accomplished by dividing the weight (lbs) by the specific gravity of the material and again dividing by the density of water (62.27 lbs/ft³ at 73.4 °F). Converting from volume to weight is accomplished simply by taking the known volume (ft³) of the ingredient and multiplying by the specific gravity of the ingredient and again multiplying by the density of water (62.27 lbs/ft³ at 73.4 °F). Volume to weight conversions for aggregates are accomplished by the same series of computations; however, bulk specific gravity (SSD) must be used. The target air content is established at 6.5% by the special provision, which converts to a volume of 1.76 ft³ within a cubic yard of concrete.

Instructions for Page 1 of Mix Design & Proportioning Worksheets

A worksheet entitled "Mix Design & Proportioning QC/QA Superstructure Concrete" has been developed and is included in Appendix D, under tab 11 of this manual. Use of this form by the Contractor and Department will provide an easy means to proportion a mix by the absolute volume method and validate compliance, thereby helping to eliminate delays due to errors and/or oversight of the specification requirements.

An example of proportioning a mix design through use of this form is detailed in Table 3.1. The contractor establishes the initial parameters for a mix design and serves as the starting point for subsequent proportioning calculations.

The initial step in proportioning the mix design is to calculate the water content per cubic yard of concrete. This is accomplished by multiplying the total cementitious content by the water/cementitious ratio. It should be noted that space was intentionally provided on the form to allow room for computations.

Example: $658 \times 0.395 = 260$ lbs water content

There is now sufficient information to begin entering known weights, volumes, and specific gravities into the second table. Table 3.2 illustrates the results for the example problem.

Initial Parameters for yd³ Concrete	
Target Cement Content, lbs	658
Target Pozzolan Content, lbs	0
Target Silica Fume Content, lbs	0
Target Water / Cementitious Ratio, by wt.	0.395
Target Cement / Pozzolan Ratio, by wt.	Infinity
Target % Silica Fume	0.0
100 FA / FA+CA, Target, % by volume	41.7
FA Bulk Sp. Gr. (SSD)	2.632
FA Absorption, %	2.00
CA Bulk Sp. Gr. (SSD)	2.711
CA Absorption, %	1.40

Table 3.1

Material	Size, Type or Class	Source	Design Batch Weights lbs	Specific Gravity	Absolute Volume ft ³
Cement	Type I		658	3.150	3.35
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS			2.632	
CA	#8 CS			2.711	
Water	potable		260	1.000	4.18
Air	entrained	see table below	0	-NA-	1.76
Σ	-NA-	-NA-		-NA-	27.00

Table 3.2

The volume of total aggregates is now calculated by subtracting the volumes of other known ingredients (i.e. cement, pozzolan, silica fume, water, and air) from 27.00 cubic feet of concrete.

Example: $27.00 - (3.35 + 4.18 + 1.76) = 17.71 \text{ ft}^3$ total aggregates

The percentage of fine to total aggregate is divided by 100 to produce the decimal equivalent, and then multiplied by the total aggregate volume to determine the volume of fine aggregate only.

Example: $17.71 \text{ ft}^3 \times 0.417 = 7.39 \text{ ft}^3$ fine aggregate

The corresponding volume of coarse aggregate is determined by subtracting the known volume of fine aggregate from the known volume of total aggregate.

Example: $17.71 \text{ ft}^3 - 7.39 \text{ ft}^3 = 10.32 \text{ ft}^3$ coarse aggregate

These calculated values are now inserted in the appropriate cells of the table as shown in Table 3.3 by the values in boldface print.

Material	Size, Type or Class	Source	Design Batch Weights lbs	Specific Gravity	Absolute Volume ft^3
Cement	Type I		658	3.150	3.35
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS			2.632	7.39
CA	#8 CS			2.711	10.32
Water	potable		260	1.000	4.18
Air	entrained	see table below	0	-NA-	1.76
Σ	-NA-	-NA-		-NA-	27.00

Table 3.3

The volumes of fine and coarse aggregate are each converted to the design batch weight (lbs) based on saturated surface dry condition. The design batch weights are added to obtain the total weight of ingredients required to make 27.00 ft^3 of concrete at 6.5% target air content. Table 3.4 illustrates tabulation of the example problem.

Material	Size, Type or Class	Source	Design Batch Weights lbs	Specific Gravity	Absolute Volume ft^3
Cement	Type I		658	3.150	3.35
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS		1211	2.632	7.39
CA	#8 CS		1742	2.711	10.32
Water	potable		260	1.000	4.18
Air	entrained	see table below	0	-NA-	1.76
Σ	-NA-	-NA-	3871	-NA-	27.00

Table 3.4

It should be noted that the volumes and weights of any water present in the admixtures are typically not included in the mix proportioning or in the water content determinations.

LINEAR EQUATION OF UNIT WEIGHT vs. AIR CONTENT

It is known that the unit weight of plastic concrete is inversely proportional to air content. That is to say, as air content increases unit weight decreases. This relationship becomes a very useful tool when

evaluating plastic concrete. Unit weight and air content are properties of plastic concrete that can be easily and quickly measured in the field. A unit weight measurement, at a known air content, that deviates excessively from the linear relationship provides information as to the possible deficiencies in the mix and potential effects on properties such as workability, durability, and strength.

The linear equation to predict unit weight based on a given air content is presented below in directional form:

$$UW = m (\text{Air}) + b$$

Where: **m** is the slope of line (also known as "rise/run")

Air is the plastic concrete air content (independent variable, x-coordinate or abscissa of point)

b is the y-intercept

UW is the plastic concrete unit weight (dependent variable, y-coordinate, or ordinate of point)

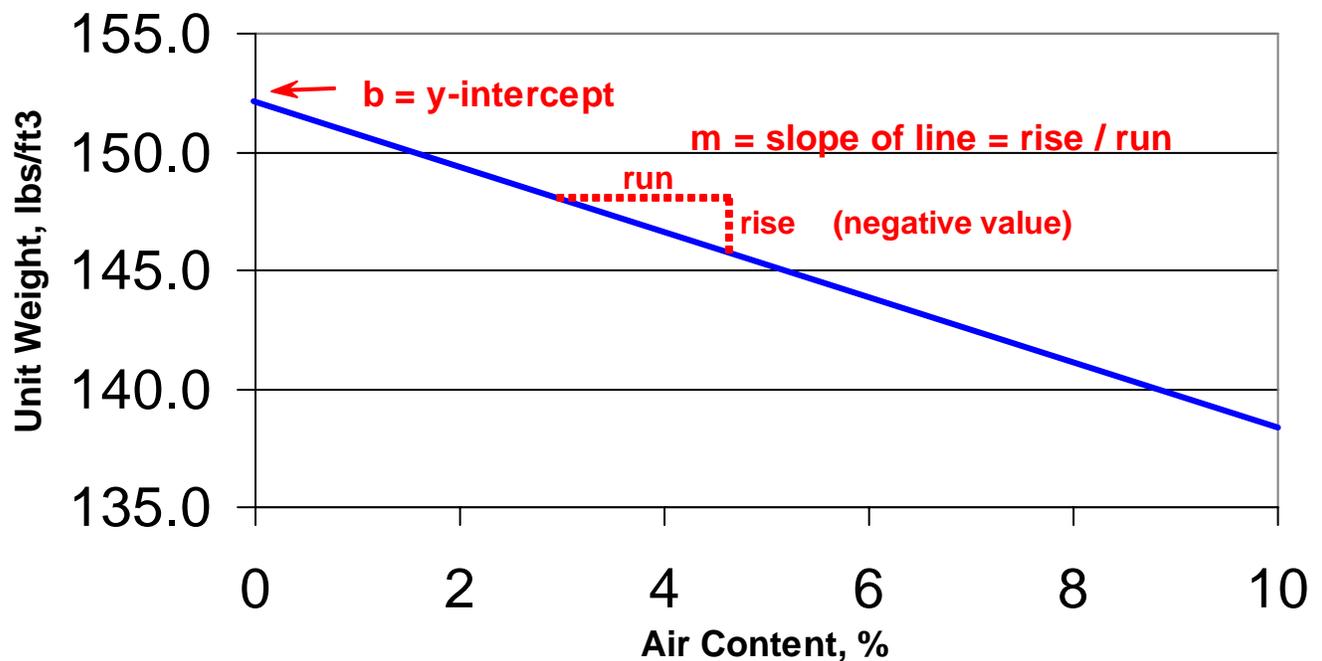


Figure 3.1

If all points (Air, UW) associated with the solution set of this linear equation were plotted on a graph, there would be a straight line as illustrated by Figure 3.1. This linear relationship can be determined for any concrete mix design.

Instructions for Page 2 of Mix Design & Proportioning Worksheets

If at least two points (Air, UW) are known to be a solution to the equation, algebra can be utilized to solve for the two unknown variables (i.e. slope and y-intercept). The form in Appendix D (under tab 11) entitled "WORKSHEET FOR CMD LINEAR EQUATION" provides the format in which two points can be defined and the equation determined

The Cartesian coordinates (Air,UW) of one solution point is already available from the mix design. We can define this as Point 2 with coordinates (x_2 , y_2). The value of x_2 is the target air content of the mix design (i.e. $x_2 = 6.5$ %). The value of y_2 is the unit weight of the concrete stated in the mix design. This is determined by obtaining the summation of the design batch weights and dividing by the summation of design absolute volumes which will always be 27.00 ft^3 . The following example calculations for the worksheet are based on the mix design and proportioning values presented earlier in this chapter.

Example: $x_2 = 6.5$ %

$$y_2 = \sum \text{Design Batch Weights} \div 27.00 \text{ ft}^3$$

$$y_2 = 3871 \text{ lbs} \div 27.00 \text{ ft}^3$$

$$y_2 = 143.4 \text{ lbs/ft}^3 \text{ (rounded to the first decimal place)}$$

A plot of the coordinates for Point 2 ($x_2 = 6.5$, $y_2 = 143.4$) is illustrated in Figure 3.2. It is important to note that the unit weight for Point 2 is calculated to the nearest 0.1 lbs/ft^3 .

Point 1, representing the y-intercept having coordinates (x_1 , y_1), must now be determined. This is accomplished by theoretically removing all the entrapped and entrained air from the mixture and calculating the concrete unit weight. The value of x_1 is 0.0 % air content. The value of y_1 is determined by again obtaining the summation of the design batch weights and divide by the summation of design absolute volumes except for entrapped or entrained air. This volume will always be $27.00 \text{ ft}^3 - 1.76 \text{ ft}^3 = 25.24 \text{ ft}^3$. The following example illustrates how the worksheet calculates the coordinates for Point 1.

Example: $x_1 = 0.0$ %

$$y_1 = \sum \text{Design Batch Weights} \div 25.24 \text{ ft}^3$$

$$y_1 = 3871 \text{ lbs} \div 25.24 \text{ ft}^3$$

$$y_1 = 153.4 \text{ lbs/ft}^3 \text{ (rounded to the first decimal place)}$$

The Cartesian coordinates of Point 1, ($x_1 = 0.0$, $y_1 = 153.4$), is graphed along with Point 2 in Figure 3.3, to illustrate the example. Again note that the unit weight is calculated to the nearest 0.1 lbs/ft^3 .

It is important to remember that as air is removed from concrete the individual weights of cementitious materials, fine aggregate, coarse aggregate, and water no longer represent amounts relative to 1.000 yd³ of concrete. Concrete without the 6.5% target air content (1.76 ft³) would only yield 0.9348 yd³ of concrete. The actual cement and water contents per 1.000 yd³ concrete would increase as a result of the under yielding. If air content increases over the 6.5 % target, the actual cement and water contents per 1.000 yd³ would be less as a result of the over yielding. However, in either case the water cementitious ratio and fine to total aggregate ratio remain unchanged.

From the x and y coordinates of Points 1 & 2, there is now enough information to solve for the variables of slope and y-intercept in the linear equation. The worksheet calculation for slope, also known as "rise / run", is exemplified as follows:

Example:

$$\begin{aligned} \text{slope} = m &= (y_2 - y_1) / (x_2 - x_1) \\ m &= (143.4 - 153.4) / (6.5 - 0.0) \\ m &= (-10.0) / (6.5) \\ m &= -1.54 \text{ (negative value, rounded to second decimal place)} \end{aligned}$$

It is important to note that slope will always be negative since unit weight is inversely proportional to air content.

The y-intercept value (b) is simply the ordinate of Point 1, which has already been determined. In the example problem, the worksheet would show the solution b as follows:

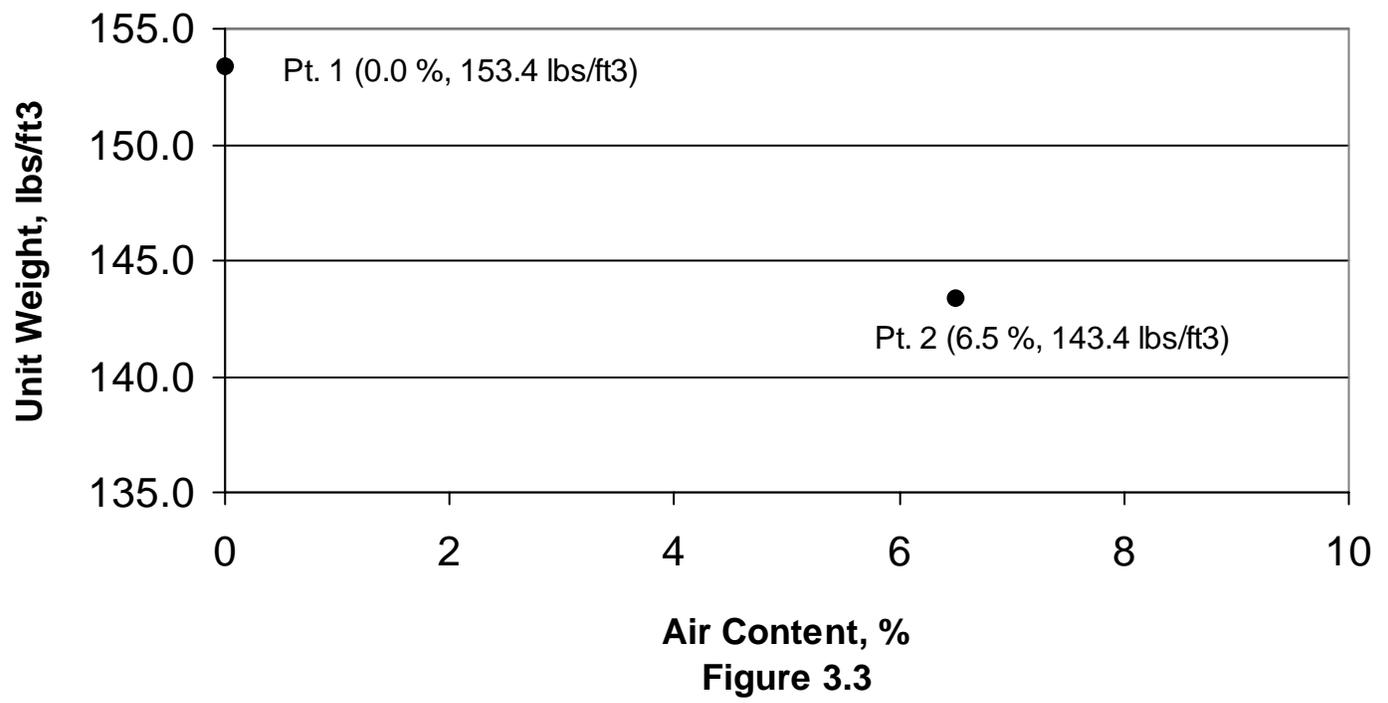
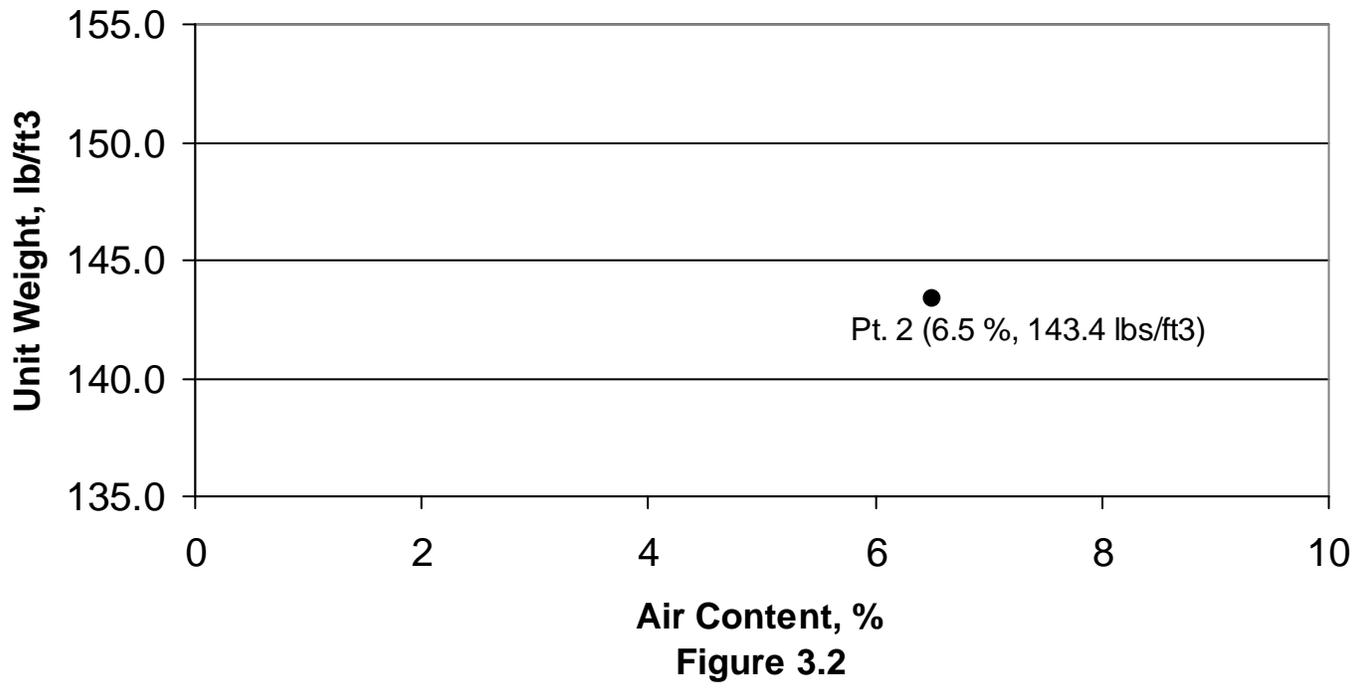
Example:

$$\begin{aligned} \text{y-intercept} = b &= y_1 \\ b &= 153.4 \text{ lbs/ft}^3 \end{aligned}$$

The calculated and rounded values for slope and y-intercept can now be inserted in the linear equation for the variables m and b, respectively. The linear equation can now be written for the concrete mix design. The numbers from the example result in the following:

Example:

$$\begin{aligned} \text{Predicted Unit Weight} &= m (\text{Air}) + b \\ \text{Predicted Unit Weight} &= -1.54(\text{Air}) + 153.4 \end{aligned}$$



THRESHOLD FOR MAXIMUM ALLOWABLE WATER / CEMENTITIOUS RATIO

Just as concrete unit weight is affected by changes in air content, it is also affected by the amount of water that is available to react with cementitious materials. As the amount of water increases the water/cementitious ratio also increases, producing concrete of inferior quality. This serves to lower the concrete unit weight at any given air content. Since the maximum allowable water/cementitious ratio for QC/QA superstructure concrete is 0.420, a threshold line or limit can be determined. This threshold line would be parallel to the linear equation for the mix design (i.e. same slope); however, the unit weight would be lower (i.e. lower y-intercept). The threshold limit has relevancy to results from quality control as well as Acceptance sampling and testing. Should the measured unit weight at any given air content be at or lower than the threshold, it could indicate that the maximum allowable water cementitious ratio was exceeded. It is important to understand that quality control works to center production about the linear equation for the mix design. Concrete production that has shifted toward the threshold line is considered very serious and requires corrective action to re-center it about the linear equation for the CMD.

There are several ways in which additional water could enter a concrete mix. The methodology presented in this chapter assumes that the increase in water/cementitious ratio is due solely to excessive batch water. This provides a simple and accurate determination of the threshold limit equation. The methodology begins with the linear equation already established for the mix design. By establishing a single point below the linear equation, representing concrete with excessive water, the equation for threshold limit can be determined. The easiest point to select is at the y-intercept, where the concrete has no entrapped nor entrained air. This point is defined as Point 3, having coordinates (x_3, y_3) . The line for the threshold equation should be parallel to the linear equation for the mix design, which results in the same slope. Knowing the slope and y-intercept the threshold limit equation can then be written.

Instructions for Page 3 of Mix Design & Proportioning Worksheets

A worksheet is provided in Appendix D (under tab 11), which follows the methodology stated previously to generate the threshold limit equation representing the maximum allowable water/cementitious ratio. The instructions for completion of this worksheet are as follows. The first step is to determine the amount of excess water to increase the water cementitious ratio to 0.420. Using the total amount of cementitious materials targeted for the mix design and multiplying it by 0.420 the resultant gives the maximum allowable water content. The example mix design within this chapter is used to provide the following sample calculations:

Example: 658 lbs cementitious \times 0.420 = 276 lbs water

This weight of water is entered under the weight subheading for Theoretical Batch Weights and Volumes without entrained or entrapped air, as illustrated in Table 3.9. The remaining mix design weights for cement, pozzolan, fine aggregate, and coarse aggregate are transferred over from the mix proportioning sheet completed previously.

Material	Theoretical Batch Weights & Volumes w/o air		
	Weight lbs	Specific Gravity	Volume ft ³
Cement	658	3.150	
Pozzolan	-----	-----	-----
Silica Fume	-----	-----	-----
FA	1211		
CA	1742		
Water	276	1.000	
Air Content	0	-NA-	0.00
Σ		-NA-	

Table 3.9

The specific gravities for each ingredient are entered in the table and used to calculate the corresponding absolute volumes. It should be noted that each ingredient has the same value as the mix design proportioning except the weight and volume of water has increased; and the volume of air has decreased to 0.00 ft³. The summations of the weight and volume columns are then determined and recorded in the table. Table 3.10 illustrates that portion of the worksheet completed thus far for the example problem. The next step in the worksheet is to numerically define the coordinates of Point 3. The following calculations are based on the example numbers presented in Table 3.10.

Example: $x_3 = 0.0$ % air content

$$y_3 = \sum \text{Theoretical Batch Wts.} \div \sum \text{Theoretical Batch Vol.}$$

$$y_3 = 3887 \text{ lbs.} \div 25.49 \text{ ft}^3$$

$$y_3 = 152.5 \text{ lbs/ft}^3$$

The y-intercept of the threshold limit equation is simply equal to y_3 , which is the Unit Weight calculated in the worksheet. Since the lines are parallel, the slope of the threshold equation is the same as the value calculated for the mix design linear equation. The solution to the Threshold Limit Equation is now straight forward.

Example: y-intercept = Unit Weight = 152.5 lbs/ft³ (rounded to 0.1 lb/ft³)

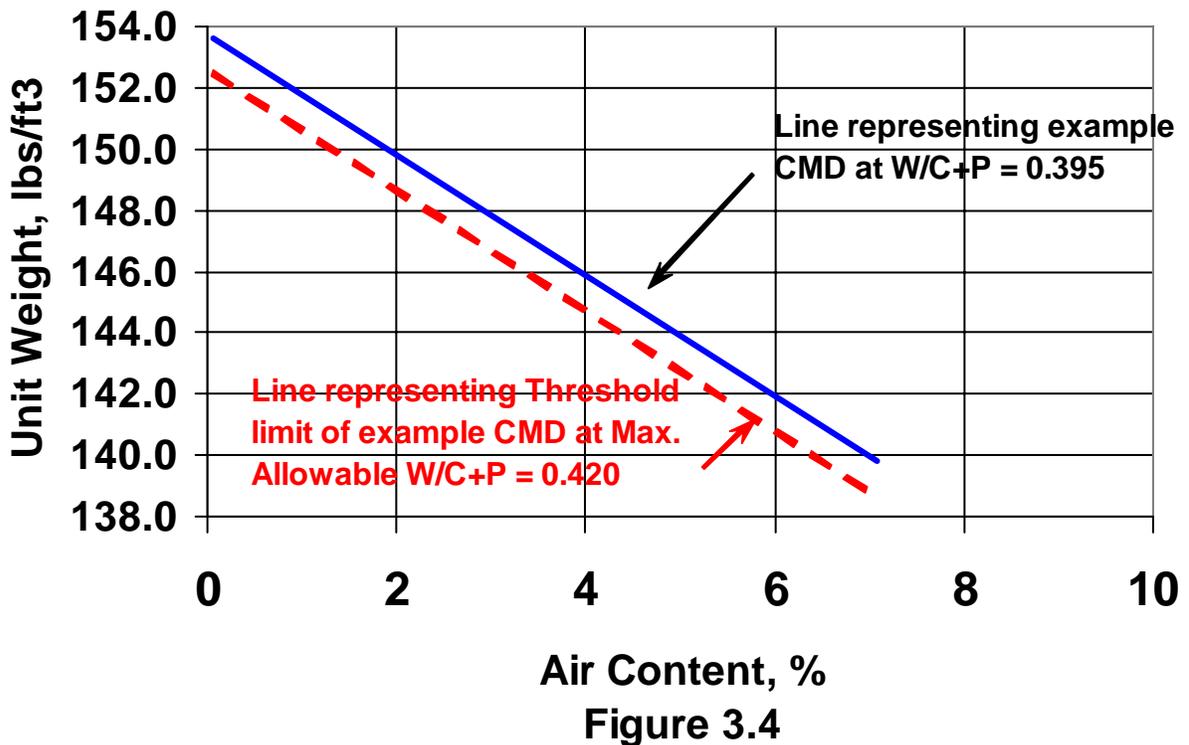
$$\text{slope} = m = -1.54$$

Example: Threshold UW = - 1.54 (Air) + 152.5 lbs/ft³

Figure 3.4 is a graphical representation of the example CMD linear equation and its corresponding threshold limit equation.

Material	Theoretical Batch Weights & Volumes w/o air		
	Weight lbs	Specific Gravity	Volume ft ³
Cement	658	3.150	3.35
Pozzolan	-----	-----	-----
Silica Fume	-----	-----	-----
FA	1211	2.632	7.39
CA	1742	2.711	10.32
Water	276	1.000	4.43
Air Content	0	-NA-	0.00
Σ	3887	-NA-	25.49

Table 3.10



DEPARTMENT CONCURRENCE OF MIX DESIGN

It is the responsibility of the Department's Project Engineer / Project Supervisor (PE/PS) to conduct a complete and thorough review of every mix design and proportioning for QC/QA Superstructure Concrete. There is a substantial amount of work that is based on the targets established by the CMD, not the least of which is the linear equation for the threshold limit that represents the maximum allowable water/cementitious ratio. This threshold limit is of critical importance in determining whether additional cylinders are to be cast as part of an acceptance sample for testing per AASHTO T 277 and subsequent action, which may involve a failed material investigation.

The first step in proper review of a CMD is to verify that the materials are from current approved sources. The list of Approved and/or Prequalified Materials is to be used to verify approved sources of cement, fly ash, GGBFS, silica fume, chemical admixtures and air entraining agents. The fine and coarse aggregate ingredients of the concrete mix must be materials from an approved Certified Aggregate Producer. The gradation and quality requirement for the aggregates must also be verified, particularly if stay-in-place metal deck forms are used to facilitate construction of the deck. If AP Quality coarse aggregate is required in the superstructure, the PE/PS will substantiate the quality status. This would include the nature of the mining operations that produce aggregates of the desired quality (e.g. individual ledges or ledge combinations within the working bench of the aggregate source). The PE/PS should contact the District Materials & Tests Engineer or the District Geologist for confirmation.

In addition to the aggregates gradations the PE/PS must verify the bulk specific gravity (SSD) and absorption for the fine and coarse aggregate as being reasonable for the source. If the Contractor's value for absorption differs by more than the multilaboratory precision defined within the appropriate test method, the discrepancy will be investigated. These values are defined in the AASHTO test method and summarized in Table 3.15.

Property	Range for FA	Range for CA
Bulk Sp. Gr. (dry)	0.066	0.038
Bulk Sp. Gr. (SSD)	0.056	0.032
Absorption, %	0.66	0.41

Table 3.15

The bulk specific gravity and absorption for aggregates are measured by the Department as part of the annual "Summary of Production Quality Results", and periodic Point-Of-Use samples. This data provides the correct basis for comparison of absorption and specific gravity. Figures 3.5 and 3.6 are graphs of bulk specific gravity (ssd) vs. absorption for a

fine and coarse aggregate and are presented as examples of what historical data might look like for specific products at an aggregate source.

Usually sources will demonstrate a trend of bulk specific gravity (SSD) being inversely proportional to absorption; however, such may not always be the case. Figure 3.6 represents data from the INDOT Summary of Production Quality Results for a specific source of #8 coarse aggregate. The AP quality stone comes from ledges 1803, 1804, 19, & 20 processed as one working bench. These four ledges have thicknesses of 7.9 ft, 8.9 ft, 5.9 ft, and 12.1 ft, respectively. Since these ledges range in absorption from 2 % to 4 %, the consistency of bulk specific gravity and absorption depends on the aggregate source's ability to process the bench in a uniform manner. The District Geologist is the best source for obtaining historical data from "Summary of Production Quality Results" and "Point-of-Use" samples obtained from the aggregate source. They will assist the PE/PS in the proper review of contractor test results for aggregates.

It is important to understand that INDOT historical records for bulk specific gravity (dry or SSD) from coarse aggregate sources are based on procedure 8.1 of AASHTO T 85. The Contractor must therefore test the coarse aggregate according to the same procedure even though the result is typically not appropriate for concrete mix design. If the mix design is submitted with enough advance notice, it becomes preferable for the Department to obtain a Point-Of-Use sample of the coarse aggregate and test for bulk specific gravity (SSD) by procedure 8.2 of AASHTO T 85, which is appropriate for concrete mix design. Splitting a sample between the Contractor and the Department to compare test results would be even better.

The air entraining and chemical admixtures that are approved for use are as stated in the special provision and the Approved/Prequalified Materials List referenced therein. It is important to recognize the limitations of Type F admixtures or HRWR Admixture Systems. These chemical admixtures have no retarding capability and would not be appropriate for superstructure concrete that is placed in conditions where concrete and ambient temperatures are above 65°F, and where dead load deflections are of concern.

After verifying the materials as being approved for the concrete, the initial parameters for the Mix Design must be checked against the specification requirements. The remainder of the PE/PS check involves checking the math for proportioning, and the linear equations for the CMD and threshold limit. Use of the forms and worksheets by the contractor will provide the quickest and most complete review by the Department and therefore help eliminate unnecessary delays by recognizing problems early on.

Figure 3.5
Bulk Sp. Gr. (SSD) Vs. Absorption, SC#23XX
#23 NS

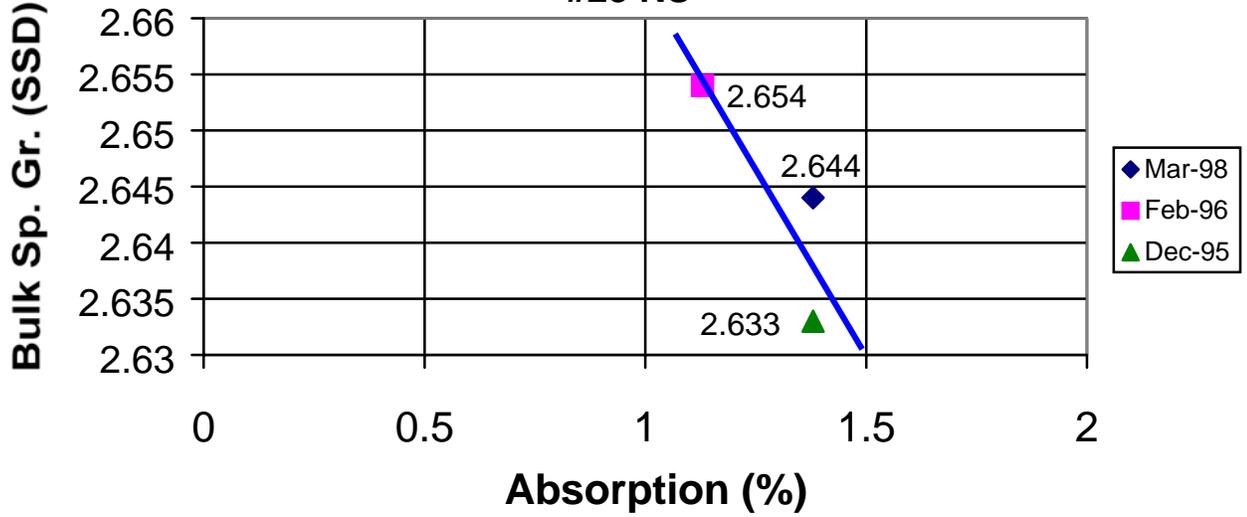
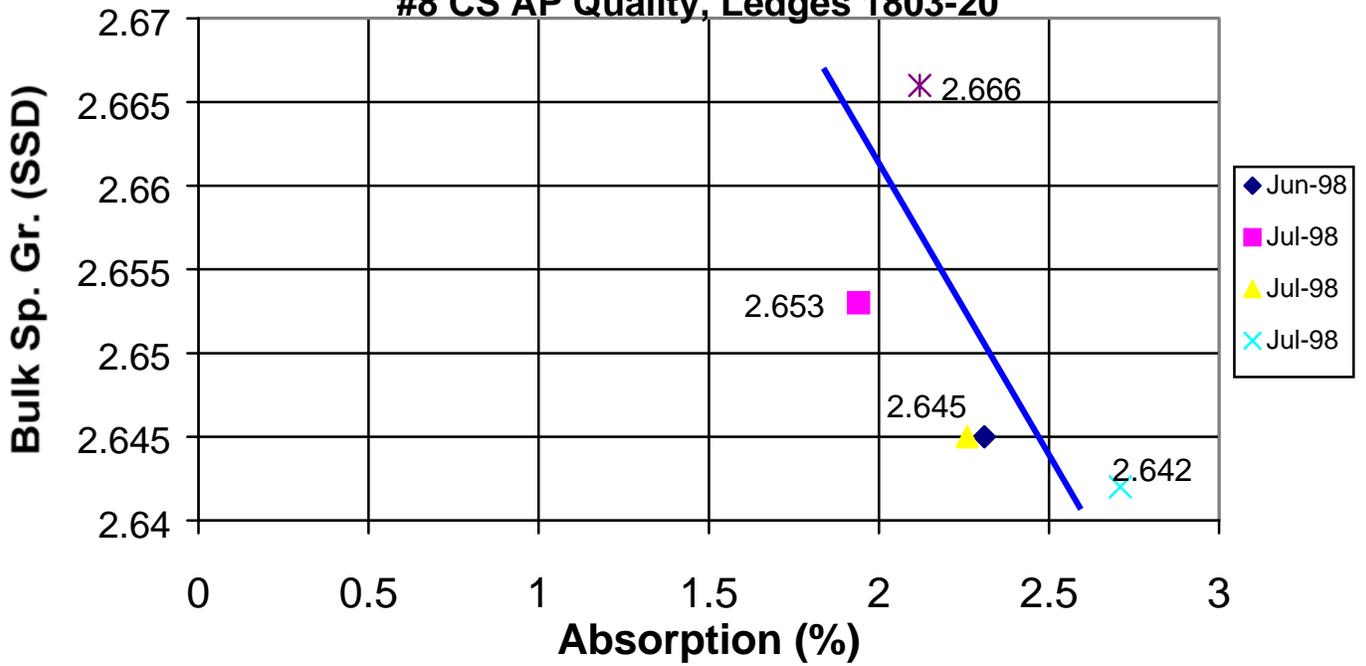


Figure 3.6
Bulk Sp. Gr.(SSD) Vs. Absorption SC #23XX
#8 CS AP Quality, Ledges 1803-20



4 TRIAL BATCH DEMONSTRATION

Purpose

Preparation

Procedure

Aggregate Properties
Concrete Batching & Mixing
Concrete Testing

CHAPTER FOUR:

TRIAL BATCH DEMONSTRATION

PURPOSE

A trial batch demonstration (TBD) is required for each proposed mix design for QC/QA superstructure concrete. The purpose of the TBD is much more than validating the required concrete properties to be within the specification requirements for the concrete mixture. The TBD also provides an opportunity for the Contractor's Certified Concrete Technician and the Departments Qualified Technician to verify proper equipment calibration and testing procedures prior to any concrete placement in the structure. The Contractor and the PE/PS should both be assured that QC testing will accurately represent the concrete for any process control decision and Acceptance testing will assess the proper adjustment points, if any. Failure to accomplish this at the TBD can result in inaccurate assessment of adjustment points or erroneous failed material investigations when job concrete is placed

The results from a successful TBD can provide the Contractor with baseline properties from which to plan process control of the concrete mixture. Future changes in properties of aggregates, pozzolans, cements, and admixtures can also be compared to the results at the time of the TBD so effects on concrete properties the day of placement can be anticipated.

The TBD also provides an opportunity for the Contractor and Engineer to witness the process upstream from the plant (i.e. material receipt, storage, and handling), through batching and actual concrete production. The complete process should be inspected to provide insight as to any potential process control problems prior to job placement. A properly conducted TBD can work to resolve many problems, which would otherwise become evident on the day of the deck's construction.

PREPARATION

Scheduling a TBD is dependent on several key items, which are as follows:

1. Both the Contractor's Certified Concrete Technician and the Departments Qualified Technician are to be present.
2. The PE/PS must concur with the concrete mix design and proportioning submitted by the Contractor. This includes review of the Contractor's testing of bulk specific gravity (SSD) and absorption properties for the fine and coarse aggregate (see pages 3-16 through 3-18).

3. Adequate time must be allocated to complete the trial batch demonstration. Experience has shown that a properly conducted TBD will typically require 4-6 hours to complete. A poorly planned TBD or questionable mix design will substantially increase the length of the TBD by several hours or even days.

A TBD is not to be used for mix design experimentation or development. The Contractor and his concrete supplier must have sufficient experience in preparing a mix design for workable concrete that will perform as expected during the TBD. Problems should be few, if any, and only of a minor nature.

PROCEDURE

A two-page form has been developed which outlines a systematic approach to conducting a proper trial batch demonstration. Proper use of this form by both the Contractor and Department has proven to be a critical element in progressing through a TBD successfully in the shortest amount of time.

Aggregate Properties

Once the preliminary information is entered at the top of the form the first major task is to evaluate the properties of the fine and coarse aggregate to be incorporated into the concrete. The absorption values for fine and coarse aggregate were determined by the Contractor's sampling and testing and were submitted as part of the mix design and proportioning. It is imperative that the Department concurs with these values prior to the TBD. An example of how to initiate the use of this form is shown in Table 4.1.

AGGREGATE PROPERTIES

Properties	Contractor Result	INDOT Result
FA Bulk Sp. Gr. (SSD)	2.632	-NA-
FA Absorption	2.0 %	-NA-
FA Moisture	%	%
FA Gradation	(attached)	(not required)
CA Bulk Sp. Gr. (SSD)	2.711	-NA-
CA Absorption	1.4 %	-NA-
CA Moisture	%	%
CA Gradation	(attached)	(not required)
Agg. Correction Factor	%	%

Table 4.1

The Certified and Qualified Technicians must obtain samples of the fine and coarse aggregate, of sufficient quantity, to test for moisture content and aggregate correction factor. The moisture contents are to be used in Water/Cementitious Ratio determination. Additional samples of the fine and coarse aggregate must also be obtained by the Contractor's representative for gradation analysis, and possibly bulk specific gravity and absorption determination

The samples should be representative of the aggregates that will actually be batched in the QC/QA superstructure concrete. If the plant is equipped with moisture probes it would be very beneficial for the samples to be from material passing over the probe so a check can be made on the accuracy of the moisture meter. Subsequent changes in the moisture meter prior to batching would then serve as a basis for adjusting the moistures originally measured by AASHTO T 255. If there are no probes to monitor moisture in the aggregates, it becomes more critical that batching contain the aggregates that were accurately represented by the samples. In such a situation it is beneficial for the TBD to occur on a day when production for commercial and/or other state work is minimal. The moisture content results between the Certified and Qualified Technicians must be fairly close otherwise there would be too much of a discrepancy in the Water/Cementitious Ratio. The TBD should not progress until discrepancies are resolved.

An example of how the aggregate properties might look on the form is presented in Table 4.2.

AGGREGATE PROPERTIES

Properties	Contractor Result	INDOT Result
FA Bulk Sp. Gr. (SSD)	2.632	-NA-
FA Absorption	2.0 %	-NA-
FA Moisture	6.8 %	6.6 %
FA Gradation	(attached)	(not required)
CA Bulk Sp. Gr. (SSD)	2.711	-NA-
CA Absorption	1.4 %	-NA-
CA Moisture	2.3 %	2.5 %
CA Gradation	(attached)	(not required)
Agg. Correction Factor	%	%

Table 4.2

The Aggregate Correction Factor may be determined at this time; however, it may be a more effective use of time to conduct the test during the agitation period after batching and mixing the QC/QA concrete which simulates the delivery time. It is critical that testing be done by both the

Certified and Qualified Technicians to establish an accurate value to be used in air content measurement. Aggregates in Indiana have been found to range from a value of 0.1 to 1.0. It should be noted that aggregates having a high absorption do not necessarily correlate to a high aggregate correction factor.

Concrete Batching & Mixing

The next step is to progress to the table on the form entitled "Concrete Batching". The mix design batch weights are simply transferred to the second column of the table as exemplified in Table 4.3.

Materials	Design Batch Wts. (SSD Agg. Wts.) lbs
Cement	658
Pozzolan	-----
Silica Fume	-----
FA	1211
CA	1742
Water	260
Σ	3871

Table 4.3

The next column on the form identifies what the aggregate batch weights would be in a completely dry condition. This is calculated by dividing the SSD aggregate weight by 1 plus the absorption (as a decimal).

Example: $1211 \div (1 + 0.020) = 1187$ lbs FA Dry Wt.

$$1742 \div (1 + 0.014) = 1718 \text{ lbs CA Dry Wt.}$$

These numbers are inserted in the form as illustrated by Table 4.4 for the example problem.

Target batch weights can now be determined based on the moisture content of the aggregates. This is calculated by multiplying the dry aggregate batch weights by 1 plus the moisture content (as a decimal).

Example: $1187 \times (1 + 0.068) = 1268$ lbs FA Moist Wt.

$$1718 \times (1 + 0.023) = 1758 \text{ lbs CA Moist Wt.}$$

Table 4.5 shows how these numbers would be entered on the form. It is important to note that the moisture content determined by the Contractor's Certified Technician is used in establishing target batch weights for aggregates.

Materials	Design Batch Wts. (SSD Agg. Wts.) lbs	Dry Aggregate Batch Weights lbs
Cement	658	-NA-
Pozzolan	-----	-NA-
Silica Fume	-----	-NA-
FA	1211	1187
CA	1742	1718
Water	260	-NA-
Σ	3871	-NA-

Table 4.4

Materials	Design Batch Wts. (SSD Agg. Wts.) lbs	Dry Aggregate Batch Weights lbs	Target Batch Wts. (Moist Agg. Wts.) lbs
Cement	658	-NA-	658
Pozzolan	-----	-NA-	-----
Silica Fume	-----	-NA-	-----
FA	1211	1187	1268
CA	1742	1718	1758
Water	260	-NA-	
Σ	3871	-NA-	

Table 4.5

The target batch weight for mix water must be reduced by the amount of free water provided by the aggregates. The difference between the aggregate batch weights in a moist condition and the saturated surface dry condition gives the proper result.

Example: $1268 - 1211 = 57$ lbs free water from fine aggregate

$1758 - 1742 = 16$ lbs free water from coarse aggregate

$$57 + 16 = 73 \text{ lbs free water contributed by aggregates}$$

The amount of free water contributed by the aggregates must be subtracted from the water content of the mix design to obtain the target.

Example: $260 - 73 = 187$ lbs mix water target

Table 4.6 illustrates where to enter target batch weight for water on the form for the example problem. The summation of all target batch weights for each component is also entered.

Materials	Design Batch Wts. (SSD Agg. Wts.) lbs	Dry Aggregate Batch Weights lbs	Target Batch Wts. (Moist Agg. Wts.) lbs
Cement	658	-NA-	658
Pozzolan	-----	-NA-	-----
Silica Fume	-----	-NA-	-----
FA	1211	1187	1268
CA	1742	1718	1758
Water	260	-NA-	187
Σ	3871	-NA-	3871

Table 4.6

It is important to note that the moist aggregate weight may not always be above the weight representing a saturated surface dry condition. It is more likely to happen with a crushed stone coarse aggregate, particularly if that material is produce by a dry crushing operation. If the moisture content of an aggregate is below the absorption value, then aggregate free water becomes a negative amount and additional mix water may be needed to batch concrete at the target water/cementitious ratio.

At this point it should be recognized that many computerized batching systems utilize what is termed "free moisture content" which is different from total moisture content. Free moisture is the amount of moisture in the aggregate beyond the saturated surface dry condition; where as, total moisture content is the amount of moisture in the aggregate beyond the totally dry condition. Dealing with differences in percentages results in target batch weight being slightly higher, and mix water requirement being slightly lower (i.e. 1269 lbs FA, 186 lbs water for the example problem). The difference becomes more pronounced as total moisture content increases.

A plant which operates using free moisture content of aggregates will result in a target water content that is slightly conservative (i.e. slightly lower water/cementitious ratio).

The next step is for the Contractor's representative to establish a target batch size of concrete to make. The batch must be sufficiently large to account for the limited accuracy of the scales at low weights. A minimum size of 3 yd³ to 4 yd³ is recommended. A lesser batch might otherwise be out of tolerance creating a yield problem or mix that does not represent the intended design.

The total batch weight of each ingredient to be charged into the mixer is calculated next by multiplying the target batch weights by the target batch size. The example problem values are presented in Table 4.7.

Materials	Target Batch Wts. (Moist Agg. Wts.) lbs	Target Batch Size yd ³	Total Target Batch Wts. lbs	Actual Batch Wts. lbs	Error ± %
Cement	658	4.0	2632		
Pozzolan	-----	4.0	-----		
Silica Fume	-----	4.0	-----		
FA	1268	4.0	5072		
CA	1758	4.0	7032		
Water	187	4.0	748		
Σ	3871	-NA-	-NA-		-NA-

Table 4.7

It is highly recommended that the total batch weight calculated for each component be checked against the values that the batch plant operator intends to use. This should even be done with a computerized batching operation. Miscommunication or errors in control panel settings can quickly create significant delays in time and effort. The amount of water to be batched by the plant may intentionally be reduced by the amount of water to be used in washing down the funnel and fins of the transit mixing truck. This amount of water, which is typically 25-42 lbs, can have a significant effect on water/cementitious ratio in a reduced size batch of 3 to 4 yd³.

Once the total batch weights are confirmed as being correct, the ingredients can be weighed and recorded in the column entitled "Actual Batch Weights." The percentage error between the total target batch weight and the actual batch weight is recorded in the last column of the form. This is calculated by subtracting the total target batch weight from the actual batch weight and divide by the total target batch weight. Multiply this number by 100 to determine the percentage.

Example: $[(2625 - 2632)/2632] \times 100 = -0.3 \%$ error in cement batching
 Table 4.8 illustrates data entry on the form for all ingredients.

Materials	Target Batch Wts. (Moist Agg. Wts.) lbs	Target Batch Size yd ³	Total Target Batch Wts. lbs	Actual Batch Wts. lbs	Error ± %
Cement	658	4.0	2632	2625	- 0.3
Pozzolan	-----	4.0	-----	-----	-----
Silica Fume	-----	4.0	-----	-----	-----
FA	1268	4.0	5072	5040	- 0.6
CA	1758	4.0	7032	7060	+ 0.4
Water	187	4.0	748	741	- 0.9
Σ	3871	-NA-	-NA-	15466	-NA-

Table 4.8

The same procedure is used for the air entraining and chemical admixtures as well.

At this stage of the TBD, it must be determined whether the batched concrete represents the intended proportioning of the mix design. Batching tolerance must be within the requirements of 702.06, which is:

<u>Material</u>	<u>Required Accuracy</u>
Cement	± 1%
Aggregates	± 2%
Water	± 1%
Admixtures	± 3 %

The example problem, presented in Table 4.8, would therefore be within the allowable error and the batch would be considered representative of the intended design.

After batching, the concrete is to be mixed for the appropriate number of revolutions of the drum at mixing speed. Once mixing is completed, the truck is to remain at agitation speed for a period of 15-45 minutes before testing.

Concrete Testing

It may be advantageous for the Contractor to conduct a series of tests on the plastic concrete after completion of the mixing cycle. This testing provides initial information on the slump, air content, and unit weight, which can then be compared to the testing conducted after the simulated transit time. Although the specification requires a minimum Air Content of 5.0% at the TBD, the Contractor may prefer a higher air content if there

are concerns about compressive strength. If the air content is less than the desirable result the Contractor may wish to add additional air entraining agent (AEA) to the mixed load of concrete in an effort to increase air content. However, this is difficult to accomplish since it typically takes a large dosage of air entraining agent to increase the air content only a few tenths of a percent. Additional water may be used to assist in dispersal of the AEA within the mixed concrete; however, it must be measured accurately and recorded as part of the batch water. If more than one adjustment is needed to obtain the desired air content the truckload should be rejected and another batch prepared.

At the end of the 15-45 minute agitation time, the concrete is tested by the Certified Concrete Technician and the Qualified Technician. Both parties must test the concrete for the specified plastic properties and cast at least four cylinders for compressive strength determination at 7 and 28 days.

The test results are to be reported on page 2 of the TBD form. Table 4.9 is an example of how the plastic properties would be recorded.

CONCRETE TESTING

Plastic Property	Contractor Quality Control Technician	INDOT Acceptance Sampler	Tolerance Check	Third Party Results
W/(C+P)	0.392	0.394	+0.002	
Unit Wt. (lbs/ft ³)	146.0	145.9	-0.1	
Air Content (%)	5.8	5.7	-0.1	
Slump (in)	6.00	6.25	+0.25	
Relative Yield	0.981	0.982	-NA-	

Table 4.9

A tolerance check is made between results from the two parties and is recorded in the appropriate column. Table 4.9 exemplifies comparative results that are well within tolerance.

A fifth column is included on the form for recording test results from a third party, should the situation arise. These results are for information only but may help to solve problems if results are out of tolerance.

The next table on page 2 of the form deals with comparison of measured unit weight with the predicted value established by the linear equation for the mix design. The predicted unit weight is calculated by simply entering the measured air content in the linear equation. Recalling the example CMD linear equation from Chapter 3 would provide the following calculations.

Example: Contractor's Predicted UW = $-1.54 (5.8)+153.4 = 144.5 \text{ lbs/ft}^3$

Department's Predicted UW = $-1.54 (5.7)+153.4 = 144.6 \text{ lbs/ft}^3$

Comparison of predicted values with their respective measured unit weight provides an easy determination of how close the batched concrete represents the intended CMD. The tolerance check of the example illustrates non-compliance with the specification requirements for a TBD, as Table 4.10 illustrates.

LINEAR EQUATION

	Predicted Unit Weight lbs/ft ³	Measured Unit Weight lbs/ft ³	Tolerance Check ± %
Contractor Rep.	144.5	146.0	+1.0
INDOT Rep.	144.6	145.9	+0.9
Third Party			

Table 4.10

If the tolerance checks of predicted versus measured unit weight is outside the specification limits, an investigation by the Contractor and PE/PS is required. If the concrete was accurately batched, mixed, sampled, and tested, the most likely cause would be an inaccurate moisture content, bulk specific gravity, or absorption for one, or both of the aggregates.

If the moisture content were actually higher than what was expected, the measured unit weight would be lower than expected. If the moisture content were actually lower than what was expected, the measured unit weight would be higher.

The relationships presented in Table 4.11 can be useful in estimating the effect on unit weight and water cementitious ratio for a variety of causes. The total effect on concrete unit weight or water cementitious ratio is cumulative from the individual causes. The values tabulated below are representative of a typical mix having 40% fine to total aggregate ratio:

Possible Causes	Effect on Concrete Unit Weight	Effect on Concrete W / (C+P)
Limits of Batching Tolerance	$\Delta \pm 0.3 \text{ lbs/ft}^3$	$\Delta \mp \mathbf{0.007}$
$\Delta \pm 0.030$ in FA Bulk (SSD)	$\Delta \pm 0.5 \text{ lbs/ft}^3$	None
$\Delta \pm 0.5 \%$ in FA Absorption	$\Delta \pm 0.3 \text{ lbs/ft}^3$	$\Delta \mp \mathbf{0.009}$
$\Delta \pm 0.5 \%$ in FA Moisture	$\Delta \mp \mathbf{0.3} \text{ lbs/ft}^3$	$\Delta \pm 0.008$
$\Delta \pm 0.030$ in CA Bulk (SSD)	$\Delta \pm 0.6 \text{ lbs/ft}^3$	None
$\Delta \pm 0.5 \%$ in CA Absorption	$\Delta \pm 0.5 \text{ lbs/ft}^3$	$\Delta \mp \mathbf{0.013}$
$\Delta \pm 0.5 \%$ in CA Moisture	$\Delta \mp \mathbf{0.5} \text{ lbs/ft}^3$	$\Delta \pm 0.012$

Table 4.11

Additional testing for aggregate moisture content and/or bulk specific gravity (SSD) and absorption may very well be required to resolve a concrete unit weight measurement being outside the tolerance from the linear equation, as encountered in the example problem.

The compressive strength cylinders must be cured and transported properly to the testing laboratory. It is imperative that the specimens be clearly identified as to which mix design and TBD they represent. The age at which the specimens are to be broken must also be clearly identified for the laboratory. Cylinders that are broken at an age of 7-days provide early age strength capability of the CMD and may be indicative of a 28-day strength result that will not meet the minimum specification requirement or the expectations of the Contractor. The tolerance check between specimens cast by Certified and Qualified technicians is conducted on the 28-day strength only. An example of recording the test data on page 2 of the form is shown in Table 4.12.

COMPRESSIVE STRENGTH

Age In Days	Contractor's Lab Result psi		INDOT District Lab Result psi		Tolerance Check ± %
	Specimen	Average	Specimen	Average	
7	4770	4820	4310	4360	-NA-
7	4870		4410		-NA-
28	5990	6035	5600	5665	-6.1 %
28	6080		5730		
					-NA- -NA-

Table 4.12

An additional row is provided at the bottom of the table for test results on additional cylinders that may be tested at an age other than the minimum specified.

The PE/PS's concurrence with a CMD requires that the trial batch demonstration be successfully completed. The Contractor's test results shall be used to validate the mix as complying with the specification requirements. The Department's results must be within the specified tolerance of the Contractor's results. Any test result that is not within tolerance is to be investigated by both parties as to the cause and corrective actions needed to resolve the discrepancy.

5 FIELD OPERATIONS

Concrete Plants

- Ready-Mix Plants**
- Central Mix Plants**

Batching

- Aggregates**
- Cement**
- Fly Ash or GGBFS**
- Water**
- Admixtures**

Mixing and Transporting

- Stationery Mixers**
- Truck Mixers**

Pumping

- Requirements**
- Causes of Air Increase**
- Causes of Air Loss**
- Controlling Air Content**

Curing

- Requirements**
- Evaporation Rate**

CHAPTER FIVE:

FIELD OPERATIONS

The production, transportation, placement, and curing of QC/QA superstructure concrete is achieved in many different acceptable ways. Because each step in the process is critical and may affect the quality of the final product, it is important to understand the proper procedures for each. This chapter explains the common techniques used for each of these steps.

CONCRETE PLANTS

Each concrete plant is required to be inspected annually by INDOT in accordance with ITM 405. All plants basically have similar operations but vary in the types of components and amount of automation. Their function is to proportion the various components in the exact quantities which will make the specified concrete. The two most common types of concrete plants are:

1. Ready-Mix Plants
2. Central Mix Plants

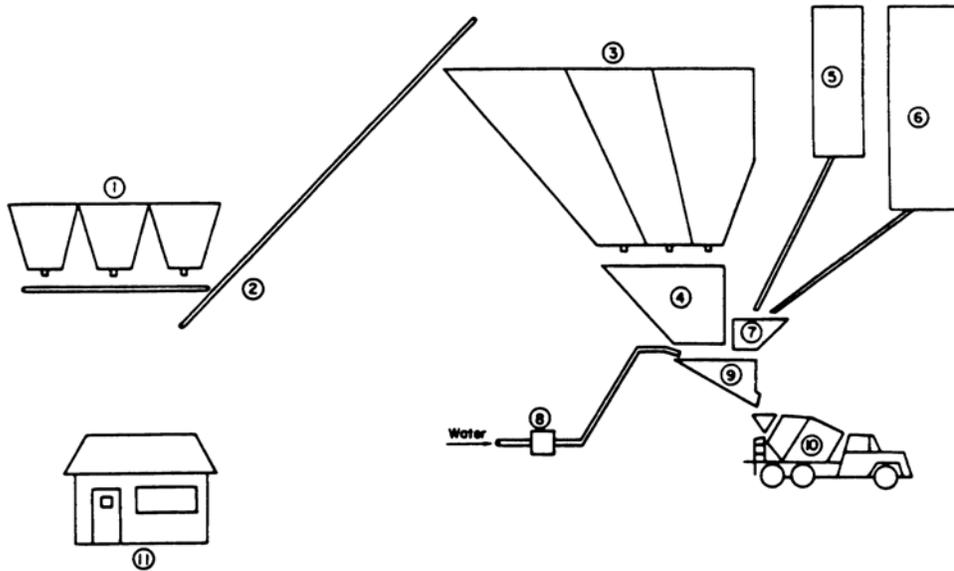
Ready-Mix Plants

Ready-mix plants are the most commonly used plants by the industry. Their function is to proportion the required components to make the desired batch of concrete. After all of the components have been discharged into the truck, the truck's mixer drum revolves and blends the components until delivery to the site of work.

Central Mix Plants

Central mix plants are normally mobile units that are located at large quantity work sites; however, more and more of these type plants are being placed at permanent locations that produce large quantities of concrete. The function of a central mix plant is very similar to a ready-mix plant with one major addition. After central plants proportion the components, a high speed, large volume mixer mixes the concrete. The freshly mixed concrete is deposited into trucks for delivery to the site of work. High volume central mix plants may have two mixer drums to increase the output capacity.

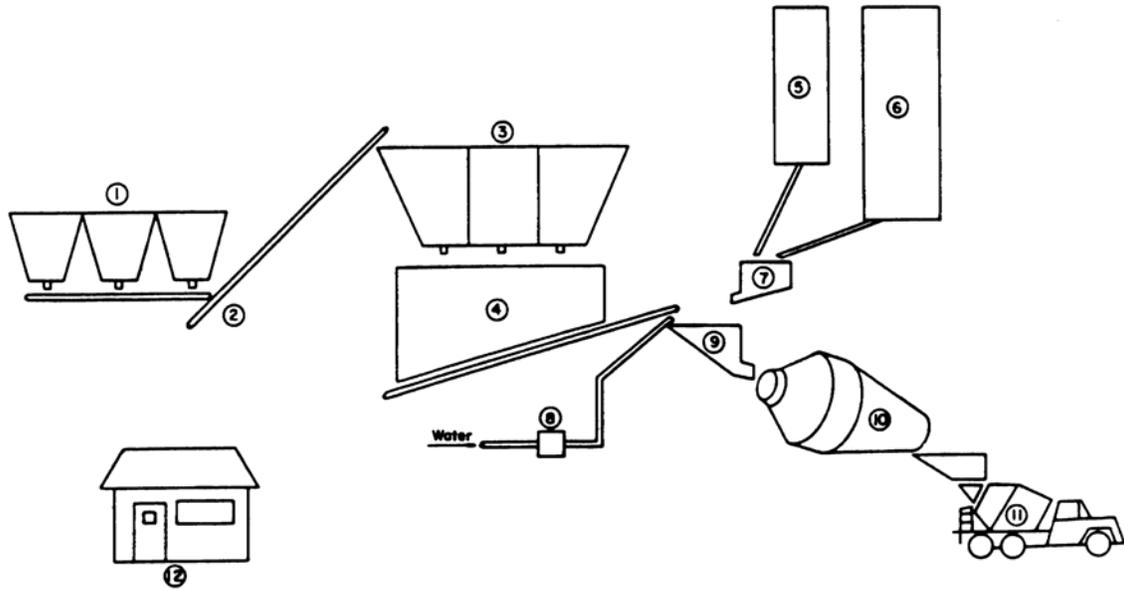
READY MIX PLANT



1. Aggregate Feeder Bins
2. Cold Feed System
3. Aggregate Proportioning Bins
4. Aggregate Weigh Hopper
5. Fly Ash Silo (OPTIONAL)
6. Cement Silo
7. Cement and Fly Ash Weigh Hopper
8. Water Meter System
9. Discharge Boot
10. Truck, Transit Mix
11. Control House

FIGURE 5.1

CENTRAL MIX PLANT



1. Aggregate Feeder Bins
2. Cold Feed System
3. Aggregate Proportioning Bins
4. Aggregate Weigh Hopper
5. Fly Ash Silo (OPTIONAL)
6. Cement Silo
7. Cement and Fly Ash Weigh Hopper
8. Water Meter System
9. Discharge Boot
10. Rotary Drum Mixer
11. Truck, Dump, Agitatory, or Transit Mix
12. Control House

FIGURE 5.2

BATCHING

Batching is the process of weighing and introducing into the mixer the ingredients for a batch of concrete. INDOT requires that the minimum batch shall be 2 yd³, unless otherwise permitted. Specific requirements for the bins and scales are designated in 702.06(d) of the Standard Specifications. The ingredients that may be batched through the plant include aggregates, cement, fly ash, ground granulated blast furnace slag, water, and the admixtures.

Aggregates

Aggregates are either stockpiled at the concrete plant or unloaded directly into the aggregate feeder bins. When stockpiling aggregates, care should be taken to prevent segregation. The most common procedure for building a stockpile is by individual truck loads. The best truck-built stockpiles are those that are constructed one dump high with each dump placed against the previously dumped material. Because of the low profile of the stockpile, large particles are less likely to roll down the sloped sides of the pile and cause segregation of the aggregate. The disadvantage of truck-built stockpiles is that they require more space than other stockpiling techniques. To reduce the stockpiling area, some dumps may be restocked on top of other dumps with an endloader operating from ground level. In this case, care should be taken to place the upper lift back from the edge far enough that a long sloped face is not created that would cause segregation. The height of the stockpile cannot exceed 6 ft.

Stockpiles should be sufficiently separated to avoid contamination and placed in well drained areas to promote uniform moisture content. Washed aggregates are required to drain for a least 12 h prior to use. Longer drainage times may be required when the moisture becomes non-uniform.

Retrieving material properly from a stockpile is just as important as building the stockpile properly. The entire front face of each stockpile should be worked by a front-end loader side to side when charging the aggregate feed bins. The sides of the face should be mixed with the center of the face and the existing yard material not included in the bucket.

Either a bucket elevator or belt elevator moves the aggregate from the aggregate feed bins into the aggregate proportioning bins. The aggregates are deposited from the proportioning bins into the weigh hopper. The flow of aggregates during this transfer is controlled to measure the exact amount. The proportioning (batching) operation can range from a fully automated system to a manually controlled system using hand pulled levers. Although the fine and coarse aggregates are deposited in the same weigh hopper, each type of aggregate must be weighed separately to maintain proper proportioning. Batching is conducted so as to obtain the aggregate weights required for one batch within a tolerance of ± 2 percent. The gate on each proportioning bin must close tightly to prevent leakage of material into the weigh hopper. The aggregate in the weigh hopper is now ready to enter the mixer. The two keys to a successful aggregate operation are segregation control and accurate weighing of each component.

Cement

Cement is typically brought to the plant by bulk transport truck and is placed into a silo. The cement weighing hopper is required to be sealed and vented to preclude dusting during operation. The correct amount of cement for the batch is deposited into the weigh hopper. The accuracy of cement batching is required to be ± 1 percent of the required weight. When the correct amount of cement is in the weigh hopper, the cement is ready to be added to the mixer through a discharge chute along with the aggregates. The discharge chute cannot be suspended from the weigh hopper and shall be so arranged that the cement does not lodge in it nor leak from it.

Fly Ash and Ground Granulated Blast Furnace Slag (GGBFS)

Fly ash or GGBFS is received at the plant by bulk transport truck and is stored in a weather proof silo similar to cement. The cement and fly ash or GGBFS are weighed in the same weigh hopper. When a manual operated plant is used, both products are normally weighed and discharged separately. When an automatic batching plant is utilized, the fly ash or GGBFS may be weighed into the cement hopper in one cumulative operation with the cement always being weighed in first.

Water

Water is controlled by either volume or weight. The majority of plants use a meter system to measure the volume of water required.

The water meter system typically pumps straight into the mixer. A holding tank is sometimes added to the plant to increase production, similar to the weigh hopper for aggregate and cement. The most accurate method to add water is to monitor the water by weight. The accuracy of measuring the water is required to be ± 1 percent of the required amount. Accurate control of the quantity of water is important in maintaining proper slump and the water/cementitious ratio of the concrete.

The quality of the water used typically is not a problem. Potable water can be used without testing. If the quality of the water is not potable, the water is required to be tested in accordance with the Standard Specifications.

Admixtures

Admixtures usually are in liquid form, although paste and powder admixtures are acceptable. Powdered admixtures are measured by weight and added to the aggregates that have been batched into the weigh hopper. Liquid or paste admixtures are measured by weight or volume and are added to the water flow. Air entraining admixtures are normally added to the fine aggregate. Liquid admixtures are most commonly introduced by means of a calibrated cylinder operated by air pressure.

The accuracy of the measuring device for all of the admixtures is required to be ± 3 percent of the amount required. When admixtures are used in small quantities in proportion to the cement, mechanical dispensing equipment is required. Admixture dispensers should be checked daily since errors in dispensing admixtures, particularly overdoses, can lead to serious problems in both freshly mixed and hardened concrete.

MIXING AND TRANSPORTING

Concrete should be mixed thoroughly until it is uniform in appearance and all ingredients are evenly distributed. Mixers should not exceed their rated capacities and should be operated at approximately the speeds for which they were designed. If an increased output of concrete is needed, a larger mixer or additional mixers should be used rather than speeding up or overloading the existing mixer. Badly worn blades should be replaced immediately and hardened concrete removed from the blades daily to maintain efficient mixing action.

Concrete may be mixed completely in a stationary mixer and the mixed concrete delivered in a truck-agitator or truck-mixer; partially mixed in a stationary mixer and the mixing completed in a truck-mixer; or mixed completely in a truck-mixer. The most common techniques for superstructure concrete are mixing in a stationary mixer and delivery by truck-mixer and mixing completely in a truck-mixer. These two procedures will be discussed in this section.

Stationary Mixers

Concrete mixed in a stationary mixer and delivered to the project in a dump, agitator, or mixer truck is known as central-mixed concrete. The mixer is required to be operated within the limits of the capacity and speed of rotations designated by the manufacturer and within the following guidelines:

1. The complete mixing time shall be no less than 60 seconds. Mixing time shall be measured from the time that all of the cement and aggregate are in the drum.
2. The batch shall be so charged into the mixer that some of the water enters in advance of the cement and aggregates.
3. All required water shall be in the drum by the end of the first quarter of the specified mixing time.
4. The "mixing speed" shall be the recommended speed by the manufacturer of the plant. Typically, the mixing speed is between 14 and 20 revolutions per minute.
5. The mixer shall be equipped with an acceptable timing device which does not permit the batch to be discharged until the specified mixing time has elapsed.

Transportation of the central-mixed concrete by a truck-mixer shall be completed to the site of work and discharged within 90 minutes after the introduction of the mixing water to the cement and aggregates. Further mixing in the truck-mixer is allowed during transportation at the speed designated by the manufacturer of the equipment as the "agitating speed."

Truck-Mixers

Concrete mixed completely in a truck-mixer is known as transit-mixed concrete. The requirements for the use of truck-mixers include:

1. The number of revolutions of the drum or blades at mixing speed shall be no less than 70 nor more than 100, and not less than that recommended by the mixer manufacturer.
2. The truck-mixer shall be equipped with means by which the number of revolutions of the drum may be readily verified. The counters shall be actuated at the time of starting the mix at mixing speed.
3. Mixing operations shall begin within 30 minutes after the cement has been added to the aggregates.

4. Wash water shall not be used as a portion of the mixing water for succeeding batches.

The truck-mixer should not mix at the mixing speed beyond the required numbers of revolutions. Extended mixing at this speed will result in concrete strength loss, temperature rise, excessive loss of entrained air, and accelerated slump loss.

PUMPING

Concrete pumping has become a common technique used in bridge construction because this method allows the placement of concrete at locations not accessible to concrete trucks. However, due to the nature of the pumping process, pumping of concrete can cause the air content of concrete to be altered. These changes can be anticipated and controlled using proper production, testing, and pumping techniques. Also, coordination and cooperation between all parties involved is essential to ensure the success of the pumping operation.

Requirements

When pumping is used to convey concrete, the material shall be handled so as to minimize the change in properties of the concrete. The pumping equipment shall be mechanically sound and adequate in capacity for the proposed work. In addition, the following requirements of the Standard Specifications must be met:

1. The concrete shall not be pumped through aluminum or aluminum alloy pipe.
2. All pipes used for pumping shall be kept clean and free from coatings of hardened concrete.
3. Pump lines shall not rest directly on epoxy coated reinforcing steel.
4. The pumping equipment shall be located such that operational vibrations will not damage freshly placed concrete.
5. When placing concrete directly from a truck mounted boom, the concrete pump lines shall have a flexible end section at least 10 ft long.
6. The method of placement shall be such as to result in a steady and continuous discharge. This may require a restrictive device at or near the end of the discharge tube, laying the flexible end section horizontally, or other means.

7. For initial placement of concrete pours which are predominately vertical, the discharge end of the flexible end section shall be within 2 ft of the bottom of the pour.

Causes of Air Increase

There are two possible causes for the increase in air content. Both can occur at delivery of the concrete. The causes are:

1. Initial pressure in the line
2. Pumping in adverse weather

Initial Pressure

An increase in air content can occur when the concrete is introduced to the pump. When concrete first enters the pump line a small amount of air is mixed into the concrete. The additional air is the result of the pressure present in the pump line. This phenomenon may be unavoidable, but should be noted when sampling is scheduled. Also, this problem should be anticipated and considered in the production process.

Adverse Weather

Pumping concrete in adverse weather should be avoided. Water from rain can be added to the concrete directly or indirectly through build up in the hopper. The excess water in the concrete mix will cause an increase in the air content. If adverse weather should come unexpectedly, immediate action should be taken to protect the concrete and the hopper from the rain.

Causes of Air Loss

The causes for a decrease in air content of pumped concrete are as follows:

1. Loss of air content due to impact force
2. Bursting of air voids by vacuum
3. High pressure dissolution of voids

Loss of Air Content Due to Impact Force

The impact of the moving concrete with stationary objects results in the loss of air. Thus, the voids are broken by mechanical action. This action can be responsible for losses of between 20 and 40 percent of the initial air content. Impact can occur on the walls and joints of the pump lines as well as the impact of the concrete on the deck.

In general, losses from the pump can be anticipated and taken into account in the initial air content of the concrete. However, control of air loss due to impact with the deck is a matter of construction technique. In order to control this type of air loss, the fall distance from the end of the pump line should be minimized. A good fall distance is considered less than 2 ft. Also, to reduce the speed at which the concrete is deposited on the deck, various attachments can be added to the end of the line. These attachments include reducers, elbows and hoses.

Bursting of Air Voids by Vacuum

Concrete may overcome the effects of friction while being pumped through a descending line. When this loss of friction occurs, a vacuum can be created in the line. In this condition, the internal pressure of larger air voids can cause them to burst. A significant drop in detected air content can be exhibited if this phenomenon occurs.

Steep, descending sections of the boom allow the concrete in the line to speed up and to become discontinuous. These two factors, speed and discontinuity, facilitate the development of a vacuum in the line. Thus, steep, descending sections of the line should be kept to a minimum. Also, reducers, elbows or hoses can be configured to reduce the speed at which the concrete flows and to keep the flow of concrete continuous.

Busting of air voids by vacuum can also occur if the mix has too stiff a consistency as may be indicated by a low slump. Again the mix will have the tendency to break apart, thus causing a vacuum to develop. To remedy this situation, a mix with a proper consistency for pumping should be used.

High pressure dissolution of voids

High pumping pressure causes the air voids in the concrete to become smaller or to disappear completely. These voids do not completely recover once the pressure is returned to lower levels. This mechanism effects smaller air voids more so than the larger voids. It is these small voids that are essential to the concrete's freeze-thaw durability. Thus, this method of air loss, when compared to the previous two methods, can have the most severe effect on the durability of concrete. This phenomenon occurs within the first few seconds that the concrete is under pressure. Thus, increasing the pump rate to decrease the amount of time the concrete is under pressure will not lower the amount of damage to the air void system.

One way to prevent this problem from occurring is to keep the pump pressure to a minimum. Also, if a concrete has a stiff consistency the pressure required to pump the concrete will be higher. Thus, using a concrete with a proper consistency will help prevent this type of air loss.

Controlling Air Content

Control of air content in pumped concrete primarily depends on the following items:

1. Proper production of the concrete
2. Proper testing of the air content of the concrete
3. Proper concrete pumping techniques.

Proper Production of Concrete

Concrete moves as a cylinder or slug through the pipeline system of the pump truck. The concrete is separated from the wall of the line by a layer of water which serves as a lubricant. The pump lines often contain tapered sections and elbows through which the concrete must pass. Aggregate size, aggregate gradation, water content, cement content, and admixtures all can have an effect on the pumping characteristics of concrete.

Consistency of the mix is a primary concern. If a mix has a stiff consistency, the pump will not be able to easily move the concrete and the line may become blocked. Also, stiff consistency type mixes tend to become discontinuous within the line. When this occurs, a vacuum can develop in the line which will cause the bursting of air voids. Further, high pumping pressures are required to pump a stiff mix. This may cause high pressure dissolution of voids.

Conversely, if the mix has a loose consistency as may be indicated by a high slump, the mix may segregate under the pressure of the pump. If segregation occurs, the aggregate may settle in the line and also cause the line to become blocked. Also, a high slump mix will flow too quickly through the line, causing vacuum pressure to develop. Further, quick movement through the line will increase the speed at which the concrete impacts objects. Impact with stationary objects also causes air loss in concrete. Thus, when developing a new mix design or when working with a mix with unknown pumping characteristics, a full-scale test of the mix is recommended.

In order to prevent any problems at the jobsite, the uniformity of the concrete from batch to batch is essential. Changes from batch to batch are likely to change the pumping characteristics of the concrete.

Proper Testing

In order to ensure that the concrete being delivered meets the mixture requirements, air content tests can be performed before the concrete is discharged into the pump. Although not required as a quality control test, these tests will serve to verify the initial air content and to monitor mix variability.

Many different mechanisms can cause the loss of air voids in the pumped concrete. Thus, in order to assure that the concrete being tested for air content most accurately represents the concrete that is being placed, samples must be taken on the bridge deck, directly at the end of the pump line. This concrete will best represent the changes made to the air content of the mix by the pumping process. Tests taken at the pump hopper cannot be used to represent the concrete that is placed in the bridge deck.

Sampling at the end of the pump line may be difficult due to boom or line configurations. Further, pumping pressure may cause added difficulties in sampling. Thus, it is necessary to plan ahead to assure that representative sampling can be done with minimal disruption to the pumping pressure.

Proper Pumping

Many of the losses of air in concrete can be controlled by proper pumping techniques. Keeping the pump at the lowest possible pressure helps prevent high pressure dissolution of air voids. Minimizing steep, descending sections of the pump line prevents bursting of air voids by vacuum. Keeping a proper fall distance helps to decrease the loss of air content due to impact force. A good rule of thumb is to match the pump rate to the speed at which the concrete falls through the line.

Different line configurations can also be utilized for pumping concrete. These configurations are used to build up resistance in the line and slow the descent of the concrete. The following configurations are used for this purpose:

1. Reducers
2. Elbows
3. Hose slung 90 degrees
4. Extended hose, laid horizontally

As is with any construction process, safety is a primary concern. Any attachment or series of attachments made at the end of the line must not exceed the maximum weight requirement as stipulated by the pump manufacturer.

Communication

Many individuals are involved with the production, testing, pumping, and placement of the concrete. Therefore, coordination and cooperation between the producer, the technician, the pumper, and the contractor are essential. A pre-pump meeting, which all involved parties attend, is recommended. This step will help assure that a clear line of communication is established between everyone before the pumping begins.

CURING

Curing of concrete is the maintenance of a satisfactory moisture content and temperature during some period immediately following placing and finishing. Curing has a major influence on the properties of hardened concrete such as durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicer salts. The top surface strength development of exposed slab surfaces can be reduced significantly when curing is defective.

The objectives of curing are to:

1. Prevent (or replenish) the loss of moisture from concrete
2. Maintain a favorable concrete temperature for a definite period of time.

Maintaining the moisture in concrete is critical for obtaining complete hydration of the cement. Most concrete mixtures contain sufficient water for workability and hydration of the cement; however, any appreciable loss of water by evaporation or otherwise will delay or prevent complete hydration and proper development of gel to close off the pore structure. It is important to retain the water the first few days after placement since hydration is relatively rapid during this time. When moist curing is interrupted or insufficient, the concrete will not develop to its full potential of strength, durability and impermeability. If moisture loss from the exposed surface exceeds the rate of bleeding, stresses will develop from the shrinkage, which may result in surface cracking.

Maintaining a favorable concrete temperature for a period of time is essential for obtaining the proper hydration. The hydration of the cement proceeds at a much slower rate when the concrete temperature is low. The strength of the concrete is effected as follows:

50°F -- unfavorable for the development of early strength

40°F -- early strength is greatly retarded

14°F - 32°F -- little or no strength develops

Requirements

QC/QA superstructure concrete is required to be wet cured per the Standard Specifications with some exceptions. After finishing and texturing the bridge deck, the exposed concrete surface shall receive an application of an approved evaporative retardant to protect against plastic shrinkage cracks. Reapplication of the retardant should be performed whenever the surface is disturbed, or when drying of the surface is observed. The evaporative retardant may be eliminated for concrete not containing silica fume, if the Contractor can substantiate that the evaporation rate for any exposed concrete does not exceed 0.15 lbs/ft²/h. Evaporative retardant shall be applied to the finished or textured surface of concrete containing silica fume, regardless of evaporation rate.

Evaporation Rate

The rate of water evaporation shall be determination by the procedure specified in ACI 308 (section 1.2.1) or the following equation:

$$E = [T_c^{2.5} - (r \times T_a^{2.5})] [1 + 0.4 V] \times 10^{-6}$$

where:

E = evaporation rate, lb/ft²/h

T_c = concrete temperature, °F

T_a = air temperature, °F

r = (relative humidity %) / 100

V = wind velocity, mph

Measurements of T_a , r , and V are obtained from on site readings and compared for accuracy with readings from the nearest weather station monitored by the National Climatic Data Center. T_c is determined from the concrete placed within the bridge deck.

A relatively simple procedure for determination of the rate of evaporation is the use of the chart in Figure 5.3. By drawing a line to intercept the appropriate air temperature, relative humidity, concrete temperature, and wind velocity values, in this order, the rate of evaporation can be approximated. If the chart value is close to the maximum allowable rate of evaporation specified, the equation described previously should be used for a more accurate measurement.

Example: (See Figure 5.3)

Air Temperature = 65°F
Relative Humidity = 45%
Concrete Temperature = 60°F
Wind Velocity = 20 mph

Evaporation Rate \approx 0.11 lb/ft²/h

Example: (using formula)

$$\begin{aligned} E &= [T_c^{2.5} - (r \times T_a^{2.5})] [1 + 0.4 V] \times 10^{-6} \\ E &= [(60 \times 60 \times \sqrt{60}) - (0.45 \times 65 \times 65 \times \sqrt{65})] [1 + (0.4 \times 20)] \times 10^{-6} \\ E &= [27885 - 15328] [1 + 8] \times 10^{-6} \\ E &= 12557 \times 9 \times 10^{-6} \\ E &= 0.11 \text{ lb/ft}^2/\text{h} \end{aligned}$$

Protective Covering for Wet Curing

Concrete in bridge decks or the top surface of reinforced concrete slabs shall be wet cured continuously for at least 168 h commencing immediately after the surface is able to support the protective covering without deformation. An extended wet cure period is not required for concrete containing pozzolans.

Surfaces to be cured shall be protected by covering with cotton mats, burlap, or other satisfactory protective material that is kept continuously and thoroughly wet during the curing period. The protective covering shall be suitably anchored. Curbs, walls, handrails, copings, and other surfaces requiring a finish in accordance with 702.21 may have the covering temporarily removed for finishing, but the cover shall be restored as soon as possible

Silica Fume Modified Concrete

If the QC/QA superstructure concrete contains silica fume, an evaporation retardant is required regardless of evaporation rate and is to be applied to the exposed concrete surface immediately after finishing or texturing operations in accordance with the manufacturer's recommendation. Reapplication of the retardant should be performed whenever the surface is disturbed, or when drying of the surface is observed.

If the rate of evaporation exceeds 0.10 lbs/ft²/h, fog misting, as recommended by the silica fume manufacturer, is required to be performed after the finishing operation prior to the texturing operation. Fog misting shall not be excessive to cause water to wash the fresh concrete surface, or to stand on the surface during floating or troweling operations. Fog misting keeps the environment at the concrete surface at high humidity to protect against plastic shrinkage cracks and is not intended to facilitate finishing.

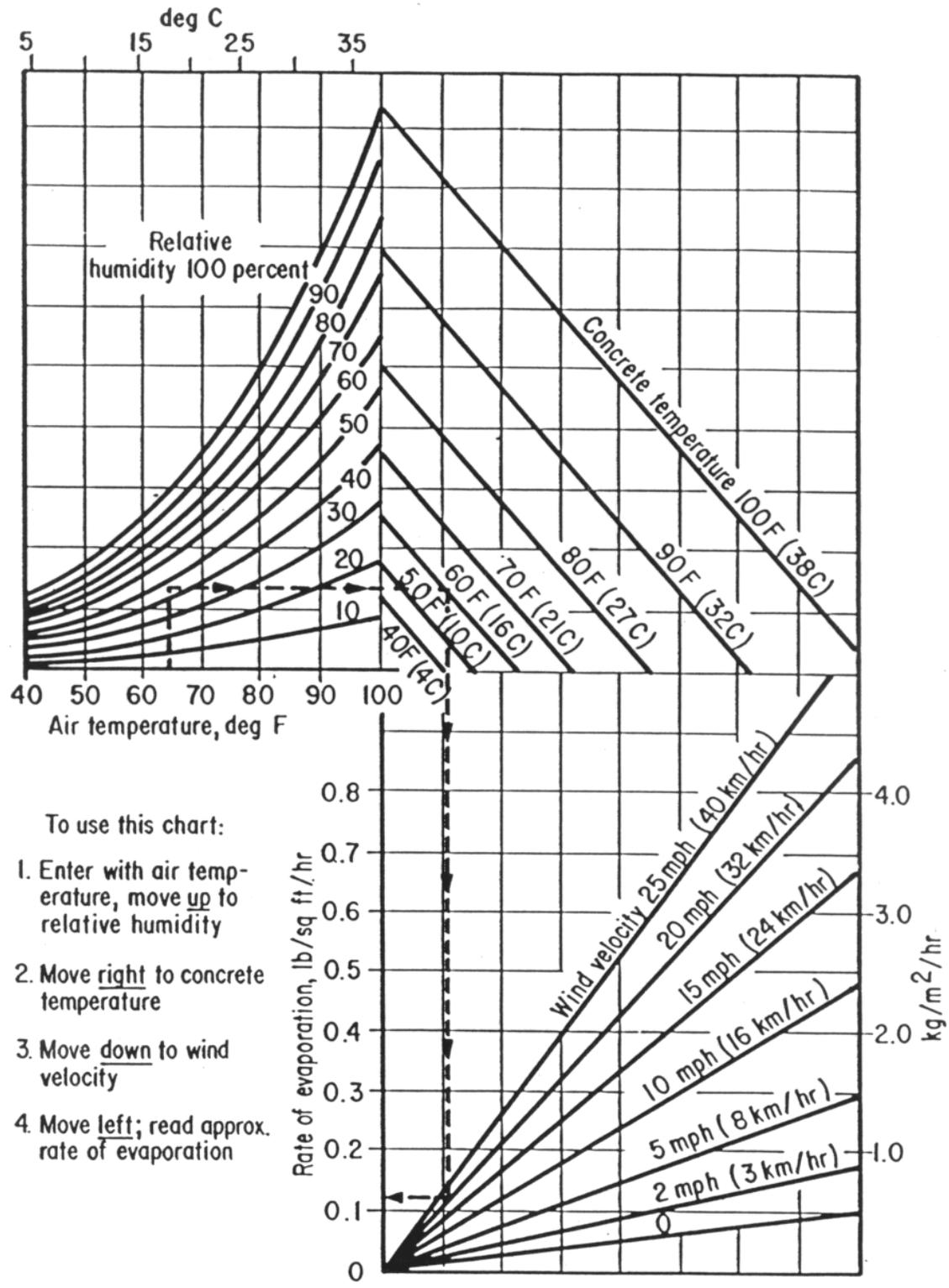


FIGURE 5.3

6 QUALITY ASSURANCE

Sublots and Lots

Random Sampling

Random Numbers

Sample Location

Sampling Procedures

Acceptance Testing

Air Content and Unit Weight

Compressive Strength

Slump

Pay Factors

Quality Assurance Adjustment

Failed Materials

Appeals

Air Content Appeal for Lot

Compressive Strength Appeal for Lot

CHAPTER SIX:

QUALITY ASSURANCE

Quality Assurance specifications require that the acceptance of material be the responsibility of INDOT. The specification addresses specifically:

1. The units of material quantity used for acceptance.
2. The process of obtaining random samples.
3. What mixture characteristics are considered of critical importance.
4. At what test values can the mixture be accepted at 100% payment.
5. At what levels can the mixture serve at less than design intent and still be of value, and be paid at some adjusted price.
6. At what level should rejection of the material be considered.
7. An appeal procedure for resolving disagreements in QC and QA test results.

This chapter discusses procedures and requirements for sampling, testing, and payment of superstructure concrete.

SUBLOTS AND LOTS

Quality Assurance specifications consider a subplot as typically 50.0 yd³ as measured against the plan quantity for each mix design of superstructure concrete. A partial subplot of 15.0 yd³ or less will be considered as part of the previous subplot and a partial subplot greater than 15.0 yd³ will be considered an individual subplot.

A lot will typically consist of three sublots or 150.0 yd³ of planned quantity of superstructure concrete for each mix design. If there is only one subplot in an incomplete lot then the subplot will be included in the previous lot. If there are two sublots in an incomplete lot then the quantity of material will be considered a lot. Therefore, a lot may contain two, three or four sublots.

If the superstructure concrete is placed at several locations on one contract, such as one bridge to another bridge or one phase to another phase, then the sublots will be determined in the order that the material was placed.

RANDOM SAMPLING

Sampling of material for acceptance testing is done by INDOT on a random basis using ITM 802. A random cubic yard of superstructure concrete within a subplot is determined and the location on the bridge deck of the random quantity is established. The random locations are not given to the Contractor so that there will be no possible influence on the production operations.

Random Numbers

A table of Random Numbers from ITM 802 (Figure 6.1) is used to determine the random quantity. The numbers occur in this table without aim or reason and are in no particular sequence. Therefore, samples obtained by the use of this table are truly random or chance, and eliminate any bias in obtaining samples.

To use this table to determine the random cubic yard of concrete to sample, select without looking one block in the table. After selecting the block the top left number in the block is the first random number used. This number will be the beginning number for the project. Proceed down the column for additional numbers and proceed to the top of the next column on the right when the bottom of the column is reached. When the bottom of the last column on the right is reached, proceed to the top of the column at the left. If all numbers in the table are used before the project is completed select a new starting number and proceed in the same manner.

Sample Location

The location where the random sample is obtained is determined by calculating the average depth of the bridge deck concrete, the random quantity within the subplot, the length of each subplot, and the random location within the subplot. The QC/QA superstructure concrete item quantities and locations are detailed in the plans and often include bridge deck and several non-bridge deck items such as wing walls, end bent diaphragms, and pier diaphragms. The width and depth of the bridge deck concrete, length of each pour, and sequence of pours are all information items that may also be obtained from the plans and are used for location of the random sample.

0.576	0.730	0.430	0.754	0.271	0.870	0.732	0.721	0.998	0.239
0.892	0.948	0.858	0.025	0.935	0.114	0.153	0.508	0.749	0.291
0.669	0.726	0.501	0.402	0.231	0.505	0.009	0.420	0.517	0.858
0.609	0.482	0.809	0.140	0.396	0.025	0.937	0.310	0.253	0.761
0.971	0.824	0.902	0.470	0.997	0.392	0.892	0.957	0.040	0.463
0.053	0.899	0.554	0.627	0.427	0.760	0.470	0.040	0.904	0.993
0.810	0.159	0.225	0.163	0.549	0.405	0.285	0.542	0.231	0.919
0.081	0.277	0.035	0.039	0.860	0.507	0.081	0.538	0.986	0.501
0.982	0.468	0.334	0.921	0.690	0.806	0.879	0.414	0.106	0.031
0.095	0.801	0.576	0.417	0.251	0.884	0.522	0.235	0.389	0.222
0.509	0.025	0.794	0.850	0.917	0.887	0.751	0.608	0.698	0.683
0.371	0.059	0.164	0.838	0.289	0.169	0.569	0.977	0.796	0.996
0.165	0.996	0.356	0.375	0.654	0.979	0.815	0.592	0.348	0.743
0.477	0.535	0.137	0.155	0.767	0.187	0.579	0.787	0.358	0.595
0.788	0.101	0.434	0.638	0.021	0.894	0.324	0.871	0.698	0.539
0.566	0.815	0.622	0.548	0.947	0.169	0.817	0.472	0.864	0.466
0.901	0.342	0.873	0.964	0.942	0.985	0.123	0.086	0.335	0.212
0.470	0.682	0.412	0.064	0.150	0.962	0.925	0.355	0.909	0.019
0.068	0.242	0.777	0.356	0.195	0.313	0.396	0.460	0.740	0.247
0.874	0.420	0.127	0.284	0.448	0.215	0.833	0.652	0.701	0.326
0.897	0.877	0.209	0.862	0.428	0.117	0.100	0.259	0.425	0.284
0.876	0.969	0.109	0.843	0.759	0.239	0.890	0.317	0.428	0.802
0.190	0.696	0.757	0.283	0.777	0.491	0.523	0.665	0.919	0.246
0.341	0.688	0.587	0.908	0.865	0.333	0.928	0.404	0.892	0.696
0.846	0.355	0.831	0.218	0.945	0.364	0.673	0.305	0.195	0.887
0.882	0.227	0.552	0.077	0.454	0.731	0.716	0.265	0.058	0.075
0.464	0.658	0.629	0.269	0.069	0.998	0.917	0.217	0.220	0.659
0.123	0.791	0.503	0.447	0.659	0.463	0.994	0.307	0.631	0.422
0.116	0.120	0.721	0.137	0.263	0.176	0.798	0.879	0.432	0.391
0.836	0.206	0.914	0.574	0.870	0.390	0.104	0.755	0.082	0.939
0.636	0.195	0.614	0.486	0.629	0.663	0.619	0.007	0.296	0.456
0.630	0.673	0.665	0.666	0.399	0.592	0.441	0.649	0.270	0.612
0.804	0.112	0.331	0.606	0.551	0.928	0.830	0.841	0.702	0.183
0.360	0.193	0.181	0.399	0.564	0.772	0.890	0.062	0.919	0.875
0.183	0.651	0.157	0.150	0.800	0.875	0.205	0.446	0.648	0.685

FIGURE 6.1 - RANDOM NUMBERS

The procedure for determining the random sample location is as follows:

1. Determine the number of lots for each concrete mix design by dividing the total quantity by 150.0 yd³ and rounding as follows:
 - a. If the resulting decimal portion is less than or equal to 0.434 then round the result down to the nearest whole number. The last lot will contain 3 or 4 sublots.
 - b. If the resulting decimal portion is greater than 0.434 then round the result up to the nearest whole number. The last lot will be less than the standard quantity, consist of 2 or 3 sublots, and likely will have one subplot of partial size.
2. Determine the average depth of bridge deck concrete for each phase on the project. The depth of concrete is calculated as follows:

$$\text{Avg. Bridge Deck Depth (ft)} = \frac{\text{Phase Quantity (yd}^3\text{)} \times 27}{\text{Width (ft)} \times \text{Length (ft)}}$$

where:

Width = Bridge Deck Width

Length = Bridge Deck Length

3. Determine the subplot size, the cumulative quantity of the phase or structure, the remainder quantity in the phase or structure, and the carry over quantity to the next phase or structure.
4. Select a random number
5. Determine the random quantity within the subplot by multiplying the subplot size by the random number.
6. Determine the random distance from the start of the phase or structure to the random sample location (nearest 0.1 ft).
7. Determine the subplot location to the nearest 0.01 ft in relation to the beginning of the lot. The beginning of lot 1 subplot 1 would be considered 0. The end of subplot 1 should be 0 plus the length of bridge deck subplot quantity. Each subsequent subplot would begin with the end of the previous subplot.

The distance to the random sample location is measured from the beginning of the QC/QA superstructure concrete on the bridge deck and along the centerline of the bridge deck pour. Distances from the beginning of the QC/QA superstructure concrete, such as each 5 ft, should be marked on the bridge deck forms to aid in determining the random location. If a subplot is not completed on the phase or structure, and there is another phase or structure on the project, then the subplot shall be completed on the other phase or structure.

Example (Figures 6.2 - 6.6)

One Structure - Two Passes

One Concrete Mix Design

Total QC/QA Superstructure Concrete = 512.5 yd³

Phase I Quantity (z) = 213.2 yd³

Phase II Quantity (z) = 299.3 yd³

$$\text{Number of Lots} = \frac{512.5}{150.0} = 3.417$$

There will be 3 lots with the last lot containing 4 sublots as follows:

CMD 1 of 1			
Sublot Nos.	LOTS		
	1	2	3
1	50.0	50.0	50.0
2	50.0	50.0	50.0
3	50.0	50.0	50.0
4			62.5
Σ	150.0	150.0	212.5

The last quantity of 12.5 yd³ in Lot 3 of Phase II is less than 15.0 yd³ and is therefore considered part of the previous subplot of 50.0 yd³. Since there is only one subplot at the completion of the structure, the 62.5 yd³ subplot (50.0 + 12.5) is included in the previous lot.

Phase I

$$\begin{aligned} \text{Bridge Deck Length (l)} &= 220.80 \text{ ft} \\ \text{Bridge Deck Width (w)} &= 35.52 \text{ ft} \\ \\ \text{Avg. Bridge Deck Depth (d)} &= \frac{213.2 \times 27}{220.80 \times 35.52} \\ &= 0.73 \text{ ft} \end{aligned}$$

Phase II

$$\begin{aligned} \text{Bridge Deck Length (l)} &= 220.80 \text{ ft} \\ \text{Bridge Deck Width (w)} &= 47.57 \text{ ft} \\ \\ \text{Avg. Bridge Deck Depth (d)} &= \frac{310.5 \times 27}{220.80 \times 47.57} \\ &= 0.80 \text{ ft} \end{aligned}$$

Lot 1 Sublot 1 (Phase I)

$$\begin{aligned} \text{Sublot Size} &= 50.0 \text{ yd}^3 \\ \text{Cummulative Quantity of Phase} &= 0+50 \\ &= 50 \text{ yd}^3 \\ \text{Remainder Quantity of Phase} &= 213.2-50.0 \\ &= 163.2 \text{ yd}^3 \\ \text{Random Number} &= 0.566 \\ \text{Random Quantity Within Sublot} &= 50.0 \times 0.566 \\ &= 28.3 \text{ yd}^3 \\ \text{Random Dist. From Start of Phase} &= \frac{(28.3-50.0+50.0)27}{35.52 \times 0.73} \\ &= 29.5 \text{ ft} \\ \text{Beginning of Sublot 1} &= 0 \text{ ft} \\ \text{End of Sublot 1} &= \frac{27 \times 50.0}{35.52 \times 0.73} \\ &= 52.06 \text{ ft} \end{aligned}$$

Therefore, the sample from Lot 1 Sublot 1 will be obtained at 28.3 yd³ which is located 29.5 ft from the start of Phase I.

Additional sample locations are indicated in Figure 6.3 - 6.6. (Notice that Lot 2 Sublot 2 begins in Phase I and ends in Phase II and the sample is required to be obtained in Phase II).

Worksheet for Planning Lot & Sublot Distribution of QC/QA Superstructure Concrete in English Units

Contract No. B-25280 Total Plan Quantity 523.7 yd³ Number of CMD's required 1

First CMD to be used, of			Second CMD to be used, of		
Construction Phase	Structure No.	Plan Quantity yd ³	Construction Phase	Structure No.	Plan Quantity yd ³
I		213.2			
II		299.3			

$$\Sigma = \frac{512.5 \text{ yd}^3}{150.0 \text{ yd}^3} = 3.417$$

$$\Sigma = \frac{\text{ } \text{yd}^3}{150.0 \text{ yd}^3}$$

1. If decimal portion is less than 0.434, round the result down to nearest whole number to determine the number of Lots. The last Lot of a CMD will contain 3 or 4 Sublots
2. If decimal portion is equal to or greater than 0.434, round the result up to the nearest whole number to determine the number of Lots. The last Lot of a CMD will be less than the standard quantity, consist of 2 or 3 Sublots, and likely will have one Sublot of partial size.
3. An individual Sublot cannot contain less than 15.1 yd³ or more than 65.0 yd³.
4. The last Lot for a CMD is required to have at least 2 Sublots, but never more than 4 Sublots.

CMD <u>1</u> of <u>1</u>										
Sublot Nos.	Quantities (yd ³) within Lot Nos.									
	1	2	3	4	5	6	7	8	9	10
1	50.0	50.0	50.0							
2	50.0	50.0	50.0							
3	50.0	50.0	50.0							
4			62.5							
Σ	150.0	150.0	212.5							

CMD <u> </u> of <u> </u>										
Sublot Nos.	Quantities (yd ³) within Lot Nos.									
	1	2	3	4	5	6	7	8	9	10
1										
2										
3										
4										
Σ										

FIGURE 6.2

**INDIANA DEPARTMENT OF TRANSPORTATION
MATERIALS AND TEST DIVISION**

**RANDOM SAMPLING FOR SUPERSTRUCTURE CONCRETE
(ENGLISH UNITS)**

Contract No. B-25280 Str. No. 227-89-45308 Construction Phase I CMD 1 of 1

QC/QA Superstructure Quantity for Phase (z) 213.2 yd³

Phase Construction Dimensions: Length (l) 220.80 ft, Width (w) 35.52 ft

Average Depth (d) = $\frac{z \times 27}{l \times w}$ 0.73 ft

Lot No. 1 Lot Size 150.0 yd³ Number of Sublots 3

Sublot No.	Sublot Size (yd ³)	Cumulative Quantity of Ph/Str (yd ³)	Remainder Quantity (yd ³)	Random No.	Random Quantity Within Sublot (yd ³)	Random Distance From Start of Ph/Str (ft)	Sublot Location	
							Begin (ft)	End (ft)
							A	B
1	50.0	50.0	163.2	0.566	28.3	29.5	0	52.06
2	50.0	100.0	113.2	0.901	45.1	99.0	52.06	104.13
3	50.0	150.0	63.2	0.470	23.5	128.6	104.13	156.19
4								

* Sublot information that carries over to the next construction phase or structure placement.

** Acceptance sample location will be obtained during next construction phase or structure placement.

FIGURE 6.3

**INDIANA DEPARTMENT OF TRANSPORTATION
MATERIALS AND TEST DIVISION**

**RANDOM SAMPLING FOR SUPERSTRUCTURE CONCRETE
(ENGLISH UNITS)**

Contract No. B-25280 Str. No. 227-89-45308 Construction Phase I CMD 1 of 1

QC/QA Superstructure Quantity for Phase (z) 213.2 yd³

Phase Construction Dimensions: Length (l) 220.80 ft, Width (w) 35.52 ft

Average Depth (d) = $\frac{z \times 27}{l \times w}$ 0.73 ft

Lot No. 2 Lot Size 150.0 yd³ Number of Sublots 3

Sublot No.	Sublot Size (yd ³)	Cumulative Quantity of Ph/Str (yd ³)	Remainder Quantity (yd ³)	Random No.	Random Quantity Within Sublot (yd ³)	Random Distance From Start of Ph/Str (ft)	Sublot Location	
							Begin (ft)	End (ft)
							A	B
1	50.0	200.0	13.2	0.068	3.4	159.7	156.19	208.26
2	50.0	250.0	-36.8*	0.713	35.7**	**	208.26	---
3								
4								

* Sublot information that carries over to the next construction phase or structure placement.

** Acceptance sample location will be obtained during next construction phase or structure placement.

Sublot 2 Sample will be obtained in Phase II

FIGURE 6.4

**INDIANA DEPARTMENT OF TRANSPORTATION
MATERIALS AND TEST DIVISION**

**RANDOM SAMPLING FOR SUPERSTRUCTURE CONCRETE
(ENGLISH UNITS)**

Contract No. B-25280 Str. No. 227-89-45308 Construction Phase II CMD 1 of 1

QC/QA Superstructure Quantity for Phase (z) 299.3 yd³

Phase Construction Dimensions: Length (l) 220.80 ft, Width (w) 47.57 ft

Average Depth (d) = $\frac{z \times 27}{l \times w}$ 0.77 ft

Lot No. 2 Lot Size 150.0 yd³ Number of Sublots 3

Sublot No.	Sublot Size (yd ³)	Cumulative Quantity of Ph/Str (yd ³)	Remainder Quantity (yd ³)	Random No.	Random Quantity Within Sublot (yd ³)	Random Distance From Start of Ph/Str (ft)	Sublot Location	
							Begin (ft)	End (ft)
							A	B
1								
2	50.0	36.8	262.5	0.713	35.7	16.6	Phase I 208.26	27.13
3	50.0	86.8	212.5	0.217	10.9	35.2	27.13	63.98
4								

* Sublot information that carries over to the next construction phase or structure placement.

** Acceptance sample location will be obtained during next construction phase or structure placement.

FIGURE 6.5

**INDIANA DEPARTMENT OF TRANSPORTATION
MATERIALS AND TEST DIVISION**

**RANDOM SAMPLING FOR SUPERSTRUCTURE CONCRETE
(ENGLISH UNITS)**

Contract No. B-25280 Str. No. 227-89-45308 Construction Phase II CMD 1 of 1

QC/QA Superstructure Quantity for Phase (z) 299.3 yd³

Phase Construction Dimensions: Length (l) 220.80 ft, Width (w) 47.57 ft

Average Depth (d) = $\frac{z \times 27}{l \times w}$ 0.77 ft

Lot No. 3 Lot Size 223.7 yd³ Number of Sublots 4

Sublot No.	Sublot Size (yd ³)	Cumulative Quantity of Ph/Str (yd ³)	Remainder Quantity (yd ³)	Random No.	Random Quantity Within Sublot (yd ³)	Random Distance From Start of Ph/Str (ft)	Sublot Location	
							Begin (ft)	End (ft)
							A	B
1	50.0	136.8	162.5	0.307	15.4	75.33	63.98	100.84
2	50.0	186.8	112.5	0.879	44.0	133.27	100.84	137.69
3	50.0	236.8	62.5	0.755	37.8	165.56	137.69	174.55
4	62.5	299.3	0	0.125	7.8	180.30	174.55	220.62

* Sublot information that carries over to the next construction phase or structure placement.

** Acceptance sample location will be obtained during next construction phase or structure placement.

FIGURE 6.6

Sampling Procedure

The Contractor is required to provide an easily assessable means of obtaining concrete samples from the point of placement, and for transporting samples off the bridge deck for testing. Sampling for acceptance will be done by INDOT in accordance with AASHTO T 141.

ACCEPTANCE TESTING

The Contractor is required to submit a mix design and provide verification of the design by a Trial Batch Demonstration. The superstructure concrete properties shall meet the concrete parameters of the specifications prior to placement.

Acceptance testing results are shared with the Contractor. The air content, plastic unit weight, and compressive strength tests are measured for each subplot during concrete operations. The slump of the concrete is visually estimated.

Air Content and Unit Weight

The frequency of tests for the air content and unit weight is one series for each sample for each subplot. The air content will be determined in accordance with AASHTO T 152 when stone or gravel coarse aggregate is used in the concrete and AASHTO T 196 when slag coarse aggregate is used. The concrete material used to obtain the unit weight may be used to conduct the air content test.

A line parallel to the CMD Linear Equation will be established to represent a threshold limit where the water/cementitious ratio becomes 0.420. An individual subplot having a unit weight, for the air content measured, at or below the value representing the maximum allowable water/cementitious ratio, will have two additional cylinders cast. A test specimen will be extracted from each cylinder and tested by INDOT for resistance to chloride ion penetration in accordance with AASHTO T 277 at an age of 56 days. The test value will be the average of the two specimens.

Compressive Strength

The frequency of tests for the compressive strength will be one set of two cylinders for each subplot. The two cylinders will be tested at 28 days in accordance with AASHTO T 22 and the test values averaged to determine the subplot compressive strength.

The Contractor is required to provide sufficient containers filled with water saturated with calcium hydroxide at the work site for initial curing of compressive strength specimens. The cylinders are completely submerged in the saturated lime water at a temperature of 60 to 80°F for no less than 16 nor more than 48 hours. After the initial curing the cylinders are transported to the laboratory within 4 hours for additional curing, capping, and testing.

Slump

The slump of the concrete is visually estimated during production. If it is suspected that the slump is not within the allowable limits at the point of placement, the Contractor will be informed. The truck in question shall discontinue placement in the structure until a slump test is conducted to verify compliance. If the slump is outside compliance, the Contractor shall test the concrete for air content and unit weight. The truck shall not continue placement in the structure until quality control test results substantiate compliance.

PAY FACTORS

Pay factors are determined for air content, the range of air content, and compressive strength at 28 days. The range of air content is defined as the difference between the highest subplot air content and the lowest subplot air content within a lot.

Test values for each subplot are entered on the Superstructure Concrete Analysis for Quality Assurance form and averaged for the lot. Unit weight and the resistance to chloride ion penetration test values, if applicable, are also entered on this form. The averages for the lot are compared to the acceptance tolerances designated in the specifications for each property. Pay factors are assigned for each property in accordance with the specifications. An example of this procedure is shown in Figure 6.3.

The Superstructure Concrete Analysis for Quality Assurance form is completed by the PE/S and sent to the Contractor. Appeals, if necessary, are required to be submitted by the Contractor within five calendar days of receipt of this completed and signed form.

QUALITY ASSURANCE ADJUSTMENT

The pay factors based on air content, range of air content, and compressive strength at 28 days are used to calculate an adjusted amount of QC/QA superstructure concrete payment for each individual lot. The adjustment for each property is calculated as follows:

$$q_i = L_i \times U_m \times (PF_{ai} + PF_{ri} + PF_{ci} - 3.00)$$

where:

q_i = quality assurance adjustment for individual i^{th} lot

L_i = quantity for i^{th} lot

U_m = unit price for material, \$96/yd³ (\$125/m³)

PF_{ai} = pay factor for air content in i^{th} lot

PF_{ri} = pay factor for air content range in i^{th} lot

PF_{ci} = pay factor for compressive strength in i^{th} lot

The total quality assurance adjustment will be calculated as follows:

$$Q = \sum q_i$$

For lots $i=1$ to n

where:

Q = total quality assurance adjustment

i = individual lot

n = last lot

An example of this procedure is shown in Figure 6.7

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**INDIANA DEPARTMENT OF TRANSPORTATION
MATERIALS AND TESTS DIVISION**

**SUPERSTRUCTURE CONCRETE ANALYSIS FOR QUALITY ASSURANCE
(ENGLISH UNITS)**

CONTRACT NO. _____ MIXTURE: w/o Silica Fume ~~w/Silica Fume~~ LOT NO. _____

Threshold Equation for CMD at Max. Allowable W/C: $UW = -1.50$ (Air) + 149.3

PAY FACTORS							
Date	9/26/01	9/26/01	9/26/01				
	Sublot 1	Sublot 2	Sublot 3	Sublot 4			
Sublot Quantity (yd ³)	<u>50.0</u>	<u>50.0</u>	<u>50.0</u>				
Properties					Average	Tolerance	Pay Factor PF
Air Content (%)	5.8	4.4	4.2		4.8	4.7 – 4.9	0.90
Threshold Unit Weight (lb/ft ³)	140.6	142.7	143.0				
Measured Unit Weight (lb/ft ³)	141.3	144.1	144.7				
Rapid CI Permeability (Coulombs)	-NA-	-NA-	-NA-				
28 Day Compressive Strength (psi)	4430	4865	5330		4875	4856 - 4891	0.92
Range of Air Content	5.8 – 4.2 = 1.6					0.0 – 2.9	1.00

Note: Insert asterisk (*) next to any failing Sublot Acceptance Sample result and submit copy of form to DMTE for processing as Failed Material.

QUALITY ASSURANCE ADJUSTMENT				
Lot Quantity L (yd ³)	Pay Factors			$q = L \times Um \times (PFa + PFc + PFr - 3.00)$ (\$)
	Air Content PFa	Compressive Strength PFc	Air Content Range PFr	
150.0	0.90	0.92	1.00	- \$2592.00

$Um = \$96/yd^3$

Project Engineer/ Project Supervisor Date

FIGURE 6.7

APPEALS

If the Contractor does not agree with the acceptance test results for a subplot of QC/QA superstructure concrete, an appeal may be submitted. The appeal shall satisfy the following criteria:

1. Appeals shall be submitted in writing to the PE/PS within five calendar days of receipt of INDOT's written results for the lot.
2. The submission shall contain quality control test data that equals or exceeds the number of tests required.
3. The difference between the acceptance test result and the nearest quality control test result shall be at least 0.5 percent for air content.
4. The difference between the acceptance test result and the nearest quality control test result shall be at least 100 psi for compressive strength at 28-days.

Cores shall be obtained by the Contractor at the location that most closely approximates the appropriate subplot acceptance sample location. The coring shall be completed within 30 days of acceptance of the appeal unless traffic restrictions prevent the coring. Cores shall be 3.75 or 4.00 inches in diameter and the Contractor shall fill all core holes with concrete within 24 hours of drilling.

Air Content Appeal for Sublot

For an air content appeal, four cores shall be taken from each subplot that qualifies and averaged. The hardened concrete air content will be determined in accordance with ITM 401 and converted to a value representing the air content in the plastic state.

The average value will be considered as the air content for the subplot in question. This value will be used to determine all subsequent actions involving the subplot and lot.

Compressive Strength Appeal for Sublot

For a 28-day compressive strength appeal, four cores shall be taken from each subplot that qualifies. Each core will be tested for compressive strength in accordance with AASHTO T 24. The four test values will be averaged for the subplot compressive strength value and this value will be used to determine all subsequent actions involving the subplot and lot.

FAILED MATERIALS

Sublot and lot values that are excessively out of tolerance are required to be submitted to INDOT for final adjudication. The test value criteria that will require such submittal include:

1. An individual sublot having an air content test value of less than 4.0 percent or more than 10.0 percent.
2. A resistance to chloride ion penetration test value greater than 4000 coulombs when this test is required for unit weight measures at or below the threshold limit.
3. An individual sublot having a 28-day compressive strength test value less than 5220 psi and 4400 psi for concrete with and without silica fume, respectively.
4. A lot having an air content test value average of 4.2 or less and 4.4 and less for concrete with and without silica fume, respectively.

A lot having an air content test value average of 10.0 or greater for concrete with or without silica fume.

5. A lot having a 28-day compressive strength test value average of 4675 psi or less and 5475 psi or less for concrete with and without silica fume, respectively.

As a minimum the Failed Materials Committee will consider the above-noted items for no additional payment adjustment, an increased payment adjustment to offset potential maintenance costs, additional payment to cover the cost of the investigation, no payment, or removal and replacement

7 QUALITY CONTROL

Contractor Personnel

- QCP Manager**
- QCP Site Manager**
- Certified Concrete Technician**

Facilities and Testing Equipment

Process Control of Aggregates

- Gradation**
- Water Absorption**
- Bulk Specific Gravity (SSD)**

Process Control of Concrete

- Slump**
- Air Content and Unit Weight**
- Water/Cementitious Ratio**
- Compressive Strength**

Process Control of Reinforcing Steel

Response to Test Results

- Slump**
- Water Absorption**
- Unit Weight**
- Water/Cementitious Ratio**
- Air Content**

Documentation

Quality Control Plan

QCP Approval

QCP Addenda

CHAPTER SEVEN: QUALITY CONTROL

The foundation for a successful Quality Assurance program is the control maintained by the Contractor to assure that all materials submitted for acceptance conform to the contract requirements. To accomplish this it is imperative that the Contractor have a functional Quality Control Plan (QCP) to keep the process in control, quickly determine when the process goes out of control, and respond adequately to bring the process back into control.

This chapter includes the minimum requirements for maintaining quality control during production of QC/QA superstructure concrete. Acceptance test results by INDOT will be shared with the Contractor; however, results of these tests should not be used for quality control purposes.

CONTRACTOR PERSONNEL

The Contractor personnel required to provide quality control on a QC/QA superstructure concrete project include a QCP Manager, QCP Site Manager, and a Certified Technician. One quality control person may perform the duties of more than one position.

QCP Manager

The QCP Manager is responsible for the overall administration of the QCP on the project.

QCP Site Manager

The QCP Site Manager is responsible for the execution of the QCP and is the liaison with the PE/PS. This person is often the QCP Manager also and is at the plant or project during production.

Certified Concrete Technician

A Certified Concrete Technician is a Contractor, Producer, or Consultant employee who has been certified by INDOT. The technician is required to be at the plant for the trial batch demonstration, and be at the plant or at the site of work at the point of placement until placement and finishing are complete. The technician is required to supervise all sampling and testing for quality control. An American Concrete Institute (ACI) certified concrete field testing technician, grade I, is required to perform all sampling and testing for quality control.

FACILITIES AND TESTING EQUIPMENT

The Contractor is required to have a container filled with water saturated with calcium hydroxide at the work site for initial curing of compressive strength specimens. Also, an easily accessible means of obtaining concrete samples at the point of placement and transporting them off of the bridge deck for testing is required for INDOT use.

The Contractor's equipment furnished for testing is required to be properly calibrated within the limits designated in the applicable test method, except as such requirements may be modified in the Standard Specifications. A record of all equipment calibration or verification results is required to be maintained for all applicable equipment listed in Figure 7.1. The procedures and forms for calibration are included in Appendix C.

Equipment	Requirements	Minimum Frequency	Procedure
Air Meter	Calibration	3 months	AASHTO T 152 or ASTM C 173
Balances	Verification	12 months	ITM 910
Sieves	Check Physical Condition	6 months	ITM 902
Slump Cones	Verifying Dimensions	12 months	ITM 911
Testing Machine	Verification	12 months	AASHTO T 67
Thermometers	Verification	6 months	ITM 909
Unit Weight Measures	Calibration	12 months	AASHTO T 121

FIGURE 7.1 - EQUIPMENT CALIBRATION REQUIREMENTS

PROCESS CONTROL OF AGGREGATES

The Contractor is required to monitor gradation, water absorption, and Bulk Specific Gravity Saturated Surface Dry (SSD) of the aggregates to verify compliance with the properties of the aggregates used at the time of the Trial Batch Demonstration.

Gradation

A copy of the gradation control charts are required to be obtained from the Certified Aggregate Producer within seven days of concrete placement operations. The charts shall represent production and load-out test results for gradation tests since the Certified Aggregate Producer was certified, but not more than the 30 most recent results. In lieu of obtaining control charts from the Certified Aggregate Producer, gradation tests of the aggregates stockpiled at the plant may be performed within seven days of concrete placement operation. Stockpile samples should be sampled in accordance with ITM 207, reduced in size by AASHTO T 248, and tested in accordance with AASHTO T 27.

The gradation tests are used to verify that 100 percent of the coarse aggregate passes the 1 in. sieve. Also, the gradation tests shall verify that the mathematically combined amount passing the No. 200 sieve of fine and coarse aggregates is from 0.0 to 2.0 percent for sand and gravel and from 0.0 to 2.5 percent for sand and stone or slag. The proportions of fine and coarse aggregate shall be in accordance with the concrete mix design.

Water Absorption

The water absorption test is required to be conducted on the fine and coarse aggregates in accordance with AASHTO T 84 and AASHTO T 85, respectively. The tests are required within ten days prior to concrete placement operations unless the aggregate is from a captive stockpile.

Bulk Specific Gravity (SSD)

The bulk specific gravity (SSD) tests are required to be conducted on the fine and coarse aggregates in accordance with AASHTO T84 and AASHTO T 85, respectively. For coarse aggregates, both procedures 8.1 and 8.2 of AASHTO T 85 are required. The tests are required within ten days prior to concrete placement operations unless the aggregate is from a captive stockpile.

PROCESS CONTROL OF CONCRETE

The Contractor is required to test the slump, air content and unit weight, water/cementitious ratio, and compressive strength for process control of the concrete during production. Samples are obtained from the site of work at the point of placement.

Slump

The slump test is required to be conducted in accordance with AASHTO T 119. The minimum frequency of tests is one slump test for each subplot; however, the slump test is required on the concrete mix from the first truck for each day of production.

Air Content and Unit Weight

The air content test is required to be conducted in accordance with AASHTO T 152 or AASHTO T 196 (Slag), and the unit weight test conducted in accordance with AASHTO T 121. The minimum frequency of tests is one test for each property for each subplot; however, the air content and unit weight are required to be determined on the concrete mix from the first truck for each day of production. An additional air content and unit weight determination shall be made if there is a change in production, delivery, or placement.

Water/Cementitious Ratio

The water/cementitious ratio is required to be determined in accordance with ITM 403 at a frequency of one determination for each day of concrete placement operations.

Compressive Strength

The compressive strength is required to be determined in accordance with AASHTO T 22 at a frequency of one set of two cylinders tested at 28 days for each subplot. Specimens shall be made and cured in accordance with AASHTO T 23 except that the initial curing shall be done by completely submerging the cylinders in water saturated with calcium hydroxide at a temperature of 60 to 80°F for no less than 16 nor more than 48 hours. Transportation of the cylinders to the laboratory shall not exceed four hours.

PROCESS CONTROL OF REINFORCING STEEL

The depth of concrete over the uppermost bar of the top mat of reinforcing steel is required to be measured at a frequency designated in the QCP. Measurements are required to be obtained as soon as the concrete is placed and struck off, and while still plastic.

A summary of the minimum testing frequencies required for process control of the aggregates, concrete mixture, and depth of cover of concrete over reinforcing steel is shown in Figure 7.2.

MINIMUM TESTING FREQUENCIES				
Material & Concrete Properties	Within 7 days of Concrete Placement	First Truck Each Day of Production	Each Sublot	Each Day
CA Bulk (SSD)	X			
CA Absorption	X			
CA Gradation	X*			
FA Bulk (SSD)	X			
FA Absorption	X			
FA Gradation	X*			
W/(C+P+SF)				X
Slump		X	X	
Air Content		X	X	
Unit Weight		X	X	
7-Day Strength			X	
28-Day Strength			X	
Depth of Cover **				

* Conducted in lieu of obtaining control charts from the Certified Aggregate Producer

** Frequency as stated in QCP

FIGURE 7.2

RESPONSE TO TEST RESULTS

The Contractor is required to take corrective action when quality control test results exceed the established limits. The corrective actions shall be designated in the QCP. As a minimum, corrective actions are required for the slump, air content, unit weight, water/cementitious ratio, water absorption, and depth of cover. Documentation of corrective actions are required.

Slump

Corrective action for slump should be taken when quality control limits are exceeded, so that test values are always maintained between 4-7 1/2 inches for concrete with HRWR, 2-4 1/4 inches for superelevated bridge decks, or the required limits in the Special Provisions.

Water Absorption

Corrective action is required when the absorption value for a particular size of aggregate differs from the mix design value by more than 0.5 percent. As a minimum, the absorption for the source, shall be investigated and an absorption percent determined.

Bulk Specific Gravity (SSD)

Corrective action is required when the bulk specific gravity (SSD) of the fine aggregate differs from the mixture design value by more than 0.056 or the bulk specific gravity (SSD) of the coarse aggregate differs from the mixture design value by more than 0.032.

Unit Weight

Corrective action is required when the unit weight varies by more than ± 1 lb/ft³ from the predicted value for the air content measured, not to exceed a unit weight representing a water/cementitious ratio of 0.420.

Water/Cementitious Ratio

Corrective action for water/cementitious ratio should be taken when the quality control limits are exceeded, so that there is confidence that the process is centered about the mix design value. Test values should always be less than 0.420 for concrete without silica fume, and always between 0.370 and 0.420 for concrete containing silica fume.

Air Content

Corrective action for air content should be taken when the quality control limits are exceeded, so that subplot test values are always maintained from 4.0 to 10.0 percent. Lot test values shall be maintained within 5.7-8.9 percent for concrete without silica fume and within 5.3-8.9 percent for concrete with silica fume.

DOCUMENTATION

The test results for quality control are required to be maintained by the Contractor for a period of three years upon completion of the contract. The records, either electronic and/or hard copies, shall be maintained at a readily accessible location for review by INDOT at any time. As a minimum the documentation shall include test results for the aggregate tests, mixture tests, and depth of cover of concrete over reinforcing steel measurements.

QUALITY CONTROL PLAN

The Contractor is required to submit a QCP that is contract specific and states how the process control of materials, equipment, and operations shall be maintained. As a minimum, the QCP shall include the following information for each project.

1. The name, telephone number, duties, and employer of all quality control personnel necessary to implement the QCP. The minimum number of quality control personnel shall be a QCP Manager, QCP Site Manager, and Quality Control Technician.
2. The location of the testing facility to be used for the determination of the compressive strength of concrete.
3. A list of the testing equipment proposed for process control testing, and the test methods and frequency of calibration and verification of the equipment.
4. The source, transportation, handling, and storage procedures, if applicable, for the materials to be used in the superstructure concrete.
5. The procedure for monitoring the aggregate gradation, water absorption, and Bulk Specific Gravity (SSD) to verify compliance with the properties of the aggregates used at the time of the trial batch demonstration(s).
6. The procedures, location, and type of equipment to be utilized during the trial batch demonstration(s).
7. The techniques and controls of the concrete batching operations. A description of the plant, including the capacity and intended batch size, and the methods and sequence by which the plant produces a batch shall be included. The plant shall have been inspected in accordance with ITM 405.

The initial and routine equipment checks, including those performed on scales, water meters, and admixture dispensers, mixing equipment, and agitators, if applicable, shall be included. All material checks, including frequencies of testing, shall be identified. The methods to monitor ingredients used, and the record of each batch shall be included.

8. The location, procedures, and frequency for sampling and testing the concrete mix for slump, air content and unit weight, water/cementitious ratio, and compressive strength.

9. The procedure and frequency for monitoring the depth of concrete over the uppermost bar of the top mat of reinforcing steel.
10. The response to process control tests not within the established requirements.
11. The equipment and methods for delivery of the concrete. The description or plan drawing of the traffic patterns for delivery of the concrete mix to the site of work shall be included.
12. The procedures for placement of the concrete to include as a minimum the placing sequence, identification of the placing equipment, and a description of the pumping procedures, if applicable.
13. The methods for finishing, texturing, and curing concrete. The description and identification of the equipment shall be included.
14. The procedure for determining when the forms, falsework, and centering may be removed. The minimum frequency of samples for determination of removal shall be two cylinders or two beams.

QCP Approval

The QCP is required to be submitted to the PE/PS for review at least 15 calendar days prior to commencing concrete operations. The Contractor shall sign and date the QCP at the time it is submitted to the PE/PS. The PE/PS will sign and date the QCP if the contents of the QCP are in compliance with the above-noted requirements. Concrete operations shall not begin before the QCP has been accepted and a successful trial batch demonstration completed. Concrete mix designs and trial batch demonstrations may be submitted for approval prior to the submittal of the QCP.

QCP Addenda

The QCP shall be maintained to reflect the current status of the operations, and revisions are required to be provided in writing prior to initiating the change. The change shall not be implemented until the revision has been accepted; however, traffic patterns for delivery of the concrete mix to the site of work may be adjusted for unanticipated conditions without an addendum to the QCP.

Appendices A-D

Appendix A - Indiana Test Methods

1. [ITM No. 207](#)
2. [ITM No. 401](#)
3. [ITM No. 402](#)
4. [ITM No. 403](#)
5. [ITM No. 405](#)
6. [ITM No. 802](#)
7. [ITM No. 803](#)

Appendix B - AASHTO Test Methods

The AASHTO Test Methods are located in the most recent Standard Specifications for Transportation Materials and Methods of Sampling and Testing - Part II - Tests publication.

Appendix C

Testing

1. [AASHTO T22](#)
2. [AASHTO T23](#)
3. [AASHTO T97](#)
4. [AASHTO T119](#)
5. [AASHTO T121](#)
6. [AASHTO T152](#)
7. [ASTM C173](#)

Calibration

1. [ITM 902](#)
2. [ITM 909](#)
3. [ITM 910](#)
4. [ITM 911](#)
5. [AASHTO T121](#)
6. [AASHTO T152 & T121](#)

Appendix D

Forms

- [Quality Control Plan Checklist](#)

Trial Batch Demonstration

- [English](#)
- [Metric](#)

Mix Design & Proportioning

- [English](#)
- [Metric](#)

Threshold Linear Equation

- [English](#)
- [Metric](#)

CMD Linear Equation

- [English](#)
- [Metric](#)

Lot summary of Pay Factors

- [English](#)
- [Metric](#)

Random Sampling Locations for QC/QA Superstructure Concrete

- [English](#)
- [Metric](#)

Worksheet for Planning Lots & Sublots

- [English](#)
- [Metric](#)