

PORTLAND CEMENT CONCRETE LEVEL III INSTRUCTION MANUAL

2023-2024



TECHNICAL TRAINING AND CERTIFICATION PROGRAM

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CLASS EVALUATIONS

Evaluations will now be completed outside of the classroom. They are available in IowaDOTU and can be found at this web address: <u>https://learning.iowadot.gov/</u>

Please login to the system and then scroll down to where you see the "My Task" line. Locate the class that you were enrolled in and completed. To the right of the class name, you will see an icon for the Evaluation. Click the Evaluation icon and it will open the evaluation for you to complete electronically.

My Task	Displaying Courses	~			Actions 🔎 I
🏟 Course 🔺		Start Datetime	Enrolled Date	Due Date	Certification Expiry Date
Aggregate Technician Certification - Enrollment Type : Elective(Self) 11-11-11 Date and Time : 06/28/2021 09:00 AM - 06/28/2021 04:00 PM CST 06/29/2021 09:00 AM - 06/30/2021 04:00 PM CST 06/30/2021 09:00 AM - 06/30/2021 04:00 PM CST 07/01/2021 09:00 AM - 06/30/2021 04:00 PM CST 07/01/2021 09:00 AM - 06/30/2021 04:00 PM CST 07/01/2021 09:00 AM - 06/30/2021 04:00 PM CST 07/01/2021 09:00 AM - 06/30/2021 04:00 PM CST 07/01/2021 09:00 AM - 06/30/2021 04:00 PM CST	ILT Evaluation Checklist	6/28/2021	8/16/2021 7:25:42 AM		

Once you have completed the 11 questions on the evaluation, scroll to the top of the page and click the "Save" button. Thank you for completing this evaluation!

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Aggre	gate Tech	nician (Certification			
	Course	Name:	Aggregate Technician Certification	Evaluation Date:	8/19/2021	
#	Group	Quest	ion			
			TION OF COURSE (DISTRICT OR CITY) MENTS			
1						
		WHAT COMN	I TYPE OF AGENCY DO YOU WORK FOR? a. DOT; b. County o MENTS	r City; c. Consultant; d. Con	tractor; e. Other;	
2						11
		Were COM	the instructor(s) effective in helping you learn? MENTS			
3						

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COMPUTER TESTING

All TTCP Exams will be done on the computer. Your instructor will guide you to the Test.Com website and assist with any registration requirements. Questions are multiple choice, and you will be able to see your score immediately as well as the questions that you missed.



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- APPENDIX A ACI 211 MIX DESIGN AND GRAPHS
- APPENDIX B EXAMPLE PROBLEMS
- **APPENDIX C WORKSHEETS**

APPENDIX D – EXCEL SPREADSHEET INSTRUCTIONS

- **APPENDIX E EXERCISES**
- APPENDIX F EXERCISES KEY

APPENDIX G – QM-C SPECIFICATION AND I.M.S

APPENDIX H – PRESENTATIONS

APPENDIX I – COMPUTER MIX DESIGN PROBLEM

CHAPTER 1 INTRODUCTION

1. Introduction

1.1. Introductions

1.2. Schedule

<u>Day 1</u>

Chapter 1 Introduction
Chapter 2 Cementitious Materials
Lunch
Chapter 3 Chemical Admixtures
Chapter 4 Aggregate

<u>Day 2</u>

Chapter 4 Aggregate
Chapter 5 Mix Design
Lunch
Chapter 5 Mix Design
Chapter 6 Mix Design Approaches

<u>Day 3</u>

9:00-11:30	Chapter 6 Mix Design Approaches
11:30-12:30	Lunch
12:30-2:30	Chapter 6 Mix Design Approaches
2:30-3:00	Chapter 6 Computer Mix Design
3:00-3:30	Review

<u>Day 4</u>

9:00-1:00 Review & Test

1.3. Grading

- 3 hour written test
- 50 multiple choice and true false including calculations
- Open book open note
- 80% or higher to receive certification
- 1 retake

1.4. Rules

- Respect one another
- Follow DMACC and Zoom rules
- Start on time and end on time
- Contact instructors if you cannot make class
- Turn off cell phones
- Limit side conversations and distractions
- 10-15 minute break about every 1-2 hours
- Maintain a positive attitude, learn, and have fun

1.5. Contacts

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1.6. Text

- Provided book
- Reference to keep so highlight, add notes, and tab
- Written by John Hart and Todd Hanson based on notes of Dr. Ken Hover

1.7. Course Objectives

- Learn about component materials of concrete
- Learn how component materials interact to form concrete
- Recognize when, why, and how to use the component materials to ensure quality concrete
- Learn the difference between mix design and mix proportioning
- Understand producer standard deviation effect on target strength
- Learn about the various mix design approaches and specifications for:
 - o lowa DOT I.M. 529
 - o ACI 211.1
 - Iowa DOT QM-C
 - lowa DOT BR
 - Iowa DOT HPC structural
 - Iowa DOT HPC overlay
 - Iowa DOT mass concrete
 - lowa DOT self-consolidating concrete (SCC)
- Calculate concrete mix proportions

1.8. Concrete Basics

- What is concrete
 - Concrete is the most widely used construction material in the world
 - Used to build pavements, bridge components, foundations, piles, dams, pipes, sidewalks, floors, curb and gutters, retaining walls, tanks, art, countertops, ships
 - o Provides excellent versatility durability, and economy
 - Simple in appearance but extremely complex internal structure and chemistry
 - Composite material made up of component materials
 - Concrete is an engineered material designed to meet the intended application
 - Concrete is <u>NOT</u> cement



Figure 1-1 Cement versus concrete

- Composite materials
 - Main categories are aggregate and paste
 - Aggregate is an economic filler that provides dimensional stability and wear resistance
 - Paste glues, bonds, adheres, ties, attaches, joins, links and holds the aggregate together
 - Other concrete composite materials can be created by combining any one or more aggregates together and then gluing them together with a paste



Figure 1-2 Composite materials of rock, sand, cement, and water

Table 1-1	Examples of aggregate and paste combinations to make
concrete and	l other composite materials

Coarse Aggregate	Fine Aggregate	Paste	Concrete or Composite Material
Crushed rock	Concrete sand	Portland cement	Portland cement concrete
Light weight rock	Concrete sand	Portland cement	Light weight concrete
Crushed rock	Coarse sand	Asphalt cement	Asphalt cement concrete
Coarse iron ore	Fine iron ore	Portland cement	Heavyweight concrete
Steel punchings	Concrete sand	Portland cement	Heavyweight concrete
Gravel	Concrete sand	Ероху	Epoxy concrete
Chopped fruit	Crushed nuts	Sugar and flour	Fruitcake

Figure 1-3 Concrete and fruitcake are similar



- What is quality concrete
 - Depends on the application being constructed and the viewpoint of the observer
 - $\circ~$ Goal of a mix designer is to identify and understand observer needs and best satisfy them

		Application	
Observer	Pavements	Structure	Streetscape Sidewalk
Public	Open quickly Smooth	Open quickly Structurally sound	Visually appealing
Owner	Durable	Durable	Durable
	Ultimate strength	Ultimate strength	Economical
	Economical	Economical	Visually appealing
Contractor	Economical	Economical	Economical
	Set properly	Set properly	Set properly
	Strength gain	Workable	Visually appealing
		Strength gain	
		Various strengths	
Finisher	Workable	Workable	Workable
	Set properly	Set properly	Set properly
Saw crew	Early strength	NA	No raveling
	Aggregate type		_
Designer	Ultimate strength	Various strengths	Visually appealing

Table 1-2 Quality concrete for different observers and applications

CHAPTER 2 CEMENTITIOUS MATERIALS

2. Cementitious Materials

2.1. Portland Cement

- 2.1.1. Overview
- Manufactured product composed primarily of calcium silicates
- Hydraulic means it reacts chemically with water to set and harden
- Expensive mix component due to energy and environmental requirements required in manufacture



Figure 2-1 Typical Portland Cement

- 2.1.2. History
- Greeks and Romans used volcanic deposits in combination with lime
- Romans called the natural occurring deposits pozzolana because it was near the village Pozzuoli, near Mt. Vesuvius
- Pantheon dome built in 126 A.D. is concrete made of volcanic pozzolan and lime, basalt aggregate and pumice aggregate



Figure 2-2 Pantheon in Rome

- In 1824, a patent for hydraulic cement was applied for in England
- Term Portland was coined because the hardened cement product resembled the stone quarried at the Isle of Portland, England
- Cement production in the United States began in the 1870's



Figure 2-3 Globe of solid stone quarried at the Isle of Portland, England

2.1.3. Manufacturing Process

• Cement plants are located where raw materials are locally abundant, such as limestone, shale, clay, sand and iron ore (used as a flux)

Figure 2-4 Typical raw materials and their chemical contribution



- Four major steps in the manufacturing process of cement are:
 - 1. Quarry Operations
 - o Raw materials are obtained, crushed, and stored
 - 2. Grinding and Blending of Raw Materials
 - Raw materials are ground to a powder and blended to produce the desired chemical composition
 - 3. Heating Raw Materials in a Kiln
 - Kiln is a brick lined rotating furnace sloped toward the burn zone

- Blended raw materials enter the upper end of kiln and move toward the burn zone controlled by the slope and rotation
- $\circ~$ Kiln is fueled from lower end with powdered coal, oil, gas, and or waste materials where the temperatures can reach 2600 to 3000 $^\circ F$
- Limestone (CaCO₃) converts to CaO releasing carbon dioxide (CO₂)
- 4. Finish Grinding of Clinker and Distribution
 - Clinker is ground in a ball mill with approximately 5 percent gypsum
 - Gypsum is added to control setting
 - Ground to fineness of 85-90% passing #325 mesh (holds water)
 - The fine gray powder is angular due to crushing of clinker
 - Stored in solos to allow blending for improved uniformity before bagging or bulk delivery

Figure 2-5 Quarry operations for cement production



Figure 2-6 Bins used for blending operation



Figure 2-7 Kiln for cement production



Figure 2-8 Clinker and gypsum



Figure 2-9 Ball mill for grinding cement clinker



- 2.1.4. Four Principle Compounds
- Approximately 90 percent of cement by weight is made of these compounds, the remainder is gypsum and other minor compounds
- Individual cement grains may contain all 4 compounds
 - 1. Tricalcium Silicate ($3CaO \cdot SiO_2 = C_3S$)
 - Temperature rise during hydration
 - Contributes to early strength
 - 2. Dicalcium Silicate ($2CaO \cdot SiO_2 = C_2S$)
 - Similar reaction as C₃S but much slower
 - Contributes to long term strength
 - 3. Tricalcium Aluminate ($3CaO \cdot Al_2O_3 = C_3A$)
 - o Can cause early stiffening without proper gypsum
 - o Temperature rise during initial hydration
 - Contributes little to strength
 - 4. Tetracalcium Aluminoferrite $(4CaO \cdot Al_2O_3 \cdot Fe_2O_3 = C_4AF)$
 - o Fairly inert
 - Reduces clinkering temperatures
 - Fe₂O₃ gives cement gray color
 - White cement limits Fe₂O₃ to 0.50 percent



Figure 2-10 White cement

2.1.5. Types

- Five major types as well as blended
- ASTM C 150 specification for hydraulic cements
- ASTM C 595 specification for blended cements
- I.M. 401 Iowa DOT approved sources of cement

Table 2-1 Five major cement types and their characteristics AST	M C150
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Cement Type	Use	Characteristic
1	Normal use	> 8% C ₃ A
II	Moderate sulfate resistance	< 8% C ₃ A
III	High early strength	Fine ground type I
IV	Low heat of hydration	< 35% C ₃ S
V	High sulfate resistance	< 5% C ₃ A

Table 2-2	Blended cements and their composition ASTM C595
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Cement Type	Composition
IS(X)	X is the percent GGBFS – (example IS(20))
IP(X)	X is the percent pozzolan – (example IP(25)
IL(X)	X is the percent limestone – (example IL(10)

Figure 2-11 Cement particles under microscope and SEM image



Red (C₃S), Blue (C₂S), Lime Green (C₃A), Orange (C₄AF), Green (Gypsum)

2.2. Fly Ash

2.2.1. Background

- Early use in 1930's for mass structures such as dams
- In 1982 use was mandated by federal law
- Used in Iowa since 1984

2.2.2. Byproduct Generation

- Pulverized coal is injected into the combustion chamber of the furnace
- During combustion coal impurities fuse in suspension and are transported in exhaust gases, the fused materials cool to form fly ash with a spherical shape
- Collected in electrostatic precipitators or bag filters
- After collection it is shipped, stored, or disposed of
- A typical large-scale electric generation station burns approximately 14,000,000 tons of coal per year resulting in 700,000 tons of fly ash
- Greater variability because plant is operated differently based on demand for electricity
- Least expensive cementitious material as no processing is required



Figure 2-12 Microscopic view of fly ash



Figure 2-13 Typical coal burning electric power generating station

2.2.3. Classes

- •
- ASTM C 618 specification for fly ashes I.M. 491.17 Iowa DOT approved sources of fly ash •

Table 2-3	Fly ash	class and	characteristics
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Class	Characteristic
С	Pozzolanic and cementitious
	CaO content of 18 to 30 percent
	Tan color – high lime
	Derived from subbituminous and lignite coal
	Common west of Mississippi River
F	Pozzolanic
	Needs CH from cement hydration to react
	CaO less than 18 percent
	Gray color – higher iron
	Derived from bituminous and anthracite coal
	Common east of Mississippi River

Figure 2-14 Class C and Class F fly ash



2.2.4. Advantages

- Economical as cement replacement
- Rounded particles improve workability
- Reduced permeability by reacting with CH and forms more CSH

2.2.5. Disadvantages

- More variable material depending on plant operations
- Slower strength gain in colder weather, especially Class F

2.2.6. Supply

- The conversion from coal to natural gas fuel sources as well as increased use of wind turbines has resulted in a 50 percent decrease in fly ash produced since 2008
- Less supply with constant demand has caused prices to increase and created supply disruptions, particularly with ready mix
- Reclaiming, blending, storing and use of less desirable sources with higher carbon (unburnt coal) are being considered to alleviate supply issues
- Research is currently underway to identify ways to properly extend the use of the fly ash supply without compromising the quality of concrete



Figure 2-15 Fly ash production and use

2.3. Ground Granulated Blast Furnace Slag (GGBFS)

2.3.1. Background

- A slow setting hydraulic cement
- White in color
- First used in Germany in 1892
- Used in Europe, Asia, east central United States, and Canada
- Used in Iowa since 1995

2.3.2. Byproduct Generation

- In an iron blast furnace, iron ore, limestone, and coke are continuously feed from the top while air heat and oxygen are forced into the furnace reaching temperatures near 2700 °F
- Limestone removes sulfur and any remaining silica (Si), alumina (AI), and magnesium (Mg) from the iron
- Molten iron collects at the bottom while molten slag floats above
- Iron and molten slag are periodically tapped
- High pressure water jets cool the molten slag rapidly to a temperature below the boiling point of water producing glassy granulated slag
- Granulated slag is then dried and ground in a ball mill to produce GGBFS with an angular shape
- Equal to cost of cement due to limited supply and additional processing
- A typical blast furnace produces 200 to 500 tons of molten slag per day
- Greater consistency due to tight process control of iron making



Figure 2-17 Granulated slag and GGBFS



2.3.3. Grades

- Three grades based on strength
- Grade 80, 100 and 120
- Iowa DOT does not allow Grade 80
- ASTM C 989 specification for GGBFS
- I.M. 491.14 Iowa DOT approved sources of GGBFS

Figure 2-18 Microscopic view of GGBFS



2.3.4. Advantages

- Increased working time in hot weather
- Higher ultimate strength and reduced permeability
- Less heat of hydration for mass concrete
- Increased sulfate resistance

2.3.5. Disadvantages

- Slow strength gain in cold weather
- Workability can be reduced due to angular particles

2.4. Silica Fume, Calcined Clay, and Shale

2.4.1. Silica Fume

- An ultrafine pure silicon dust captured during production of ferrosilicon alloys in an electric arc furnace
- Expensive material with limited supply
- Used in high performance applications to produces concrete with very high strengths and very low permeability
- Requires a HRWR and extreme control in the field
- Increased susceptibility to plastic shrinkage cracking on flat work

2.4.2. Calcined Clay and Shale

- Calcining is the process of using high temperature to drive off moisture and alter materials (clay and shale) to form a pozzolan
- After calcining the pozzolans are ground to the proper fineness
- Metakaolin is a calcined clay produced from a high purity kaolin clay
- Calcined shale contains calcium which gives cementing properties
- Reacts with CH to form CSH to provide higher strength, lower permeability and sulfate resistance concrete
- Mitigates alkali silica reactivity by trapping and isolating alkalis



Figure 2-19 Silica fume and metakaolin

2.5. Hydration Process

- Portland cement is combined with water to produce a glue or the paste
- Hydration reaction is exothermic, meaning heat is released
- Basic hydration reactions
 - Calcium Silicates + Water => Calcium Silicate Hydrate (CSH) Gel + Calcium Hydroxide (CH)
 - Calcium Aluminates + Gypsum + Water => Ettringite
- Initial set occurs when temperature rises as the C₃S particles react with water forming CSH gel – paste begins to stiffen
- Final set occurs when enough CSH gel has formed that the concrete can sustain some load



Figure 2-20 Heat profile of hydration reaction

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- Hydrated paste contains the following:
 - 1. Reaction products (CSH, CH, ettringite, and monosulfate)
 - 2. Un-reacted cement particles never achieve full hydration
 - 3. Capillary pore space, or space originally occupied by mix water
 - 4. Water (gel water and pore water)
- CSH is the main contributor to strength
- CH, ettringite, and monosulfate contribute little to strength
- CH major factor in acid attack and causes leaching/efflorescence (white material in cracks)
- Ettringite and monosulfate are major factors in sulfate attack
- Supplementary cementitious materials react with CH to from more CSH
- Silica fume, Class F fly ash, metakaolin, and calcined clays are pozzolanic and need CH plus water to react
- Class C fly ash and calcined shales are both pozzolanic and cementitious
- GGBFS is a slow setting hydraulic cement



Figure 2-21 Microscopic view of reacted cement grains

2.6. Water to Cement Ratio (w/c ratio)

- Weight of all water added divided by weight of all cementitious materials
- 0.42 is a critical w/c ratio
- At a w/c ratio of 0.42 capillaries are full of water during hydration and enough water exists to fully hydrate the cement when the water is kept inside the concrete with proper curing

- At a w/c ratio between 0.36 and 0.42 additional water must be added though internal or external curing to achieve full hydration
- At a w/c ratio greater than 0.42 excess water creates larger and more porous capillaries
- At a w/c ratio of 0.70 and above it is not possible to achieve concrete with capillary pores that will be watertight in the hardened paste
- A w/c ratio must be targeted to ensure adequate workability while meeting the desired strength and permeability requirements

2.7. Effect of w/c Ratio on Strength and Permeability

- w/c ratio impacts both strength and permeability
- A higher w/c ratio results in a lower strength and higher permeability
- A lower w/c ratio results in a higher strength and lower permeability
- As w/c ratio increases cement grains are pushed further apart creating larger more porous capillaries and less interconnected needle like growths

Figure 2-22 Graphical representation of low and high w/c ratio



- Supplementary cementitious materials (SCMs) provided additional strength and reduced permeability by reacting with CH to form more CSH and a more complete and tight hydration product
- Permeability is directly related to durability since it controls the rate of moisture and contaminant intrusion
- If moisture is present strength can continue to develop, emphasizing the importance of proper curing
- Adding 1 gallon of water per cubic yard increases slump by approximately 1 inch and w/c ratio by approximately 0.015 while lowering compressive strength by approximately 250 psi

Figure 2-23 Relationship of w/c ratio to strength and permeability



2.8. Paste Volume

2.8.1. Heat

- Hydration is an exothermic chemical reaction meaning it releases heat
- One sack of cement generates approximately 17,500 BTU when hydrating for 28 days (1 BTU is the energy required to raise 1 pound of water 1 °F)
- 10 cubic yards of a mix with 560lbs of cement per cubic yard releases approximately 1,000,000 BTUs which is equivalent to the energy released by two 20lb propane tanks
- Heat generated becomes a concern in mass structures
- Limit maximum temperature to 160 °F to prevent delayed ettringite
- Excessive heat internally (expands) while extremities cool (shrinks)
- These temperature differentials cause strength variations and thermal stresses which can cause cracking
- Differentials should be kept to 35 °F or less
- Type and amount of cement controls the heat generated
 Type I/II, II or IV
 - Type I/II, II or IV
 - Optimizing cement content for aggregate gradation and size
 - $_{\odot}$ Replacement of cement with SCMs like GGBFS and class F ash
- An acceptable initial mix temperature may be estimated using the following

$Temperature \ rise = 0.\ 16^{\circ}F\ X\ (C+0.\ 5\ X\ FA+0.\ 8\ X\ CA+1.\ 2\ X\ SF+F\ X\ S)$

0.16°F rise per 1lb/yd³ equivalent cement C is Type I/II cement, lbs/yd³ FA is Class F fly ash, lbs/yd³ CA is Class C fly ash, lbs/yd³ SF is silica fume or metakaolin, lbs/yd³ F is the equivalent cement factor based on the percent GGBFS replacement S is GGBFS, lbs/yd³

Table 2-4 Factor for percent GGBFS replacement

Percent GGBFS Replacement	Equivalent Cement Factor
< 20	1.1
20 to 45	1.0
45 to 65	0.9
> 80	0.8

Initial temperature $^{\circ}F = Maximum$ temperature $^{\circ}F - T$ emperature rise $^{\circ}F$



Figure 2-24 Mass concrete temperature profile

2.8.2. Shrinkage

- Detrimental volume changes that occur in concrete and results in cracking which impacts strength and durability
- Concrete is at its largest volume while plastic and immediately after being placed
- Types of shrinkage are:
 - 1. Plastic shrinkage occurs when concrete is plastic resulting from loss of water from evaporation at the surface or from absorption of water from dry underlying materials
 - 2. Drying shrinkage is unavoidable and occurs when water dries out of the hardened concrete in its service environment
 - 3. Chemical shrinkage occurs because the hydration reaction products occupy less space than the cement and water
 - 4. Autogenous shrinkage is due to water leaving the capillaries and gel pores during hydration, particularly for very low w/c ratio mixes
 - 5. Carbonation shrinkage occurs due to a reaction between CO₂ in the atmosphere and CH which decomposes into calcium carbonate





Figure 2-26 Plastic shrinkage cracks form perpendicular to wind direction



- Mitigation methods:
 - Plastic shrinkage limit excessive evaporation, cure properly, dampen subgrade and forms, use synthetic fibers and limit paste content
 - 2. Drying shrinkage limit paste content, increase coarse aggregate content and optimize gradation and top size, cure properly, control with joints
 - 3. Chemical shrinkage limit paste content, use lower heat generating cements, use fly ash, use internal curing/lightweight aggregates
 - 4. Autogenous shrinkage use lower heat generating cements, use fly ash, use internal curing/lightweight aggregates
 - 5. Carbonation shrinkage limit paste content, use SCMs



Figure 2-27 Drying shrinkage cracking controlled at joint

2.9. Cement Content

- Cement content should be optimized to provide the needed workability for the placement technique and element being constructed while maintain the desired w/c ratio for adequate strength and permeability
- Perfect optimization of cement allows paste (cement and water) to coat all particles and fill void spaces entirely
- Mixes with too little paste can be considered harsh and non-workable
- Mixes with too much paste can be sticky and expensive
- Cement reductions should not occur if water additions are needed to maintain workability and the desired w/c ratio cannot be maintained
- PCA and ACPA recommend a minimum cementitious content of 564 lbs/yd³ for pavements exposed to severe freeze thaw and deicing chemicals (w/c ratio 0.40 to 0.45)
- Performance engineered mixes (PEM) for paving with cement contents of 500 to 520 lbs/yd³ are currently being evaluated in Iowa
- Mixes that must be pumped and close at form faces contain more fine aggregate and have cement contents typically above 600 lbs/yd³
- Aggregate service histories are reduced when Class B mix proportions (lower cement and higher w/c ratios) are compared to Class C mix proportions (higher cement and lower w/c ratios)
- ACI 211.1 mix designs are often found to have very high cement contents

2.10. Curing

- Proper curing of concrete ensures adequate moisture and temperatures are maintained at early ages for continued hydration and development of strength, resistance to freezing, volume stability, and scaling resistance
- Air dried concrete hydrates for a short amount of time resulting in reduced strengths and higher permeability
- Moist cured concrete hydrates as long as moisture is present resulting in higher strengths and reduced permeability



Figure 2-28 Effect of moist curing on strength

- Higher curing temperatures increase early strength but reduce ultimate strength and increase permeability due to a coarser less consistent hydration product
- Lower curing temperatures reduced early strength but increase ultimate strength and reduce permeability due to a finer more consistent hydration product



Figure 2-29 Curing temperature effect on strength

CHAPTER 3 CHEMICAL ADMIXTURES

3. Chemical Admixtures

- Large variety capable of modifying almost any mix property
- Most common properties modified are air, workability, and set
- Enhance properties of a good mix NOT fix a poor mix or bad construction practices
- Allow designer to achieve desired mix properties efficiently and economically
- Address unique conditions
- Multiple effects exist and must be understood and accounted for
- Derived from waste products of other industries
- Technical assistance provided by manufacturer is useful
- I.M. 403 Iowa DOT approved sources chemical admixtures

Appendix	Admixture	Intent	Application
А	Air entraining	Entrain air	All
В	Retarding and water reducing	Retard and reduce water demand for extended working time	Bridge decks and drilled shafts
С	Water reducing admixtures (low and mid range)	Reduce water demand	Paving or structural concrete
D	High range water reducing	Reduce water demand or enhance workability	SCC
E	Non-chloride accelerating	Reduce set time	Concrete with steel
F	Prestressed/precast	Better compatibility, appearance, and production	Dry cast
G	Retarding and water reducing	Retard, reduce water demand, or both for normal working time	Paving or structural concrete
H	Special performance admixtures	Viscosity modifying, anti-segregation, strength enhancing, permeability reducing	Specialty

Table 3-1I.M. 403 Appendix summary



Figure 3-1 Chemical admixture and dispensing equipment

3.1. Air Entraining

- 3.1.1. Background
- Most commonly used admixture
- Stabilize and entrain millions of tiny bubbles formed during mixing
- Entrained bubbles provide freeze thaw protection in the hardened state
- Bubbles improve workability and decrease potential for bleeding and segregation in the plastic state
- Discovered in the 1930's when beef tallow was used as a grinding aid resulting in a network of tiny spherical bubbles in the concrete and exceptionally durability in harsh winter conditions
- Derived from pine wood resins, vinsol resins, and synthetic detergents
- Made of complex molecules that are attracted to water (hydrophilic salts) at one end and repel water (hydrophobic resin) at the other end
- Folding and mixing introduces tiny air bubbles into the concrete
- The hydrophobic resin end of the air entraining agent attaches itself into air bubbles while the hydrophilic end affixes itself into the water in the paste
- The ends attached into the paste are charged and attracted to the cement grains while repelling other bubbles with the same charge, resulting in the bubbles being anchored and not consolidating into large bubbles
- ASTM C 260 specification requirements



Figure 3-2 Stabilization of air bubbles with air entraining agent

3.1.2. Use and Multiple Effects

- Air entrainment is used on exterior concrete exposed to wet conditions and freeze thaw
- Items exposed to severe conditions or mixes with higher paste contents will require greater protection
- Prestressed beams do not include air entrainment as they are protected from the deck and not exposed to water
- Interior floors with a steel trowel finish do not typically use air entrainment as blistering may result
- Drilled shafts are completely air entrained to prevent the oversight of not including air entrainment above the frost line
- Multiple effects of air entrainment include reduced strength as well as increased workability
- Compressive strength is reduced approximately 5 percent for every 1 percent of entrained air
- Workability is improved as the bubbles reduce the interaction between coarse aggregate

3.1.3. Freeze Thaw Damage

- Concrete is porous due to capillary pores left after hydration is complete
- When concrete is exposed to water, the capillary pores wick water into the concrete and act as channels to move the water further into the concrete
- When freezing occurs, the water will start to turn to ice in the center of the largest capillaries expanding about 9 percent in volume
- Air bubbles act as pressure relief valves to accept the water being displaced by the expanding ice in the larger capillaries
- If no air bubbles exist, the water will be confined in the smaller capillaries and extreme pressures will develop internally in the concrete, causing cracking and allowing further water infiltration and freeze thaw damage

Figure 3-3 Freezing liquid expansion and air void relieving pressure







3.1.4. Air Void System

- Amount and bubble size distribution defines the air void system
- Proper air void system is required to provide adequate freeze thaw protection
- Amount of air bubbles or air content is expressed as a percentage of concrete volume
- Air content must be in the range of 5.0 to 8.0 percent for adequate freeze thaw protection in Iowa
- Iowa DOT targets 6.0 percent (0.060 by volume) air content for inplace hardened concrete
- Air content is tested in the plastic state with the air pot in the field
- Bubble size distribution is determined in the hardened concrete using microscopic methods
- To ensure adequate freeze that protection, water should travel no further than 0.008 inches before an air void is reached
- The theoretical distance water must travel to reach an air void is termed spacing factor
- Many small bubbles distributed throughout the paste provides better protection by ensuring all parts of the paste are within 0.008 inches of an air void realm of protection



Figure 3-5 Air size distribution effect on paste protection

3.1.5. Super Air Meter (SAM)

- SAM is a modified Type B Pressure Meter that functions in two ways
- Provides the same information on air content as a standard air test in addition to subjecting the concrete to a series of high pressures
- Takes approximately 10 to 15 minutes to run
- Concrete response to the series of high pressure allows for the air void system to be characterized with a SAM number that relates directly to spacing factor
- Precision and repeatability are still being evaluated
- Devices are being used for development and monitoring of performance engineered mixes (PEM) and quality control but not acceptance



Figure 3-6 Spacing factor versus SAM number lowa DOT Q-MC mix

- 3.1.6. Material and Placement Factors Influence on Air Content
- Air content is influenced by many factors and therefore needs to be constantly tested and adjusted
- Critical placements like bridge decks have higher testing frequencies

Figure 3-7 Effects of materials and placement factors on air content

Material/ practice	Change	Effect	
Cement	Increase in cement content Increase in fineness Increase in alkali content	t ↓ ↓ ↑	
Supplementary cementitious materials	Fly ash (especially with high carbon) Silica fume Slag with increasing fineness Metakaolin	+ + < + + ↓	
Aggregates	Increase in maximum size Sand content	↓ ↑	
Chemical admixtures	Water reducers Retarders Accelerators High-range water reducers	^ ↑ ↑	
w/cm	Increase w/cm	1	
Slump	Increase in slump up to 6 in High slump (>6 in.) Low slump concrete (<3 in.) ↓) ↓	
Production	Batching Increased mixer capacity Mixer speeds to 20 rpm Longer mixer time	↑ ↓ ↑ ↑ <	
Transport and delivery	Transport Long hauls Retempering	↓ ↓ ↑	4
Placing and finishing	Belt conveyers Pumping Prolonged internal vibratior Excessive finishing		

Key: ↓ decrease in air content

- + + significant decrease
- † increase in air content
- ↔ no significant change
- ↑ ↓ increase or decrease in air content

3.2. Water Reducers

3.2.1. Background

- Reduce the quantity of water required to achieve a given degree of workability
- Can be used in three ways:
 - 1. Same amount of cement but a reduced amount of water
 - Water reducing
 - W/C ratio reduced and workability remains the same
 - Improved concrete quality
 - 2. Cement and water are reduced by same proportion
 - Cost reducing
 - W/C ratio and workability are maintained
 - o Similar concrete quality
 - 3. Use the same amount of water and cement
 - Workability enhancer
 - W/C ratio maintained and workability is increased
 - Similar concrete quality
- Water reducers can be classified into the general types of low, mid, and high range
- Mid and high range are similar materials at different dosage rates

Table 3-2 General types of water reducers

Туре	Use	Percent Water Reduction	Slump Range	Material
Low	General use for a variety of applications to reduce w/c ratio, increase slump, and improve workability	5 - 10	1 - 5	Lignosulfates, hydroxylated carbolic acid, carbohydrates
Mid	General use for a variety of applications to reduce w/c ratio, increase slump, and improve workability	8 - 15	5 - 8	Lignosulfates and polycarboxylates
High	Specialized applications with very low w/c ratios and high strengths or congested placements requiring significant increases in slump and improved workability	12 - 30+	> 8 inches or SCC	Lignosulfates, polycarboxylates, and others

- After grinding, the cement particles carry residual positive or negative charges, the oppositely charged particles attract to one another tying up a considerable amount of water and reducing workability
- All water reducers neutralize the residual charges and deflocculate the cement particles releasing the tied-up water
- Polycarboxylates provide additional defloculation through steric hindrance in which a negatively charged carbon chain attaches to the cement particles causing the particles to repel one another

Figure 3-8 Dispersion of cement particles by a water reducer



Water Reducers separate flocs into individual grains. Trapped water is released and the grains slip by each other like ball bearings, improving the workability of the concrete

3.2.2. Use and Multiple Effects

- May or may not be required by specification
- Normal (low or mid) water reducers are typically used on pavement, patching, structures, and decks
- Mid or high range water reducers are required on drilled shafts
- High range is used on prestressed beams, some precast, and special applications like SCC

- Multiple effects of water reducers include increased air content and retardation of hydration
- High range water reducers may entrain larger bubbles and cause air instability
- ASTM C 494 specification requirements

3.3. Retarders

3.3.1. Background

- Delay and slow the early stages of hydration
- Similar to low range water reducers and have active ingredients of either lignosulfonates, hydroxyl carboxylic acids, or sugars
- Often classified as combination water reducer/retarder
- Typically, 0.03 to 0.15 percent sugar added to concrete will retard set indefinitely
- Retarders work by forming a film on the cement grains which prevents the water from fully contacting the cement grain and delays and slows down hydration from occurring
- After the film dilutes and wears off hydration begins and occurs normally
- Although hydration is delayed and slowed, ultimate strength and durability are the same or slightly increased



Figure 3-9 Retarder coating cement grain

3.3.2. Use and Multiple Effects

- May or may not be required by specification or engineer based on conditions
- Used in hot weather to increase working times, with long hauls, in large mass pours to prevent cold joints, on decks to avoid deflection cracks, and in elements with difficult placements or with special finishing
- Required on drilled shafts
- Extend mixed to placed time by 30 minutes for paving concrete transported without agitation
- Multiple effects of higher final strength and a greater potential for bleeding
- ASTM C 494 specification requirements

3.4. Accelerators

3.4.1. Background

- Shorten the rate of setting and increase early strength
- Three chemical types are calcium chloride (CaCl₂), calcium nitrate, and calcium nitrite
- Calcium chloride is a soluble inorganic salt and is not for use in applications with reinforcement
- Calcium nitrate is a soluble organic compound and is safe for use in applications with reinforcement
- Calcium nitrite is an inorganic compound and is safe for use in applications with reinforcement as it is a corrosion inhibitor
- Calcium chloride is the most commonly used and most effective accelerator
- Accelerators work by breaking down cement particles, making them more permeable and increasing the rate at which tricalcium silicate (C₃S) reacts with water
- Increased C₃S reactivity increases the rate of calcium hydroxide (CH) growth resulting in higher strength in the first 24 hours

3.4.2. Use and Multiple Effects

- Not required by specification and should only be used when other options such as type III cement, insulating blankets, a lower w/c ratio, heating, and/or rapid setting bagged mixes are ineffective
- Most commonly used in pavement patching
- Multiple effects included reduced ultimate strength, durability, rapid stiffening, and corrosion of reinforcement
- ASTM C 494 specification requirements

3.5. Specialty Admixtures

- Viscosity modifying
 - Used in SCC and underwater concrete
 - Minimize the movement of water and fines away from the bulk concrete
- Shrinkage reducing
 - Used in crack critical flatwork and decks
 - Reduce the surface tension of the mix water limiting the formation of menisci in capillaries and reducing shrinkage as concrete dries
- Hydration control
 - Used for extremely long haul times
 - Very potent retarders used to stop hydration, activator is needed to wake mix and start hydration
- Alkali-silica reaction inhibiting
 - Used to stop ASR when supplementary cementitious materials are not available
 - Lithium based, chemical stops ASR reaction
- Colorants
 - Used to provide coloring for aesthetics
 - o Liquid or powder pigments in the desired color

CHAPTER 4 AGGREGATE

4. Aggregate

4.1. Iowa Overview

- Iowa has been repeatedly subjected to successive periods of sea coverage, uplift and faulting, and erosion, most recently followed by a period of glacial advances and retreats
- During periods of sea coverage limestone, shale, and sandstone were deposited
- Glacial advances and retreats resulted in gravels and sands being deposited and carried in the glacial outwash in rivers and streams
- Rock formations in Iowa slant from the north and east to the south and west
- At easily accessible depth, the oldest and best rocks occur in the northeast and the youngest and worst rocks occurring in the southwest
- Quartzite, originally a sandstone metamorphized under high pressure and temperature, occurs only in the northwest
- All approved aggregate sources in Iowa are listed in the T-203 by county



Figure 4-1 Geological cross section of lowa

Bedrock Aquifer Systems across Iowa

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4.1.1. Coarse – Article 4115

- Material retained on the #4 sieve and above
- Typically meets gradation 3 or 5 on Table 4109.02-1
- Crushed limestone, crushed quartzite, or gravel
- A washed crushed limestone is commonly used in Iowa
- Meet specified durability class

4.1.2. Intermediate – Article 4112

- Material passing the 1/2 inch sieve and retained on the #4 sieve
- Meets gradation 2 on Table 4109.02-1
- Used to obtain a well graded combined grading on QM-C, BR, and HPC-D
- Crushed limestone, crushed quartzite, or pea gravel
- Produced during coarse aggregate production and often scalped out
- Often reintroduced as separate third bin, providing easy adjustments to aggregate blends
- Limestone and quartzite are required to have the same durability classification as the coarse aggregate for the mix being designed
- Pea gravel not to exceed 15 percent of total aggregate used in the mix if it is a lower durability class the than coarse aggregate

4.1.3. Class V Aggregate - Article 4116

- Sand gravel blend from Platte River in Nebraska with approximately a $\frac{1}{2}$ inch top size
- Meets gradation 7 on Table 4109.02-1
- Well graded combination typically at a 45% coarse aggregate and 55% Class V
- Requires use of class F fly ash or GGBFS to reduce potential alkali silica reactivity

4.1.4. Fine – Article 4110

- Material passing the #4 sieve
- Meets gradation 1 on Table 4109.02-1
- Natural sand is used exclusively
- Shale and coal limits but no durability classes



Figure 4-2 Comparison of Class V sand/gravel blend and 4110 sand

4.2. Aggregate Properties to Consider for Concrete

4.2.1. Strength

- Soft coarse and intermediate aggregate will limit concrete strength and wear resistance
- Critical for very high strength concrete or pavements that will be ground and have exposed aggregates
- Soft aggregates can also degrade during handling and transport resulting in excessive fines
- Excessive fines require additional paste and can affect workability, air entrainment, and paste to aggregate bond

4.2.2. Texture

- Texture can be classified from rough to smooth
- Rough textured aggregates have fractured faces creating more surface area, requiring more paste to achieve a desired workability
- Smooth textured aggregates do not have fractured faces and require less paste to achieve a desired workability
- Rough texture of limestone provides a better bond with paste and typically higher strengths compared to the glassy quartzite or smooth gravel texture

4.2.3. Shape

- Shape can be classified as rounded, cubical, or flat and elongated
- Rounded and cubical shaped aggregates pack closer together and have less interference when being placed, resulting in less paste being required to fill void spaces and achieve a desired workability
- Flat and elongated aggregates do not pack tightly and conflict each other when being placed, resulting in more paste to fill void spaces and achieve a desired workability
- Flat and elongated particles can settle on top of one another causing segregation
- Crushing techniques have a direct influence on the shape obtained

4.2.4. Ideal Texture and Shape

- For normal strengths concrete, the ideal aggregate shape and texture for optimizing paste content while providing the desired workability is smooth and rounded
- Relationships between texture and shape and paste required to provide a desired workability is more critical for intermediate aggregate due to increased amount of surface area and interaction points

- Smooth and rounded particles have a lower surface to volume ratio and a decreased amount of void space between adjoining particles, requiring less paste to coat the surfaces and fill the void spaces while providing workability
- River gravels are typically smooth and rounded



Figure 4-3 Gravel coarse and intermediate aggregates

- Slightly rough and cubical particles will require more paste to be coated and fill void space between adjoining particles while providing workability
- Crushed limestone is typically slightly rough and cubical



Figure 4-4 Limestone coarse and intermediate aggregates

- Rough and flat and elongated particles will require the most paste to be coated and fill void space between adjoining particles while providing workability
- Crushed quartzite may have more flat and elongated particles



Figure 4-5 Quartzite coarse and intermediate aggregates

4.2.5. Freeze Thaw Durability

- Freeze thaw durability of coarse and intermediate aggregate is affected by the continuity and size of pores and the presence of clay
- The pore system is characterized by the Iowa Pore Index test
- Coarse grain dolomitic limestone have large interconnected pore systems which allow water to move out freely during freezing
- Very fine grain limestone have very small pore systems which prevent water from entering completely
- Poor quality aggregates with intermediate interconnected pore systems that trap water during freezing causing expansion and cracking
- Clay content is determined through X-ray fluorescence testing
- Clays expand in the presences of water causing expansion and cracking
- Damage due to aggregate freeze thaw durability is called D-cracking

Figure 4-6 Coarse grained dolomitic limestone (top) versus fine grained limestone susceptible to freeze thaw damage (bottom)









4.2.6. Deleterious Materials

- Aggregate impurities that adversely affect concrete performance and/or appearance
- Coal, shale, chert, and other organic materials are the primary deleterious materials
- Readily absorb moisture and degraded or experience disruptive expansion when freezing in a moist state
- Coal and shale are light and float to the top of finished concrete resulting in a concentration of pop outs and a marred surface
- Localized pop outs occur at individual chert and oolite particles
- Pop outs are a cosmetic flaw and generally do not affect durability
- lowa DOT specifications and durability classes are not developed for aesthetically critical concrete
- Specifying highest durability rating does not guarantee elimination of pop outs
- For aesthetic or highly visible concrete, aggregates containing minimal amounts of deleterious materials should be used



Figure 4-8 Oolite pop outs(left) and shale/chert pop outs (right)

4.2.7. Chemical Reactivity

- Primary reaction mechanisms are related to alkalis and deicing salts
- Alkali-silica reactions form expansive gel like material around reactive silica aggregate
- When severe, expansive gels lead to random internal and surface cracking
- Although present in Iowa aggregates, alkali-silica reactivity is not severe enough to cause durability issues
- Salt susceptibility occurs in impure dolomitic limestones when the deicing salts destabilize the crystal structure of the aggregate
- Destabilization leads to failure of the aggregate paste bond and ultimately cracking and strength loss



Figure 4-9 Alkali silica gel

4.2.8. Durability Classes

- Classes are assigned based on physical and chemical testing
- Physical testing includes the Iowa Pore Index test
- Chemical testing includes X-ray fluorescence and diffraction for mineralogy makeup and X-ray fluorescence for clay content
- Physical and chemical test results are used to calculate a quality number and assign the durability class
- Three durability classes for intermediate aggregate in Iowa
 - Class 2 = minimal deterioration only after 20 years, non-interstate usage
 - Class 3 = minimal deterioration only after 25 years, non-interstate usage
 - Class 3I = minimal deterioration only after 30 years, interstate usage

4.3. Moisture Conditions and Batch Weight Corrections

4.3.1. Pores

- Nearly all aggregates have permeable and impermeable pores
- Permeable pores connect with the outside surface and permit liquids and gases to penetrate
- Impermeable pores are entirely enclosed within the aggregate and cannot be filled by liquids or gases from the outside
- Amount of permeable pores determines the absorption of the aggregate

Figure 4-10 Porous aggregate with permeable and impermeable pores



4.3.2. Moisture Corrections

- Four aggregate moisture conditions exist
- Oven dry and saturated surface dry (SSD) are theoretical conditions
- Airdry and damp or wet are conditions that occur in practice
- SSD has water equal to absorption, air dry has water less than absorption, and damp or wet has water greater than absorption
- SSD conditions properly represent the equilibrium condition the aggregates become in the mix when they neither contribute or absorb mix water
- Aggregate with moisture conditions other than SSD must be corrected to a SSD condition
- Corrections are required to batch weights of aggregates and mix water
- Corrections help to provide a mix that is batched near or at the design w/c ratio and is more consistent over time
- Iowa DOT uses pycnometer to determine moisture content and calculate corrections
- Dry batch weight is the same as SSD batch weights
- Wet batch weight is the corrected or adjusted batch weight



Figure 4-11 Moisture conditions of aggregates

4.4. Gradation

- 4.4.1. Influence on Concrete Performance
- Aggregate gradation controls packing potential and the surface area to be coated by paste, which substantially influences the mix proportions, economy, water demand, workability, finishability, air entrainment, and shrinkage

4.4.2. Nominal Maximum Aggregate Size

- Largest sieve that retains some of the aggregate particles but generally not more than 10 percent
- Decision point in ACI 211.1 mix design
- Desirable to use largest available nominal maximum aggregate size available meeting project constraints

4.4.3. Surface Area

- Surface area of the aggregate controls the amount of paste required for coating
- Finer particles have a greater surface area for a given volume compared to coarser particles
- Increased amount of fine aggregate requires more paste

Figure 4-12 Relationship of particle size to volume and surface area



4.4.4. Fineness Modulus (FM)

- Index to describe how fine or coarse a given aggregate is
- Higher FM indicates a coarser gradation
- Lower FM indicates a finer gradation
- Typically used for fine aggregate but may be applied to any aggregate including combined
- Steps for determining FM:
 - 1. Determine the percent retained for the 6", 3", 1.5", 3/4", 3/8" #4, #8, #16, #30, #50, and #100
 - 2. Determine the cumulative percent retained for each sieve
 - 3. Sum all the cumulative percent retained and divide by 100

Sieve Size	Percent Retained	Cumulative Percent Retained
6"	0	0
3"	0	0
1.5"	0	0
3/4"	0	0
3/8"	0	0
#4	2	2
#8	13	_15
#16	20	_35
#30	20	_55
#50	24	_79
#100	18	97
Pan	3	NA
Sum		283
Calculation		283 ÷ 100
FM		<u>2.83</u>

Example: FM calculation

4.4.5. ASTM-C33

- Standard specification for concrete aggregates
- Individual aggregate grading requirements
- Iowa DOT has adopted portions of ASTM-C33
- Differences are in fine aggregate gradations and special requirements (lowa DOT)
 - Fine aggregate must have no more than 45 (40) percent retained between two consecutive sieves
 - FM of the fine aggregate must not be less than 2.3 nor more than 3.1 (no FM requirement 2.60 minimum)
 - \circ Limits on minus #200 may be adopted (0-1.5)
- ASTM and Iowa DOT fine aggregate gradations are for natural sand
- Manufactured sands require a high amount of minus #200 to produce a workable mix
- Designing concrete mixes with individual aggregate gradations does not guarantee a mix is optimized or has desirable properties
- Open bands can lead to significant variation between sources
- Missing material requirements, particularly on the 3/8", #4, and #8 sieve can lead to gaps in these particle sizes

• Individual gradations are often specified and used in mixes due to ease and because aggregate producers have these products available

Sieve Size	ASTM #57 Iowa DOT No. 3	ASTM #67 Iowa DOT No. 5	ASTM	lowa DOT No. 1
	Coarse	Coarse	Fine	Fine
1.5"	100			
1.0"	95 to 100	100		
3/4"		90 to 100		
1/2"	25 to 60			
3/8"		20 to 55	100	100
#4	0 to 10	0 to 10	95 to 100	90 to 100
#8	0 to 5	0 to 5	80 to 100	70 to 100
#16			50 to 85	
#30			25 to 60	10 to 60
#50			5 to 30	
#100			0 to 10	

 Table 4-1
 ASTM-C33 and Iowa DOT gradation bands comparison

4.4.6. Combined Aggregate Grading

- Since 1930's, the emphasis has been on an individual two aggregate approach, focusing on nominal maximum size for coarse aggregate and FM for fine aggregate
- Earlier fundamental work focused on FM of combined aggregate grading
- Recently, Shilstone and others have revived fundamental approach of focusing on combined aggregate grading
- Optimizes packing and fineness allowing for reduced paste demand while maintaining or improving workability and other mix properties
- Used on Iowa DOT QM-C, BR and HPC-D mixes

4.4.7. Combined Aggregate Gradation Classifications

4.4.7.1. Uniformly Graded

- Aggregate particles are almost all the same size
- Nearly vertical curve when plotted on percent passing chart
- Loose packing requiring more paste to fill voids
- Difficult to place because particles are in conflict when moving

4.4.7.2. Gap graded

- Aggregates particles with deficiencies in 3/8", #4, and #8 sieve sizes
- S shape curve when plotted on the percent passing chart
- Tend to segregate more easily
- Higher amount of fines is often required resulting in higher paste and greater water demand
- Sticky and difficult to finish

4.4.7.3. Well graded

- Aggregate particles are over a wide range of sizes in relatively equal amounts
- Constant sloped line when plotted on the percent passing chart
- Less prone to segregation
- Easier to place because particles are moving together
- Lower amount of fines is often required resulting in lower paste and lower water demand
- Not sticky and easier to finish



Figure 4-13 Examples of aggregate gradation classifications

4.4.8. Mathematically Combined Aggregate Gradation

- Combined aggregate grading is accomplished by mathematically combining coarse, fine, and intermediate individual gradations
- Relative percentages are the percentages of each individual aggregate being combined, their sum must equal 100 percent
- Relative percentages will be determined by the designer
- Individual percent passing will be determined in a laboratory
- Individual percent passing for the #16, #30, #50, and #100 sieves for the coarse and intermediate aggregate are theoretical and provided so that combined calculations can be determined
- Steps for mathematically combining aggregates:
 - 1. Estimate the relative percentages
 - 2. Determine the combined percent passing by multiplying the relative percentage by the percent passing for each individual aggregate and sum the total for each sieve size

P=Aa + Bb + Cc

P= Combined percent passing of a given sieve *A*,*B*,*C* = Percent passing given sieve for aggregate *A*, *B*, and *C a*,*b*,*c* = Relative percentage of aggregate *A*,*B*, and *C*

3. Convert the combined percent passing to combined percent retained by subtracting the combined percent passing on the top sieve from 100 and the combined percent passing from each subsequent sieve, thereafter

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative Percent	0.48	0.12	0.40		
1 1/2"	100.0	100.0	100.0	100.0	100-100 = 0.0
1"	98.0	100.0	100.0	99.0	100-99 = 1.0
3/4"	75.0	100.0	100.0	88.0	99-88 = 11.0
1/2"	38.0	100.0	100.0	70.2	88-70.2 = 17.8
3/8"	21.0	86.0	100.0	60.4	70.2-60.4 = 9.8
#4	4.0	21.0	92.0	41.2	60.4-41.2 =19.2
#8	1.8	4.1	82.0	34.2	41.2-34.2 = 7.0
#16	1.6	3.7	66.0	27.6	34.2-27.6 = 6.6
#30	1.5	3.3	42.0	17.9	27.6-17.9 = 9.7
#50	1.3	2.9	14.0	6.6	17.9-6.6 = 1.3
#100	1.2	2.5	1.4	1.42	6.6-1.4 = 5.2
#200	1.0	2.1	0.3	0.85	1.4-0.85 = 0.55

Example: mathematically combined grading

Combined percent passing calculations

1 ½"	$100 \times 0.48 + 100 \times 0.12 + 100 \times 0.40 = 100$
1"	98x0.48 + 100x0.12 + 100x0.40 = 99.0
³ /4"	75x0.48 + 100x0.12 + 100x0.40 = 88.0
1⁄2"	38x0.48 + 100x0.12 + 100x0.40 = 70.2
3/8"	21x0.48 + 86x0.12 + 100x0.40 = 60.4
#4	$4.0 \times 0.48 + 21 \times 0.12 + 92 \times 0.40 = 41.2$
#8	$1.8 \times 0.48 + 4.1 \times 0.12 + 82 \times 0.40 = 34.2$
#16	$1.6 \times 0.48 + 3.7 \times 0.12 + 66 \times 0.40 = 27.6$
#30	$1.5 \times 0.48 + 3.3 \times 0.12 + 42 \times 0.40 = 17.9$
#50	$1.3 \times 0.48 + 2.9 \times 0.12 + 14 \times 0.40 = 6.6$
#100	1.2x0.48 + 2.5x0.12 + 1.4x0.40 = 1.4
#200	1.0x0.48 + 2.1x0.12 + 0.3x0.40 = 0.85

4.4.9. Graphical Techniques for Evaluating Combined Gradations

- Obtaining a satisfactory combined aggregate gradation is an iterative process done by selecting relative percentages and using graphical techniques to evaluate acceptability
- Graphical techniques used are Shilstone coarseness and workability (CW) chart, 0.45 power, percent retained/tarantula curve
- I.M. 532 explains these techniques and their use in detail
- A spreadsheet is used to quickly determine the mathematically combined grading and the resulting graphs

4.4.10. Shilstone CW Factors

- Developed by Jim Shilstone from years of field observations
- Numerical values are determined from the combined aggregate gradation and then plotted on the CW chart
- Primary technique used to optimize QM-C, BR, and HPC-D mixes
- Easy to specify and interpret as it is a plotted point
- Does not provide information about specific sieves
- Coarseness factor indicates if a combined aggregate is gap or well graded
- Workability factor indicates if a combined aggregate is fine or coarse

Coarseness factor = $\frac{Sum \ combined \ percent \ retained \ 3/8" \ sieve \ and \ above}{Sum \ combined \ percent \ retained \ #8 \ sieve \ and \ above} X \ 100$

Workability factor = Combined percent passing #8 Sieve

Example: CW factor calculations

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative Percent	0.48	0.12	0.40		
1 1/2"	100.0	100.0	100.0	100.0	0.0
1"	98.0	100.0	100.0	99.0	1.0
3/4"	75.0	100.0	100.0	88.0	11.0
1/2"	38.0	100.0	100.0	70.2	17.8
3/8"	21.0	86.0	100.0	60.4	9.8
#4	4.0	21.0	92.0	41.2	19.2
#8	1.8	4.1	82.0	34.2	7.1
#16	1.6	3.7	66.0	27.6	6.5
#30	1.5	3.3	42.0	17.9	9.7
#50	1.3	2.9	14.0	6.6	11.3
#100	1.2	2.5	1.4	1.42	5.2
#200	1.0	2.1	0.3	0.85	0.6

Coarseness factor = $\frac{0+1+11+17.8+9.8}{0+1+11+17.8+9.8+19.2+7.1}$ X 100 = $\frac{39.6}{65.9}$ X 100 = $\underline{60.1}$

Workability factor = 34.2

4.4.11. Shilstone CW Chart

- Assumptions
 - Cementitious content is 564 lbs/yd³
 - For every 94 lbs of cementitious below or above 564 lbs/yd³ the workability factor is adjusted down or up by 2.5 percent
 - Aggregate shape is rounded or cubical aggregate
 - Additional cementitious may be required when using rough, angular, and/or flat and elongated aggregate
 - \circ Nominal maximum aggregate size of 1 to 1 ½ inches
 - Placement is by slip form
 - Increase fine aggregate and cementitious for hand work, pumping, or more restrictive placements

- Workability is plotted on the Y axis and coarseness is plotted on the X axis
- Zone II is considered well graded for ³/₄" to 1 ¹/₂" aggregate top size
- Zone I indicates a gap graded mix that may tend to segregate
- Zone III is same as Zone II for aggregate top size of less than 1/2"
- Zone IV indicates a sandy sticky mix
- Zone V indicate a very rocky mix
- As plot approaches other zones, mix may tend to exhibit characteristics of zone that is closest
- Aggregate shape may cause mixes plotting on the same point to exhibit dissimilar workability and paste demand
- Zone II blue box has worked best for QM-C paving
- For slip form paving, Shilstone recommends a target CF of 60 and WF of 35
- Zone II red box has worked best for BR and HPC-D mixes
- Typically, relative percentages of 48% coarse, 12% intermediate, and 40% fine have been found to plot in Zone II



Figure 4-14 Shilstone CW chart
4.4.12. 0.45 Power Curve

- Used as a tool to identify gap or well graded combined aggregate as well as problem sieves
- Sieve sizes in millimeters are raised to the 0.45 power and combined percent passing is plotted
- Maximum density line is straight and passes through the origin and 100 percent of the sieve one size larger than the nominal maximum aggregate size
- Three maximum density lines are shown in red on the chart to accommodate different nominal maximum aggregate sizes
- A well graded gradation will have a line that is relatively straight and follows the maximum density line
- A gap graded combination will have a S pattern and cross the maximum density line
- Sometimes the gradation line will fall between two maximum density lines, this is acceptable provided it is relatively straight
- Typically, the gradation line will deviate below the maximum density line at the #16 sieve, this is acceptable as it is providing space for cementitious material
- Deficient sieves will plot below, and excess sieves will plot above the maximum density line



Figure 4-15 0.45 power curve for a well graded combined aggregate



Figure 4-16 0.45 power curve for a gap graded combined aggregate

4.4.13. Percent Retained Chart

- Used as a tool to identify gap or well graded combined aggregate as well as problem sieves
- Percent retained on each sieve is plotted with limits of 8 and 18
- Limits are set so that no more nor less than a certain amount are retained on individual or consecutive sieves
- A well graded gradation will have a plot that does not contain excessive peaks or valleys and falls within limits of the bands
- A gap graded combination will show excessive peaks with a valley in the middle
- In some cases, four to five aggregates may need to be combined to fit perfectly within the bands
- The effort of fitting perfectly within the bands is not justified as it does not provide a noticeably improved mix compared to a mix that uses three aggregates and is barely out on one or two sieves
- Typically, well graded QM-C combined gradations will have one or two sieves outside of the band limits
- One or two sieves outside the limits is acceptable provided they are not out excessively, and the sieves are not consecutive



Figure 4-17 Percent retained chart for a well graded combined aggregate

Figure 4-18 Percent retained chart for a gap graded combined aggregate



4.4.14. Tarantula Curve

- Modified percent retained chart developed by Dr. Tyler Ley at Oklahoma State University
- Based on lab work removing individual sieve sizes and observations of workability with the box test
- Combined gradation must be within boundary limits for each sieve size
- Total volume of coarse sand (#8 #30) must be a minimum of 15 percent
- Total volume of fine sand (#30 #200) must be between 24 to 34 percent
- Limit flat or elongated particles to 15 percent or less at a ratio of 1:3
- Over a hundred historical QM-C gradations have been plotted on the tarantula curve and less than five have fallen outside of the limits



Figure 4-19 Tarantula curve with an optimized gradation

4.4.15. Combined Aggregate Grading and Mix Design

- Design approaches using combined grading require additional effort but produce mixes with desired workability and optimized paste
- Design approaches using fixed relative percentages of individual aggregates is simpler and faster but may or may not produce mixes with desired workable and optimized paste
- Iowa DOT standard I.M. 529 mixes do not consider combined grading and use fixed relative percentages of coarse and fine aggregate
- Iowa DOT Q-MC, BR, and HPC-D mixes use graphing techniques to optimize the combined aggregate gradation
- ACI 211.1 adjusts mix proportions for aggregate grading as coarse aggregate content depends on FM, nominal maximum aggregate size, and packing potential

4.5. I.M. 529 Mixes Using Midpoint of Gradation Limits

- Coarse gradation 3 and fine gradation 1 at midpoint of gradation limits
- C-2 through C-6 mix proportions
- Graphs show variation, excessive fineness, and gap grading tendency



Figure 4-20 CW chart midpoint gradation C-2 through C-6



Figure 4-21 0.45 power curve midpoint gradation C-2 through C-6

Figure 4-22 Percent retained midpoint gradation C-2 through C-6



CHAPTER 5 BASIC CONCEPTS

5. Mix Design

5.1. Overview

- Provides a first approximation of proportions that may need to be adjusted based on laboratory and field performance
- ONE mix design does not work for every application
- Trial batches must always be conducted to verify mix design performance
- Several mix design methods exist

5.2. Objectives

- Utilize local materials and provide greatest economy
- Practical for supplier to mix and transport
- Practical for contractor to place, consolidate, and finish
- Satisfies strength and durability requirements
- Provides consistent reproducible properties in all life stages
- Performs in lab and field

5.3. Life stages

- Fresh, transitional, and hardened life stages must be considered when designing a concrete mix
- Fresh properties will depend upon method of placement
- Transitional properties will depend upon temperature, evaporation, and admixtures
- Hardened properties will depend upon environment and structural design

Table 5-1	Times and	concrete	properties	for life stages

Life Stage	Fresh	Transition	Hardened
Time	Mixer, transport, placement	Placement, end product	End product
	Placeability	Rate of slump loss	Strength
	Workability	Initial and final set time	Air void system
	Slump and consistency	Rate of strength gain	Frost resistance
es	Air content and stability	Time to freeze resistance	ASR resistance
erti	Segregation	Rate of evaporation	Sulfate resistance
do	Response to vibration	Plastic shrinkage	Permeability
Ъ	Finishability	Drying shrinkage	Abrasion resistance
	Bleeding		Shrinkage
	Temperature		Aesthetics
	Yield		Cost

5.4. Process

- The following are the general steps used to design and proportion a mix:
 - 1. Identify the job parameters
 - 2. Identify the properties and technical description needed to satisfy the job parameters
 - 3. Proportion 1.0 yd³ of materials to meet the technical description
 - 4. Determine the batch weights
 - 5. Develop and test trial batches to ensure technical description is met
 - 6. Adjust proportions and repeat steps 4 and 5 until the technical description is met with the greatest economy
 - 7. Finalize mix design batch weights using the acceptable trial batch
- Some mix design methods will skip steps because they are prescriptive or are based upon years of acquired knowledge
- While skipping steps makes the process simpler and faster, the ability to completely optimize the mix and ensure the best economy may be lost



Figure 5-1 Mix design process

5.5. Job Parameters

- Basis for the mix design
- Describe the element being built, methods and equipment to build it, conditions the element will be subjected to, and design requirements
- May also include specific specification requirements of the owner
- For many projects, including Iowa DOT projects, described in the plans
- Could be described by the customer directly without plans or specifications
- Job parameters must be determined first and defined clearly

5.6. Properties

- Properties describe how the mix must perform to meet the job parameters
- Workability, durability, strength, as well as aggregate size, gradation, and quality are common properties
- Properties may impact more than one job parameter
- With multiple job parameters and multiple impacts designers may need to prioritize, compromise, and balance properties
- In some cases, it may be difficult to completely satisfy all job parameters

5.7. Technical Description

- Provides specific measurable requirements of the properties and is used to proportion the mix
- May include slump, w/c ratio, air content, resistivity, flexural or compressive strength, cement type, use of SCMs, as well as aggregate size, gradation, and quality
- For many projects, including lowa DOT project, described in the plans and specification
- Specifications are developed for specifically for the work type
- Very specialized or project specific requirements may be added with special specifications or plan notes

5.8. Proportioning

- Provides a ratio of component materials meeting the technical description
- A properly proportioned mix has acceptable workability, strength, durability, and uniformity, while providing the greatest economy
- Producer capabilities relative to equipment, materials, and quality control must be considered
- Representative material properties must be known such as specific gravities, gradations, and unit weights
- Adjustments to proportioning will occur until a successful trial batch is obtained and may continue to occur on the project based on field performance

5.9. Material Properties

5.9.1. Particle Density

• Weight of solid particle of material divided by the volume the solid particle occupies

$\rho = \frac{Mass \ of \ solid \ particle}{Volume \ of \ solid \ particle}$

- Does not include the volume of void space between the particles
- Used for aggregates and cementitious materials to obtain the specific gravity
- For concrete, impermeable pores are included when determining the particle density of aggregates
- Typical units are lbs/ft³
- Water has a constant particle density of 62.4 lbs/ft³

5.9.2. Specific Gravity (SPG)

- Dimensionless ratio relating particle density to the density of water
- For aggregates, different specific gravities exist depending on the moisture condition and if impermeable pores are included
- For concrete, bulk specific gravity SSD (BSG_{SSD}) is used for aggregates
- B indicates impermeable pores are included and SSD is the moisture condition
- Water always has a specific gravity of 1.0
- In water, a solid piece of material with a specific gravity less than 1.0 will float and greater than 1.0 will sink
- Must be know for all mix materials for all mix design approaches

$$SPG = rac{Weight of solid material of known volume}{Weight of water of equal volume}$$

or

$$SPG = \frac{Particle\ density\ of\ material}{Particle\ density\ of\ water}$$

Example: specific gravity calculation

Given 1.0 ft³ of solid material weighs 172 lbs, what is the specific gravity?

$$SPG = \frac{172 \text{ lbs/ft}^3}{62.4 \text{ lbs/ft}^3} = \underline{2.76}$$

5.9.3. Unit weight

- Indicates the weight of a material for a given volume
- Same as particle density for liquids and solid materials
- Water has a constant unit weight of 62.4 lbs/ ft³
- If voids are included between the aggregate particles, then it is a bulk unit weight or more commonly referred to as dry rodded unit weight
- Dry rodded unit weight must be known for ACI 211.1 mix design approach
- Typical units are lbs/ft³

$$Unit weight = \frac{Weight of material}{Volume of material}$$

Example: unit weight calculations

Given 0.5 ft³ of coarse aggregate weighs 47 lbs, what is the dry rodded unit weight?

Given 0.25 ft³ of concrete weighs 34.8 lbs, what is the unit weight?

5.9.4. Individual Aggregate Gradations

- Need to be known for the Iowa DOT QM-C, BR, and HPC-D mix design approaches so that a combined grading can be optimized
- Need to know for ACI 211.1 mix design to verify nominal maximum aggregate size for coarse aggregate and calculate the FM for fine aggregate
- Average production gradations provided by and agreed upon by the aggregate producer should be used when developing a mix

5.10. Mix Design Concepts

5.10.1. Volume

- A three-dimensional space of length by width by height
- 1 ft³ is equal to a 1 foot by 1 foot by 1 foot cube
- 1 yd³ is equal to a 1 yard by 1 yard by 1 yard cube
- Conversion between ft³ and yd³ is <u>27 ft³ = 1 yd³</u>
- Concrete is batched by weight and sold by cubic yard



Figure 5-2 1 yd³ volume made of 27 individual 1 ft³ volumes

Example: volume conversions

8.5 ft³ is equal to how many yd^3 ?

$$8.5 \text{ ft}^3 X \frac{1 \text{yd}^3}{27 \text{ft}^3} = \underbrace{0.315 \text{ yd}^3}_{\blacksquare}$$

0.114 yd³ is equal to how many ft³?

$$0.114 \text{ yd}^3 \text{ X} \frac{27 \text{ ft}^3}{1 \text{ yd}^3} = \underline{3.078 \text{ ft}^3}$$

5.10.2. Absolute and Bulk Volume

- Absolute volume is the volume of solid matter in particles not including the void spaces
- Bulk volume is the volume of solid mater in particles as well as the void spaces separating the solid particles
- Void spaces included in the bulk volume will be filled with other mix ingredients

Figure 5-3 Absolute volume versus bulk volume of an aggregate



5.10.3. Absolute Volume

- Almost all mix design approaches are based on absolute volume
- Provides greater yield accuracy and mix consistency by accounting for changes in specific gravity of component materials
- An arbitrary volume of 1yd³ of concrete is used and component materials are proportioned to fill the volume exactly
- Iowa DOT I.M. 529, QM-C, BR and HPC-D mix design approaches use yd³ when determining the volumes of component materials
- ACI 211.1 mix design approach uses ft³ when determining the volumes of component materials
- The arbitrary selection of 1 yd³ results in units for component materials of ft³/yd³, yd³/yd³, and lbs/yd³
- Absolute volumes should be calculated to three decimal places when in yd³/yd³ and two decimals when in ft³/yd³
- Batch weights should be rounded to the nearest whole number



Figure 5-4 Absolute volume of concrete and component materials

Abs. Vol.
$$\frac{yd^3}{yd^3} = \frac{Weight \, lbs}{SPG \, X \, 62. \, 4 \frac{lbs}{ft^3} \, X \, 27 \frac{ft^3}{yd^3}}$$

Abs. Vol.
$$\frac{ft}{yd^3} = \frac{Weight ibs}{SPG X 62.4 \frac{lbs}{ft^3}}$$

$$Weight \frac{lbs}{yd^3} = Abs. Vol. \ \frac{yd^3}{yd^3} X SPG X 62. 4 \frac{lbs}{ft^3} X 27 \frac{ft^3}{yd^3}$$
$$Weight \frac{lbs}{yd^3} = Abs. Vol. \ \frac{ft^3}{yd^3} X SPG X 62. 4 \frac{lbs}{ft^3}$$

Example: absolute volume calculations

What is the absolute volume of cement in yd^{3}/yd^{3} for 593 lbs/yd³ (SPG = 3.14)?

What is the absolute volume of cement in ft^3/yd^3 for 593 lbs/yd³ (SPG = 3.14)?

Abs. Vol.
$$\frac{\text{ft}^3}{\text{yd}^3} = \frac{593\frac{\text{lbs}}{\text{yd}^3}}{3.14 \text{ X } 62.4\frac{\text{lbs}}{\text{ft}^3}} = \frac{3.026\frac{\text{ft}^3}{\text{yd}^3}}{\frac{\text{max}}{\text{max}}}$$

What is the weight of sand in lbs/yd^3 with an Abs. Vol. of 0.325 yd^3/yd^3 (SPG =2.59)?

Weight
$$\frac{\text{lbs}}{\text{yd}^3} = 0.325 \frac{\text{yd}^3}{\text{yd}^3} \text{ X } 2.59 \text{ X } 62.4 \frac{\text{lbs}}{\text{ft}^3} \text{ X } 27 \frac{\text{ft}^3}{\text{yd}^3} = 1.418 \frac{\text{lbs}}{\text{yd}^3}$$

What is the weight of sand in lbs/yd³ with an Abs. Vol. of 8.25 ft^{3}/yd³ (SPG = 2.59?

Weight
$$\frac{\text{lbs}}{\text{yd}^3} = 8.25 \frac{\text{ft}^3}{\text{yd}^3} \times 2.59 \times 62.4 \frac{\text{lbs}}{\text{ft}^3} = 1,333 \frac{\text{lbs}}{\text{yd}^3}$$

Table 5-2	Absolute volumes	accounting for	different SPGs

Coarse Aggregate	Specific Gravity	Absolute Volume	Weight
River gravel	2.66	0.377	1690
Lava stone	1.80	0.377	1143
River gravel	2.66	0.377	1690
Lava stone	1.80	0.557	1690

5.10.4. Water to Cement Ratio

- Total water divided by total cementitious in the mix
- Important technical description impacting strength and durability, see page 20
- Total water includes all water added at all stages and water added or subtracted from the aggregate
- Total cementitious includes cement and all SCMs
- Units for water and cement are in pounds and cancel out resulting in a unitless ratio
- Water added on grade will be estimated in gallons and must be converted to pounds to match the batch weight units
- Conversion between gallons and pounds is **<u>1 gallon = 8.33 lbs</u>**

 $w/c = \frac{Total water weight lbs}{Total cementitious weight lbs}$

$$Total \ cementitious \ weight \ lbs = \frac{Total \ water \ weight \ lbs}{w/c}$$

Example: w/c ratio calculation

Determine the w/c ratio given 450 lbs cement, 109 lbs fly ash, water of 200 lbs plant, 24 lbs from aggregates, 3 gals added on grade. All information given is per cubic yard of concrete.

w/c =
$$\frac{200 \text{ lbs} + 24 \text{ lbs} + 3 \text{ gal } X 8.33 \frac{\text{lbs}}{\text{gal}}}{450 \text{ lbs} + 109 \text{ lbs}} = \underline{0.445}$$

Determine the weight of water given 482 lbs cement, 121 lbs fly ash and a w/c ratio of 0.400.

Total water weight lbs = $(482 \text{ lbs} + 121 \text{ lbs}) \times 0.400 = 241 \text{ lbs}$

- 5.10.5. Paste, Mortar, and Concrete
- Paste is water, cement, and air
 - Typically accounts for 25 to 35 percent of the total concrete volume
 - o Concrete quality depends substantially on the quality of paste
 - Higher paste results in higher potential for shrinkage, increased heat, and increased costs, see page 26
- Mortar is paste and fine aggregate
 - Typically accounts for 50 to 65 percent of the total concrete volume
 - Provides lubricant for coarse aggregate and can control mix economy
- Concrete is mortar and coarse aggregate
 - Typically, coarse aggregate accounts for 30 to 40 percent of the total concrete volume
 - o Economic filler that should be well graded and durable

Figure 5-5 Paste, mortar, and coarse aggregate percentages of total concrete volume



- 5.10.6. Mortar Influence on Mix Design and Placement
- Strictly defined, mortar consists of paste and all aggregate finer than the #8 sieve
- Insufficient mortar results in a harsh mix, susceptible to segregation when pumping and placing and is difficult to finish and close
- Excessive mortar results in a sticky mix that may segregate, and will require more cement/paste due to more fine aggregate that needs to be coated
- Mortar requirement needs to be optimized based on the method of placement, aggregate shape, texture, gradation, and presence of formed or finished surfaces
- Wall effect describes the increased mortar fraction that is required at formed surfaces, finished surfaces, and in pump pipe walls
- Inadequate mortar can result in surface defects such as honeycombing or bugholes that may need to be fixed



Figure 5-6 Wall effect zone

normal mortar content



Figure 5-7 Bugholes and honeycombing at wall effected zone

Table 5-3	Percent mortar reg	uired for different	placement methods

Class	Description	Approximate Percent Mortar Required
1	Placed by steep sided bottom-drop	48 to 50
	bucket, conveyor, or paving machine.	
2	Placed by bottom drop bucket or chute	50 to 52
	in open vertical construction.	
3	Placed by chute, buggy, or conveyor in	51 to 53
	an 8 in. (200 mm) or deeper slab.	
4	Placed by 5 in. (125 mm) or larger	52 to 54
	pump for use in vertical construction,	
	thick flat slabs and larger walls, beams,	
	and similar elements.	
5	Placed by 5 in. (125 mm) pump for pan	53 to 55
	joist slabs, thin or small castings, and	
	high reinforcing steel density.	
6	Placed with a 4 in. (100 mm) pump.	55 to 57
7	Long, cast-in-place piling shells.	56 to 58
8	Placed by pump smaller than 4 in. (100	58 to 60
	mm).	
9	Toppings less than 3 in. thick.	60 to 62
10	Flowing fill.	63 to 66

Shilstone guidelines for mortar fraction from "Concrete Mixture Optimization," Concrete International, June 1990, pp. 33-39. Used by permission of the author.

5.10.7. Producer Capabilities

- Number of cement and SCMs silos as well as aggregate bins will govern the number of materials that can be blended
- Consideration especially with older and/or rural ready-mix plants
- Transport capabilities must also be considered as this could impact the desired workability and time to initial set
- When possible, materials should be selected that are readily available locally
- Selecting materials that need to be transported significant distances or specially made will substantially increase mix costs
- Ability for a producer to consistently meet or exceed strength requirements is extremely important

5.10.8. Standard Deviation and Strength Adjustments

- Terms:
 - Design strength (f'_C)is the concrete strength the element is designed to
 - Target strength (f'_{cr}) is the strength the mix is designed for
 - Standard deviation (S) is a measure of variability of the concrete producer
- Specifications are based on a minimum design strength requirement
- Engineers, owners, and contractors will need to have confidence that the design strength is being met
- Setting the target strength to the average strength is not acceptable as this will result in half of the strengths below the design strength

Figure 5-8 Half of strengths are below design using average strength



- To ensure design strength is met the target strength will be adjusted upward to account for producer variation
- Target strength will always be greater than the design strength
- ACI 211.1 uses a statistical approach to account for producer variation by adopting ACI 318 Building Code
- ACI 318 Building Code requires the target strength, based on the average of two cylinders, meet the largest value of the following:
 - 1. A one percent chance a single test will be below the minimum specified strength requirement

$$f'_{CT} = f'_{C} + (2.33 \text{ S} - 500)$$

2. A one percent chance that the average of three consecutive test values will be less than the minimum specified strength requirement

$$f'_{CT} = f'_{C} + (1.34 \text{ S})$$

- S is typically based on a minimum of 30 tests of average strength of at least two cylinders
- S must be increased if less than 30 tests are available
- A lower S indicates better quality control and will result in less strength overdesign and a mix with less cement that is more economical
- When there is no strength history, or less than 15 tests available then special equations must be used to determine the target strength

 Table 5-4
 Factor to increase S when less than 30 tests

Number of Tests	Factor to Increase Standard Deviation
15 to 19	1.16
20 to 24	1.08
25 to 29	1.03

Table 5-5 S	Special equations	for required	target strength
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Design Strength, <i>f'_C</i> (psi)	Target Strength, <i>f'_{Cr}</i> (psi)
Less than 3000	<i>f</i> ′ <i>c</i> + 1000 psi
3000 to 5000	<i>f</i> ′ _{<i>c</i>} + 1200 psi
Over 5000	1.1 x <i>f'_C</i> + 700 psi

Figure 5-9 Target strength adjusted to account for producer variation



Example: target strength calculation

What is the target strength given a design strength of 4,500 psi and a producer standard deviation (S) of 550 psi for 35 tests?

f[°]cr = 4500 + (2.33 X 550 – 500) = <u>5281.5 psi</u>

f'_{cr} = 4500 + 1.34 X 550 = <u>5237 psi</u>

Select the largest value 5281.5 and round to the next highest 10 psi

f'_{cr} = <u>5290 psi</u>

5.10.9. Strength Adjustments for Iowa DOT Mixes

- Occur by using design strengths well below known actual strengths and ensuring the w/c ratio is monitored and controlled
- Quality control is established and maintained by specifying certified plant inspection
- Result in a high confidence that design strengths are achieved

 Table 5-6
 Class C mix design and actual strengths

Class C Mix	Design (psi)	Actual Statewide Average (psi)
Compressive	4,000	5,800
Flexural	575	640

- 5.10.10. Other Strength Considerations
- Strength is specified in a variety of ways
 - Compressive, common for structural applications
 - Center point flexural, common for opening to traffic or form removal on pavements
 - Third point flexural, common for pavement design
- 28-day strength is age commonly used
- Early strength will be lower and ultimate strengths will be higher especially if SCMs were used
- More important to know strength for removing forms, building up, loading with construction traffic, or putting into service
- Many factors can cause inaccurate field strength test specimen results
 - Improper casting and handling can result in defects or damage and lower strengths
 - High cure temperature can result in high early strength and reduced long term strength
 - Low cure temperatures can result in low early strength
 - Improper testing procedures can lower or increase strength
- When determining strength for specification compliance standard curing according to I.M. 315 I C 3 or I.M. 328 B 2, 3, 6 should be used
- Field curing should only be used for form removal or determining when an element may be loaded
- Maturity method may be used as a replacement to field curing

5.11. Laboratory Trial Batch

- 1. AASHTO T126 should be followed and describes the scope, equipment, and procedure for developing a trial batch
- 2. Key concepts are as follows:
 - All equipment used (scales, slump cone, air meter, temperature device, molds, etc.) should meet requirements
 - An appropriate revolving drum or revolving pan/paddle mixer should be used
 - Batch size should not overload the mixer
 - For greater accuracy and to prevent segregation, coarse and intermediate aggregates should be weighed into individual size fractions and recombined to proper proportions
 - For batches less than 2 cubic feet, aggregates should be in SSD condition
- 3. Laboratory mix procedure:
 - 1. Divide coarse and intermediate aggregate into individual sieve sizes
 - 2. Soak #8 material and above in water for 24 hours
 - 3. Bring soaked aggregate to SSD condition before weighing



4. Weigh all materials, dividing water into 2 containers, one with $\frac{1}{2}$ the mix water and air agent and one with $\frac{1}{2}$ mix water





- 5. Butter the mixer with a concrete batch of similar mortar content
- 6. Remove the butter batch materials leaving the mortar that sticks to sides and paddles
- 7. Add coarse aggregate



8. Add $\frac{1}{2}$ water with air entraining admixture in mixing water



9. Turn on mixer and add sand



10. Add cement and remaining water



11. Add water reducing admixture or retarding admixture12. Start stopwatch and begin 3 minute mix cycle



13. Cover and rest 3 minutes



14. Remove cover and re-mix an additional 2 minutes



15. To prevent segregation, transfer to clean, damp container and re-mix with shovel or trowel, until it appears uniform



16. Check air content, slump, unit weight, and temperature



17. If necessary, adjust air content and slump and re-mix for 30 seconds 18. Cast specimens

- 19. Observe workability, finishability, response to vibration, and set characteristics
- 20. Hardened concrete should be tested for strength and other required properties (F/T durability, permeability, etc.)21. If necessary, adjust mix proportions and perform a new trial batch
- based on test results

CHAPTER 6 MIX DESIGN

6. Mix Design Approaches

6.1. Proportional

- Extremely simple and based entirely on acquired field experience
- Proportion volumes of cement to fine aggregate to coarse aggregate of 1:2:3
- Add water slowly to achieve desired workability
- Other ratios can be tried or used to achieve different results
- Old method used before concrete was more developed and scientifically understood
- Used for backyard mixing noncritical elements
- Not used for engineering work as better methods are available

6.2. Formal Methods

- Developed from empirical data relying on experience and observation over time
- Utilize tables, graphs, nomographs, and empirical relationships
- Follow general process of determining:
 - 1. Nominal maximum aggregate size
 - 2. Target strength adjusted for producer variation
 - 3. Water cement ratio to meet target strength and compared with required durability
 - 4. Desired workability and water content
 - 5. Cement content
 - 6. Percentage of aggregates
 - Various methods:
 - Trial and adjustment
 - o ACI 211.1
 - British DoE
 - o Rapid method
 - Proportioning by IS guidelines
- Absolute volumes used for all methods
- Aggregate grading is considered through use of FM, coarse aggregate packing, and grading zones of fine aggregate
- ACI 211.1 will be presented in detail and is covered in Appendix A

6.3. Iowa DOT I.M. 529

- Prescriptive traditional lowa DOT approach to mix design
- Field experience and theoretical concepts were used in development
- Mixes are organized by class and are application specific
- Knowledge of concrete use and of component material properties is required

- Proportions have been predetermined based on absolute volume for 1.000 yd³, a basic w/c ratio, no fly ash or GGBFS substitution, and a cement with a SPG of 3.14
- Mixes based on these proportions are accepted without trial batches due to extensive use and historic record in Iowa since 1950's
- Proportions for various mix classes and aggregate ratios are presented in I.M. 529
- Little if any change occurs to these mix proportions
- All batch weights are in SSD condition
- Strength is not defined directly but these mixes have historically significantly exceeded design strengths and need to meet w/c ratio and quality control requirements
- Durability is addressed by specifying w/c ratio limits, air contents, and coarse aggregate durability classes
- Adjustments for aggregate gradation and size are not considered and may lead to non-optimized mixes and variation in performance

6.3.1. Calculations

- 1. Obtain a blank 820150 form or computer spreadsheet
- 2. Determine the SPG for each component material from appropriate I.M.s or tests
- 3. Determine the absolute volume for cement from I.M. 529 for the desired mix number
- 4. Determine the cement weight using the absolute volume equation
- 5. If needed, determine the weight of fly ash and or GGBFS by using a 1:1 weight substitution for the percent substituted of cement
- 6. If needed, determine the adjusted cement weight by subtracting the fly ash and or GGBFS substitution weights from the original cement weight
- 7. Determine the amount of water used by solving the w/c ratio for the weight of water
- 8. Determine the absolute volumes for cement, fly ash, GGBFS, water, and air using the adjusted weights using the absolute volume equation
- 9. Determine the subtotal of the absolute volumes for cement, fly ash, GGBFS, water, and air by adding each absolute volume
- 10. Subtract the subtotal from 1.000
- 11. Ensure the subtotal and subtotal subtracted from 1.000 equals 1.000 when added
- 12. Determine the absolute volume of each aggregate by multiplying the percent of each aggregate used by the subtotal subtracted from 1.000 and dividing by 100
- 13. Determine the aggregate total by adding the absolute volumes for each aggregate
- 14. Ensure the aggregate total is equal to the subtotal subtracted from 1.000

- 15. Determine the weight of each aggregate by using the absolute volume equation
- 16. Summarize the weights of the cement, fly ash, GGBFS, water, fine aggregate, and coarse aggregate

6.4. Iowa DOT QM-C

- Less prescriptive Iowa DOT approach to mix design for paving projects
- Applied using developmental specification to slip form paving over 50,000 yd²
- Uses Shilstone principles to provide and optimized combined aggregate gradation, see page 58
- Knowledge of component material properties is required, specifically aggregate gradation, texture, and shape
- Proportions are based on absolute volume for 1.000 yd³ and must meet specific concrete mixture constraints in the QMC DS

Technical Description	Requirement
Nominal maximum coarse aggregate	Greater than or equal to I inch
size	
Combined gradation	CW factor plots in zone II
Cementitious content	560 lbs/yd ³ *
W/C ratio	Basic 0.40, maximum 0.42
Air content	Design absolute volume 0.060 yd ³ , $6 \pm 1\%$,
Third point 28-day flexural strength	Minimum 640 psi

Table 6-1 Concrete mixture constraints

* The minimum cement content assumes the use of Type I/II cement with a specific gravity of 3.14 for an absolute volume of 0.106 yd³. If cement other than Type I/II is used, use an absolute volume of 0.106 yd³ and determine the weight of cement using the cement specific gravity.

- Mixes must be developed by a Level III Certified Technician and submitted to the District Materials Engineer for review and approval
- Trial batches are no longer required due to extensive use and historic record in Iowa since 2000
- All batch weights are in SSD condition
- Target strength is specified in the concrete mixture constraints and is approximately 1.5 times the S above the design strength
- Historically mixes meeting the concrete mixture constraints have met or exceeded the target strength
- Durability is addressed by specifying w/c ratio limits, air contents, and coarse and intermediate aggregate durability classes

6.4.1. Calculations

- Download the most recent version of the QM-C mix PC Batch Weights spreadsheet from the Iowa DOT Construction and Materials webpage (*pcbatchQMC.xlsx*)
- 2. Obtain percent passing production gradations from aggregate producers for each aggregate being considered for use
- 3. Calculate the average percent passing production gradation for each aggregate and enter them into Gradation sheet
- 4. Input initial relative percentages for aggregates being considered into the Gradation sheet (recommended starting point is 48% coarse, 12% intermediate, and 40% fine)
- 5. Review the calculated values for the CW factors as well as the FM
- 6. Evaluate the combined gradation using the Shilstone CW chart, 0.45 power curve, and percent retained chart sheets
- 7. Based on the evaluation, determine what adjustments, if any, need to be made to the relative percentages
- 8. Adjust the relative percentages on the Gradation sheet and repeat steps 4 through 7 until satisfactory results are achieved
- 9. Enter all information on the 955QMC sheet and use the completed sheet as an agreement between the aggregate producer and the contractor
- 10. Enter all known general data, source information, substitution rates, aggregate percentages, and target air content on the Mix Design sheet
- 11. Based on aggregate strength, gradation, shape, and texture estimate the volume of cement as well as a base w/c ratio and enter them on the Mix Design sheet
- 12. Submit the completed mix design for review and approval

6.4.2. Quality Control Plan and Sampling and Testing

- Contractor must develop a quality control plan and conduct quality control sampling and testing at rates specified
- Intent of quality control plan, sampling and testing is to ensure the contractor has qualified staff and a process to quickly identified and resolve issues
- Quality control plan identified in I.M 530 should:
 - Provide names, credentials, and duties of quality control staff
 - Describe stockpile management, mixing, transportation, placement, consolidation, and finishing
 - Define sampling and testing frequencies and documentation
 - Detail criteria for adjusting materials approaching control limits or rejecting non-complying materials
 - o Identify the process for providing corrective actions
- Contractor must submit the quality control plan and mix design at least 7 days prior to the preconstruction conference for review and approval
- Quality control sampling and testing is the responsibility of the contractor and is identified in DS-23027
- Overseen by a Level II PCC Certified Technician
- Conducted by a Level I PCC Certified Technician
- Equipment shall be calibrated and correlated prior to use for testing
- Quality control testing is performed on QM-C bid item concrete

Test	Limits	Testing Frequency	Test Methods
Unit weight (mass) of plastic concrete	Monitor for changes, ± 3%	Twice/day	AASHTO T 121
Gradation combined % passing	Zone II, I.M. 532	1/1500 cubic yard	Materials I.M. 216, 301, 302, 531
Aggregate moisture contents	See Materials I.M. 527	1/1500 cubic yard	Materials I.M. 308
Air content plastic concrete in front of paver	See Article 2301.02, B, 4	1/350 cubic yard 1/100 cubic yard ready mix	Materials I.M. 318
Air content plastic concrete in back of paver	May be used by engineer to adjust target air in front of paver	2/day for first 3 days and 1/week thereafter (for each paver used)	Materials I.M. 318
Water/cementitious ratio	0.42 maximum	Twice/day	Materials I.M. 527
Vibrator frequency	See Article 2301.03, A, 3, a, 6, a	With electronic vibration monitoring: twice/day Without electronic vibration monitoring: twice/vibrator/day	Materials I.M. 384

 Table 6-2
 Quality control testing

- Running average of three combined aggregate gradation tests should be within the limits established from the mix target gradation and the working range
- Working range limits are not for specification compliance

Sieve Size	Working Range
#4 or greater	± 5%
#8 to #30	± 4%
#50	± 3%
#100	± 2%
Minus #200	See below

 Table 6-3
 Combined aggregate working ranges

- For combined aggregate gradations, take corrective action when the running average of three tests approaches working range limits and notify the engineer if they are exceeded
- For concrete tests, take corrective action when an individual test result approaches the control limits and notify the engineer if they are exceeded
- Quality control test results for combined gradations, moistures, unit weights, air contents, CW factors, and w/c ratios shall be plotted on the lowa DOT QM-C quality control spreadsheet
- Notify engineer when adjusting combined gradation target
- Upon project completion the QM-C quality control spreadsheet should be submitted to the engineer

6.4.3. Verification Sampling and Testing

- Performed by the certified agency inspectors for accepting concrete
- Identified in I.M. 530

Table 6-4 Verifi	cation testing
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Test	Testing Frequency	Test Method
Unit weight plastic concrete	None	I.M. 340
Gradation (each agg., % passing)	Sample 1/day if production >500 yd3 Test 1st/day, then twice per week	I.M. 302
Flexural strength, third Point loading - 28 days *	1/10,000 cu. yd. Maximum of three sets	I.M. 328
Air content unconsolidated concrete	1/700 cu. yd. central batch 1/200 cu. yd. ready mix	I.M. 318
Water/cement ratio	None	I.M. 527
Vibration frequency	1/week	I.M. 384

- Verification based on gradation zone for the combined aggregate, not individual aggregates.
- If minus #200 exceeds the following limits, the material represented by that test for this sieve will be considered non-complying:
 - Combined percent passing #200 sieve shall not exceed 1.5%
 - For crushed limestone or dolomite (maximum of 2.5% passing the #200 sieve when production less than 1%), the combined percent passing the #200 sieve shall not exceed 2.0%

6.4.4. Acceptable Field Adjustments

- Identified in the QMC DS
- All mix changes must be mutually agreed upon by the contractor and engineer
- Documented on QM-C Mix Adjustment form
- When the water cement ratio varies more than ±0.03 from the basic water cement ratio, the mix design shall be adjusted to a unit volume of 1.000
- New mix design not required for:
 - Increase cementitious content
 - Decrease fly ash substitution rate
 - \circ Adjust aggregate proportions $\pm 4\%$ for all aggregates
 - Change from water reducer to water reducer retarder
 - Adjust chemical admixture dosage rates
 - Change source of fly ash
 - Change in source of sand, provided target gradation limits met
- Other changes should be discussed and approved by the District Materials Engineer and may require a new mix design or 28 day flexural strength validation

6.4.5. Basis of Payment

- Costs for furnishing labor, equipment, and materials for the work required to design, test, and provide quality control sampling and testing shall be included in the unit price for QM-C bid items
- Average CW factors are determined per I.M. 530 for each lot and price adjustments are applied when they plot outside of zone II on the CW chart

Table 6-5 Price adjustment for lot CW factors outside zone II

CW Chart Zone	Price Adjustment Per Lot
IV	2%
1	5%

• Contractor weekly (lot) samples are validated by engineer weekly (lot) samples so they may be used for payment

- Validation process:
 - 1. Engineer obtains sample and runs gradation tests on first day of paving
 - 2. Thereafter, the engineer obtains aggregate samples daily and randomly tests gradation on a minimum of two samples weekly (lot)
 - 3. Relative percentages are determine based on the batch weights at the time the sample was obtained
 - 4. Using the determined relative percentages, the combined gradation is determined along with the CW factors
 - 5. Average CW factors are calculated for the lot
 - If the average engineer and contractor CW factors for the lot fall within the same zone the contractor results are validated and can be used for payment
 - If the average engineer and contractor CW factors for the lot fall in different zones, the engineer will test the remaining aggregate samples in the lot and average all results for the lot
 - If the average of all engineer verification samples and contractor CW factors for the lot fall within the same zone the contractor results are validated and can be used for payment
 - If the average of all engineer verification samples and contractor CW factors for the lot fall in different zones, the engineer results will govern and be used for payment

6.5. Iowa DOT BR

- Required for all slip formed rails
- Developed from field observations of improved placement versus Class D mix
- Uses Shilstone principles to provide and optimized combined aggregate gradation, see page 58
- Knowledge of component material properties is required, specifically aggregate gradation, texture, and shape
- Proportions are based on absolute volume for 1.000 yd^3 and must meet the mix requirements of specification 2513 and I.M 529
- Do not need to be developed by a Level III Certified Technician
- Trial batches are not required due to extensive use and historic record in lowa since 2000
- Submit mix design to the District Materials Engineer 7 calendar days prior to placement for approval
- All batch weights are in SSD condition
- Strength is not defined directly but these mixes have historically significantly exceeded design strengths and need to meet w/c ratio and quality control requirements
- Durability is addressed by specifying w/c ratio limits, air contents, and coarse aggregate durability classes
- Calculations are the same as a QM-C mix, see page 94

Table 6-6BR mix requirements

Technical Description	Requirement
Individual gradation	Meet division 41
Combined gradation	CW factor plots in zone II
Cementitious content	Minimum 0.114 yd ³ *
W/C ratio	Basic 0.40, maximum 0.45
Air content	Design absolute volume 0.060 yd ³
Fly ash and GGBFS substitution	See table 2513.03-3

Table 6-7 BR mix fly ash and GGBFS requirements

Cement Type	Maximum Allowable Substitution ^(a)	Time Period
Type I, II	35% GGBFS	March 16 to October 15
	20% fly ash	
Type IS, IP	20% fly ash	March 16 to October 15
Type I, II	20% fly ash	October 16 to March 15
Type IS, IP	0%	October 16 to March 15
(a) Maximum total SCM substitution is 50%		

6.6. Iowa DOT HPC Structural

- Used for bridge substructure and decks on high traffic corridors
- Developed from field observations on I-235 for higher strength and lower permeability

Table 6-8Target strength and permeability for HPC substructure and
deck mixes

Target	Substructure	Deck
Compressive strength (psi)	4,500 to 5,000	4,500 to 5,000
Permeability (coulombs)	2,000	1,500
Resistivity (K ohm-cm)	> 20	> 30

- Deck mixes, uses Shilstone principles to provide and optimized combined aggregate gradation, see page 58
- Knowledge of component material properties is required, specifically aggregate gradation, texture, and shape for deck mixes
- Proportions are based on absolute volume for 1.000 yd³ and must meet the mix requirements of DS-23034
- Do not need to be developed by a Level III Certified Technician
- HPC-S (substructure) and HPC-D (deck) mix proportions are provided in I.M. 529

- Trial batches are not required due to extensive use and historic record in Iowa since 2000
- Mix design does not need to be submitted to the District Materials Engineer for approval
- Contractor designed mixes may be used
 - Trial batches may be required depending on historical use and data
 - Mix design needs to be submitted to the District Materials Engineer for approval
- Calculations for the substructure are the same as an I.M. 529 mix, see page 92
- Calculations for the deck are the same as a QM-C mix, see page 94

	Requirement		
Technical	Substructure	Deck	
Description			
Coarse and	3i	3i	
intermediate			
aggregate durability			
Individual gradation	Meet division 41	Meet division 41	
Combined gradation	NA	CW factor plots in zone II	
Cement type	Type IS	Type IS	
	Type I, II with a minimum	Type I, II with a minimum	
	of 30% weight	of 30% weight	
	replacement with GGBFS	replacement with GGBFS	
	Type IP	Type IP	
Fly ash substitution	20% maximum	20% maximum	
Maximum SCM	50%	50%	
substitution			
W/C ratio	Basic 0.42, maximum 0.45	Basic 0.40, maximum 0.42	
Air content	Design absolute volume	Design absolute volume	
	0.060 yd ³	0.060 yd ³	

 Table 6-9
 HPC substructure and deck mix requirements

6.7. Iowa DOT HPC Overlay

- Optional for bridge deck overlays
- Developed for low permeability, higher slump with ready mix delivery, and to eliminate nuclear density testing versus O mix
- Knowledge of component material properties is required
- Proportions are based on absolute volume for 1.000 yd^3 and must meet the mix requirements of specification 2413 and I.M. 529
- Trial batch and mix design submittal are not required
- All batch weights are in SSD condition

- Strength is not defined directly but these mixes have historically significantly exceeded design strengths and need to meet w/c ratio and quality control requirements
- Durability is addressed by specifying w/c ratio limits, air contents, coarse aggregate durability classes, and the use of SCMs
- Calculations are the same as an I.M. 529 mix, see page 92

Technical Description	Requirement
Individual gradation	Meet division 41
Slump	Target 1 to 4 inches, maximum 5 inches
Chemical admixture	Use a water reducer and a retarder
	If haul time is less than 30 minutes or
	maximum air temperature expected is
	less than 75°F, addition of a retarder is
	not required
W/C ratio	Basic 0.39, maximum 0.42
Cement type	Type IS
	Type I, II with a minimum of 25% weight
	replacement with GGBFS
	Type IP
Fly ash substitution	20% maximum
Air content	Design absolute volume 0.060 yd ³

Table 6-10 HPC-O mix requirements

6.8. Iowa DOT Mass Concrete

- Required on elements with a least dimension of 4.5 feet excluding drilled shafts
- Developed from field observations to limit temperatures and temperature differentials
- Knowledge of component material properties is required
- Proportions are based on absolute volume for 1.000 yd^3 and must meet the mix requirements of DS-15081 and I.M. 529
- All batch weights are in SSD condition
- Two tiers based on size of element

Table 6-11Tier 1 and 2 size and requirements

Tier	Size	Thermal Control Plan	Mix Class
1	4.5 to 6.5 feet	Submitted by contractor	C or MCM
2	> 6.5 feet	Submitted by thermal control engineer	MCM

- Class C and MCM mix proportions are provided in I.M. 529
- Do not need to be developed by a Level III Certified Technician
- Trial batches are not required due to extensive use and historic record in lowa
- Mix design should be identified in the thermal control plan (TCP)
- TCP shall be submitted to the engineer for review and approval at least 30 calendar days prior to first placement
- Strength is not defined directly but these mixes have historically significantly exceeded design strengths and need to meet w/c ratio and quality control requirements
- Durability is addressed by specifying w/c ratio limits, air contents, coarse aggregate durability classes, and the use of SCMs
- Calculations are the same as an I.M. 529 mix, see page 92

	Requirement		
Technical Description	Class C	Class MCM	
Individual gradation	Meet division 41	Meet division 41	
Class F fly ash substitution	35% maximum	35% maximum	
Maximum GGBFS substitution	70%	70%	
Maximum SCM Substitution	70%	70%	
W/C ratio	Basic 0.43, maximum 0.488/9	Basic 0.40, maximum 0.45	
Cementitious content	0.108 to 0.128 depending on mix number	0.106	
Air content	Design absolute volume 0.060 yd ³	Design absolute volume 0.060 yd ³	
Thermal modeling	NA	Required	

Table 6-12 Mass concrete mix requirements

6.8.1. Temperature Control Requirements

- Concrete placement temperature shall not exceed 70°F or be less than 40°F
- For Tier 2, the maximum concrete temperature may be modified by the thermal control engineer, when supported by thermal analysis, up to 90°F
- Maximum temperature within the mass concrete shall not exceed 160°F

• Maximum temperature difference between the interior of the section and the outside surface of the section shall not exceed the limits in Table DS-15081.03-1

Hours After Placement	Maximum Temperature Differential °F
0-24	20
24-48	30
48-72	40
>72	50

 Table 6-13
 Temperature differential limits, Table DS-15081.03-1

6.9. Iowa DOT SCC

- Highly flowable and non-segregating concrete used for structural concrete placements that are complex in shape, congested with reinforcement, and/or inaccessible to placement and vibration
- Developed to optimize flow and stability using the following typical characteristics
 - Well graded combined grading
 - ³/₄ inch or less nominal maximum aggregate size
 - Sand to coarse aggregate ratio of 0.40 to 0.50
 - Paste volume from 28 to 40 percent
 - Water to cementitious ratio of 0.25 to 0.45
- Knowledge of component material properties is required, specifically aggregate gradation, texture, and shape
- Proportions are based on absolute volume for 1.000 yd³ and must meet the mix requirements of 2403, 2412, and I.M 529 Appendix A
- Do not need to be developed by a Level III Certified Technician
- All batch weights are in SSD condition
- Trial batches are required
- Recommend assistance from admixture technical representative
- Submit mix design to the District Materials Engineer 7 calendar days prior to the trial batch for review and approval
- Strength is application specific and addressed by validating compressive strength during the trial batch and meeting w/c ratio and quality control requirements
- Durability is application specific and addressed by specifying w/c ratio limits, air contents, and coarse aggregate durability classes
- Calculations are the same as a QM-C mix, see page 94

Technical Description	Requirement
Nominal maximum aggregate size	No larger than 1/3 rd the minimum clear
	spacing between reinforcing steel
Chemical admixtures	Use a high range water reducer
	When a viscosity modifying admixture is
	used it must be compatible with the
	HRWR
	Use a retarding admixture or hydration
	stabilizer when extended plasticity is
	needed
W/C ratio	Maximum 0.45
Cementitious content	Minimum 624 lbs/yd ³
Slump flow	Target 23.0 +/- 3.0 inches
Visual stability index	Not to exceed 1
J-ring flow	Passing with a maximum allowable
	difference of 2.0 inches from slump flow
Static segregation	Not to exceed 1
Air content	Application specific
Compressive strength	Application specific

Table 6-14 SCC mix requirements

APPENDIX A ACI 211 MIX DESIGN

ACI Mix Design



ACI Mix Design Example Problem

A reinforced wall 8" wide by 6' high will be thawing in a moist condition and deicing chemicals. The minimum clear spacing placed with exposure to freezing and between reinforcing steel is 6".

ACI Mix Design Example Problem

Specifications

- A minimum compressive strength of 3500 psi.
- Assume a standard deviation of 350 psi.
- A maximum w/c ratio of 0.50

ACI Mix Design Example Problem

- The maximum aggregate size available is 34".
- Mid range water reducer shall be used
- Assume a 10% water reduction.
- Air Entrainment
- Assume 10% water reduction
- Coarse Aggregate
- SpG = 2.60
- Dry Rodded Unit Wt. = 92.0 lbs/ft3
- Fine Aggregate
 - SpG = 2.65
- Fineness Modulus = 2.6

ACI 211 Mix Design

- Select initial Slump
- Select Aggregate Size
- Air Content or Non-air Entrained
- Water cement ratio (minimum required)
 - Durability
- Strength
- Water reduction –admixtures, gradation,etc.
- Bulk Volume Coarse Aggregate
- Batch Weights

Select Slump

Table 6.3.1 — Recommended slumps for various types of construction*

o, in.	Minimum	Ι	Ţ	П		-
Slum	Maximum'	Ē	5		4 m	2
	Types of construction	Reinforced foundation	Plain footings, caissons, and	Beams and reinforced walls	Building columns Pavements and slabs	Mass concrete

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or watercementitious material ratio and does not exhibit segregation potential or excessive bleeding.

⁺May be increased 1 in. for methods of consolidation other than vibration.

Select Slump

ACI MIX EXAMPLE page 1 of 3 **Mix Design and Mix Ingredients Data Sheet** By Date + Mixture:

	Project Analysis			
1.	Parement	Building slab	Footing	Bridge Deck
-	Wall	Beam	Column	Curb
	Other	- 20110 - 1000-100 - 1000-1000		
2.	Minimum dim. betv	veen formed (or slip-	formed) faces	8 inches
3.	Minimum pavemen	t/ slab/ overlay thickr	less	
				inches
4.	Minimum clear spa	cing between reinforc	ing bars	6 inches
5.	Minimum clear cov	er between bars and f	orms	
				inches
6.	Method of placing	concrete		
	Slip form	Truck Chute	Conveyor	Pump
	Crane & Bucket	Tremie	Machine finish	Hand finish
7.	Method of consolid	lating concrete		
	Form vibrators	Immersion vibr.	Fixed vibr.	Hand consol.
8	Select initial slump			4 inches



Select Max. Aggregate Size

	Selecting Nominal Maximum Aggregate Size		
9.	1/5 minimum dimension between formed faces	16	
	8/5 =	0.1	inches
10.	1/3 minimum slab depth		
			inches
11.	3/4 minimum clear opening between reinforcing bars	4 L	
	$6 \times 0.75 =$	C*+	inches
12.	3/4 minimum clear cover between bars and forms		
	(optional requirement for architectural concrete)		inches
13.	Specified nominal maximum aggregate size		7
			inches
14.	Minimum of all values (rows 9-13)	1.6	inches
15.	Largest size available not exceeding size in row 14.	3/4	inches
16.	Nominal Maximum Aggregate Size selected	3/4	inches

Select Air Content

Table 4.2.1-TOTAL AIR CONTENT FOR FROST RESISTANT **ACI 318-99 Building Code for Structural Concrete** CONCRETE

_← 	Nominal maximum aggregate size, in inches.	Air conte percentag concrete	e of total volume.
	9% mortar air for Severe F/T	Severe Exposure	Moderate Exposure
	3/8	7.5	9
	1/2	2	5.5
	3/4	6	5
	1	9	4.5
	1-1/2	5.5	4.5
	2	5	4
	S	4.5	3.5

I finetreasing Paste Content I

Select Air Content

	Air Entrained or Non Air- Entrained Concrete	(
17.	Air required when concrete exposed to freezing and thawing in a moist condition or exposed to deicing chemicals	(Air))r (Non-Air)?
18.	Exposure mild, moderate, or severe?	(mild) (moderate) extreme)
19.	Specified Total Air Content?	6.0 %

Select minimum w/c ratio - Durability

W/C ratio requirements for special exposure conditions Table 4.2.2

Exposure Condition	Maximum water-	Minimum f'c,
	cementitious	normal weight
	materials ratio, by	aggregate
	weight, normal	concrete, psi.
	weight aggregate	
Concrete intended to have low	0:50	4000 psi
permeability when exposed to water		
Concrete exposed to freezing and	0.45	4500 psi
thawing in a moist condition or to		
deicing chemicals		
For corrosion protection of	0.40	5000 psi
reinforcement in concrete exposed to		
chlorides from deicing chemicals, salt,		
salt water, brackish water, seawater. or		
spray from these sources.		

Select minimum w/c ratio - Durability

ACI MIX EXAMPLE page 2 of 3 Mix Design and Mix Ingredients Data Sheet By Date Mixture:

	Selecting w/c or w/cm for durability	
20.	Concrete intended to have low permeability when	W/c or $w/cm \le 0.50$
	exposed to water	
21.	Concrete exposed to freezing and thawing in a moist	W/c or w/cm ≤ 0.45
	condition or exposed to deicing chemicals	$\Big)$
22.	For corrosion protection of reinforcement in concrete	W/c or w/cm ≤ 0.40
	exposed to chlorides from deicing chemicals, salt, salt	
	water, brackish water, seawater. or spray from these	
	sources.	
23.	Minimum w/c or w/cm for durability from rows	17 0
	20.21.22.	U.45

Select minimum w/c ratio - Strength

- 4500 psi for Durability
 - 3500 psi specified
- Producer standard deviation
- Select largest value of following
- □4500 + (2.33 x 350) 500 = 4815
- □4500 + (1.34 X 350) = 4969 ~ 5000 psi

Select minimum w/c ratio





Strength is based on cylinders moist-cured 28 days in accordance with ASTM C 31 (AASHTOT 23). Relationship assumes nominal maximum size aggregate of about $\frac{3}{4}$ in. to 1 in. Adapted from ACI 211.1 and ACI 211.3.

nship Between and	rials ratio by mass	Air-entrained concrete	I	0.32	0.40	0.48	0.59	0.74
Pound Units). Relatio titious Material Ratio trength of Concrete	Water-cementitious mate	Non-air-entrained concrete	0.33	0.41	0 48	0.57	0.68	0.82
Table 9-3 (Inch- Water to Cemer Compressive St	Compressive	strength at 28 days, psi	7000	6000	5000	4000	3000	2000

Select minimum w/c ratio - Strength

	Selecting w/c or w/cm for strength	
24.	If concrete intended to have low permeability when	f_c minimum =
	exposed to water, f_c min. = 4000 psi.	
25.	If concrete exposed to freezing and thawing in moist	f_{c} minimum = 4500
	condition or exposed to deicers, f_{ce} min. = 4500 psi.	
26.	If conc. is reinforced and exposed to chlorides from	
	deicers, salt, salt water, brackish water, seawater. or	f_c minimum =
	spray from these sources, f_c min = 5000 psi.	
27.	Specified 28-day compressive strength, Le	$f_{e} = 3500$
		psi
28.	Maximum of rows 24-27.	$f_{c}^{*} = 4500$
		psi
29.	Producer's standard deviation, S, for similar mix	S = 350
	(index of producer's precision)	psi
30.	f_{c}^{*} + 2.33 $S - 500 \text{ psi}$	4815
		psi
31.	$f_{c}^{*} + 1.34 S psi$	4969
		psi
32.	Mix design target strength, f.a. = Larger of two values in rows 30 and 31.	$f_{eff} = 5000$
33.	w/c or w/cm required for target strength (From	
	documented producer data, 3-point trial mix test data, or from ACI 211 1 data)	0.40
34.	Specified maximum w/c or w/cm	0.50
35.	Mix Design w/c or w/cm Durability w/c =0.45	
	= Minimum value from rows 23(durability), 23(strength) and 24(specifications)	0.40
	22(Sucingur), and 24(Specificanous)	

Water Adjustment

• -25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25 • -15% -10% -5% 0% 5% 10% 15% 20% 25 • Aggregate Shape and Texture (-5 to +5%) round, smooth flat, elongated, rough Combined Aggregate Grading (-10 to + 10%) well-graded gap-graded Air Entrainment (-10 to 0%)
• -25% -20% -15% -10% -5% 0% 5% 10% 15% 20% 25 • -25% -20% -15% -10% -5% 0% 5% • Aggregate Shape and Texture (-5 to +5%) • round, smooth flat, elongated, rough • Combined Aggregate Grading (-10 to + 10%) • well-graded gap-graded • Air Entrainment (-10 to 0%)
Aggregate Shape and Texture (-5 to +5%) Aggregate Shape and Texture (-5 to +5%) round, smooth flat, elongated, rough Combined Aggregate Grading (-10 to + 10%) well-graded gap-graded Air Entrainment (-10 to 0%)
Aggregate Shape and Texture (-5 to +5%) round, smooth flat, elongated, rough Combined Aggregate Grading (-10 to + 10%) well-graded gap-graded Air Entrainment (-10 to 0%)
round, smooth flat, elongated, rough Combined Aggregate Grading (-10 to + 10%) well-graded gap-graded Air Entrainment (-10 to 0%)
Combined Aggregate Grading (-10 to + 10%) well-graded gap-graded Air Entrainment (-10 to 0%)
well-graded gap-graded Air Entrainment (-10 to 0%)
Air Entrainment (-10 to 0%)
6-10 % air 1-3% air
Normal Range water Reducer (-10 to -5%)
high dos
Mid-Range Water Reducer (-15 to -8%)
high dose Iow dose
High-Range Water Reducer (-30 to -12%)
igh dose low dose
Mineral Admixtures (-10 to +15%)
fly ash silica fume
Other Factors (-10 to +10%)
barse cement, high w/cm, cold conc. fine cement, low w/cm, hot c

•Water Reducer (-10%) •Air Entrain (-10%)

Water Adjustment

ACI MIX EXAMPLE page 3 of 4 Mix Design and Mix Ingredients Data Sheet By Date Mixture:

Percentage Selected Adjustment 80% -20% -10% -10% = 1.00 + (sum/100)Water Reduction Effectiveness (-5 to +5%) (-10 to + 15%)(-10 to +10%) (-10 to +10%) (-30 to -12%) (-15 to -8%) (-10 to -5%) (-10 to 0%) = sum Water Adjustment and Admixture Data Normal range water reducing admixture High-range water reducing admixture Mid-range water reducing admixture Other factors: w/c, cement fineness, Cumulative adjustment percentage Combined aggregate grading (HRWRA= Superplasticizer) Aggregate shape & texture Water Adjustment Factor Air entraining admixture Fly ash to Silica Fume (suggest no less than 0.70) Mineral Admixtures Water reduction (MRWRA) temp. 36. 37. 43. 45. 38. 39. 40. 42. 44 41.

Enter Known Data on Mix Proportioning Worksheet

Exposure: Aild Moderate Extreme	ft ³) Subtotal Vol.	(ff^3)	c	(ff^3)	(ft ³)	$(\mathfrak{t}^{\mathfrak{d}})$		%	(ff^3)	(ff^3)		SD	(tf)	(ff^3)	$\begin{array}{c c} (ft^3) & Total agg - (coal & \& & \\ \& & interm & vol \end{array}$			27.00
:oncrete? F	Absolute Vol. (Selection=			$b/b_0 =$	<i>92.0</i> (lbs/ft ³)S				I		
Air Entrained o YES	Specific Gravity	1.0		3.14				18% of paste=% Paste Vol X 18/27%		27- (air + paste)	FM (Sand) = 2.6	Unit Wt. Crs.Agg=	Sp. G. SSD	Sp. G. SSD	Sp. G. SSD 2.65			
gn target strength =	Weight (lbs/CY)	(lb)		(lb)	(lb)	(lb)		ACI 318 Value%					= Bulk Vol. x unit wt. (lb,SSD)		(lb,SSD)		(ql)	
7.40 Mix desi 5			(lb)	%	%	0%		Specified Value%					Bulk Vol. = $b/b_0 \ge 27$ (ft ³)					
Controlling w/c or $w/cm = c$	Mix Component	Adjusted Water	Total cementitious	Portland Cement	Fly ash	Other Pozzolan	Total (water + cm) = Paste Volume	Total Air Content	Air + Paste Volume	Total Agg Volume	Agg. Data		Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Total Agg Volume	Total Weight / CY	Total Absolute Volume
	ControllingMix design target strength =Air Entrained concrete?Exposure:w/c or w/cm =0.40psi 5000 MildModerate	ControllingMix design target strength =Mix Entrained concrete?Exposure:w/c or w/cm = 0.40 psi 5000 MildModerateMix ComponentWeight (lbs/CY)Specific GravityAbsolute Vol. (ft3)Subtotal	Controlling w/c or w/cm =Mix design target strength =Mix Entrained concrete?Exposure:W/c or w/cm = 0.40 psi 5000 MildModerateMix ComponentNoNONONONIAdjusted Water $(1b)$ 1.0 $(1b)$ 1.0 (fi^3) Subtotal	Controlling w/c or w/cm =D. 40Mix design target strength =Air Entrained concrete?Exposure: Mild ModerateW/c or w/cm =0. 40psi 5000 NOMild ModerateExposure: Mild ModerateMix ComponentNWeight (lbs/CY)Specific GravityAbsolute Vol. (ft3)SubtotalAdjusted Water(lb)1.01.0(ft3)SubtotalTotal cementitious(lb)1.01.0(ft3)	Controlling w/c or w/cm=D. 40Mix design target strength= psiAir Entrained concrete?Exposure: Exposure:W/c or w/cm=0. 40psi5000NOMildModerateExposure: Total centerMix ComponentMix ComponentNONONOMildModerateExposure: Total centerExposure: Total centerAdjusted Water(lb)1.01.0(lb)1.0(ft ³)Subtotal Total centerPortland Cement $\%$ (lb)3.14(ft ³)Subtotal	Controlling w/c or w/cm=O. 40Mix design target strength= psiAir Entrained concrete?Exposure: Exposure:W/c or w/cm=0. 40psi5000MidModerateMix ComponentNoNoNoNoNoAdjusted WaterNoNoNoNoNoAdjusted Water(lb)1.01.0(ft3)SubtotalPortland Cement itious%(lb)3.14(ft3)SubtotalFly ash%(lb)3.14(ft3)(ft3)(ft3)	Controlling w/c or w/cm=O. 40Mix design target strength= psiAir Entrained concrete?Exposure: Exposure:Mix con w/cm w/c or w/cm=0. 40psi5000YESNOMix ComponentNoNoNONildNoderateAdjusted WaterImaget strengthImaget strengthImaget strengthImaget strengthAdjusted WaterImaget strengthNoImaget strengthImaget strengthAdjusted WaterImaget strengthImaget strengthImaget strengthImaget strengthPortland Cement itiousImaget strengthImaget strengthImaget strengthImaget strengthPortland CementNoImaget strengthImaget strengthImaget strengthImaget strengthFly ashImaget strengthImaget strengthImaget strengthImaget strengthImaget strengthOther PozzolanNoImaget strengthImaget strengt strengthImaget strengthImaget strengthImaget strength	Controlling w/c or w/cm =O. 40Mix design target strength =Air Entrained concrete?Exposure:w/c or w/cm =0. 40psi5000YESNOMildMix ComponentNoNoNoNONoNoAdjusted Water(lb)NoNoNoNoNoAdjusted Water(lb)NoNoNoNoNoAdjusted Water(lb)1.0(lb)1.0(lf)NoPortland Cement%(lb)3.14(lf)(lf)Portland Cement%(lb)3.14(lf)(lf)Other Pozzolan%(lb)(lb)(lb)(lf)Paste Volume%(lb)(lb)(lb)(lf)Paste VolumeNoNoNoNo(lf)	Controlling w/c or w/cm=O.40Mix design target strength =Air Entremined concrete?Exposure:w/c or w/cm=0.40psi5000NoMildModerateMix ComponentNeight (lbs/CY)Specific GravityAbsolute Vol. (ft3)SubtotalAdjusted Water(lb)1.0(lb)1.0(ft3)NutotalPortland Cement $\%_6$ (lb)3.14(ft3)(ft3)Portland Cement $\%_6$ (lb) $\%_6$ (ft3)Portland Volume<	Controlling w/c or w/cm=O. 40Mix design target strength =Air Hatained concrete?Exposure:Mix Component w/c or w/cm = 0.40 $psii$ 5000 Nid $ModenneMix Componentw/c or w/cm =0.40psii5000NidModenneAdjusted Waterw/cw/c or w/cmw/c or w/cmModennew/cAdjusted Waterw/c(lb)1.0(lb)1.0(lf)^3Portland Cement\frac{9}{6}(lb)3.14(lf)^3m/cPortland Cement\frac{9}{6}(lb)3.14(lf)^3m/cPortland Cement\frac{9}{6}(lb)3.14(lf)^3m/cPortland Cement\frac{9}{6}(lb)\frac{1}{2}m/cm/cPortland Cement\frac{9}{6}(lb)\frac{1}{2}m/cm/cPortland Cement\frac{9}{6}(lb)\frac{1}{2}m/cm/cPortland Cement\frac{9}{6}(lb)\frac{1}{2}m/cm/cPortland Cement\frac{9}{6}m/cm/cm/cm/cPortland Cement\frac{9}{6}m/cm/cm/cm/cPortland Cement\frac{9}{6}m/cm/cm/cm/cPortland Cement\frac{1}{6}\frac{1}{6}m/cm/cm/cPortland Cement\frac{1}{6}\frac{1}{6}m/cm/cm/cPortland Cement\frac{1}{6}\frac{1}{$	Controlling w/c or w/cm =O. 40Mix design target strength =Air Extration concrete?Exposure:W/c or w/cm =0. 40psi5000YESNONOMix ComponentWeight (lbs/CY)Specific GravityAbsolute Vol. (ft3)SubtotalAdjusted Water(lb) </td 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(fh)SubtotalTotal cementitious(lb)NO(lb)1.0(fh)MidPortland Cement9_0(lb)1.0(fh)MidPortland Cement9_0(lb)3.14(fh)(fh^2)Portland Cement9_0(lb)3.14(fh)(fh^2)Portland Cement9_0(lb)3.14(fh)(fh^2)Portland Cement9_0(lb)3.14(fh)(fh^2)Portland Cement9_0(lb)$3.14$$(fh^2)$$(fh^2)$Portland Cement$9_0$($lb$)$3.14$$(fh^2)$$(fh^2)$Portland Cement$9_0$$(lb)$$3.14$$(fh^2)$$(fh^2)$Portland Content$9_0$$(lb)$$3.14$$(fh^2)$$(fh^2)$Portland Content$9_0$$(lb)$$3.14$$(fh^2)$$(fh^2)$Portland Content$9_0$$(lb)$$3.14$$(fh^2)$$(fh^2)$Portland Content$9_0$$1018$$3.14$$(fh^2)$$(fh^2)$Portland</td> <td>Controlling w/c or w/cm=O.40Mix design target strength=YESNOKeyosure:w/c or w/cm=0.40psi5000Nid design target strength=YESNONidMix Component0.40psi5000Specific GravityAbsolute Vol. (\hat{H})SubtotalAdjusted Water(b)$0$$10$$10$$(\hat{H})$$0$Portland Cement$\frac{9}{60}$$(b)$$3.14$$(\hat{H})$$(\hat{H})$Portland Cement$\frac{9}{60}$$(b)$$3.14$$(\hat{H})$Portland Cement$\frac{9}{60}$$180$$\frac{18}{60}$$\frac{18}{60}$Portland Cement$\frac{18}{60}$$\frac{18}{60}$$\frac{18}{60}$$\frac{18}{60}$Portland Content$\frac{18}{60}$$\frac{18}{60}$$\frac{10}{60}$$\frac{10}{60}$Portland Cont</td> <td>Controlling w/c or w/cm=0.40Mix design target strength =$vremained concrete?$Exposure:w/c or w/cm =0.40psi5000NoNoNow/c or w/cm =0.40psi5000NoNoMix ComponentNoNoNoNoNoAdjusted Water(lb)No1.0(lb)1.0(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland Cement$\frac{96}{96}$(lb)3.14(lt)Portland CementSpecified Value$\frac{96}{9}$No(lb)Portland CementSpecified Value$\frac{96}{9}$No(lb)Portland CementSpecified 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<td>Controlling w(c or w(cm = 0.40Mix design target strength = psiVERS NOExposure: NoMix design target strength = w(c or w(cm = 0.400.40Mix design target strength = NESExposure: NoMix Component outer to diated water0.40Mix design target strength = NESNoExposure: NoAdjusted Water Total cementitions0.40Nix design target strength = NoNoNoAdjusted Water Total cementitions0.101.00.100.10Total cementitions0.103.140.100.1Portand Cement Portand0.00.103.140.1Total water + cm) = Paste Volume0.01.00.00.1Adjusted Vater Paste Volume0.01.00.10.1Adjusted Vater Paste VolumeNo1.181.00.1Adjusted Vater Paste VolumeNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjated VolumeNo1.181.01.00.1Adjated Vater Adjated MaterNo1.8%0.11.0Adjated VolumeNo1.8%0.11.01.0Adjated Vater AdjatedNo1.8%0.11.0Adjated VolumeNo1.8%0.11.01.0</td> <td>Controlling w/c or w/cm O.40 Mix design target strength witch mathematication of the mathematication of themathmathmathematication of the mathematicatio</td>	Controlling w/c or w/cm=Mix design target strength =Exposure:Controlling w/c or w/cm=0.40Mix design target strength =YESNOSuposure:Mix ComponentNoNONOMidModenteExposure:Mix ComponentNoNONOMidModenteMix ComponentNoNONOMidModenteAdjusted WaterNONONOMitModenteTotal clement itious(lb)NONO(ft²)NOTotal clement itious%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%(lb)3.14(ft²)ModentePortland Cement%%(lb)3.14(ft²)Portland Cement%NoNoModenteModentePortland Cement%NoNoNoModentePortland Cement%%NoNoNo	Controlling w(c or w/cm=O. 40Mix design target strength =Air Energined concrete?Exposure:We convoluteNoNoMix design target strength =YESNOMidMix ComponentNoNoNONOMidModenteMix ComponentNoNoNoNOMidModenteAdjusted Water(lb)NoNOMix Compute Vol. (fh)SubtotalTotal cementitious(lb)NO(lb)1.0(fh)MidPortland Cement 9_0 (lb)1.0(fh)MidPortland Cement 9_0 (lb) 3.14 (fh) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh^2) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh^2) (fh^2) Portland Cement 9_0 (lb) 3.14 (fh^2) (fh^2) Portland Content 9_0 1018 3.14 (fh^2) (fh^2) Portland	Controlling w/c or w/cm=O.40Mix design target strength=YESNOKeyosure:w/c or w/cm=0.40psi5000Nid design target strength=YESNONidMix Component0.40psi5000Specific GravityAbsolute Vol. (\hat{H})SubtotalAdjusted Water($ b $) $ 0 $ $ 10 $ $ 10 $ $ (\hat{H}) $ $ 0 $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ (b) 3.14 $ (\hat{H}) $ Portland Cement $\frac{9}{60}$ 180 $\frac{18}{60}$ $\frac{18}{60}$ Portland Cement $\frac{18}{60}$ $\frac{18}{60}$ $\frac{18}{60}$ $\frac{18}{60}$ Portland Content $\frac{18}{60}$ $\frac{18}{60}$ $\frac{10}{60}$ $\frac{10}{60}$ Portland Cont	Controlling w/c or w/cm=0.40Mix design target strength = $vremained concrete?$ Exposure:w/c or w/cm =0.40psi5000NoNoNow/c or w/cm =0.40psi5000NoNoMix ComponentNoNoNoNoNoAdjusted Water(lb)No1.0(lb)1.0(lt)Portland Cement $\frac{96}{96}$ (lb)3.14(lt)(lt)Portland Cement $\frac{96}{96}$ (lb)3.14(lt)Portland CementSpecified Value $\frac{96}{9}$ No(lb)Portland CementSpecified Value $\frac{96}{9}$ No(lb)Portland CementSpecified Value $\frac{96}{9}$ No(lb)Portland CementSpecified Value $\frac{96}{9}$ No(lb)Portland Volue $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Age ConterSpecified Value $\frac{100}{$	Controlling we or wicm=0.40Mix design target strength =ve Envarined concrete?Exposure:we or wicm =0.40psi5000NoNessNoWix cor wicm =0.40psi5000NoNoMix corponent0.40psi1001.0(ft)NoAdjusted Water0.01001.01.0(ft)NoTotal cementitions0.00.01.00.0(ft)NoTotal cementitions0.00.03.14(ft)(ft)NoOther Pozzolan0.00.01.00.0(ft)NoNotal Kater + cm) =9.6(1b)3.14(ft)(ft)Total water + cm) =9.6(1b)3.14(ft)(ft)Paste Volume9.6(1b)3.14(ft)(ft)Paste Volume9.6(1b)3.14(ft)(ft)Adjusted Water + cm) =7.21Paste Volume(ft)(ft)Anir + Paste Volume9.60.18/13Nate(ft)Anir + Paste Volume7.6Paste Vol X 18/27Nate(ft)Age Data2.7Paste Volume1.0(ft)(ft)Age DataActi + PasteNo.27Bulk Vol. = b/b, x 27Bulk Vol. SD2.60Age DataActi + PasteNo.27SP.0.5No.2.55(ft)Age DataActi + PasteNo.2.55(ft)NateAge DataNoNo.2.50SP.0.55(f	Controlling w(c or w(cm = 0.40Mix design target strength = psiVERS NOExposure: NoMix design target strength = w(c or w(cm = 0.400.40Mix design target strength = NESExposure: NoMix Component outer to diated water0.40Mix design target strength = NESNoExposure: NoAdjusted Water Total cementitions0.40Nix design target strength = NoNoNoAdjusted Water Total cementitions0.101.00.100.10Total cementitions0.103.140.100.1Portand Cement Portand0.00.103.140.1Total water + cm) = Paste Volume0.01.00.00.1Adjusted Vater Paste Volume0.01.00.10.1Adjusted Vater Paste VolumeNo1.181.00.1Adjusted Vater Paste VolumeNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjusted Vater Adjated MaterNo1.181.00.1Adjated VolumeNo1.181.01.00.1Adjated Vater Adjated MaterNo1.8%0.11.0Adjated VolumeNo1.8%0.11.01.0Adjated Vater AdjatedNo1.8%0.11.0Adjated VolumeNo1.8%0.11.01.0	Controlling w/c or w/cm O.40 Mix design target strength witch 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PLE	stment Factor AE Conc.) 0.80	at Extreme	ibtotal Vol. (ft ³)						(H)	(Ħ3)							al agg – (coarse iterm vol)	(£3)		27.00(ft ³)	
I MIX EXAM	Water Adju (note impact of .	Exposure: Mild Moder	7ol. (ft ³) St	(#3)		(H ₃)	(H3)	(ft3)		%	(ŧ ³)	(tH3)		ft-)SSD	(H ³)	(Ħ ³)	(ft ³) Tot & ii			-	
ared by AC	5 lb/CY	concrete? NO	Absolute V	× 0			6 3			Selection=			$b/b_0 =$	92 0 (Ibs/		e	2 5				
e Prep	Basic Water 34.	AirEntrained	Specific Gravity	1.0		3.14				18% of paste=% Paste Vol X 18/27		27- (air + paste)	FM(Sand) = 2.6	Unit Wt. Crs.Agg=	sp. G. SSD 2.60	Sp. G. SSD	Sp. G. SSD 2.65				
xture Dat	ax. Agg. Size= 3/4 (m.)	gn target strength = 000	Weight (lbs/CY)	(Ib)		(ql)	(ql)	(Jb)		ACI 318 Value – 6 %					= Bulk Vol. x unit wt. (lb,SSD)		(lb,SSD)		(qI)		
orksheet Mi	(m) Nom. M	Mix desi			(qI)	%	%	%		fied Value%					Vol. = $b/b_0 \ge 27$: (fi ³)				2		
ioning Wo		0.40	t I			Q	8-0		=	Specif	Je		5		Bulk						
Mix Proport	Slump = 4	Controlling w/c or w/cm =	Mix Componen	Adjusted Water	Total cementitious	Portland Cement	Fly ash	Other Pozzolan	Total (water + cm Paste Volume	Total Air Content	Air + Paste Volurr	Total Agg Volume	Agg. Data		Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Total Agg Volume	Total Weight / CY	Total Absolute Volume	10000000000000000000000000000000000000
4							Ð	ļsi	² d	۸i۲		Ĩ	10		gate	erep	1		-		-

Paste Volume Determine

Calculate Batch Proportions & Volumes

Water Adjustment = $345 \text{ lbs} \times 0.80 = 276 \text{ lbs}$ Cement Content = 276 lbs / 0.40 = 690 lbsAbs Vol. (ft³)

7.94 ft3 Water = 276 lbs / (62.4 lbs/ft3 X 1.00) = 4.42 ft³ Cement = 690 lbs / (62.4 lbs/ft3 X 3.14) = 3.52 ft³ Volume of Paste =

	Slump = 4	(in.)	Nom. N	<i>A</i> ax. Agg. Size= 3/4 (in.)	Basic Water Demand 345	lb/CY	Water A (note impa	Adjustment Factor tof AE Conc.)	
	Controlling w/c or w/cm =	0.40	Mix de psi	sign target strength = 5000	Air Entrained co YES N	increte? O	Exposu Mild	re: Moderate Extreme	
	Mix Component			Weight (lbs/CY)	Specific Gravity	Absolute Vo	l. (ft ³)	Subtotal Vol. (ft ³)	
	Adjusted Water			276 (lb)	1.0	4.42	(ft^3)		
	Total cementitious		(lb)						_
	Portland Cement	100	%	(dl) (1b)	3.14	3.52	(ft^3)		
Ð,	Fly ash		%	(lb)			(ft^3)		
ļse	Other Pozzolan		%	(lb)			(ft^3)		-
9	Total (water + cm) = Paste Volume							(ft ³)	-
٦iA	Total Air Content	Specified Valu	le%	ACI 318 Value%	18% of paste=% Paste Vol X 18/27	Selection=	%	(ft ³)	
	Air + Paste Volume						(ff^3)		
	Total Agg Volume				27- (air + paste)		(ft^3)		-
	Agg. Data				FM (Sand) = 2.6	$b/b_0 =$			
					Unit Wt. Crs.Agg=	<i>92.0</i> (lbs/ft ³)SSD		
)	Coarse Aggregate	Bulk Vol. = h	$p/b_0 \ge 27$ (ft ³)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 7 60		(ft ³)		
grega	Intermediate Aggregate				Sp. G. SSD		(ft^3)		_
6 A	Fine Aggregate			(lb,SSD)	Sp. G. SSD 2.65		(ft^3)	Total agg – (coarse & interm vol)	r
	Total Agg Volume							(ft^3)	
	Total Weight / CY			(qI)					
	Total Absolute Volume							<i>27.00</i> (ft ³)	
	Design Yield							(%)	

¢
Determine Air Volume

h Volumes	of 18% of paste volume. 8 X 100	X 100= 5.3%	Select highest	0.06 X 27 ft ³ = 1.62 ft ³
Calculate Batc	Air must be minimum = Paste Vol /27 X 0 1	$= 7.94 \text{ ft}^3/27 \text{ft}^3 \times 0.18$	6% required by ACI	Air Vol =

	Slump = 4	(in.)	Nom. N	Aax. Agg. Size= 3/4 (in.)	Basic Water Demand 345	lb/CY	Water A (note impa	Adjustment Factor tot of AE Conc.)
	Controlling w/c or w/cm =	0.40	Mix de psi	sign target strength = 5000	Air Entrained co YES N	oncrete? VO	Exposu Mild 1	re: Moderate Extreme
	Mix Component			Weight (lbs/CY)	Specific Gravity	Absolute V	V ol. (ft ³)	Subtotal Vol. (ft ³)
	Adjusted Water			276 (lb)	1.0	4.4	42 (ft ³)	
	Total cementitious		(lb)					
	Portland Cement	100	%	(lb) (lb)	3.14	3.5	-7 (ft ³)	
Ð,	Fly ash		%	(lb)			(ft^3)	
ļse	Other Pozzolan		%	(lb)			(ft^3)	
;q	Total (water + cm) = Paste Volume							7.94 (ft ³)
viA	Total Air Content	Specified Va	lue%	ACI 318 Value%	18% of paste= <u>5</u> 3 % Paste Vol X 18/27	Selection=	<i>9</i> %	1.62 (ft ³)
7	Air + Paste Volume						(ff ³)	
	Total Agg Volume				27- (air + paste)		(\mathfrak{t}^3)	
	Agg. Data				FM (Sand) = 2.6	$b/b_0 =$		
					Unit Wt. Crs.Agg=	92.0 (Ibs/	/ft ³)SSD	
)	Coarse Aggregate	Bulk Vol. =	$b/b_0 \ge 27$ (ft ³)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2 60		(ft^3)	
grega	Intermediate Aggregate				Sp. G. SSD		(ft^3)	
6 4	Fine Aggregate			(lb,SSD)	Sp. G. SSD 2.65		(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					I		(ft^3)
	Total Weight / CY			(q])				
	Total Absolute Volume							<i>27.00</i> (ft ³)
	Design Yield							(%)

Paste + Air Volume Aggregate Volume Determine

Calculate Batch Volumes

Volume of Paste = Volume of Air =

7.94 ft3 1.62 ft³

9.56 ft3 Volume of Paste + Air = Volume of Aggregate = 27_{ft3} - 9.56 $_{\text{ft3}}$ = 17.44 $_{\text{ft3}}$

4 (in) 3.4 0.40 Mix design target strength = Tensined cont Controlling Mix Component Mix design target strength = Virespin target strengt strengt strengt strengt strengt strengt str		Slump =		Nom. N	fax. Agg. Size=	Basic Water		Water /	Adjustment Factor on
Controlling wic or wiem=Mix design target strength =VESVESNOWix ComponentMix ComponentWeight (hs/CY)Specific GravityAMix Component100 $\frac{10}{60}$ $\frac{10}{690}$ $\frac{10}{10}$ $\frac{10}{10}$ Total commines100 $\frac{9}{60}$ $\frac{10}{10}$ $\frac{10}{3}$ $\frac{10}{10}$ $\frac{100}{10}$ Portland Cement100 $\frac{9}{60}$ $\frac{10}{10}$ $\frac{10}{3}$ $\frac{10}{10}$ $\frac{100}{10}$ Paste Volume $\frac{9}{60}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Paste Volume $\frac{9}{60}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste Volume $\frac{9}{10}$ $\frac{100}{10}$ $\frac{9}{6}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste Volume $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste Volume $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste Volume $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste Volume $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ Arit + Paste $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ $\frac{100}{10}$ <		4	(in.)		3/4 (in.)	Demand 345	lb/CY	(note impa	act of AE Conc.) U.OU
Mix ComponentMix ComponentMeight (lbs/CY)Specific GravityAAdjusted Water776(lb)1.01.0Total cement100 $\frac{9}{66}$ 690(lb)3.14Portland Cement100 $\frac{9}{66}$ 690(lb)3.14Collar ergentitious00(lb)3.141.01.0Collar ergentitious $\frac{9}{66}$ 6103.141.01.0Collar Pozzolan $\frac{9}{66}$ 6103.141.01.0Paste Volume $\frac{9}{66}$ ACI 318 Value $\frac{9}{6}$ 1.8% of paste5.0Paste Volume $\frac{100}{100}$ $\frac{100}{100}$ $\frac{100}{100}$ $\frac{100}{100}$ $\frac{100}{100}$ $\frac{100}{100}$ Air + Paste Volume $\frac{9}{60}$ ACI 318 Value $\frac{9}{6}$ 1.8% of paste $\frac{9}{6}$ $\frac{100}{100}$ Air + Paste Volume $\frac{9}{100}$ ACI 318 Value $\frac{9}{6}$ $\frac{100}{100}$ $\frac{100}{10$		Controlling w/c or w/cm =	0.40	Mix de psi	sign target strength = 5000	Air Entrained co YES N	oncrete? IO	Exposu Mild 1	re: Moderate Extreme
Adjusted WaterAdjusted WaterAdjusted Water(h)1.01.0Total cementitious(h) 0.0 0.0 1.0 1.0 1.0 Perturned Cement 1.00 0.0 0.0 3.14 1.0 1.0 Fly ash 0.0 0.0 0.0 0.0 3.14 1.0 1.0 Fly ash 0.0 0.0 0.0 1.0 3.14 1.0 1.0 Parte Volume 0.0 0.0 0.0 1.0 0.0 1.0 0.0 Air Paste VolumeSpecified Value 0.0 0.0 1.0 1.0 0.0 Air Paste VolumeSpecified Value 0.0 0.0 1.0 1.0 0.0 1.0 Air Paste VolumeSpecified Value 0.0 0.0 1.0 1.0 1.0 1.0 Air Paste Volume 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 Air Paste Volume 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Air Paste Volume 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Air Paste Volume 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Air Paste Volume 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Air Paste Volume 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 Air Paste Vol		Mix Component			Weight (lbs/CY)	Specific Gravity	Absolute Vol.	(ft ³)	Subtotal Vol. (ft ³)
Total comentitious(lb) 0 (lb) 3.14 Portland Coment 100 $\%$ 690 (lb) 3.14 Portland Coment 100 $\%$ 690 (lb) 3.14 Portland Coment 100 $\%$ 690 (lb) 3.14 Other Pozzolan $\%$ 690 (lb) 3.14 Paste Volume $\%$ $ACI 318 Value - 6^{.0}$ 18% of paste- 5.2 Paste Volume 701 $ACI 318 Value - 6^{.0}$ 18% of paste- 5.2 5.2 Address $ACI 318 Value - 6^{.0}$ 18% of paste- 5.2 5.2 5.2 Address $ACI 318 Value - 5^{.0}$ $7.01 X 18/27$ 2.7 2.7 2.7 Address $ACI 318 Value - 5^{.0}$ $7.01 X 18/27$ 2.7 2.7 2.7 Address $AUI ComentSpecified Value - 5^{.0}ACI 318 Value - 5^{.0}5.65.7AddressAuth Vol. = b/b_0 x 27AUI Unit Wr. Crs.Agge-2.79.01 X 18/27AdgressAuth Vol. = b/b_0 x 27Auth Wr. Sp. G. SSD5.767.00AdgressAuth Vol. = b/b_0 x 27Bulk Vol. x unit Wr. Sp. G. SSD2.6010AdgressAuth Vol. = b/b_0 x 27Bulk Vol. x unit Wr. Sp. G. SSD2.6010Adgress101010101010Adgress101010101010Adgress1010101010A$		Adjusted Water			276 (lb)	1.0	4.42	(\mathfrak{fl}^3)	
Portland Cement100 $\%$ 690 (lb) 3.14 Fly ash Other Pozzolan $\%$ (lb) 3.14 1.04 Dital (water + cm) = $\%$ (lb) (lb) 3.14 Total (water + cm) = $\%$ (lb) (lb) 3.14 Paste Volume $\%$ $ACI 318$ Value 6^{-6} 18% of paste 53% 54 Diate Volume 5 $ACI 318$ Value 6^{-6} 18% of paste 53% 54 Air + Paste Volume 7 $ACI 318$ Value 6^{-6} 18% of paste 52% 60% Air + Paste Volume 7 $ACI 318$ Value 6^{-6} 18% of paste 52% 60% Agg Data $Air + Paste Volume7ACI 318 Value5\%5050\%50\%Agg DataAir + Paste Volume8ACI 318 Value5\%5\%5\%5\%5\%Agg DataAir + Paste Volume7Air + Paste Volume5\%<$		Total cementitious		(lb)					
Fly ash Other Pozzolan%(lb)iPaste Volume%(lb)iiPaste Volume%ACI 318 Value% $[18\% of paste53\% ofPaste VolumeSpecified Value%ACI 318 Value%[10\% X, 18/27]SetAir + Paste VolumeSpecified Value%ACI 318 Value%[10\% X, 18/27]SetAir + Paste VolumeTotal Agg Volume[10\% X, 18/27][10\% X, 18/27][10\% X, 18/27]SetAgg. DataMulk Vol. = b/b_0 x 27Bulk Vol. = b/b_0 x 27Bulk Vol. = b/b_0 x 27[10\% W, Crs. Agge9Agg. DataCoarse AggregateBulk Vol. = b/b_0 x 27Bulk Vol. = b/b_0 x 27[10\% W, Crs. Agge9Agg. DataTotal Agg VolumeSp. G. SSD2.602.6010\%AggregateTotal Weight / CYTotal Weight / CY[10, SSD]5p. G. SSD2.65Fine AggregateTotal Weight / CYTotal Weight / CY[10, SSD]2.6510\%Foral Weight / CYTotal Weight / CYTotal Weight / CY10\%10\%10\%Design YieldTotal Weight / CYDesign Yield10\%10\%10\%$		Portland Cement	100	0%	(ql) (lp)	3.14	3 22	(ff^3)	
Colter Pozzolan $\%$ (lb) \land Total (water + cm) = \checkmark (lb) (lb) (lb) Paste VolumeSpecified Value $\%$ $ACI 318 Value$ $\%$ 18% of paste= 5.3% $SelPaste VolumeSpecified Value\%ACI 318 Value\%18\% of paste= 5.3\%SelAir + Paste VolumeSpecified Value\%ACI 318 Value\%18\% of paste= 5.3\%SelAir + Paste Volume\checkmark27(lm)10\%10\%10\%27MAgg. DataMK Vol. = b/b_0 x 27= Bulk Vol. x unit wt.Sp. G. SSDMMAgg. DataMK Vol. = b/b_0 x 27= Bulk Vol. x unit wt.Sp. G. SSDMAgg. DataMK Vol. SSDSp. G. SSDMMAgg. DataMMMMMMAgg. DataMK Vol. SSDSp. G. SSDMMAgg. DataMKMMMMMAgg. DataMMMMMMMAgg. DataMMMMMMMMAgg. DataMMMMMMMMAgg. DataMMMMMMMMMAdd MatheMMMMMMMMM$	Ð	Fly ash		%	(ql)			(\mathfrak{fl}^3)	
Pite Total (water + cm) = Paste Volume Act 318 Value 6% 18% of paste 53% 84 Paste Volume Specified Value % ACI 318 Value 6% 18% of paste 53% 84 Air + Paste Volume Specified Value % ACI 318 Value 6% 18% of paste 54 96 Air + Paste Volume Specified Value % ACI 318 Value 6% 7 18% 7 18% 84 96	ļse	Other Pozzolan		0%	(lb)			(ff^3)	
AirTotal Air ContentSpecified Value%ACI 318 Value 6 18% of paste 53% SelAir + Paste VolumeAir + Paste Volume 71	,q	Total (water + cm) = Paste Volume							7.94 (ft ³)
Agg Volume 27 - (air + paste)Total Agg Volume 27 - (air + paste)Total Agg Volume 27 - (air + paste)Agg. Data 27 - (air + paste)Agg. Data $1000000000000000000000000000000000000$	ліА	Total Air Content	Specified Va	lue%	ACI 318 Value -6-%	18% of paste= <u>5</u> 3% Paste Vol X 18/27	Selection= 6	%	1.62 (ft ³)
Total Agg Volume 27 - (air + paste)Agg. Data 26 bh Agg. Data $P_{M}(Sand) = 2.6$ bh Agg. Data 10 unit wt. $Crs.Agg = 9.6$ Coarse AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ Darse AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ Coarse AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ Price AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ Coarse AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ AggregateBulk Vol. = $b/b_0 x 27$ $= Bulk Vol. x unit wt.$ AggregateDavid tette $(h), SSD$ Aggregate $P_0 x 27$ $Sp. G. SSD$ Aggregate $Total Agg VolumeTotal Ags VolumeTotal AbsoluteVolumeTotal AbsoluteDesign YieldTotal Absolute$		Air + Paste Volume		_			9.56	(ff^3)	
Agg. DataEM (Sand) = 2.6 b/tAgg. DataUnit Wt. Crs. Agg - 9.1 Coarse AggregateBulk Vol. = $b/b_0 x 27$ = Bulk Vol. x unit wt.Bulk Vol. = $b/b_0 x 27$ = Bulk Vol. x unit wt.Sp. G. SSDIntermediate(ft ³)(lb.SSD)Aggregate(lb.SSD)Fine Aggregate(lb.SSD)Fine Aggregate(lb.SSD)Total AggVolumeTotal Agsolute(lb.SSD)Total Absolute(lb.SSD)Sp. G. SSD2.65Total Absolute(lb.SSD)Total Absolute(lb.SSD)Design Yield(lb)		Total Agg Volume				27- (air + paste)	17.44	(\mathfrak{fl}^3)	
Coarse AgregateBulk Vol. = $b/b_0 x 27$ Unit Wt. Crs. Agg=Coarse AgregateBulk Vol. = $b/b_0 x 27$ = Bulk Vol. x unit wt.Sp. G. SSDIntermediate(h ³)(h), SSDSp. G. SSD $2,60$ Aggregate(h), SSDSp. G. SSD $2,60$ 10 Fine Aggregate(h), SSDSp. G. SSD $2,60$ 10 Total Aggregate(h), SSDSp. G. SSD $2,60$ 10 Total Aggregate(h), SSDSp. G. SSD $2,65$ 10 Total Aggregate(h), SSD $10, SSD2,6510Total Weight / CY(h)(h)1010Total Absolute(h)(h)1010Design YieldDesign Yield101010$		Agg. Data		i		FM (Sand) = 2.6	$b/b_0 =$		
Coarse AggregateBulk Vol. = $b/b_0 x 27$ (ff.)Bulk Vol. x unit wt. (lb,SSD)Sp. G. SSD 2.60IntermediatemeteriateperegateSp. G. SSD2.60AggregatemeteriatemeteriateSp. G. SSD2.65Fine AggregatemeteriatemeteriateSp. G. SSD2.65Total Agg Volumemeteriatemeteriate1010Total Weight / CYmeteriatemeteriate1010Total Absolutemeteriatemeteriation1010Volumemeteriatemeteriation1010Design Yieldmeteriationmeteriation1010						Unit Wt. Crs.Agg=	<i>92.0</i> (lbs/ft ³)	SSD	
InternediateSp. G. SSDAggregate(lb,SSD)Fine Aggregate(lb,SSD)Total Agg Volume(lb,SSD)Total Weight / CY(lb,SSD)Total Weight / CY(lb)Total Absolute(lb)VolumeVolumeDesign YieldInternet in the second)]	Coarse Aggregate	Bulk Vol. =	$\frac{b/b_0 \ge 27}{(ft^3)}$	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD		(ft ³)	
Fine Aggregate(lb,SSD)Sp. G. SSD2.65Total Agg VolumeTotal Weight / CY(lb)Image: Second Se	grega	Intermediate Aggregate				Sp. G. SSD		(ft^3)	
Total Agg Volume(lb)Total Weight / CY(lb)Total AbsoluteVolumeVolumeDesign Yield	<u>6</u> 4	Fine Aggregate			(lb,SSD)	^{Sp. G. SSD} 2.65		(ft^3)	Total agg – (coarse & interm vol)
Total Weight / CY(lb)Total AbsoluteVolumeVolumeDesign Yield		Total Agg Volume							(\mathfrak{fl}^3)
Total Absolute		Total Weight / CY			(q])				
Design Yield		Total Absolute Volume							<i>27.00</i> (ft ³)
		Design Yield							(%)

Estimate Aggregate Proportions



Bulk volume of coarse aggregate (b/b₀) is the percent of loosely packed (dry rodded) volume the coarse aggregate occupies in one cubic yard

stimate Aggregate Proportions



Table 9-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

Nominal maximum size of	Bulk v aggregate different fi	/olume of dr e per unit vo neness mod	y-rodded co lume of cor luli of fine a	oarse ncrete for iggregate
mm (in.)	2.40	2.60	2.80	3.00
9.5 (%)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
19 (%)	0.66	0.64	0.62	09.0
25 (1)	0.71	0.69	0.67	0.65
37.5 (1½)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

te Size (In.) *Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C 29 (AASHTO T 19), Adapted from ACI 211.1.

BBO00.GRF

Data from Table 6.3.6 ACI 211.1-91.

Coarse Aggregate Volume Determine

	Slump = 4 Controlling	(in.) No	m. Max. Agg. Size= $\frac{3/4}{}$ (in.)	Basic Water Demand 345 Air Entrained or	Ib/CY (note imposed to the imposed t	Adjustment Factor 80 act of AE Conc.) 0.80 LITE:
_	w/c or $w/cm =$	U.4U psi	<i>5000</i> °	YES	[O Mild	Moderate Extreme
	Mix Component		Weight (lbs/CY)	Specific Gravity	Absolute Vol. (ft^3)	Subtotal Vol. (ft ³)
	Adjusted Water		276 (lb)	1.0	4.42 (ft ³)	
_	Total cementitious)	lb)		¢	
_	Portland Cement	100	% 690 (lb)	3.14	357 (ft ³)	
Ð	Fly ash		% (dl)		(ff^3)	
SE	Other Pozzolan		% (1b)		(ft^3)	
d	Total (water + cm) = Paste Volume					7.94 (ft ³)
λiΑ	Total Air Content	Specified Value	% ACI 318 Value -6-%	18% of paste= <u>53</u> % Paste Vol X 18/27	Selection=6%	<i>1.62</i> ^(ft³)
_	Air + Paste Volume				9.56 (ft ³)	
	Total Agg Volume			27- (air + paste)	17.44 (ft ³)	
_	Agg. Data			FM (Sand) = 2.6	$b/b_0 = 0.64$	
_				Unit Wt. Crs.Agg=	92.0 (lbs/ft ³)SSD	
əj	Coarse Aggregate	Bulk Vol. = $b/b_0 \ge 2$	$\begin{array}{l l} \begin{array}{l} \begin{array}{c} 1 \\ \hline 1 \\ \hline 1 \\ \hline 1 \\ \end{array} \end{array} = Bulk Vol. x unit wt. \\ \begin{array}{c} \hline 1 \\ \hline 1 \\ \end{array} \\ \begin{array}{c} \begin{array}{c} 1 \\ \hline 1 \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\ \begin{array}{c} 1 \\ \end{array} \\$	Sp. G. SSD 7 60	(\mathbf{f}^3)	
grega	Intermediate Aggregate			Sp. G. SSD	(ft ³)	
6A	Fine Aggregate		(lb,SSD)	^{Sp. G. SSD} 2.65	(ft ³)	Total agg – (coarse & interm vol)
	Total Agg Volume					$(\hat{\mathrm{fl}}^3)$
_	Total Weight / CY		(qI)			
	Total Absolute Volume					<i>27.00</i> (ft ³)
	Design Yield					(%)

	Slump = 4	(in.)	Nom. N	<i>A</i> ax. Agg. Size= 3/4 (in.)	Basic Water Demand 345	Ib/CY	Water / (note impa	Adjustment Factor tot of AE Conc.)
	Controlling w/c or w/cm =	0.40	Mix de psi	sign target strength = 5000	Air Entrained co YES N	oncrete? VO	Exposu Mild 1	re: Moderate Extreme
	Mix Component			Weight (lbs/CY)	Specific Gravity	Absolute Vol.	(ft ³)	Subtotal Vol. (ft ³)
	Adjusted Water			276 (lb)	1.0	4.42	(\mathfrak{fl}^3)	
	Total cementitious		(lb)					
	Portland Cement	100	0%	(lb) (lb)	3.14	357	(\mathfrak{fl}^3)	
Ð	Fly ash		0%	(lb)			(\mathfrak{fl}^3)	
ļse	Other Pozzolan		%	(lb)			(ft^3)	
9	Total (water + cm) = Paste Volume							7. <i>9</i> 4 (ft ³)
٦iA	Total Air Content	Specified Val	ue%	ACI 318 Value%	18% of paste= <u>53</u> % Paste Vol X 18/27	Selection= 6	%	<i>1.62</i> (ft ³)
	Air + Paste Volume					9.56	(ff^3)	
	Total Agg Volume				27- (air + paste)	17.44	(ff^3)	
	Agg. Data				FM (Sand) = 2.6	$b/b_0 = 0.64$		
					Unit Wt. Crs.Agg=	92.0 (lbs/ft ³)	SSD	
9ji	Coarse Aggregate	Bulk Vol. = 17.2	$\frac{b/b_0 \ge 27}{\delta}$ (ft ³)	= Bulk Vol. x unit wt. 1590 (lb,SSD)	Sp. G. SSD 2.60	9.80	$(\hat{\mathbf{fl}}^3)$	
gregs	Intermediate Aggregate				Sp. G. SSD		(ft ³)	
6 A	Fine Aggregate			(lb,SSD)	^{Sp. G. SSD} 2.65		(ft ³)	Total agg – (coarse & interm vol)
	Total Agg Volume							(ff^3)
	Total Weight / CY			(lb)				
	Total Absolute Volume							<i>27.00</i> (ft ³)
	Design Yield							(%)

-

Fine Aggregate Volume Determine

Calculate Aggregate Batch Proportions

Fine Aggregate

Weight (lbs) = 7.64 ft³ X 62.4 lbs/ft3 X 2.65=1263 lbs Abs. Vol.(ft3) = 17.44 ft3 - 9.80 ft3 = 7.64 ft3

	Slump = 4	(in.)	Nom. N	1ax. Agg. Size= 3/4 (in.)	Basic Water Demand 345	- Ib/CY	Water A (note imp	Adjustment Factor act of AE Conc.)	_
	Controlling w/c or w/cm =	0.40	Mix de psi	sign target strength = 5000	Air Entrained co YES N	oncrete? IO	Exposu Mild	re: Moderate Extreme	
	Mix Component			Weight (lbs/CY)	Specific Gravity	Absolute V	V ol. (ft ³)	Subtotal Vol. (ft^3)	
	Adjusted Water			276 (lb)	1.0	4.4	42 (ft ³)		
	Total cementitious		(lb)						
	Portland Cement	100	0%	(90 (Ib)	3.14	5 2	7 (ft ³)		
Ð	Fly ash		%	(lb)			(ff^3)		
ļse	Other Pozzolan		%	(lb)			(ft^3)		
\$d	Total (water + cm) = Paste Volume							7. <i>94</i> (f [†]	
٦iA	Total Air Content	Specified Va	llue%	ACI 318 Value -6-%	18% of paste= <u>5</u> 3% Paste Vol X 18/27	Selection=	<u>6</u> %	1.62 ^(f)	(
	Air + Paste Volume					9.50	(\mathfrak{t}^3)		
	Total Agg Volume				27- (air + paste)	17.44	f (ft ³)		
	Agg. Data				FM (Sand) = 2.6	$\mathbf{b}/\mathbf{b}_0 = 0.$	64		
					Unit Wt. Crs.Agg=	<i>92.0</i> (Ibs/	ft ³)SSD		
9j	Coarse Aggregate	Bulk Vol. = 17.2	$\frac{1}{8} \frac{b/b_0 \ge 27}{(ff^3)}$	= Bulk Vol. x unit wt. 1590 (lb,SSD)	Sp. G. SSD 2.60	08'6	(\mathfrak{fl}^3)		
di.eds	Intermediate Aggregate				Sp. G. SSD		(ft^3)		
<u>p</u> ba	Fine Aggregate			1263 (lb,SSD)	Sp. G. SSD 2.65	7.64	(ff^3)	Total agg – (coarse & interm vol)	
	Total Agg Volume							17.44 (ft ³)
	Total Weight / CY			(lb) 3819					
	Total Absolute Volume							27.00(ft	$\widehat{}$
	Design Yield							100 (%	

¢

APPENDIX B EXAMPLE PROBLEMS

Example 1 Fineness Modulus Worksheet

Sieve Size	Percent retained	Cumulative Percent Retained
6"	0	0
3"	0	0
1.5"	0	0
3/4"	0	0
3/8"	0	0
#4	2	
#8	11	
#16	18	
#30	20	
#50	25	
#100	18	
Pan	4	NA
Sum		
Calculation		
FM		

Example 1 Answer Fineness Modulus Worksheet

Sieve Size	Percent retained	Cumulative Percent Retained
6"	0	0
3"	0	0
1.5"	0	0
3/4"	0	0
3/8"	0	0
#4	2	2
#8	11	13
#16	18	31
#30	20	51
#50	25	76
#100	18	94
Pan	4	NA
Sum		267
Calculation		267 ÷ 100
FM		<u>2.67</u>

Example 2 – Mathematically Combined Gradation

An aggregate blend of 45% coarse, 15% intermediate, and 40% fine aggregate is to be combined. Determine the combine percent passing and combined percent retained.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative Percent	0.45	0.15	0.40		
1 1/2"	100.0	100.0	100.0		
1"	98.0	100.0	100.0		
3/4"	76.0	100.0	100.0		
1/2"	38.0	100.0	100.0		
3/8"	22.0	86.0	100.0		
#4	4.8	21.0	92.0		
#8	1.8	4.1	84.0		
#16	1.7	3.7	66.0		
#30	1.6	3.4	42.0		
#50	1.5	2.9	14.0		
#100	1.4	2.5	1.4		
#200	1.3	2.1	0.3		

Mathematical Combined Aggregate Gradation, by Weight

Example 2 – Mathematically Combined Gradation Answer

An aggregate blend of 45% coarse, 15% intermediate, and 40% fine aggregate is to be combined. Determine the combine percent passing and combined percent retained.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative Percent	0.45	0.15	0.40		
1 1/2"	100.0	100.0	100.0	100.0	100-100 = 0.0
1"	98.0	100.0	100.0	99.1	100-99.1 = 0.9
3/4"	76.0	100.0	100.0	89.2	99.1-89.2 = 9.9
1/2"	38.0	100.0	100.0	72.1	89.2-72.1 = 17.1
3/8"	22.0	86.0	100.0	62.8	72.1-62.8 = 9.3
#4	4.8	21.0	92.0	42.1	62.8-42.1 = 20.7
#8	1.8	4.1	84.0	35.0	42.1-35.0 = 7.1
#16	1.7	3.7	66.0	27.7	35.0-27.7 = 7.3
#30	1.6	3.4	42.0	18.0	27.7-18.0 = 9.7
#50	1.5	2.9	14.0	6.7	18.0-6.7 = 11.3
#100	1.4	2.5	1.4	1.6	6.7-1.6 = 5.1
#200	1.3	2.1	0.3	1.0	1.6 -1 = 0.6

Mathematical Combined Aggregate Gradation, by Weight

Combined %Passing

1 ½"	$100 \times 0.45 + 100 \times 0.15 + 100 \times 0.40 = 100$
1"	98x0.45 + 100x0.15 + 100x0.40 = 99.1
³ ⁄4"	76x0.45 + 100x0.15 + 100x0.40 = 89.2
1⁄2"	38x0.45 + 100x0.15 + 100x0.40 = 72.1
3/8"	21x0.45 + 86x0.15 + 100x0.40 = 62.8
#4	$4.8 \times 0.45 + 21 \times 0.15 + 92 \times 0.40 = 42.1$
#8	$1.8 \times 0.45 + 4.1 \times 0.15 + 84 \times 0.40 = 35.0$
#16	$1.7 \times 0.45 + 3.7 \times 0.15 + 66 \times 0.40 = 27.7$
#30	$1.6 \times 0.45 + 3.4 \times 0.15 + 42 \times 0.40 = 18.0$
#50	$1.5 \times 0.45 + 2.9 \times 0.15 + 14 \times 0.40 = 6.7$
#100	$1.4 \times 0.45 + 2.5 \times 0.15 + 1.4 \times 0.40 = 1.6$
#200	1.3x0.45 + 2.1x0.15 + 0.3x0.40 = 1.0

Example 3 Calculating Coarseness and Workability Factors

Given crushed limestone coarse aggregate, crushed intermediate aggregate, and sand at the percentages indicated, determine the coarseness and workability factors.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative Percent	0.45	0.15	0.40		
1 1/2"	100.0	100.0	100.0	100.0	0.0
1"	98.0	100.0	100.0	99.1	0.9
3/4"	76.0	100.0	100.0	89.2	9.9
1/2"	38.0	100.0	100.0	72.1	17.1
3/8"	22.0	86.0	100.0	62.8	9.3
#4	4.8	21.0	92.0	42.1	20.7
#8	1.8	4.1	84.0	35.0	7.1
#16	1.7	3.7	66.0	27.7	7.3
#30	1.6	3.4	42.0	18.0	9.7
#50	1.5	2.9	14.0	6.7	11.3
#100	1.4	2.5	1.4	1.6	5.1
#200	1.3	2.1	0.3	1.0	0.6

Example 3 Calculating Coarseness and Workability Factors Answer

Given crushed limestone coarse aggregate, crushed intermediate aggregate, and sand at the percentages indicated, determine the coarseness and workability factors.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combine % Retair	ed ned	
Relative Percent	0.45	0.15	0.40				
1 1/2"	100.0	100.0	100.0	100.0	0.0		
1"	98.0	100.0	100.0	99.1	0.9		
3/4"	76.0	100.0	100.0	89.2	9.9	Y	
1/2"	38.0	100.0	100.0	72.1	17.1		۲
3/8"	22.0	86.0	100.0	62.8	9.3		
#4	4.8	21.0	92.0	42.1	20.7		
#8	1.8	4.1	84.0	35.0	7.1		
#16	1.7	3.7	66.0	27.7	7.3		
#30	1.6	3.4	42.0	18.0	9.7		
#50	1.5	2.9	14.0	6.7	11.3		
#100	1.4	2.5	1.4	1.6	5.1		
#200	1.3	2.1	0.3	1.0	0.6		

 $Coarseness \ factor = \frac{Combined \ Percent \ Re \ tained \ Above \ 3 / 8'' \ Sieve}{Combined \ Percent \ Re \ tained \ Above \ #8 \ Sieve} \ X \ 100$

$$= \frac{0+0.9+9.9+17.1+9.3}{0+0.9+9.9+17.1+9.3} X 100$$

= $\frac{37.2}{65} \times 100 = 57.2$

Workability factor = *Combined Percent Passing #8 Sieve*

Examples 4 – 14 Volume, Unit Weight, Specific Gravity, and Water Cement Ratio

- 4. 8.0 ft³ = _____ yd³
- 5. 0.118 yd³ = _____ ft³
- 6. How many pounds does 6.8 gallons of water weigh?

- 7. What is the absolute volume (yd³) of 235 lbs of water?
- 8. Determine the unit weight of 0.25 ft³ of concrete that weighs 35.7 lbs?
- 9. 1.0 ft³ of a material weighs 167 lbs. Determine the specific gravity (SPG).

10. Given 6% air content in a cubic yard. What volume of air in cubic feet?

11. What is the absolute volume of cement <u>**vd**</u>³ per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd³?

12. What is the absolute volume of cement <u>**ft**</u>³ per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd³?

13. What is the weight of material (lbs/yd³) given an absolute volume of 0.330 and a specific gravity of 2.65? What is the weight in (lbs/ft³) ?

14. Determine the w/c ratio, given the following mix design:

300 lbs cement	200 lbs water at plant
90 lbs fly ash	10 lbs from coarse aggregate
210 lbs ggbfs	30 lbs from fine aggregate
	2 gallons water per yd ³ added on truck

15. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume	Absolute Volume	Weight
	(yd³/yd³)	(ft ³ /yd ³)	(lbs/yd ³)
Cement (SPG =3.14)	0.106	b)	a)
Water	d)	e)	c)
Fine Aggregate	g)	h)	1650
Coarse Aggregate	f)	10.6	1560
Total	1.000 yd ³	27.0 ft ³	

Answers 4 – 15 Volume, Unit Weight, Specific Gravity, and Water Cement Ratio

4. 8.0 ft³ = yd^3

8.0 ft³ \div 27 ft³ / yd³ = 0.296 yd³

5. 0.118 yd³ = _____ ft³

```
0.118 yd<sup>3</sup> × 27 ft<sup>3</sup>/ yd<sup>3</sup> = 3.186 ft<sup>3</sup>
```

6. How many pounds does 6.8 gallons of water weigh?

 $(6.8 \text{ gal}) \times (8.33 \text{ lbs})/\text{gal}. = 56.64 \text{ lbs}$

7. What is the absolute volume (yd³) of 235 lbs of water?

Abs Vol (yd³) = 235 lbs \div (1.00 x 62.4 lbs/ ft³ x 27 ft³ yd³) 235 lbs \div 1684.8 lbs/yd³ = 0.139 yd³

8. Determine the unit weight of 0.25 ft³ of concrete that weighs 35.7 lbs?

 $\frac{35.7 \text{lbs}}{0.25 \text{ ft}^3}$ = 142.8 lbs/ft³

9. 1.0 ft³ of a material weighs 167 lbs. Determine the specific gravity (SPG).

10. Given 6% air content in a cubic yard. What volume of air in cubic feet?

 $0.06 \text{ yd}^3/\text{yd}^3 \times 27 \text{ ft}^3/\text{yd}^3 = 1.62 \text{ ft}^3$

11. What is the absolute volume of cement <u>**vd**</u>³ per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd³?

Abs. Vol (yd3/yd3) = $\frac{709 \text{ lbs/yd}^3}{(3.14 \times 62.4 \text{ lbs/ft}^3 \times 27 \text{ ft}^3/\text{yd}^3)} = 0.134 \text{ yd}^3/\text{yd}^3$

12. What is the absolute volume of cement <u>**ft**</u>³ per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd³?

Abs. Vol (ft3/yd3) = $\frac{709 \text{ lbs/yd}^3}{(3.14 \times 62.4 \text{ lbs/ft}^3)} = 3.61 \text{ ft}^3/\text{yd}^3$

13. What is the weight of material (lbs/yd³) given an absolute volume of 0.330 and a specific gravity of 2.65? What is the weight in (lbs/ft³) ?

Weight lbs/ ft³ = 1473 lbs/yd³ ÷ 27 ft³/yd³ = 54.57 lbs/ft³

14. Determine the w/c ratio, given the following mix design:

300 lbs cement	200 lbs water at plant
90 lbs fly ash	10 lbs from coarse aggregate
210 lbs ggbfs	30 lbs from fine aggregate
	2 gallons water per yd ³ added on truck

 $w/c = \frac{200 + 10 + 30 + 2x8.33}{300 + 90 + 210} = \frac{256.66}{600} = 0.428$

15. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. The **w/c ratio** is given as **0.45**.

Component Material Absolute Volume		Absolute Volume	Weight
	(yd ³ /yd ³)	(ft³/yd³)	(lbs/yd ³)
Cement (SPG =3.14)	0.106	b)	a)
Water	d)	e)	c)
Fine Aggregate	g)	h)	1650
Coarse Aggregate	f)	10.6	1560
Total	1.000 yd ³	27.0 ft ³	

- a) 0.106 X 62.4 X 27 X 3.14 = 561 lbs
- b) 0.106 X 27 = 2.86 ft³
- c) 561 X 0.45 = 252.45 lbs
- d) 252.45 ÷ (1.00 X 62.4 X 27) = 0.150 yd³
- e) 0.150 X 27 = 4.05 ft³
- f) $10.6 \div 27 = 0.393 \text{ yd}^3$
- g) $1.000 0.393 0.150 0.106 = 0.351 \text{ yd}^3$
- h) 0.351 X 27 = 9.48 ft^3

Example Problem 16

16. Determine the SSD weights for a QMC mix using form 820150 given the following source information:

٠	LafargeHolcim I/II	3.14
٠	Port Neal #4 fly ash (20% replacement)	2.66
٠	Fine agg. Halletts Materials, Army Post East, Polk Co.	2.65
٠	Coarse agg. Martin Marietta, Ames Mine, Story Co.	2.68
٠	Intermediate agg. Martin Marietta, Ames Mine, Story Co.	2.68

Assume the following aggregate Proportions:

- Coarse = 0.48
- Intermediate = 0.12
- Fine = 0.40

Rev 05/09		lowa Depart	ment Of Transportation		Form E820150E
		PORTLAND	CEMENT CONCRETE		
Project No.: P	roblem 16		-	County : /	Any
Mix No.:	QMC	Α	bs Vol. Cement: 0.1059	Type: _	1/11
Cement (IM 401):	560	lbs	Source: LafargeHolcim I/II	Sp. Gr.: _	3.14
Fly Ash (IM 491.17):	20	112	Source: Port Neal #4	Sp. Gr.: _	2.66
Slag (IM 491.14):		0	Source:	Sp. Gr.: _	
Adjus	ted lbs. Cement:	448]		
То	tal Cementitious_	560	Total % Replacement =20		
IM T203	Fine Aggregate	Source:	Army Post East	Sp. Gr.:	2.65
IM T203	Interm. Aggregat	e Source:	Ames Mine	Sp. Gr.:	2.68
IM T203	Coarse Agregate	e Source:	Ames Mine	Sp. Gr.:	2.68
Basia w/a	0.400		Water (lbc/ou) - Decian w/o (ut coment +	ut Ely Ach +Slag) -	224
Max w/c	0.400		Mater (Ibs/cy) = Design w/c (wt. cement + Max Water (Ibs/cy) = Design w/c (wt. cement +	wt Fly Ash +Slag) = $_{\rm sharphi}$	224
	0.120				
Absolute Volumes	Cement		(lbs/cy) / (Sp. Gr. X 62.4 X 27)	= -	0.085
	Fly Ash		(lbs/cy) / (Sp. Gr. X 62.4 X 27)	= _	0.025
	Slag		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	
	Water		(lbs/cy) / (1.00 X 62.4 X 27)	=_	0.133
	Air				0.060
			Subtotal	=	0 303
			1.000 - Subtotal		0.697
			Total	=	1.000
% FA Agg.:		Fine A	ggregate(1.000 - Subtotal)X % In Mix	=	
% In. Agg.:		Interm.	Aggregate (1.000 - Subtotal) X % In Mix	=	
% CA Agg.:		Coarse	Aggregate (1.000 - Subtotal) X % In Mix	=	
			Aggregate Total	= _	0.697
Aggregate Weights		Fine Agg	regate (abs vol.) X Sp. Gr. X 62.4 X 27	=	
		Intermediate	Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	
		Coarse A	ggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	
Summary			Cement (Ibs/cy)		
			Fly Ash (Ibs/cy)		
			Slag (lbs/cy)		
			Water (Ibs/cy)		
			Fine Agg. (Ibs/cy)		
			Interm. Agg. (Ibs/cy)		
Distribution: Materials, D	ME, Proj. Engr.,	_ Contractor			

Example 16 Answer

Rev 05/09		Iowa Depart	ment Of Transportation		Form E820150E
		PORTLAND	CEMENT CONCRETE		
Project No.: <u>Pro</u>	oblem 16		-	County :	Any
Mix No.:	QMC	At	os Vol. Cement: 0.1059	Туре:	1/11
Cement (IM 401):	<u>560</u> %	lbs	Source: LafargeHolcim I/II	Sp. Gr.:	3.14
Fly Ash (IM 491.17):	20	112	Source: Port Neal #4	Sp. Gr.:	2.66
Slag (IM 491.14):	Γ	0	Source:	Sp. Gr.:	
Adjust	ed lbs.Cement:	448]		
Tota	al Cementitious	560	Total % Replacement = 20		
IM T203	Fine Aggregate	Source:	Army Post East	Sp. Gr.:	2.65
IM T203	Interm. Aggregate	e Source:	Ames Mine	Sp. Gr.:	2.68
IM T203	Coarse Agregate	Source:	Ames Mine	Sp. Gr.:	2.68
Basic w/c	0.400		Water (lbs/cv) = Design w/c (wt cement	+ wt Fly Ash +Slag) =	224
Max w/c	0.420		Max. Water (lbs/cy) = Design w/c (wt. cement	+ wt Fly Ash +Slag) =	235
Absolute Volumes	Cement		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	0.085
	Fly Ash		(lbs/cy) / (Sp. Gr. X 62.4 X 27)	= _	0.025
	Slag		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	
	Water		(Ibs/cy) / (1.00 X 62.4 X 27)	=_	0.133
	Air				0.060
			Subtotal	=	0.303
			1.000 - Subtotal	=	0.697
			Total	=	1.000
% FA Agg.:	40	Fine Ac	igregate (1.000 - Subtotal) X % In Mix	=	0.278
% In. Agg.:	12	Interm. A	Aggregate (1.000 - Subtotal) X % In Mix	=	0.084
% CA Agg.:	48	Coarse A	Aggregate(1.000 - Subtotal)X % In Mix	=	0.335
			Aggregate Total	=_	0.697
Aggregate Weights		Fine Agg	regate (abs vol.) X Sp. Gr. X 62.4 X 27	=	1241
		Intermediate	Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	379
		Coarse Ag	gregate (abs vol.) X Sp. Gr. X 62.4 X 27	=]	1513
Summary			Cement 448 (lbs/cy)		
			Fly Ash <u>112</u> (lbs/cy)		
			Slag 0 (lbs/cy)		
			Water 224 (IDS/Cy)		
			Interm. Agg. 379 (lbs/cv)		
			Coarse Agg. 1513 (lbs/cy)		
Distribution: Materials, DM	1E, Proj. Engr.,	Contractor			

APPENDIX C WORKSHEETS

PCC Level III Basic Equations

Abs. Vol. (yd3/yd3) = weight (lbs) / (SpG X 62.4 lbs/ft3 X 27 ft3/yd3)

Abs. Vol. (ft3/yd3) = weight (lbs) / (SpG X 62.4 lbs/ft3)

Weight (lbs/yd3) = Abs. Vol. (yd3/yd3) X SpG X 62.4 lbs/ft3 X 27 ft3/yd3

Weight (lbs/yd3) = Abs. Vol. (ft3/yd3) X SpG X 62.4 lbs/ft3

w/c ratio = (weight water) / (weight cementitious materials)

weight of cement = (weight water) / (w/c ratio)

weight of water = (weight cementitous materials) X (w/c ratio)

unit weight of water = 62.4 lbs/ft3

SpG of water = 1.00

1 gallon of water = 8.33 lbs

Fineness Modulus Worksheet

Sieve Size	Percent Retained	Cumulative Percent Retained
6"		
3"		
1.5"		
3/4"		
3/8"		
#4		
#8		
#16		
#30		
#50		
#100		
Pan		NA
Sum		
Calculation		
FM		

Mathematical Combined Aggregate Gradation, by Weight

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative					
Percent					
1 1/2"					
1"					
3⁄4"					
1/2"					
3/8"					
#4					
#8					
#16					
#30					
#50					
#100					
#200					

Rev 05/09 Iowa Department Of Transportation						Form E820150E
		Offic PORTLAND	e Of Materials	RETE		
		I OITLAID				
Project No.:					County :	
Mix No.:		Ab	s Vol. Cement:		Туре:	
Cement (IM 401): _	%	lbs	Source:		Sp. Gr.:	
Fly Ash (IM 491.17): _			Source:		Sp. Gr.:	
Slag (IM 491.14):			Source:		Sp. Gr.:	
Adjus	ted lbs. Cement:					
Тс	otal Cementitious		Total % Rep	lacement =		
IM T203	Fine Aggregate	Source:			Sp. Gr.:	
IM T203	Interm. Aggregat	e Source:			Sp. Gr.:	
IM T203	Coarse Agregate	e Source:			Sp. Gr.:	
Basic w/c			Water (lbs/c)	() = Design w/c (wt_cement +	wt Fly Ash +Slag) =	
Max w/c		M	ax. Water (lbs/c)	/) = Design w/c (wt. cement +	wt Fly Ash +Slag) =	
Absolute Volumes	Cement			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
				(
	Fly Ash			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Slag			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Water			(lbs/cy) / (1.00 X 62.4 X 27)	=	
	Air					0.060
				Subtotal	=	
				1.000 - Subtotal	=	
				Total	=	1.000
% FA Agg.: Fine Aggregate (1.000 - Subtotal) X % In Mix						
% In. Agg.: Interm. Aggregate (1.000 - Subtotal) X % In Mix					=	
% CA Agg.: Coarse Aggregate (1.000 - Subtotal) X % In Mix				- Subtotal) X % In Mix	=	
				Aggregate Total	=	
Aggregate Weights	Fine Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27			=		
		Intermediate Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27			=	
Coarse Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27					=	
Summary			Cement	(lbs/cv)		
· ······,			Fly Ash	(lbs/cy)		
			Slag	(lbs/cy)		
			Water	(lbs/cy)		
			Fine Agg.	(lbs/cy)		
			Interm. Agg.	(lbs/cy)		
			Coarse Agg.	(lbs/cy)		
Distribution: Materials, DI	ME, Proj. Engr.,	Contractor				
Rev 05/09		lowa Departr	nent Of Transpo	tation		Form E820150E
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		Offic PORTLAND	e Of Materials	RETE		
		I OITLAID				
Project No.:					County :	
Mix No.:		Ab	s Vol. Cement:		Туре:	
Cement (IM 401): _	%	lbs	Source:		Sp. Gr.:	
Fly Ash (IM 491.17): _			Source:		Sp. Gr.:	
Slag (IM 491.14):			Source:		Sp. Gr.:	
Adjus	ted lbs. Cement:					
Тс	otal Cementitious		Total % Rep	lacement =		
IM T203	Fine Aggregate	Source:			Sp. Gr.:	
IM T203	Interm. Aggregat	e Source:			Sp. Gr.:	
IM T203	Coarse Agregate	e Source:			Sp. Gr.:	
Basic w/c			Water (lbs/c)	() = Design w/c (wt_cement +	wt Fly Ash +Slag) =	
Max w/c		M	ax. Water (lbs/c)	/) = Design w/c (wt. cement +	wt Fly Ash +Slag) =	
Absolute Volumes	Cement			(lbs/cv) / (Sp. Gr. X 62.4 X 27)	=	
				(
	Fly Ash			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Slag			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Water			(lbs/cy) / (1.00 X 62.4 X 27)	=	
	Air					0.060
				Subtotal	=	
				1.000 - Subtotal	=	
				Total	=	1.000
% FA Agg.:		Fine Ag	aregate (1.000 -	Subtotal) X % In Mix	=	
% In. Agg.:		Interm. A	ggregate (1.000	- Subtotal) X % In Mix	=	
% CA Agg.:		Coarse A	ggregate (1.000	- Subtotal) X % In Mix	=	
				Aggregate Total	=	
Aggregate Weights		Fine Aggr	egate (abs vol) X Sp. Gr. X 62.4 X 27	=	
		Intermediate	Aggregate (abs	vol.) X Sp. Gr. X 62.4 X 27	=	
		Coarse Ag	gregate (abs vo	l.) X Sp. Gr. X 62.4 X 27	=	
Summary			Cement	(lbs/cv)		
· ······,			Fly Ash	(lbs/cy)		
			Slag	(lbs/cy)		
			Water	(lbs/cy)		
			Fine Agg.	(lbs/cy)		
			Interm. Agg.	(lbs/cy)		
			Coarse Agg.	(lbs/cy)		
Distribution: Materials, DI	ME, Proj. Engr.,	Contractor				

¹ Workability Factor VS Coarseness Factor for Combined Aggregate Assumptions: 564 lbs cement per cubic yard, 1 inch Aggregate, and Slipformed







Combined Aggregate Gradation, % Retained



Tarantula Curve Combined Aggregate Gradation, % Retained



APPENDIX D EXERCISES & ANSWER KEY

Ch. 2 Cementitious Materials

- 1 Which of the following statements are true regarding fly ash?
 - a. Class F is pozzolanic
 - b. Class C is both cementitious and pozzolanic
 - c. Class F is predominantly available in Iowa
 - d. All of the above
 - e. A and B
- 2 Which of the following statements are correct regarding supplementary cementitious materials?
 - a. GGBFS is more variable because the molten limestone contains steel
 - b. Fly ash is tightly controlled because it's based on electricity production
 - c. GGBFS is less variable than fly ash because of the tight controls in steel production
 - d. GGBFS is cheaper than fly ash because it does not need further processing
- 3 What are the potential benefits to using slag and fly ash in a mix design?
 - a. Reduced permeability and increased strength
 - b. Increased permeability and increased strength
 - c. Reduced cost
 - d. a and b
 - e. a and c
- 4 The w/c ratio has the biggest impact on what major concrete properties?
 - a. Abrasion resistance and frost resistance
 - b. Air void system
 - c. Strength and permeability
 - d. Sulfate resistance
- 5 What effect does w/c ratio have on capillary pores?
 - a. As the w/c ratio increases, the strength and permeability increase
 - b. As the w/c ratio decreases, the strength and permeability decrease
 - c. As w/c ratio increases, more water is available for hydration so strength is increased and permeability is decreased
 - d. As w/c ratio increases, the cement grains become further apart increasing permeability and decreasing strength

Ch. 2 Cementitious Materials Answers

- 1 Which of the following statements are true regarding fly ash?
 - a. Class F is pozzolanic
 - b. Class C is both cementitious and pozzolanic
 - c. Class F is predominantly available in Iowa
 - d. All of the above
 - e. A and B
- 2 Which of the following statements are correct regarding supplementary cementitious materials?
 - a. GGBFS is more variable because the molten limestone contains steel
 - b. Fly ash is tightly controlled because it's based on electricity production
 - c. GGBFS is less variable than fly ash because of the tight controls in steel production
 - d. GGBFS is cheaper than fly ash because it does not need further processing
- 3 What are the potential benefits to using slag and fly ash in a mix design?
 - a. Reduced permeability and increased strength
 - b. Increased permeability and increased strength
 - c. Reduced cost
 - d. a and b
 - e.aand c
- 4 The w/c ratio has the biggest impact on what major concrete properties? a. Abrasion resistance and frost resistance
 - b. Air void system
 - c. Strength and permeability
 - d. Sulfate resistance
- 5 What effect does w/c ratio have on capillary pores?
 - a. As the w/c ratio increases, the strength and permeability increase
 - b. As the w/c ratio decreases, the strength and permeability decrease
 - c. As w/c ratio increases, more water is available for hydration so strength is increased and permeability is decreased
 - d. As w/c ratio increases, the cement grains become further apart increasing permeability and decreasing strength

Ch 3 Chemical Admixtures

- 1. Which of the following statements are correct regarding chemical admixtures?
 - a. All admixtures are designed to improve only one concrete property
 - b. An admixture may be used to enhance a poor mix design and improve placement
 - c. Admixtures should be used to enhance the properties of a good mix design
 - d. Admixtures are liquid and will likely increase the w/c ratio
- 2. Which of the following describes the impact of bubble size and spacing on concrete freeze thaw protection?
 - a. Many small bubbles spaced relatively close to each other provides the maximum freeze thaw protection
 - b. A few large bubbles spaced as close as possible will provide adequate freeze thaw protection
 - c. Freeze thaw protection is not a concern in Iowa because the concrete remains frozen for an extended time
 - d. Since the capillaries contain all the water, the bubble size has little impact on freeze thaw protection
- 3. Which of the following describe multiple effects of admixtures on concrete properties?
 - a. Water reducers aid in air entrainment as well as reduce water for a given slump
 - b. Retarders provide water reduction as well as retard the set
 - c. Air entrainment improves workability and improves F/T resistance
 - d. All of the above
 - e. None of the above
- 4. Water reducers can be used in which of the following manners to achieve various effects?
 - a. Use same cement and reduce the water
 - b. Reduce cement and water the same amount
 - c. Cement and water remain the same
 - d. All of the above
 - e. None of the above

- 5. Which of the following statements are correct regarding retarders?
 - a. Retarders reduce the ultimate strength because it delays the initial hydration
 - b. Retarders coat the cement grains, increasing placement period, yet have relatively little impact on the ultimate strength
 - c. Retarders greatly increase the ultimate strength because of the long slow hydration
 - d. Retarders are used in cold weather to delay freezing of the concrete

Ch 3 Chemical Admixtures Answers

- 1. Which of the following statements are correct regarding chemical admixtures?
 - a. All admixtures are designed to improve only one concrete property
 - b. An admixture may be used to enhance a poor mix design and improve placement
 - c. Admixtures should be used to enhance the properties of a good mix design
 - d. Admixtures are liquid and will likely increase the w/c ratio
- 2. Which of the following describes the impact of bubble size and spacing on concrete freeze thaw protection?

a. Many small bubbles spaced relatively close to each other provides the maximum freeze thaw protection

- b. A few large bubbles spaced as close as possible will provide adequate freeze thaw protection
- c. Freeze thaw protection is not a concern in Iowa because the concrete remains frozen for an extended time
- d. Since the capillaries contain all the water, the bubble size has little impact on freeze thaw protection
- 3. Which of the following describe multiple effects of admixtures on concrete properties?
 - a. Water reducers aid in air entrainment as well as reduce water for a given slump
 - b. Retarders provide water reduction as well as retard the set
 - c. Air entrainment improves workability and improves F/T resistance

d. All of the above

- e. None of the above
- 4. Water reducers can be used in which of the following manners to achieve various effects?
 - a. Use same cement and reduce the water
 - b. Reduce cement and water the same reduce cost
 - c. Cement and water remain the same increase workability

d. All of the above

e. None of the above

- 5. Which of the following statements are correct regarding retarders?
 - a. Retarders reduce the ultimate strength because it delays the initial hydration
 - b. Retarders coat the cement grains, increasing placement period, yet have relatively little impact on the ultimate strength
 - c. Retarders greatly increase the ultimate strength because of the long slow hydration
 - d. Retarders are used in cold weather to delay freezing of the concrete

Ch. 4 Aggregate

- 1. Which of the following statements are correct concerning aggregate shape and cement content?
 - a. Flat and elongated and rough textured aggregates require more paste to reduce particle interactions
 - b. Smooth and rounded particles require more cement to keep the particles suspended in the mix
 - c. Angular fine aggregate may require more cement versus a rounded sand
 - d. a and b
 - e. a and c
- 2. What is the ideal aggregate shape and texture for workability in a concrete mix design?
 - a. Smooth and rounded have lower surface to volume ratio
 - b. Flat and elongated particles can stack better
 - c. A cubical aggregate with a rough texture
 - d. All of the above
- 3. What moisture condition should be used when developing a concrete mix?
 - a. SSD is the condition the aggregate when it is in equilibrium
 - b. Dry condition allows more water to be added
 - c. Any moisture condition is okay
 - d. Wet condition allows better slump
- 4. What graphical techniques can be used to check individual sieves for a combined aggregate gradation?
 - a. Shilstone CW and 0.45 Power curve
 - b. Shilstone CW and Percent Retained chart
 - c. 0.45 Power curve and Percent Retained chart
 - d. Shilstone CW, 0.45 Power curve, and Percent Retained chart

Sieve Size	Percent retained	Cumulative Percent Retained
6"	0	0
3"	0	0
1.5"	0	0
3/4"	0	0
3/8"	10	
#4	12	
#8	17	
#16	16	
#30	23	
#50	10	
#100	7	
Pan	5	NA
Sum		
Calculation		
FM		

5. Calculate the FM for the following gradation:

6. Calculate the Combined percent passing and Combined percent retained given the following gradations and relative percentage of aggregates.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative percent ->	0.45	0.14	0.41		
1 1 /2 //	100.0	100.0	400.0	100.0	
1 1/2 **	100.0	100.0	100.0	100.0	0.0
1″	99.0	100.0	100.0	99.6	0.5
3/499	84.0	100.0	100.0	92.8	6.8
1/2"	44.0	100.0	100.0	74.8	18.0
3/8"	15.0	100.0	100.0		
No. 4	2.4	38.0	98.0		
No. 8	1.2	5.2	84.0		
No. 16	1.1	4.3	65.0		
No. 30	1.0	3.3	43.0	18.6	9.2
No. 50	1.0	2.4	13.0	6.1	12.5
No. 100	0.9	1.4	1.3	1.13	5.0
No. 200	0.8	0.5	0.8	0.76	0.4

	Passing	Passing	Passing	Passing	Retained
Sieve Size	Coarse	Intermediate	Fine	(Combined Agg)	(Combined Agg)
1 1/2"	100	100	100	100.0	0.0
1"	100	100	100	100.0	0.0
3/4"	86	100	100	92.9	7.1
1/2"	53	100	100	76.0	16.8
3/8"	32	97	100	65.1	11.0
#4	9	27	98	46.2	18.8
#8	2.7	2.9	86	36.0	10.2
#16	2.42	2.64	68	28.7	7.4
#30	2.14	2.38	42	18.1	10.6
#50	1.86	2.12	11	5.5	12.6
#100	1.58	1.86	1	1.4	4.2
#200	1.3	1.6	0.05	0.8	0.5
Total					100

7. Calculate the coarseness and workability factors for the following gradations:

Ch. 4 Aggregate Answers

- 1. Which of the following statements are correct concerning aggregate shape and cement content?
 - a. Flat and elongated and rough textured aggregates require more paste to reduce particle interactions
 - b. Smooth and rounded particles require more cement to keep the particles suspended in the mix
 - c. Angular fine aggregate may require more cement versus a rounded sand
 - d. a and b
 - <mark>e. a and c</mark>
- 2. What is the ideal aggregate shape and texture for workability in a concrete mix design?
 - a. Smooth and rounded have lower surface to volume ratio
 - b. Flat and elongated particles can stack better
 - c. A cubical aggregate with a rough texture
 - d. All of the above
- 3. What moisture condition should be used when developing a concrete mix?
 - a. SSD is the condition the aggregate when it is in equilibrium
 - b. Dry condition allows more water to be added
 - c. Any moisture condition is okay
 - d. Wet condition allows better slump
- 4. What graphical techniques can be used to check individual sieves for a combined aggregate gradation?
 - a. Shilstone CW and 0.45 Power curve
 - b. Shilstone CW and Percent Retained chart
 - c. 0.45 Power curve and Percent Retained chart
 - d. Shilstone CW, 0.45 Power curve, and Percent Retained chart

5.	Calculate the	FM fo	r the	followina	aradation:
. .				i en en ing	gradation

Sieve Size	Percent retained	Cumulative Percent Retained
6"	0	0
3"	0	0
1.5"	0	0
3/4"	0	0
3/8"	10	10
#4	12	22
#8	17	39
#16	16	55
#30	23	78
#50	10	88
#100	7	95
Pan	5	NA
Sum	100	387
Calculation		387 / 100
FM		<u>3.87</u>

6.	Calculate the Combined percent passing and Combined percent retained
	given the following gradations and relative percentage of aggregates.

Sieve, in.	Coarse % Passing	Intermediate % Passing	Fine % Passing	Combined % Passing	Combined % Retained
Relative percent →	0.45	0.14	0.41		
1 1/2 "	100.0	100.0	100.0	100.0	0.0
1"	99.0	100.0	100.0	99.6	0.5
3/4"	84.0	100.0	100.0	92.8	6.8
1/2"	44.0	100.0	100.0	74.8	18.0
3/8"	15.0	100.0	100.0	<mark>61.8</mark>	<mark>13.0</mark>
No. 4	2.4	38.0	98.0	<mark>46.6</mark>	<mark>15.2</mark>
No. 8	1.2	5.2	84.0	<mark>35.7</mark>	<mark>10.9</mark>
No. 16	1.1	4.3	65.0	<mark>27.8</mark>	<mark>7.9</mark>
No. 30	1.0	3.3	43.0	18.6	9.2
No. 50	1.0	2.4	13.0	6.1	12.5
No. 100	0.9	1.4	1.3	1.13	5.0
No. 200	0.8	0.5	0.8	0.76	0.4

<u>% Passing</u> 3/8" 0.45 0.45x15 + 0.14x100 + 0.41x100 = 61.8#4 0.45x2.4 + 0.14x38 + 0.41x98 = 46.6#8 0.45x1.2 + 0.14x5.2 + 0.41x84 = 35.7#16 0.45X1.1 + 0.14x4.3 + 0.41x65 = 27.8

<u>% Retained</u>

3/8"	74.8-61.8=13
#4	61.8-46.6=15.2
#8	46.6-35.7=10.9
#16	35.7-27.8=7.9

	Passing	Passing	Passing	Passing	Retained
Sieve Size	Coarse	Intermediate	Fine	(Combined Agg)	(Combined Agg)
1 1/2"	100	100	100	100.0	0.0
1"	100	100	100	100.0	0.0
3/4"	86	100	100	92.9	7.1
1/2"	53	100	100	76.0	16.8
3/8"	32	97	100	65.1	L 11.0
#4	9	27	98	46.2	18.8
#8	2.7	2.9	86	<mark>36.0</mark>	10.2
#16	2.42	2.64	68	28.7	7.4
#30	2.14	2.38	42	18.1	10.6
#50	1.86	2.12	11	5.5	12.6
#100	1.58	1.86	1	1.4	4.2
#200	1.3	1.6	0.05	0.8	0.5
Total					100

7. Calculate the coarseness and workability factors for the following gradations:

WF = 36

$$CF = \underbrace{0+0+7.1+16.8+11}_{0+0+7.1+16.8+11+18.8+10.2} X \ 100 = \underbrace{34.9}_{63.9} X \ 100 = \underbrace{54.6}_{63.9}$$

Ch. 5 Basic Mix Design Concepts

- 1. Why is standard deviation of producer important in mix design?
 - a. A producer with a high standard deviation can use less cement
 - b. A producer with a low standard deviation needs to use more cement
 - c. A producer with a lower standard deviation has tighter quality control, requiring lower over design and perhaps lower cement content
 - d. Standard deviation is not a requirement for mix design
- 2. What typical unit of volume is used when selling or placing concrete? a. Tons
 - a. rons b. Pounds
 - c. Cubic foot
 - d. Cubic tool
- 3. Why is it preferable to design mixes using absolute volumes?
 - a. Because it equals on cubic yard
 - b. It is easy to determine the number of bags of cement in the mix
 - c. Because there are 27 cubic feet in a cubic yard
 - d. To achieve consistent yield by accounting for specific gravity differences
 - e. None of the above

4. _____ $ft^3 = 0.118 \text{ yd}^3$

5. 5.0
$$ft^3 = yd^3$$

- 6. What is the weight of water (lbs/yd³), if the w/c ratio is 0.40 and the cement content is 448 lbs/yd³ and fly ash content is 112 lbs/yd³?
- 7. What is the absolute volume(ft³) of cement if the SPG is 3.14 and there are 625lbs/yd³?

8. What is the W/C ratio given 500 lbs cement, 100lbs fly ash, 220 lbs of water at the plant, and 3 gallons added at the grade?

- 9. Which of the following would be considered a reasonable concrete mix design?
 - a) A mix with 10% paste and 90% aggregate
 - b) A mix with 30% paste and 70% aggregate
 - c) A mix with 75% paste and 25% aggregate
 - d) None of the above

10. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume	Absolute Volume	Weight
	(yd ³ /yd ³)	(ft³/yd³)	(lbs/yd ³)
Cement (SPG =3.14)	d)	e)	c)
Water	0.159	a)	b)
Fine Aggregate	g)	h)	1650
Coarse Aggregate	f)	9.45	1560
Total	1.000 yd ³	27.0 ft ³	i)

11. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. w/c=0.40

	Absolute Volume	Absolute Volume	Weight
Component Material	(yd ³ /yd ³)	(ft ³ /yd ³)	(lbs/yd ³)
Cement (SPG =3.14)	0.118	a)	b)
Water	d)	e)	c)
Fine Aggregate	0.335	f)	1550
Coarse Aggregate	g)	h)	1625
Total	1.000 yd^3	27.0 ft^3	i)

12. Acme Ready Mix has a standard deviation of 640 psi when producing 4000 psi compressive strength concrete. What should the target strength be for a structure to ensure they meet the minimum design compressive strength of 4000 psi?

Ch. 5 Basic Mix Design Concepts Answers

- 1. Why is standard deviation of producer important in mix design?
 - a. A producer with a high standard deviation can use less cement
 - b. A producer with a low standard deviation needs to use more cement
 - c. A producer with a lower standard deviation has tighter quality control, requiring lower over design and perhaps lower cement content
 - d. Standard deviation is not a requirement for mix design
- 2. What typical unit of volume is used when selling or placing concrete?
 - a. Tons
 - b. Pounds
 - c. Cubic foot
 - d. Cubic yard
- 3. Why is it preferable to design mixes using absolute volumes?
 - a. Because it equals on cubic yard
 - b. It is easy to determine the number of bags of cement in the mix
 - c. Because there are 27 cubic feet in a cubic yard
 - d. To achieve consistent yield by accounting for specific gravity differences
 - e. None of the above

4. _____ ft³ = 0.118 yd³

$0.118 \text{ yd}^3 X (27 \text{ ft}^3 / 1 \text{ yd}^3) = \frac{3.186 \text{ ft}^3}{3.186 \text{ ft}^3}$

5. 5.0 ft³ = ____yd³

5 $ft^3 \div 27 ft^3 = 0.185 yd^3$

6. What is the weight of water (lbs/yd³), if the w/c ratio is 0.40 and the cement content is 448 lbs/yd³ and fly ash content is 112 lbs/yd³?

wt. water (lbs/yd^3) = 0.40 X 560 = 224 lbs/yd^3

7. What is the absolute volume(ft³) of cement if the SPG is 3.14 and there are 625lbs/yd³?

AV = Wt / (SpG x UW_(water)) = 625 lbs/yd3 / (3.14 x 62.4 lbs/ft3) = 3.19 ft3/yd3

8. What is the W/C ratio given 500 lbs cement, 100lbs fly ash, 220 lbs of water at the plant, and 3 gallons added at the grade?

w/c = (220+ 3 gal X 8.33 lbs/gal) / (500 + 100) = 245 / 600 = 0.408

- 9. Which of the following mixes will be considered a reasonable concrete mix design?
 - e) A mix with 10% paste and 90% aggregate
 - f) A mix with 30% paste and 70% aggregate
 - g) A mix with 75% paste and 25% aggregate
 - h) None of the above

10. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume	Absolute Volume	Weight
	(yd ³ /yd ³)	(ft ³ /yd ³)	(lbs/yd ³)
Cement (SPG =3.14)	d)	e)	c)
Water	0.159	a)	b)
Fine Aggregate	g)	h)	1650
Coarse Aggregate	f)	9.45	1560
Total	1.000 yd ³	27.0 ft ³	i)

- a) 0.159 yd³/yd³ x 27 ft³/yd³ = 4.29 ft³/yd³
- b) $0.159 \text{ yd}^3/\text{yd}^3 \times 27 \text{ ft}^3/\text{yd}^3 \times 62.4 \text{ lbs/ft}^3 \times 1.00 = 268 \text{ lbs/yd}^3$

c)
$$w/c = 0.45$$
 0.45 = 268/c $c = 268 / 0.45 = 596 \text{ lbs/yd}^3$

- d) 596 lbs/yd³ / (27 ft³/yd³ x 62.4 lbs/ft³ x 3.14) = 0.113 yd³/yd³
- e) $0.113 \text{ yd}^3/\text{yd}^3 \text{ x } 27 \text{ ft}^3/\text{yd}^3 = 3.05 \text{ ft}^3/\text{yd}^3$
- f) 9.45 ft³/yd³ / 27 ft³/yd³ = 0.350 yd³/yd³
- g) 1.000yd³/yd³ -0.113yd³/yd³ -0.159yd³/yd³-0.350yd³/yd³ = 0.378 yd³/yd³
- h) $0.378 \text{ yd}^3/\text{yd}^3 \text{ x } 27 \text{ ft}^3/\text{yd}^3 = 10.21 \text{ ft}^3/\text{yd}^3$
- i) 596 + 268 + 1650 + 1560 = 4074 lbs/yd³

Check totals

 $0.113 + 0.159 + 0.350 + 0.378 = 1.000 \text{ yd}^3/\text{yd}^3$ $4.29 + 3.05 + 10.21 + 9.45 = 27.0 \text{ ft}^3/\text{yd}^3$ 11. Given that a concrete mix is designed on the basis of 1 yd³ (27 ft³) provide the correct answer in each box so that <u>ALL</u> of the missing information in the following table is completed. w/c = 0.40

	Absolute Volume	Absolute Volume	Weight
Component Material	(yd ³ /yd ³)	(ft ³ /yd ³)	(lbs/yd ³)
Cement (SPG =3.14)	0.118	a)	b)
Water	d)	e)	c)
Fine Aggregate	0.335	f)	1550
Coarse Aggregate	g)	h)	1625
Total	1.000 yd^3	27.0 ft^3	i)

a) 0.118 yd³/yd³ x 27 ft³/yd³ =
$$3.19$$
 ft³/yd³

- b) $0.118 \text{ yd}^3/\text{yd}^3 \text{ x } 27 \text{ ft}^3/\text{yd}^3 \text{ x } 62.4 \text{ lbs/ft}^3 \text{ x } 3.14 = 624 \text{ lbs/yd}^3$
- c) w/c = 0.40 0.40 = w/624 lbs $w = 624 \times 0.40 = 250$ lbs/yd³
- d) $250 \text{ lbs/yd}^3 / (27 \text{ ft}^3/\text{yd}^3 \text{ x } 62.4 \text{ lbs/ft}^3 \text{ x } 1.00) = 0.148 \text{ yd}^3/\text{yd}^3$
- e) $0.148 \text{ yd}^3/\text{yd}^3 \text{ X } 27 \text{ ft}^3/\text{yd}^3 = 4.00 \text{ ft}^3/\text{yd}^3$
- f) $0.335 \text{ yd}^3/\text{yd}^3 \times 27 \text{ ft}^3/\text{yd}^3 = 9.05 \text{ ft}^3/\text{yd}^3$
- g) $1.000yd^3/yd^3 0.118yd^3/yd^3 0.148 yd^3/yd^3 0.335 yd^3/yd^3 = 0.399 yd^3/yd^3$
- h) $0.399 \text{ yd}^3/\text{yd}^3 \text{ x } 27 \text{ ft}^3/\text{yd}^3 = 10.77 \text{ ft}^3/\text{yd}^3$
- i) 624 lbs/yd³ + 250 lbs/yd³ + 1550 lbs/yd³ + 1625 lbs/yd³ = 4049 lbs/yd³

Check totals

12. Acme Ready Mix has a standard deviation of 640 psi when producing 4000 psi compressive strength concrete. What should the target strength be for a structure to ensure they meet the minimum design compressive strength of 4000 psi?

f'cr = 4000 + (2.33 X 640 – 500) = <u>4991 psi</u> f'_{Cr} = 4000 + 1.34 X 640 = 4858 psi Select the largest value 4991 and round to the next highest 10 psi Target = <mark>5000 psi</mark>

Chapter 6 - Mix Design

- 1. According to ACI, what is the maximum recommended w/c ratio for concrete exposed to freezing and thawing in a moist condition or exposed to deicing chemicals?
- 2. Using the chart in ACI, estimate the approximate water content when using a 1 inch nominal aggregate size and a 3 inch slump?
- 3. Given 6% air content in a cubic yard of concrete. What is the volume of air, in cubic feet?
- 4. What are the mix design requirements for an HPC-D mix design?

Exercise 6A -QMC Mix Design

Given aggregate proportions of 47% Coarse, 10% Intermediate and 43% fine aggregate, determine the combined % passing, combined % retained. Calculate the coarseness & workability (CW) factors. Plot the %passing, %retained, and CW factors on the graphs.

	%	%	%	%	%
	Passing	Passing	Passing	Passing	Retained
Sieve Size	Coarse	Intermediate	Fine	(Combined Agg)	(Combined Agg)
1 1/2"	100.0	100.0	100.0	100.0	0.0
1"	93.0	100.0	100.0	96.4	3.6
3/4"	75.0	100.0	100.0	87.3	9.2
1/2"	38.0	100.0	100.0		
3/8"	20.0	100.0	100.0		
#4	4.0	40.0	99.0		
#8	1.5	3.1	84.0		
#16	1.4	2.5	59.0	24.5	10.1
#30	1.3	2.0	32.0	13.6	10.9
#50	1.1	1.4	10.0	4.7	8.9
#100	1.0	0.9	2.1	1.4	3.3
#200	0.9	0.3	0.6	0.7	0.7

Based on relative aggregate proportions determined above, determine the dry batch weights for a QMC mix design, using Form 820150E. Given the following:

Cement:	Continental IS(20)	Sp. G. = 3.10
Fly Ash:	Port Neal (20%)	Sp. G. = 2.66
Coarse Agg:	Ames Mine A85006	Sp. G. = 2.68
Interm. Agg:	Ames Mine A85006	Sp. G. = 2.68
Fine Agg:	Saylorville Sand A77538	Sp. G. = 2.66

Assumptions: 564 lbs cement per cubic yard, 1 inch Aggregate, and Slipformed

¹ Workability Factor VS Coarseness Factor

for Combined Aggregate



Rev 05/09		lowa Departr Offic	nent Of Transp ce Of Materials	ortation		Form E820150E
		PORTLAND	CEMENT CON	CRETE		
Project No.: _					County :	
Mix No.: _		Ab	s Vol. Cement	:	Туре:	
Cement (IM 401):		lbs	Source		Sp. Gr.:	
Fly Ash (IM 491.17):	%		Source		Sp. Gr.:	
Slag (IM 491.14): _			Source		Sp. Gr.:	
Adjus	sted lbs. Cement:]			
Тс	- otal Cementitious		Total % Re	placement =		
IM T203	Fine Aggregate	e Source:	-		Sp. Gr.:	
IM T203	Interm. Aggrega	te Source:			Sp. Gr.:	
IM T203	Coarse Agregat	te Source:			Sp. Gr.:	
Basic w/c			Water (lbs/	cv) = Design w/c (wt_cement + w	t Fly Ash +Slag) =	
Max w/c		м	ax. Water (lbs/	cy) = Design w/c (wt. cement + w	t Fly Ash +Slag) =	
Absolute Volumes	Cement .			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Ely Ach			(lbo/ou) / / Sp. Cr. X 62 4 X 27)	_	
	FIY ASIL.			(ibs/cy) / (3p. Gl. X 62.4 X 27)	-	
	Slag .			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Water .			(lbs/cy) / (1.00 X 62.4 X 27)	=	
	Air .					0.060
				Subtotal	=	
				1.000 - Subtotal	=	
				Total	=	1.000
% FA Agg.:		Fine Ag	gregate (1.000	- Subtotal) X % In Mix	=	
% In. Agg.:		Interm. A	ggregate (1.00	0 - Subtotal) X % In Mix	=	
% CA Agg.:		Coarse A	ggregate (1.00	0 - Subtotal) X % In Mix	=	
				Aggregate Total	=	
Aggregate Weights		Fine Agg	regate (abs vo	ol.) X Sp. Gr. X 62.4 X 27	=	
		Intermediate A	Aggregate (at	os vol.) X Sp. Gr. X 62.4 X 27	=	
		Coarse Ag	gregate (abs v	rol.) X Sp. Gr. X 62.4 X 27	=	
Summarv			Cemen	(lbs/cv)		
-			Fly Ash	(lbs/cy)		
			Sla	g (lbs/cy)		
			Wate	r (lbs/cy)		
			Fine Agg	(lbs/cy)		
			Interm. Agg	(lbs/cy)		
			Coarse Agg	(lbs/cy)		
Distribution: Materials, D	ME, Proj. Engr.,	Contractor				

Example 6B -QMC Mix Design

Using Form 820150E for a QMC mix design, determine the dry batch weights for the aggregates, based on relative aggregate proportions of 45% Coarse, 12% Intermediate and 43% fine aggregate. Given the following:

Cement:	Ash Grove I/II	Sp. G. = 3.14
Fly Ash:	Council Bluffs (20%)	Sp. G. = 2.62
Coarse Agg:	Moore A76004	Sp. G. = 2.62
Interm. Agg:	Emmetsburg A74502	Sp. G. = 2.71
Fine Agg:	Emmetsburg A74502	Sp. G. = 2.64

Rev 05/09		lowa Depart Offi PORTLAND	ment Of Transportation ice Of Materials O CEMENT CONCRETE		Form E820150E
Project No.: <u>N</u>	HSX-020		-	County : /	Any
Mix No.:	QMC	A	bs Vol. Cement: 0.106	Туре: _	1/11
Cement (IM 401):	560 %	lbs	Source: Ash Grove I/II	Sp. Gr.:	3.14
Fly Ash (IM 491.17):	20	112	Source: Council Bluffs	Sp. Gr.: _	2.62
Slag (IM 491.14):		0	Source:	Sp. Gr.:	
Adjus	ted lbs. Cement:	448]		
Тс	otal Cementitious	560	Total % Replacement = 20		
IM T203	Fine Aggregate	Source:	Emmetsburg	Sp. Gr.:	2.64
IM T203	Interm. Aggregat	e Source:	Emmetsburg	Sp. Gr.:	2.71
IM T203	Coarse Agregate	e Source:	Moore	Sp. Gr.:	2.62
Pasia w/a	0.400		Water (lbc/ou) = Design w/s (ut coment	hut Ely Ach +Slag) -	224
Max w/c	0.400		Max. Water (lbs/cy) = Design w/c (wt. cement -	+ wt Fly Ash +Slag) = _ + wt Fly Ash +Slag) = _	235
Absolute Volumes	Cement		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	0.085
	Fly Ash		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	0.025
	Slag		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	= _	
	Water		(Ibs/cy) / (1.00 X 62.4 X 27)	=_	0.133
	Air				0.060
			Subtotal	=	0 303
			1.000 - Subtotal	= -	0.697
			Total	=	1.000
% FA Agg.:		Fine A	ggregate (1.000 - Subtotal) X % In Mix	=	
% In. Agg.:		Interm.	Aggregate (1.000 - Subtotal) X % In Mix	=	
% CA Agg.:		Coarse	Aggregate (1.000 - Subtotal) X % In Mix	=	
			Aggregate Total	=	
Aggregate Weights		Fine Agg	regate (abs vol.) X Sp. Gr. X 62.4 X 27	= [
		Intermediate	Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	
		Coarse Aç	ggregate (abs vol.) X Sp. Gr. X 62.4 X 27	= [
Summary			Cement 448 (Ibs/cy)		
			Fly Ash 112 (lbs/cy)		
			Slag0 (lbs/cy)		
			Water 224 (lbs/cy)		
			Fine Agg (lbs/cy)		
			Interm. Agg. (Ibs/cy)		
			Coarse Agg. (IDS/Cy)		
Distribution: Materials, [DME, Proj. Engr.,	Contractor			

Chapter 6 - Mix Design Answers

 According to ACI, what is the maximum recommended w/c ratio for concrete exposed to freezing and thawing in a moist condition or exposed to deicing chemicals?
0.45 from table 4.2.2 or mix datasheet

 Using the chart in ACI, estimate the approximate water content when using a 1 inch nominal aggregate size and a 3 inch slump?
~320 lbs of water from chart

3. Given 6% air content in a cubic yard of concrete. What is the volume of air, in cubic feet?

0.06 yd³/yd³ × 27 ft³/yd³ = 1.62 ft³

4. What are the mix design requirements for an HPC-D mix design? Basic w/c ratio = 0.40, Maximum w/c ratio = 0.42. A mid-range water reducer shall be used Type IP or IS cement. Type I/II cement with a minimum of 25% replacement with GGBFS. Use fly ash with maximum fly ash replacement not to exceed 20% Maximum total replacement of 50% by weight (mass) of the cement. Maximum w/c ratio of 0.45 for substructure & 0.42 for deck

	0.51	0.09	0.40		
	%	%	%	%	%
	Passing	Passing	Passing	Passing	Retained
Sieve Size	Coarse	Intermediate	Fine	(Combined Agg)	(Combined Agg)
1 1/2"	100.0	100.0	100.0	100.0	0.0
1"	93.0	100.0	100.0	96.4	3.6
3/4"	75.0	100.0	100.0	87.3	9.2
1/2"	38.0	100.0	100.0	68.4	18.9
3/8"	20.0	100.0	100.0	59.2	9.2
#4	4.0	40.0	99.0	45.2	14.0
#8	1.5	3.1	84.0	34.6	10.6
#16	1.4	2.5	59.0	24.5	10.1
#30	1.3	2.0	32.0	13.6	10.9
#50	1.1	1.4	10.0	4.7	8.9
#100	1.0	0.9	2.1	1.4	3.3
#200	0.9	0.3	0.6	0.7	0.7

QMC Mix Design Example 6A Answer Key

WF = 34.6

$$CF = \underbrace{0 + 3.6 + 9.2 + 18.9 + 9.2}_{0 + 3.6 + 9.2 + 18.9 + 9.2 + 14 + 10.6} \times 100 = \underbrace{40.9 \times 100}_{65.5} = 62.4$$


¹ Workability Factor VS Coarseness Factor

Rev 05/09		Iowa Depart	ment Of Transportation		Form E820150E
		PORTLAND			
Project No.: <u>E</u>	xercise 6A		-	County :	Any
Mix No.:	QMC	Ał	bs Vol. Cement: 0.106	Туре:	IS(20)
Cement (IM 401):	553	lbs	Source: Continental IS(20)	Sp. Gr.:	3.10
Fly Ash (IM 491.17):	20	111	Source: Port Neal	Sp. Gr.:	2.66
Slag (IM 491.14):	[0	Source:	Sp. Gr.:	
Adjus	sted lbs. Cement:	442]		
Тс	otal Cementitious	553	Total % Replacement = 36		
IM T203	Fine Aggregate	Source:	Saylorville	Sp. Gr.:	2.66
IM T203	Interm. Aggregat	e Source:	Ames Mine	Sp. Gr.:	2.68
IM T203	Coarse Agregate	e Source:	Ames Mine	Sp. Gr.:	2.68
Basic w/c	0.400		Water (lbs/cu) = Design w/c (wt cement	± wt Fly Ash +Slan) =	221
Max w/c	0.420		Max. Water (lbs/cv) = Design w/c (wt. cement	+ wt Flv Ash +Slag) =	232
Absolute Volumes	Cement		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	=	0.085
	Fly Ash		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	=	0.025
	Slag		(Ibs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Water		(lbs/cy) / (1.00 X 62.4 X 27)	=	0.131
	Air				0.060
			Subtotal	=	0.301
			1.000 - Subtotal	=	0.699
			Total	=	1.000
% FA Agg.:	43	Fine Aç	ggregate(1.000 - Subtotal)X % In Mix	=	0.300
% In. Agg.:	10	Interm. A	Aggregate (1.000 - Subtotal) X % In Mix	=	0.070
% CA Agg.:	47	Coarse A	Aggregate(1.000 - Subtotal)X % In Mix	=	0.329
			Aggregate Total	=	0.699
Aggregate Weights		Fine Agg	regate (abs vol.) X Sp. Gr. X 62.4 X 27	=	1344
		Intermediate	Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	316
		Coarse Ag	ggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	1486
Summary			Cement 442 (lbs/cy)		
			Fly Ash <u>111</u> (lbs/cy)		
			Water 221 (lbs/cy)		
			Fine Agg. 1344 (lbs/cv)		
			Interm. Agg. 316 (lbs/cy)		
			Coarse Agg. 1486 (lbs/cy)		
Distribution: Materials. [DME, Proj. Engr	Contractor			

Example 6B -QMC Mix Design

Using Form 820150E for a QMC mix design, determine the dry batch weights for the aggregates, based on relative aggregate proportions of 45% Coarse, 12% Intermediate and 43% fine aggregate. Given the following:

Cement:	Ash Grove I/II	Sp. G. = 3.14
Fly Ash:	Council Bluffs (20%)	Sp. G. = 2.62
Coarse Agg:	Moore A76004	Sp. G. = 2.62
Interm. Agg:	Emmetsburg A74502	Sp. G. = 2.71
Fine Agg:	Emmetsburg A74502	Sp. G. = 2.64

Rev 05/09		lowa Depai Of	tment Of Transpo fice Of Materials	rtation		Form E820150E
		PORTLAN	D CEMENT CONC	RETE		
Project No.: <u>N</u>	HSX-020		_		County :	Any
Mix No.:	QMC	ļ	Abs Vol. Cement:	0.106	Type:	1/11
Cement (IM 401):	560	lbs	Source:	Ash Grove I/II	Sp. Gr.:	3.14
Fly Ash (IM 491.17):	% 20	112	Source:	Council Bluffs	Sp. Gr.:	2.62
Slag (IM 491.14):	Г	0	Source:		Sp. Gr.:	
Adjus	sted lbs. Cement:	448				
Тс	otal Cementitious_	560	Total % Re	placement = 20		
IM T203	Fine Aggregate	Source:	Emmetsburg		Sp. Gr.:	2.64
IM T203	Interm. Aggrega	te Source:	Emmetsburg		Sp. Gr.:	2.71
IM T203	Coarse Agregat	e Source:	Moore		Sp. Gr.:	2.62
Basic w/c	0.400		Water (lbs	s/cy) = Design w/c (wt. cement	+ wt Fly Ash +Slag) =	= 224
wax w/c_	0.420		wax. water (ibs	a/cy) = Design w/c (wt. cement	+ wt Fly Ash +Slag) =	- 235
Absolute Volumes	Cement			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	0.085
	Fly Ash			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	0.025
	Slag			(lbs/cy) / (Sp. Gr. X 62.4 X 27)	=	
	Water			(lbs/cy) / (1.00 X 62.4 X 27)	=	0.133
	Air					0.060
				Subtotal	=	0.303
				1.000 - Subtotal	=	0.697
				Total	=	1.000
% FA Agg.:	43	Fine A	- Aggregate (1.000	Subtotal) X % In Mix	=	0.299
% In. Agg.:	12	Interm.	Aggregate (1.000	- Subtotal) X % In Mix	=	0.084
% CA Agg.:	45	Coarse	Aggregate (1.000) - Subtotal) X % In Mix	=	0.314
				Aggregate Total	=	0.697
Aggregate Weights		Fine Ag	gregate (abs vo	l.) X Sp. Gr. X 62.4 X 27	=	1330
		Intermediate	eAggregate (abs	s vol.) X Sp. Gr. X 62.4 X 27	=	384
		Coarse A	vggregate (absvo	ol.) X Sp. Gr. X 62.4 X 27	=	1386
Summary			Cement	448 (Ibs/cy)		
			Fly Ash	112 (lbs/cy)		
			Slag	0 (lbs/cy)		
			Water	224 (lbs/cy)		
			Fine Agg.	1330 (lbs/cy)		
			Interm. Agg.	384 (lbs/cy)		
			Coarse Agg.	1386 (IDS/CY)		
Distribution: Materials I	DME ProjEngr	Contractor				

APPENDIX E QMC DS & IMs



Construction & Materials Bureau

April 16, 2024 Supersedes October 17, 2023

PORTLAND CEMENT (PC) CONCRETE PROPORTIONS

<u>GENERAL</u>

Materials for pavement concrete and structural concrete shall be mixed in any one of the following proportions for the class of concrete specified. Each mixture will have specific requirements for the coarse and fine aggregates and the type of cement. Concrete mix proportions include the unit volumes of all materials.

Mix numbers designate numerous aspects of the particular mix. The following is an explanation of the various aspects of the mix number:

- The first letter designates the class of concrete as designated in the contract documents.
- In certain mix designations, the letter V or L appears after the first hyphen. This indicates either Class V or Class L aggregate is to be used. If no letter is shown, aggregate other than Class V or Class L shall be used.
- The number indicates the relationship of coarse aggregate to fine aggregate. A mix with a 4 is a 50/50 mix. The following chart shows the number within the mix number and the proportions of the aggregates for each number:

2	is composed of 40% fine and 60% coarse
3	is composed of 45% fine and 55% coarse
4	is composed of 50% fine and 50% coarse
5	is composed of 55% fine and 45% coarse
6	is composed of 60% fine and 40% coarse
7	is composed of 65% fine and 35% coarse
8	is composed of 70% fine and 30% coarse
57	is composed of 50% fine and 50% coarse
57-6	is composed of 60% fine and 40% coarse

- The letters WR indicate water reducer is used in this mixture.
- When a C or an F is shown toward the end of the mix number, fly ash is a part of the mixture and C-fly ash or an F-fly ash, respectively, is used. The percentage of fly ash being used in the mixture shall be designated at the end of the mix number.
- When used as a mineral admixture, Ground Granulated Blast Furnace Slag (GGBFS) shall be designated through the letter "S," followed by the percent substitution, and shown at the end of the mix number. This would be in the same convention used for fly ash substitution. When GGBFS is a portion of a blended cement, the cement type will be designated as IS, but special notation will not be made in the mix number.
- The following example illustrates a mix number showing a Class C concrete mixture, 50/50 aggregate proportions, using Class L aggregate, water reducer, and 35% GGBFS substitution.

<u>Example:</u> C - L 4 W R – S35

The following example illustrates a mix number showing a Class C concrete mixture, 50/50 aggregate proportions, using water reducer and a Class C fly ash substitution at a rate of 10%.

Example: C - 4 W R - C10

The following example illustrates a mix number showing a Class C concrete mixture, 50/50 aggregate proportions, using a water reducer, Class C fly ash substitution at 20%, and GGBFS substitution at 20%.

<u>Example:</u> C – 4 W R –C20-S20

The Class D mixtures and the Class V mixtures vary somewhat from the above pattern but follow the general format.

MIX REQUIREMENTS

General requirements for the mixes are:

- Fly Ash and GGBFS used in concrete mixtures shall meet the requirements of <u>Section 4108</u>. Fly Ashes for use in concrete mixtures shall be included on the list of approved sources (Materials <u>IM 491.17</u>). GGBFS for use in concrete mixtures shall be included on the list of approved sources (Materials <u>IM 491.14</u>).
- 2. A water-reducing admixture shall be used in concrete mixtures with the designation as follows: Those mixtures have mixture numbers which have the letters "WR" following a single digit number, all following the first hyphen in the mixture number. These mixtures have reduced cementitious contents to produce concrete of approximately equal strength compared with other mixtures in a particular class of concrete. A water-reducing admixture may be added to other concrete mixtures, without cement reduction, to aid in workability and air entrainment. Other admixture combinations may be approved based on manufactures recommendations.

The water-reducing admixture shall meet the requirements of <u>Section 4103</u> and shall be included on the list of Approved Sources of Water Reducing Admixtures (<u>Materials IM 403</u>, <u>Appendix C</u>). The dosage shall be as described in <u>IM 403</u>.

- 3. The total quantity of water in the concrete, including water in the aggregate, shall not exceed the maximum water to cement and fly ash ratio.
- 4. Type I, Type II, Type III, Type IP, and Type IS Cement shall be used as provided for in the specifications. All cement shall be from an approved source as per <u>IM 401</u>. The cement type shall be documented on all reports pertaining to a project.
- 5. The fine aggregates other than Class V (<u>Section 4117</u>) and Class L (<u>Section 4111</u>) shall meet the requirements of <u>Section 4110</u> of the current specifications. The coarse aggregates for mixtures using aggregates, other than Class V aggregates, shall meet the requirements of <u>Articles 4115.01</u> through <u>4115.04</u> of the current specifications. The coarse aggregates for Class O or Class HPC-O concrete mixtures shall meet the requirements of <u>4115.05</u> of the current specifications, for overlays (<u>Article 2413</u>). Intermediate aggregates used for QMC, BR, or HPC-D mixes shall meet <u>4112</u>.
- 6. When approved by the Engineer, combined fine and coarse aggregate may be used in combination with screened coarse aggregate to produce proportions specified for Class D and

Class X concrete mixtures according to the percentage of particles passing the No. 4 sieve in the combined aggregate at the time the material is used.

- 7. With Engineer approval, proportions designated for mixtures A-V or C-V with and without fly ash may be substituted for Class X concrete.
- 8. With Engineer approval, Class M concrete may be substituted for Class A or Class C concrete.
- 9. Certain structural placements with congested steel and narrow forms may require higher slump to place the concrete. The Engineer may approve the use of a high range water reducer with standard mixes. When a high range water reducer is used, the allowable slump may be increased to a target range of 1 to 7 inches, with a maximum of 8 inches. If highly flowable concrete is needed for the placement, the Engineer may approve the use self-consolidating concrete (SCC) in accordance with <u>Appendix A</u>.

<u>A-MIX</u>

A-Mixes are specified primarily as paving mixes. They have a lower cement content and lower ultimate strength when compared to a Class C-Mix. A-Mix may be used on lower traffic roadways or detour pavement.

<u>C-MIX</u>

C-Mixes are specified for use in both paving and structures. The C-WR mixes are typically used in paving and bridge decks. Class C or C-WR mixes are typically used in box culverts, bridge piers, bridge abutments, and other miscellaneous placements. When Class C is specified, any mix beginning with the letter C may be utilized.

D-MIX

D-Mixes are specified for use primarily in structures. A typical use includes drilled shafts.

<u>M-MIX</u>

M-Mixes are designed for high early strength, suitable for many applications for which they are allowed. Calcium chloride should only be used when needed, for patching and other placements without steel reinforcement. Do not include water in calcium chloride solution when calculating water cement ratio.

<u>O-MIX</u>

O-Mixes are specified for low slump concrete, primarily for use in bridge deck overlays. The watercement ratio is intended to be controlled by the slump specified elsewhere for concrete where these mixtures are used. A water-reducing agent is required for this mix, as described in <u>IM 403</u>. O-Mixes require coarse aggregate specifically intended for repair and overlay. See <u>Article</u> <u>4115.05</u>. HPC-O is also used in bridge deck overlays. The HPC-O mix requires the use of slag or blended cements. Fly ash replacement up to a maximum of 20%. The maximum water-cement ratio is 0.42 (basic of 0.39).

<u>X-MIX</u>

X-Mixes are specified to be used as seal course concrete, primarily in cofferdams. No air entraining is required. No maximum water-cementitious ratio is specified. See <u>Article 2405.05</u> for limits on water usage.

<u>QMC</u>

Contractor-designed aggregate proportioning mixes for paving. Minimum absolute volume of cement is 0.106. Basic water-cement ratio is 0.40. Maximum water-cement ratio is 0.42.

<u>BR</u>

BR mixes are used in slip form barrier rail in accordance with <u>Section 2513</u>. Determine aggregate proportions based on production gradations. Unless major changes occur to aggregate gradations, utilize aggregate proportions determined and assess gradation of individual aggregates during concrete production. The minimum absolute volume of cement is 0.114. Maximum water-cement ratio is 0.45.

<u>HPC</u>

HPC mixes are used in bridge substructures and decks to achieve low permeability and higher compressive strength. HPC mixes require the use of slag or blended cements. Fly ash replacement up to a maximum of 20%. Maximum water-cement ratio is 0.42 (basic of 0.40) for decks and 0.45 (basic of 0.42) for substructures. Aggregate proportioning is required for HPC-D mixes with an absolute volume of cement of 0.118.

MCM

Mass Concrete Mix (MCM) mixes are used for mass concrete placements. MCM Mixes may utilize higher replacement rates of slag. Minimum absolute volume of cement is 0.106. Basic water-cement ratio is 0.40. Maximum water-cement ratio is 0.45.

<u>CLASS V</u>

Class V is an aggregate classification, specified in Section 4116 Section 4117. The fine limestone aggregates in concrete mixes using Class V aggregate with/without fly ash shall meet the requirements of Article 4117.03 4116.03 of the current specifications. Allowable cements and substitutions shall meet the requirements of Article 4117.05 4116.05. This material may be used in various concrete mixes, including HPC mixes. The mixes utilizing this material will be designated with a Roman numeral V, in the Mix Number.

<u>CLASS L</u>

Class L is an aggregate classification, specified in <u>Section 4111</u>. This material may be used in various concrete mixes, so designated. The mixes utilizing this material will be designated with a Roman Numeral L, in the Mix Number.

SUDAS CONCRETE MIXTURES

Class C-SUD and CV-SUD mixes are utilized on SUDAS projects where higher durability is desired to reduce joint deterioration due to deicing chemicals. These mixes are designed with a lower water to cement ratio of 0.42 maximum (basic w/c 0.40) to reduce permeability.

QMC and C-SUD mixes are designed for slipform paving with a very low w/c ratio. For handwork, a C-3WR or C-4WR mix is recommended.

FLY ASH & GGBFS SUBSTITUTION

At Contractor option, fly ash or GGBFS may be substituted for a portion of the cement in concrete mixes, within the limitations set forth in the appropriate Article for each type of placement. <u>IM 527</u> gives instructions on how to determine the proper batch proportions in a mix.

When fly ash or GGBFS is substituted for the cement, the replacement shall be on a pound-forpound basis. Tables 1, 2, and 3 define concrete mixes with no substitution. These mixes shall be used as the basis for determining the final batch proportions and shall be adjusted accordingly. The change in volume resulting from the substitution shall be determined and an adjustment in both coarse and fine aggregate proportions shall be determined in order to ensure a unit volume. The change in aggregate proportions shall be in the same ratio as that of the specific mix. In those cases where the cement content is increased, relative to the standard design mix, the mix proportions shall be adjusted and a change in the aggregate content shall be determined, as described above.

When both fly ash and GGBFS are substituted for the cement in ready-mixed concrete, the replacement shall be on a pound-for-pound basis and shall be substituted as shown in the following example.

Example: C-3WR-C20-S20

Absolute Volume Cement = 0.108

Cement = 0.108 X 62.4 X 27 X 3.14 = 571 lbs. per cubic yard

Fly ash substitution 20% = 571 X 0.20 = 114 lbs. per cubic yard

Slag substitution 20% = 571 X 0.20 = 114 lbs. per cubic yard

Type IP, Type IS, Type IL, and Type IT cements shall be considered cement with regard to substitution of fly ash. Refer to appropriate Article for limitations. A Type IS(25) cement with a 20% fly ash replacement is equivalent to a 40% weight replacement of Portland cement.

Example: C-3WR-C20 using Type IS(20) cement

Absolute Volume Cement = 0.108

Cement = 0.108 X 62.4 X 27 X 3.10 = 564 lbs. per cubic yard

Fly ash substitution 20% = 564 X 0.20 = 113 lbs. per cubic yard

Weight of cement = 564 - 113 = 451 lbs. per cubic yard

Type IS(20) cement contains Portland cement and slag

451 x 0.80 = 361 lbs. Portland cement 451 X 0.20 = 90 lbs. slag

Total replacement of Portland cement $((113 + 90) / 564) \times 100 = 36\%$

Example: C-3WR-C10-S20 using Type IL cement

Absolute Volume Cement = 0.108

Cement = 0.108 X 62.4 X 27 X 3.11 = 566 lbs. per cubic yard

Fly ash substitution 10% = 566 X 0.10 = 57 lbs. per cubic yard

Slag substitution 20% = 566 X 0.20 = 113 lbs. per cubic yard

Weight of cement = 566 - 57 - 113 = 396 lbs. per cubic yard

Type IL(10) cement contains Portland cement and inter-ground limestone

 $396 \times 0.90 = 356$ lbs. Portland cement $396 \times 0.10 = 40$ lbs. inter-ground limestone

Total replacement of Portland cement $((57 + 113 + 40) / 566) \times 100 = 37\%$

CARBONCURE PORTLAND CEMENT REDUCTION

Producers that are using CarbonCure or other carbon sequestration admixtures and have been approved for Portland cement reduction following the approval process in IM 403 are eligible to reduce Portland cement content by up to 3 percent. The reduction is for Portland cement only and is determined after substitutions of fly ash and GGBFS have occurred. Blended cements will be considered cement when determining Portland cement reductions. The reduced Portland cement content should be used when calculating total replacement of Portland cement.

Example: C-3WR-C20 using Type IL(10) cement and CarbonCure with a 3 percent Portland cement reduction

Absolute Volume Cement = 0.108

Cement = 0.108 X 62.4 X 27 X 3.11 = 566 lbs. per cubic yard

Fly ash substitution 20% = 566 X 0.20 = 113 lbs. per cubic yard

Weight of cement = 566 - 113 = 453 lbs. per cubic yard

3 percent Portland cement reduction = 0.03 X 453 = 14 lbs. per cubic yard

Weight of cement = 453 - 14 = 439 lbs. per cubic yard

Type IL(10) cement contains Portland cement and inter-ground limestone

 $439 \times 0.90 = 395$ lbs. Portland cement $439 \times 0.10 = 44$ lbs. inter-ground limestone

Adjusted original cement weight = 566 - 14 = 552 lbs. per cubic yard

Total replacement of Portland cement ((113 + 44) / 552) X 100 = 28%

Proportion Table 1 Concrete Mixes Using <u>Article 4110</u> and <u>4115</u> Aggregates Basic Absolute Volumes of Materials Per Unit Volume of Concrete

A MIXES	Basic w/c = 0.4	74 Max w/c	= 0.532					
Mix No.	Cement	Water	Air	Fine	Coarse			
A-2	0.101	0.150	0.060	0.276	0.413			
A-3	0.104	0.155	0.060	0.306	0.375			
A-4	0.108	0.161	0.060	0.335	0.336			
A-5	0.111	0.165	0.060	0.365	0.299			
A-6	0.115	0.171	0.060	0.392	0.262			
BR MIXE	S Basic w/c =	0.400 Max	w/c = 0.450					
Mix No.	Cement	Water	Air	Fine	Coarse			
BR	0.114	0.143	0.060	*	*			
C MIXES	Basic w/c = 0.43	30 Max w/c	= 0.488					
Mix No.	Cement	Water	Air	Fine	Coarse			
C-2	0.110	0.149	0.060	0.272	0.409			
C-3	0.114	0.154	0.060	0.302	0.370			
C-4	0.118	0.159	0.060	0.331	0.332			
C-5	0.123	0.166	0.060	0.358	0.293			
C-6	0.128	0.173	0.060	0.383	0.256			
C-WR MIXES Basic w/c = 0.430 Max w/c = 0.450								
Mix No.	Cement	Water	Air	Fine	Coarse			
C-3WR	0.108	0.146	0.060	0.309	0.377			
C-4WR	0.112	0.151	0.060	0.338	0.339			
C-5WR	0.117	0.158	0.060	0.366	0.299			
C-6WR	0.121	0.163	0.060	0.394	0.262			
D MIXES	Basic w/c = 0.42	23 Max w/c	= 0.450					
Mix No.	Cement	Water	Air	Fine	Coarse			
D-57	0.134	0.178	0.060	0.314	0.314			
D-57-6	0.134	0.178	0.060	0.377	0.251			
M MIXES	Basic w/c = 0.32	28 Max w/c	= 0.400					
Mix No.	Cement	Water	Air	Fine	Coarse			
M-3	0.149	0.153	0.060	0.287	0.351			
M-4	0.156	0.161	0.060	0.311	0.312			
M-5	0.160	0.165	0.060	0.338	0.277			
O MIXES	Basic w/c = 0.32	27 Max w/c	=					
Mix No.	Cement	Water	Air	Fine	Coarse			
O-4WR	0.156	0.160	0.060	0.312	0.312			
HPC-O MIXE	ES Basic w/c =	0.390 Max	w/c =0.420					
Mix No.	Cement	Water	Air	Fine	Coarse			
HPC-O	0.134	0.164	0.060	0.321	0.321			
HPC-S M	IXES Basic w/c =	= 0.420 Max	w/c =0.450					
Mix No.	Cement	Water	Air	Fine	Coarse			
HPC-S	0.118	0.156	0.060	0.333	0.333			

HPC-D MIXES Basic w/c = 0.400		= 0.400 Max	w/c =0.420		
Mix No.	Cement	Water	Air	Fine	Coarse
HPC-D	0.118	0.148	0.060	*	*
QMC MIX	KES Basic w/c =	: 0.400 Max	w/c =0.420		
Mix No.	Cement	Water	Air	Fine	Coarse
QMC	0.106	0.133	0.060	*	*
MCM MI	XES Basic w/c =	: 0.400 Max	w/c =0.450		
Mix No.	Cement	Water	Air	Fine	Coarse
MCM	0.106	0.133	0.060	0.315	0.386
X MIXES	Basic w/c = 0.42	23 Max w/c	=		
Mix No.	Cement	Water	Air	Fine	Coarse
X-2	0.124	0.165	0.000	0.284	0.427
X-3	0.129	0.171	0.000	0.315	0.385
X-4	0.134	0.178	0.000	0.344	0.344

Above mixtures are based on Type I or Type II cements (Sp. G. = 3.14). Mixes using blended cements (Type IP, IS, IL, or IT) must be adjusted for cement gravities listed in <u>IM 401</u>.

*These mixes require optimized aggregate proportioning in accordance with the specifications.

Proportion Table 2 Concrete Mixes Using Class V Aggregates Combined with Limestone Basic Absolute Volumes of Materials Per Unit Volume of Concrete

V47B MIXES							
Mix No.	Cement	Water	Air	Class V.	Coarse Limestone	Basic w/c	Max. w/c
A-V47B	0.107	0.148	0.060	0.479	0.206	0.440	0.560
C-V47BF ¹	0.113	0.145	0.060	0.477	0.205	0.430	0.488
C-V47BS ³	0.113	0.145	0.060	0.477	0.205	0.430	0.488
M-V47B ²	0.155	0.170	0.060	0.338	0.277	0.350	0.400
V MIXES	-			-		•	

Mix No.	Cement	Water	Air	Class V.	Fine Limestone	Basic w/c	Max. w/c		
A-V	0.135	0.188	0.060	0.586	0.031	0.444	0.467		
C-V	0.135	0.188	0.060	0.586	0.031	0.444	0.467		
M-V	0.160	0.196	0.060	0.555	0.029	0.390	0.420		
CV-HPC M	CV-HPC MIXES								

Mix No.	Cement	Water	Air	Class V.	Coarse Limestone	Basic w/c	Max. w/c
CV-HPC-D ¹	0.123	0.147	0.060	0.368	0.302	0.400	0.420
CV-HPC-S ¹	0.123	0.155	0.060	0.364	0.298	0.420	0.450

Above mixtures are based on Type I or Type II cements (Sp. G. = 3.14). Mixes using blended cements (Type IP, IS, IL, or IT) must be adjusted for cement gravities listed in IM 401.

¹When Type IP cement is used.

²M-V47B mix shall use Type I/II cements for patching projects.

³When Type IS cement is used.

Proportion Table 3 Concrete Mixes Using Class L Aggregates Basic Absolute Volumes of Materials Per Unit Volume of Concrete

A-L MIXES	Basic w/c = 0.474	Max w/c = 0.532
-----------	-------------------	-----------------

Mix No.	Cement	Water	Air	Fine	Coarse
A-L-2	0.107	0.159	0.060	0.270	0.404
A-L-3	0.111	0.165	0.060	0.299	0.365
A-L-4	0.115	0.171	0.060	0.327	0.327
A-L-5	0.118	0.176	0.060	0.355	0.291

C-L MIXES Basic w/c = 0.430 Max w/c = 0.488

Mix No.	Cement	Water	Air	Fine	Coarse
C-L-2	0.117	0.158	0.060	0.266	0.399
C-L-3	0.121	0.163	0.060	0.295	0.361
C-L-4	0.125	0.169	0.060	0.323	0.323
C-L-5	0.131	0.177	0.060	0.348	0.284

C-LWR MIXES Basic w/c = 0.430 Max w/c = 0.489

	UNCEO DUOI	0 11/0 0.400		400	
Mix No.	Cement	Water	Air	Fine	Coarse
C-L3WR	0.115	0.155	0.000	0.301	0.369
C-L4WR	0.119	0.161	0.000	0.330	0.330
C-L5WR	0.124	0.167	0.000	0.357	0.292

Above mixtures are based on Type I or Type II cements (Sp. G. = 3.14). Mixes using blended cements (Type IP, IS,IL, or IT) must be adjusted for cement gravities listed in <u>IM 401</u>.

Proportion Table 4 SUDAS Concrete Mixes

Using Article 4110 and 4115 Aggregates

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

C-SUD MIXES Basic w/c = 0.400 Max w/c = 0.420

Mix No.	Cement	Water	Air	Fine	Coarse
C-SUD	0.106	0.133	0.060	*	*

Above mixture is based on Type I or Type II cements (Sp. G. = 3.14). Mixes using blended cements (Type IP, IS, IL, or IT) must be adjusted for cement gravities listed in $\underline{IM \ 401}$. *These mixes require optimized aggregate proportioning in accordance with the specifications.

Using Class V Aggregates (<u>4116</u> <u>4147</u>) Combined with Limestone Basic Absolute Volumes of Materials Per Unit Volume of Concrete **CV-SUD MIXES** Basic w/c = 0.400 Max w/c = 0.420

Mix No.	Cement	Water	Water Air		Coarse Limestone
CV-SUD	0.114	0.135	0.060	0.379	0.311

Above mixture is based on Type IP cements.

GUIDELINES FOR APPROVING AND TESTING SCC MIX DESIGNS FOR FIELD PLACED CONCRETE

Description

- **A.** Develop and provide self-consolidating concrete (SCC) for cast in place structural concrete. SCC is defined as a concrete mix that provides the following:
 - Filling ability to flow and fill completely spaces within formwork, under its own weight.
 - Passing ability to flow through tight spaces between reinforcement without segregation or blocking.
 - Ability to resist segregation by remaining homogenous during transport and placement.
- **B.** Apply <u>Sections 2403</u>, <u>2412</u>, and Division 41 of the Standard Specifications with the following modifications.

Typically, aggregates are well graded with a maximum top size of $\frac{3}{4}$ " or less. Aggregate angularity and shape can affect the slump flow. Typical sand to aggregate ratio is 0.40 to 0.50. Paste volume can range from 28 to 40% depending on slump flow required. Water to cementitious ratio is typically in the 0.25 to 0.44 range.

If the producer has no previous experience with SCC, it is recommended that a technical representative of the admixture company be present during initial trial batches.

<u>Materials</u>

Meet the requirements of Division 41 for the appropriate materials and the following:

- Use a high range water reducer (HRWR) from Material <u>IM 403 Appendix D</u>.
- When a viscosity modifying admixture (VMA) is used, manufacturer shall provide documentation indicating compatibility with HRWR.
- Use maximum nominal aggregate size no larger than one third the minimum clear spacing between reinforcing steel
- Maximum w/c ratio of 0.45
- Minimum cementitious content shall be 700 pounds per cubic yard
- When required to maintain plasticity during a placement, use a retarding admixture or hydration stabilizer.

Mix Design

Mix designs will be approved by the District Materials Engineer (DME). New mix designs for SCC shall be verified through trial batches. Other mix designs will be qualified by previous performance. Field validation shall be required for all new mixes.

- Work with the admixture supplier representative to develop the mix design
- Slump flow in accordance with Materials <u>IM 389</u>. The target slump flow value is 23.0 inches. The allowable tolerance range of the slump flow is plus or minus 3 inches. The contractor may submit a target slump flow if placement requires different flow characteristics.

- Target Visual Stability Index (VSI) in accordance with Materials <u>IM 389</u>. The VSI Rating shall not exceed 1.0.
- Passing ability by J-Ring in accordance with ASTM C 1621. Calculate the difference between slump flow and J-Ring flow. The maximum allowable difference is 2 inches (50 mm).
- Static segregation using hardened cylinders in accordance with Material IM 390

Producer shall submit material sources, proportions, individual gradations of each aggregate, combined aggregate gradation, slump flow, visual stability index, air content, and compressive strength for the proposed mix design.

Trial Batch Validation

- 1. Allow the District Materials Engineer ample opportunity to witness the trial batching. Provide the District Materials Engineer notice and mix proportions 7 calendar days prior to this event.
- 2. Mix the trial batch with a minimum of 3 cubic yards at least 30 calendar days prior to planned placement. Establish the batching sequence of the materials during the trial batch.
- **3.** Transport the concrete a distance comparable to the distance from the ready-mix plant to the placement site.
- 4. Test concrete samples that are representative of the entire batch for air content, slump flow, visual stability index, J-Ring, density (unit weight), static segregation and temperature. Cast specimens from each sample for compressive strength tests. Modify the consolidation method of all materials test procedures, including <u>IM 315</u>, <u>IM 316</u>, <u>IM 318</u>, and <u>IM 340</u> by placing the concrete in the molds in one layer without vibration or tamping.
- **5.** Cast a minimum of eight 4 inch by 8-inch cylinders for testing. Trial batch concrete will be tested for strength and static segregation. All samples will be cast, cured, and handled according to Materials <u>IM 315</u>.
- 6. Strength samples will be stripped of their molds and wet cured until their break age. Strength samples will be tested according to AASHTO T 22. Three cylinders will be tested for strength at each age of 7 and 28 days. The District Materials Engineer may witness the strength testing. The samples for static segregation may be sent to the Central Materials Laboratory for sawing.
- 7. Submit a trial batch report to the District Materials Engineer no later than 7 calendar days after trial batching. Approval will be based on successful trial batch mixing and properties. The District Materials Engineer may waive the trial batch testing provided satisfactory mix properties have been achieved through testing of previous trial batches or production placements.

Quality Control Plan

Submit for approval a written Quality Control Plan describing the procedures to be used to control the production and placement of SCC. Submit the Quality Control Plan at least 30 calendar days before the first intended structural concrete placement. Do not place structural concrete before receiving written approval from the engineer of the Quality Control Plan and having all equipment and materials necessary to facilitate the plan on site and ready for use.

Include the following in the Quality Control Plan:

- Develop mix design that meets the design criteria for strength, flowability, passing ability, and consistency.
- Define concrete batching sequence, mixing time, and minimum revolutions to prevent cement balls and mix foaming. Include procedures for ensuring wash water is removed before batching.
- Define concrete placement pattern and methods. Include maximum horizontal flow distance from point of discharge.
- Describe additional quality control procedures at the plant to ensure consistent delivery of concrete.
- Define field procedures to accept or reject concrete during production.
- Describe procedures used when continuous placements are interrupted.
- Other information as needed.

Provide stability analysis of proposed formwork for full static pressure and proposed methods used to prevent leakage.

Placement

Deliver concrete without any interruption of flow such that a continuous placement is achieved. Deposit concrete continuously or in horizontal layers of such thickness that no new concrete will be placed on concrete that has hardened enough to cause seams or planes of weakness. Do not exceed 30 minutes between placement of successive batches unless engineer has reviewed placement conditions. If a section cannot be placed continuously, provide construction joints as specified.

If deemed necessary by the Engineer, construct a mock-up of the section to verify placement procedures.

Do not re-temper SCC.

Do not vibrate SCC without permission of the Engineer. If Engineer approves vibration, maximum insertion time is 2 seconds or less. If emergency delay occurs, concrete may be rodded with a piece of lumber or conduit if the material has lost its fluidity prior to placement of additional concrete. The DME may approve other methods of consolidation, if necessary.

Validate drop distance to demonstrate that separation does not occur.

<u>Testing</u>

Notify the Engineer 48 hours prior to placement of production concrete. Use only approved SCC mixes for production concrete. Ensure mix has the same materials, proportions, and properties established in the trial batch.

Perform air content testing in accordance with Materials <u>IM 318</u>, except place SCC in one layer, without consolidation or tapping. Cast cylinders in accordance with Materials <u>IM 315</u>, except place SCC in one layer, without consolidation or tapping.

The Engineer will perform air content testing at sampling at testing rate described in <u>IM 204</u>. The contractor will perform quality control testing of slump flow in accordance with <u>IM 389</u> at rate of 1/30 cubic yards. Slump flow range shall be ± 2 inches of the mix design target value. The visual stability index shall not exceed 1. If the slump flow exceeds the range up to a maximum of 28 inches, the concrete may be placed provided the visual stability index does not exceed 1. The producer will make adjustments to move the slump flow back into range.

The District Materials Engineer will obtain verification strength samples on a minimum of two random placements. Strength samples will be tested at the District Materials Laboratory according to AASHTO T 22. A set of five cylinders will be cast, cured, and handled according to Materials <u>I.M. 315</u>. Three cylinders will be tested for strength at 28 days. The remaining two cylinders will be checked for static segregation of hardened cylinders in accordance with Material <u>IM 390</u>.

Since SCC mixes are highly sensitive to moisture, the Producer should perform aggregate moistures at a minimum of once per day prior to mixing. The DME may adjust moisture testing depending on weather conditions and aggregate storage.



Construction & Materials Bureau

Matls. IM 530

April 18, 2023 Supersedes April 20, 2021

QUALITY MANAGEMENT & ACCEPTANCE PC CONCRETE PAVEMENT

GENERAL

This Instructional Memorandum is based on the concept of mutual benefit partnership between the Contracting Agency and the Contractor during progress of the work. Technical partnering shall be a part of this work and a formal partnership agreement may or may not be in effect.

The Contractor shall submit and comply with a Quality Control Program. The Contractor shall be responsible for the design of a Portland Cement Concrete Design Mixture (CDM) for use in pavement and shall be approved by the District Materials Engineer. The Contractor shall perform process control sampling, testing, and inspection during all phases of the concrete work at the rate specified in the contract documents, with monitor inspection by the agency personnel. Inspection of all other aspects of the concrete paving operation remains the responsibility of the Engineer.

The Contractor shall have an Iowa DOT PCC Level II Certified Technician responsible for all process control sampling and testing and execution of the Quality Control Plan as specified in the specification and this Instructional Memorandum. An Iowa DOT PCC Level I Concrete Field Testing Technician may perform the sampling and testing duties for which he or she is certified.

MIX DESIGN PROCEDURE

An lowa DOT PCC Level III Certified Technician shall perform the mix design. The Engineer shall concur with the Contractor designee.

The CDM shall be developed using the Excel spreadsheet developed by the Office of Construction and Materials. ACI 211 procedure, PCA procedure, or alternative methods may also be used. Aggregate proportions are contained on Form #955QMC (<u>IM 532, Appendix A</u>). When a CDM is developed, the absolute volume method shall be used.

The Contractor shall submit the CDM with test data, including a list of all ingredients, the source of all materials, target gradation, and the proportions, including absolute volumes.

A CDM with a satisfactory record of performance strength may be submitted in lieu of a new CDM. The concrete used for paving per this IM shall be produced with the same material sources and batched and mixed with the same equipment used to produce the concrete represented by the performance strength documentation.

QUALITY CONTROL PLAN

The Contractor shall submit a Quality Control Plan listing the type and frequency of inspection, sampling, and testing deemed necessary to measure and control the various properties of materials and construction governed by the specifications. As a minimum, the sampling and testing plan shall detail sampling location, sampling procedures, and the test frequency to be utilized. This Contractor Quality Control Plan shall be submitted to the Project Engineer prior to paving. A copy of the Quality Control Plan shall be available on the project at all times. Periodic updates may be required as necessary.

The Quality Control Plan shall include the Project Information Plan submitted for each project. The plan shall identify the personnel responsible for the contractor quality control. This should include the

company official who will act as liaison with Iowa DOT personnel, as well as the certified technician who will direct the inspection program. The certified technician shall be responsible to an upper-level company manager and not to those responsible for daily production. The Project Information Plan shall also include the mix design and mix design properties.

A. Elements of the Quality Control Plan

The plan shall address all elements that affect the quality of the concrete, including but not limited to, the following:

- 1. Stockpile management
- 2. Mixing time and transportation, including time from batching to completion of delivery and batch placement rate (batches per hour)
- 3. Placement and consolidation
- 4. The frequency of sampling and testing, coordination of activities, corrective actions to be taken, and documentation
- 5. How the duties and responsibilities are to be accomplished and documented, and whether more than one certified technician would be provided
- 6. The criteria used by the technician to correct or reject noncompliant materials, including notification procedures

B. Personnel Requirements

- 1. Perform and utilize process control tests and other quality control practices to ensure that delivered materials and proportioning meets the requirements of the mix design(s).
- 2. Periodically inspect all equipment utilized in transporting, proportioning, mixing, placing, consolidating, finishing, and curing to ensure proper operation. Monitor placement, consolidation, finishing, and curing to ensure conformance with the mix design and other contract requirements.

C. Elements of Project Information Plan

- 1. Mix design(s)
- 2. Mix design properties, as specified in the Specifications
- 3. The Contractor shall furnish name(s) and credentials of the quality control staff to the Engineer prior to the beginning of construction.
- 4. Project-related information

DOCUMENTATION

The Contractor shall maintain records of all inspections and tests. The records shall indicate the nature and number of observations made, the number and type of deficiencies found, the quantities

represented by the test, and any corrective action taken. The contractor documentation procedures will be subject to the approval of the lowa DOT prior to the start of the work and prior to regular monitoring during the progress of the work. Use standard lowa DOT forms. Batch tickets and gradation data shall be documented in accordance with lowa DOT requirements. Copies shall be submitted to the engineer as work progresses.

A control chart and running tabulation of individual test results shall be prepared for the following tests. An Excel spreadsheet is available from the Office of Construction and Materials to plot the test results. These shall be available to the Engineer at any time and submitted to the Engineer weekly:

- 1. Gradation (% passing) for each of the following sieves: 1 1/2 in., 1 in., 3/4 in., 1/2 in., 3/8 in., #4, #8, #16, #30, #50, #100, #200, and pan. Gradation test frequency is based on the running total of concrete production.
- 2. Moisture: Coarse Aggregate, Intermediate Aggregate & Sand. See IM 527
- 3. Unit Weight tested in front of the paver. Unit weight is used as a check on air content and batch changes. If the unit weight range exceeds the theoretical unit weight at the target air content, check batch proportions, scales, etc. for any problems. Unit weight test frequency is twice per day for normal production or once per week for intermittent production. No testing required for hand placements.
- 4. Plastic Air Content
- 5. Coarseness & Workability Factors
- 6. Water/cementitious Ratio

Charting will be completed within 24 hours after testing. Working range limits shall be indicated on the control charts.

The Contractor shall notify the Engineer whenever the process approaches a specification limit and shall take action, which results in the test results moving toward the specification target, away from the limit.

All charts and records documenting the contractor quality control inspections and tests shall become property of the Iowa DOT upon completion of the work.

The PCC Level II Technician shall document the changes to the mix design, allowed by the specification, on the Iowa DOT QM-C Mix Adjustment form (<u>IM 530, Appendix A</u>). The PCC Level III Technician shall concur with the changes and shall periodically review mix changes effect on workability and placement in the field.

FIELD VERIFICATION TESTING

For continuous construction operation, a lot will be defined as a week of paving. Lots less than three days of paving will be grouped with the previous week. If less than 500 cu. yd. are produced in one day that day's production, group with the following day's production.

Intermittent construction operation involving quantities less than 500 cubic yards per day, shall be grouped to establish a lot, not to exceed one week.

The Engineer will perform verification testing at the following minimum test frequencies:

MINIMUM TEST FREQUENCIES

	Verification	
Unit Weight Plastic Concrete	None	<u>IM 340</u>
Gradation	Sample 1/day if production >500 yd3	
(Individual aggr., % passing)	Test 1st/day, then twice per week	<u>IM 302</u>
Flexural Strength, Third	1/10,000 cu. yd.	
Point Loading - 28 days *	Maximum of three sets	<u>IM 328</u>
Air Content		
Unconsolidated Concrete	1/700 cu. yd.	<u>IM 318</u>
Water/Cement Ratio	None	<u>IM 527</u>
Vibration Frequency	1/week	<u>IM 384</u>

*One set of two beams at the above rate shall be cast for pavement design purposes. The beams shall be delivered to the Central Laboratory in Ames for testing. Transported beams shall be stripped and wrapped in wet burlap and plastic to ensure adequate curing during delivery. Include information on project number, contractor, date cast and air content with delivery. Date of testing will be increased to 90 days when quartzite coarse aggregate is used.

CONTROL & ACCEPTANCE PROCESS OF PLASTIC AIR TESTING

On the first air test of each day, the Contractor and Agency shall run side by side tests to ensure both air meters are within the tolerance in $\underline{IM \ 216}$. If the air tests are outside the tolerance, both air meters should be calibrated in accordance with $\underline{IM \ 318}$ to resolve the difference.

Thereafter, the Engineer will randomly test the plastic air content at the minimum frequency in the table above. The Contractor may elect to run side by side comparison at the same time as the Engineer to ensure both meters are operating properly. When a verification test result is outside the tolerance for the target air content, the Contractor will be immediately notified.

The unconsolidated air content limits will be established according to <u>Article 2301.04C</u> using Contractor test results. The Contractor shall notify the Engineer whenever an individual quality control test result is outside the tolerance for the target air content. Lot acceptance shall be based on the agency verification test results on the unconsolidated mix on the grade.

VALIDATING COARSENESS & WORKABILITY FACTOR

On the first day of paving, the Engineer will direct and witness sampling and splitting of one sample of each aggregate. The split sample shall meet the requirements of $\underline{IM \ 216}$. If correlation is not established, the District Materials Engineer will resolve the differences.

Thereafter, the Engineer will direct and witness sampling of one random independent sample per day, for normal production. The agency will take immediate possession of the samples.

The Engineer will randomly test a minimum of two samples per lot. The samples will be tested in a timely manner and the results will be given to the Contractor within a week after results are obtained. The Engineer will determine aggregate percentages based on the batch weights at the time the sample was obtained, compute the average coarseness and workability factors in accordance with IM 532 for the combined samples tested, and average the results. Report each weekly lot for aggregate coarseness/workability factor validations on the verification gradation report (821283 COMPUTER). (See IM 530, Appendix B).Enter the contractor average coarseness/workability factors for the lot. If the average results obtained by the Engineer fall within the same zone as the Contractor, the results are validated for the lot.

If the average results obtained by the agency are not in the same zone as the Contractor, the Engineer will test the remaining samples representing the lot and average all results for the lot. The average results obtained by the agency shall govern as validation for the lot.

CORRECTIVE ACTION

The Contractor shall take prompt action to correct conditions that have resulted, or could result, in the incorporation of noncompliant materials.

NONCOMPLIANT MATERIALS

The Contractor shall establish and maintain an effective and positive system for controlling noncompliant material, including procedures for its identification, isolation and disposition. Reclaiming or reworking of noncompliant materials shall be in accordance with procedures acceptable to the Iowa DOT.

All noncompliant materials and products shall be positively identified to prevent use, shipment, and intermingling with conforming materials and products.

AVOIDANCE OF DISPUTES

Every effort should be made by Contractor and Engineer personnel to avoid any potential conflicts in the Quality Assurance Program prior to and during the project by using partnering concepts. Potential conflicts should be resolved at the lowest possible levels between the Contractor and Engineer personnel. Correction of problems and performance of the final product should be the primary objective of this resolution process.

******THIS IS A NEW APPENDIX.** – **PLEASE READ CAREFULLY.****** IOWA DOT QM-C MIX ADJUSTMENT FORM

Project Number:

Contractor:

Date of Mix Adjustment (m/d/yy):

Station of Mix Adjustment:

Number of Mix Changes to Date:

Old Mix ID:

New Mix ID:

Mix Adjustment 1: Reason:

Mix Adjustment 2: Reason:

Mix Adjustment 3: Reason:

	Old Mix Proport	ions	New Mix Proportions		
	Source	SSD Weight	Source	SSD Weight	
		or Dosage		or Dosage	
Cement					
Fly Ash					
Water					
Coarse					
Aggregate					
Intermediate					
Aggregate					
Fine Aggregate					
Air Entraining					
Agent					
Water Reducer					
Retarder					

PCC II Technician

Cert No. _____

Copies To: District Materials Engineer Resident Construction Engineer



Matls. IM 531

Supersedes April 16, 2013

TEST METHOD FOR COMBINING AGGREGATE GRADATIONS

When the aggregate gradations for a PCC mixture are sampled and tested individually, the results must be mathematically combined to create a theoretical combined gradation. This combined gradation is based on their relative percent volume in the mixture.

Each individual aggregate gradation shall start with the largest appropriate sieve for that material and shall include all the consecutive smaller sieve sizes through the #200 sieve. They shall include: 1/2-in., 1/a., 3/4-in., 1/2-in., 3/8-in., #4, #8, #16, #30, #50, #100, and #200 sieves. For coarse and intermediate aggregates, the #16 through #100 sieves may be determined mathematically.

The following methods outline the procedures to be used to determine the combined gradation. Method A is generally used for most aggregate combinations. Method B should be used when the specific gravity of the individual aggregates differ by more than 0.25.

<u>METHOD A</u>

October 20, 2015

Multiply relative percentage by the percent passing and sum all aggregates for each sieve size.

Р	=	Aa + Bb + Cc
Р	=	Combined percent passing of a given sieve
A,B,C	=	Percent passing given sieve for aggregate A, B, and C
a,b,c	=	Relative percent of total aggregates A, B, and C

Convert combined percent passing to combined percent retained by subtracting the combined percent passing on the top sieve from 100 and the combined percent passing from each subsequent sieve, thereafter.

				Theoretical	Theoretical
				Combined	Combined
	Coarse	Intermediate	Fine	Gradation	Gradation
Sieve	Aggregate	Aggregate	Aggregate	% Passing	% Retained
Relative Percent→	0.472	0.118	0.410		
1 1/2 inch	100	100	100	100	0.0
1 inch	83	100	100	92	8.0
3/4 inch	65	100	100	83.4	8.5
1/2 inch	35	100	100	69.3	14.2
3/8 inch	14	100	100	59.4	9.9
No. 4	2.1	33	96	44.2	15.2
No. 8	0.9	2.8	82	34.4	9.8
No. 16	0.8	2.3	63	26.5	7.9
No. 30	0.7	1.8	37	15.7	10.8
No. 50	0.5	1.2	9.4	4.3	11.4
No. 100	0.4	0.7	1	0.7	3.6
No. 200	0.3	0.1	0.4	0.3	0.4

METHOD B

STEP 1:

The percent volume of each of the aggregates is determined from the volume proportions of the mixture design. The relative proportion of each aggregate of the total aggregate is determined by dividing the individual aggregate portion in the mix by the total aggregate portion in the mix.

Example:

A mixture design has the following mix proportions by volume:

Cement	0.110
Water	0.150
Air Entraining	0.070
Fine Aggregate (PCC Sand)	0.270
¹ / ₂ inch Intermediate Aggregate (Limestone Chip)	0.100
1 ¹ / ₂ inch Coarse Aggregate (Limestone PCC Stone)	0.300
Total	1.000

The total aggregate portion is: 0.270 + 0.100 + 0.300 = 0.670

The relative percent retained portion for each aggregate by volume is determined as follows:

Fine Aggregate (0.270/0.670) = 0.403 Intermediate Aggregate (0.100/0.670) = 0.149 Coarse Aggregate (0.300/0.670) = 0.448

Check the total aggregate relative portions. They should equal 1.000.

0.403 + 0.149 + 0.448 = 1.000 (OK)

STEP 2:

These volume proportions are then adjusted by the specific gravity of the aggregates, since gradations are based on percent weight retained on each sieve. The proportion retained by weight is determined by multiplying each aggregate's volume proportion by its specific gravity. These weights are then summed to obtain a total weight. The proportion by weight is then determined by dividing each aggregate's weight by the total weight.

Example:

	Proportion	Specific		Proportion
Aggregate	Volume	Gravity	Weight	By Weight
Fine	0.403	2.67	1.07601	(1.07601/2.64912)= 0.406
Intermediate	0.149	2.59	0.38591	(0.38591/2.64912 = 0.146
Coarse	0.448	2.65	1.18720	(1.18720/2.64912)= 0.448
Total	1.000		2.64912	1.000

STEP 3:

Determine the theoretical combined gradation from the individual gradations. This is done by multiplying the percent retained on each sieve for the individual gradations by the relative portion of the aggregate volumes. Then total the percent retained of each product for each sieve size. This is the theoretical combined percent retained for each sieve. The total of these percents retained should equal 100.0. If the total is off due to rounding, prorate the rounding error.

Example:

Coarse Aggregate

		Relative	Adjusted
Sieve	% Retained	Volume	% Retained
1 1/2 inch	0.0	0.448	0.0
1 inch	1.4	0.448	0.6
3/4 inch	23.7	0.448	10.6
1/2 inch	31.0	0.448	13.9
3/8 inch	24.5	0.448	11.0
No. 4	14.1	0.448	6.3
No. 16	0.7	0.448	0.3
No. 30	0.8	0.448	0.4
No. 100	0.4	0.448	0.2
No. 200	0.2	0.448	0.1
Minus 200	0.8	0.448	0.4

Similar calculations are done for the intermediate and fine aggregates.

STEP 4:

The individual adjusted gradations are summed to get the theoretical combined gradation, percent retained. The theoretical combined gradation, percent passing, may be calculated by subtracting subsequent sieves beginning with 100, as per IM 302. The following table shows the calculations:

				Theoretical	Theoretical
				Combined	Combined
	Coarse	Intermediate	Fine	Gradation	Gradation
Sieve	Aggregate	Aggregate	Aggregate	% Retained	% Passing
1 1/2 inch	0.0			0.0	100
1 inch	0.6			0.6	99.4
3/4 inch	10.6	0.0		10.6	88.8
1/2 inch	13.9	3.2		17.1	71.7
3/8 inch	11.0	5.4	0.0	16.4	55.3
No. 4	6.3	4.9	2.0	13.2	42.1
No. 8	0.9	0.4	4.1	5.4	36.7
No. 16	0.3	0.3	5.6	6.2	30.5
No. 30	0.4	0.1	12.9	13.4	17.1
No. 50	0.1	0.2	12.0	12.3	4.8
No. 100	0.2	0.1	3.1	3.4	1.4
No. 200	0.1	0.1	0.2	0.4	1.0
Minus 200	0.4	0.2	0.4	1.0	0.0

The theoretical combined gradations are used in graphically displaying aggregate blends of PCC mixture designs and for plotting control charts to compare target gradation with working ranges of the mixture design.



Construction & Materials Bureau

Matls. IM 532

October 19, 2021 Supersedes October 20, 2020

AGGREGATE PROPORTIONING GUIDE FOR PC CONCRETE PAVEMENT

GENERAL

This Instructional Memorandum covers procedures for developing a well-graded aggregate combination for use in Portland Cement Concrete paving. It is the responsibility of the mix designer to design a mix with appropriate properties for the intended application and placement method. The mixture should be economical, meet workability and finishing requirements, and allow for a proper air void system at a minimum water/cementitious ratio. Regardless of how the mix performs in controlled conditions, ultimately it must be evaluated on how well it performs during production and placement in the field.

Concrete mixtures produced with a well-graded aggregate combination tend to reduce the need for water, provide and maintain adequate workability, require minimal finishing, and consolidate without segregation. These characteristics tend to enhance placement properties as well as strength and long-term performance. Concrete mixtures produced with a gap graded aggregate combination tend to segregate easily, contain higher amounts of fines, require more water, and increase susceptibility to shrinkage. These characteristics tend to limit placement properties as well as strength and long term performance.

Achieving a uniform gradation may require the use of three or more different aggregate sizes. It is the responsibility of the mix designer to consider particle shape when designing a mix. When using the coarseness/workability chart it is assumed that particles are rounded or cubical shaped. Rounded or cubical shaped aggregates typically enhance workability and finishing characteristics. Flat and elongated aggregates typically limit workability and finishing characteristics.

COARSENESS/WORKABILITY CHART¹

The mathematically combined gradation, expressed as percent retained, shall be calculated in accordance with IM 531. The coarseness and workability factors shall be calculated and then plotted in a coarseness/workability chart as shown in Figure 1.

 $Coarseness Factor = \frac{[combined \% retained above 3/8 in. sieve]}{[combined \% retained above No. 8 seive]} \times 100$

Workability Factor = Combined % Passing No. 8 Sieve*

*The workability factor shall be increased by 2.5% for each increase of 94 pounds of cement over 564 pounds per cubic yard.

¹ Shilstone, J. Sr., "Concrete Mixture Optimization", Concrete International, June 1990

Zone II is considered well graded for $\frac{3}{4}$ " to 1 $\frac{1}{2}$ " aggregate top size. For slipform paving, Shilstone recommends a target of 60 Coarseness Factor and 35 Workability Factor. For a nominal maximum aggregate size of 1 in. to 1 1/2 in., Shilstone recommends a Workability Factor of 34 to 38 when the Coarseness Factor is 52 and a Workability Factor of 32 to 36 when the Coarseness Factor is 68.

Aggregate blends that plot close to the bottom boundary line may tend to have too much coarse aggregate. Aggregate blends with a point below the bottom boundary line (Zone V) will produce rocky mixtures with inadequate mortar and shall not be allowed.

Aggregate blends above the top boundary line (Zone IV) will produce sandy mixtures with high amounts of fines requiring higher water contents and potential for segregation.

Aggregate blends with coarseness factors higher than 75 (Zone I) will produce gap graded mixtures with inadequate workability and high potential for segregation.

Aggregate blends with a point in Zone III, respectively, corresponds with Zone II for aggregate sizes less than 1/2 in.

0.45 POWER CURVE

The 0.45 power curve is based on the mathematically combined percent passing gradation determined in accordance with <u>IM 531</u>. Historically, the 0.45 power curve has been used to develop uniform gradations for asphalt mix designs; however, it is increasingly being used to develop uniform gradations for Portland Cement Concrete mix designs.

To create a 0.45 power curve plot the mathematically combined percent passing for each sieve on a chart having percent passing on the y-axis and sieve sizes raised to the 0.45 power on the x-axis. Sieve sizes shall include the Connect the plotted points as shown in Figure 2. Plot the maximum density line from the origin of the chart to the sieve one size larger than the first sieve to have 90 percent or less passing.

A well-graded aggregate combination will follow the maximum density line to the No. 16 sieve. A slight deviation below the maximum density line at the No. 16 sieve will occur to account for the effect of the fines provided by the cementitious materials (Figure 2). A gap graded aggregate combination will produce an "S- shaped" curve deviating above and below the maximum density line (Figure 3).

PERCENT-RETAINED CHART

The percent-retained chart is based on the mathematically combined percent-retained gradation for each sieve in accordance with <u>IM 531</u>. The percent-retained chart has evolved from efforts to limit disproportionate amounts of material retained on any one sieve. Typical limits are no more than 18% retained on the 1 in. to the #100 sieve and no less than 8% retained on the 1/2 in. to the #30 sieve.

To create a percent-retained chart plot the mathematically combined percent retained for each sieve on a chart having percent retained on the y-axis and sieve sizes on the x-axis. Sieve sizes shall include the 1 1/2 in., 1 in., 3/4 in., 1/2 in., 3/8 in., No. 4, No. 8, No 16, No. 30, No 50, No. 100, and the No. 200. Connect the points and plot the boundary lines as shown in Figure 4.

A well-graded aggregate combination will have no significant peaks and/or dips (Figure 4). A gap graded aggregate combination will have significant peaks and dips (Figure 5). Shilstone recommends that the sum of percent retained on two consecutive sieves should be at least 13% to be an optimum gradation.

TARANTULA CURVE

The Tarantula curve is a modified percent retained curve developed by Tyler Ley² Oklahoma State University. The percent retained band limits are shown in the table below.

	1 ½ in.	1 in.	¾ in.	½ in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
Max.		0	0	4	4	4	0	0	4	4	0	2
Min.	0	16	20	20	20	20	12	12	20	20	10	0

Other required parameters include the following:

- The sum of percent retained on the #8 through #30 sieve shall retain at least 15% for mix cohesion.
- The sum of percent retained on the #30 through #200 sieve shall retain at between 24% and 34% to retain mix workability.
- Limit flat or elongated particles to 15% or less at a ratio of 1:3.

A well graded combination will fall within the limits as shown in Figure 6.

AGGREGATE SHAPE EFFECT ON OPTIMUM GRADATION

The shape and texture of aggregate particles affect the volume of paste needed to coat particles and decrease interactions during placement. The ideal aggregate shape for workability is smooth and round. Smooth and round particles, such as gravels, have a low surface to volume ratio and require less paste to coat the surfaces of each particle. Crushed limestone aggregates, which usually tend to be more angular and rough than gravel aggregates, have a higher surface to volume ratio, and may require more paste to reduce particle interactions. These rules are generalized and the mix designer must determine the actual optimum gradation, considering particle shape, with placing and finishing characteristics as the ultimate assessment of workability.

OPTIMUM AGGREGATE BLEND

Determining an optimum combined aggregate blend will require the use of all 3 graphical representations as well as sound practical experience. The coarseness/workability chart should be the primary method used to develop an aggregate combination that will produce a mixture with appropriate properties for the intended application and placement method. The 0.45 power curve and the percent-retained chart should be used as secondary means to verify the coarseness/workability chart results and to identify areas deviating from a well-graded aggregate combination. Aggregate blend for QMC mixes may be found on Form #955QMC (Appendix A).

Depending on aggregate top size, shape, and texture, typical optimum aggregate combinations tend to fall within the range of 44-48% coarse, 10-15% intermediate, and 38-42% fine aggregate.

² Cook D, Seader N, Ley T, Russell B. *Investigation of Optimized Graded Concrete for Oklahoma- Phase* 2. FHWA-OK-15-07. Oklahoma City, OK: Oklahoma Department of Transportation; 2015

The following may be used as a guide to determine aggregate combinations for optimum placement characteristics. For QMC paving, use aggregate combinations in the gray box of Zone II.



For BR and HPC-D mixes, use aggregate combinations in the hatched box Zone II.



FIGURE 1

¹ Workability Factor VS Coarseness Factor for Combined Aggregate

Assumptions: 564 lbs cement per cubic yard, 1 inch Aggregate, and Slipformed



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9

1 1/2

-

3/4

1/2

3/8 Sieve Size

4

°∰ ∰

#16

#200 #100 #50 #30



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FIGURE 5

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FIGURE 6

9

Form 955QMC		Iowa I High Proportio	Department of way Division-Offi on & Production Li	Transportation ice of Materials mits For Aggregates			
County :		Projec	t No.:		Date:		
Project Location:				Ν	lix Design No.:		
Contractor:			Producer:		Location:		
Material	Ident # % in Mi	A#		Producer & Location		Class	Beds
	0.0%	0	0				
	0.0%	0	0				
Conc. Sand	0.0%	0	0				

		In	dividual.	Aggregat	es Sieve A	Analysis -	- % Passi	ng (Targ	et)			
Material	1 1/2 "	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
0	0	0	0	0	0	0	0					0
	0	0	0	0	0	0	0					0
Conc. Sand	100	100	100	0	0	0	0	0	0	0	0	0
			-	3								

Preliminary Target Gradation

* Upper Tolerance	5	5	5	5	5	5	4	4.0	4.0	3.0	2.0	
Comb Grading	0	0	0	0	0	0	0	0	0	0	0	0
* Lower Tolerance	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0

Comments:

The above individual target gradations are based on an average of normal productions and have been discussed and reviewed with an authorized representative of the aggregate producer. Producer acknowledges these results are representative of typical production gradations.

		Check	k(X)		
Signed:		Coarse	Signed:		
	Producer	Interm.	191825.5	Contractor	
		Interm.			
Signed:		Fine	Signed:		
	Producer			Contractor	

DS-23027 (New)



DEVELOPMENTAL SPECIFICATIONS FOR QUALITY MANAGEMENT CONCRETE (QM-C)

Effective Date October 17, 2023

THE STANDARD SPECIFICATIONS, SERIES 2023, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

23027.01 DESCRIPTION.

- **A.** This specification identifies a concrete mixture design with an optimum combined aggregate gradation, and the Contractor's testing and quality control responsibilities. Optimization of the aggregates should produce concrete with low water requirement as well as improved workability and finishing characteristics. While concrete strength is important and is measured, it is not the basis for optimization of the concrete mixture design.
- **B.** Testing and quality control apply to all Contractor produced concrete using the Concrete Design Mixture (CDM). The CDM applies to mainline slip form pavement. At the Contractor's option, the CDM may apply to any other slip form paving.

23027.02 MATERIALS.

For all materials, meet the quality requirements for the respective items in Division 41 of the Standard Specifications. Compatibility of all material combinations is the Contractor's responsibility based on acquired field experience with proposed materials.

23027.03 CONCRETE DESIGN MIXTURE.

A. An Iowa DOT PCC Level III Certified Technician is responsible for the development of the CDM. Develop a CDM based on a unit volume of 1.000 according to industry standard practice, and containing proportions of materials, including admixtures. Base the proportions upon saturated surface dry aggregates to produce a workable concrete mixture meeting the constraints of Table DS-23027.03-1:

Nominal Maximum Coarse Aggregate Size	Greater than or equal to 1 inch
Gradation	Materials I.M. 532
Cementitious Content	Minimum, 560 pounds per cubic yard*
Fly Ash Substitution Rate	See Article 2301.02, B, 6
Water/Cementitious Ratio	Maximum, 0.42
Air Content	6% ± 1%, Design Absolute Volume = 0.060
28 Day Flexural Strength, Third Point	Minimum, 640 pounds per square inch

Table DS-23027.03-1: Concrete Mixture Constraints

The minimum cement content assumes the use of Type I/II cement with a specific gravity of 3.14 for an absolute volume of 0.106. If cement other than Type I/II is used, use an absolute volume of 0.106 and determine the weight of cement from the specific gravity of the cement. Cement content may need to be increased to maintain the water to cementitious ratio during hot weather conditions.

- B. Develop a target combined gradation in Zone II for each CDM based on normal production gradations and the relative percentages of each individual aggregate. Submit Form 955QMC to aggregate producer(s) to ensure individual gradations used are acceptable. Limit the percent passing the No. 200 sieve to no more than 1.5% for the combined aggregate gradation. When the coarse aggregate used meets the increase in percent passing the No. 200 sieve, according to <u>Section 4109</u>, Aggregate Gradation Table, Note 10 of the Standard Specifications, limit the percent passing the No. 200 sieve to no more than 2.0% for the combined aggregate gradation.
- **C.** Contractor may use water reducing admixture, Type A, or water reducing and retarding admixture, Type D, in the CDM.

23027.04 MIX DESIGN DOCUMENTATION.

At least 7 calendar days prior to the start of paving, submit a CDM report to the District Materials Engineer for approval on Iowa DOT form. Contract extensions will not be allowed due to inadequate or additional CDMs.

23027.05 QUALITY CONTROL.

A. General.

- The Contractor is responsible for quality control of the concrete. An Iowa DOT PCC Level II Certified Technician is required to oversee quality control operations. The individual conducting the testing on grade is required to be an Iowa DOT PCC Level I Certified Technician. Calibrate and correlate testing equipment prior to and during paving operations.
- 2. At least 7 calendar days prior to the preconstruction conference, submit to the Engineer a Quality Control Plan complying with <u>Materials I.M. 530</u>. Include the proposed mix design(s) with the Quality Control Plan. Do not begin paving until the plan is reviewed for compliance with the contract documents. Maintain equipment and qualified personnel to direct and perform all field quality control sampling and testing necessary to:
 - Determine the various properties of the concrete governed by the contract documents, and
 - Maintain the properties described in this specification.

B. Quality Control Testing.

1. Perform all quality control tests necessary to control the production and construction processes applicable to this specification and as set forth in the Quality Control Plan. Take samples for quality control testing in a random manner according to the prescribed sampling rate. Perform the tests listed in Table DS-23027.05-1:

	Limits	Testing Frequency	Test Methods				
Unit Weight (Mass) of Plastic Concrete	Monitor for changes, ± 3%	Twice/day	AASHTO T 121				
Gradation Combined % Passing	See Paragraph 2 below	1/1500 cubic yard	<u>Materials I.M. 216,</u> <u>301, 302, 531</u>				
Aggregate Moisture Contents	See Materials I.M. 527	1/1500 cubic yard	Materials I.M. 308				
Air Content Plastic Concrete In Front of Paver	See <u>Article</u> 2301.02, B, 4	1/350 cubic yard 1/100 cubic yard (ready mix)	Materials I.M. 318				

Table DS-23027.05-1: Quality Control Table

Air Content Plastic Concrete In Back of Paver	May be used by Project Engineer to adjust target air in front of paver	2/day for first 3 days and 1/week thereafter (for each paver used)	Materials I.M. 318
Water/Cementitious Ratio	0.42 maximum	Twice/day	Materials I.M. 527
Vibrator Frequency	See Article <u>2301.03, A, 3, a, 6, a</u>	With Electronic Vibration Monitoring: Twice/day Without Electronic Vibration Monitoring: Twice/Vibrator/Day	Materials I.M. 384

2. Maintain the running average of three combined aggregate gradation tests within the limits established by the CDM target gradation and the working ranges of Table DS-23027.05-2:

Sieve Size	Working Range						
No. 4 or greater	± 5%						
No. 8 to No. 30	± 4%						
No. 50	± 3%						
No. 100	± 2%						
minus No. 200	See Article DS-23027.03						

Table DS-23027.05-2: CDM Target Gradations

C. Corrective Action.

For QM-C mixes only, plot all process control test results on control charts as described in <u>Materials I.M. 530</u>.

1. Aggregate Tests.

Take corrective action when the running average approaches the working range limits. When a combined gradation test result for a sieve exceeds the working range limits, adjust the target and notify the Engineer. If the verification test result for the minus No. 200 exceeds the limits in Article DS-23027.03 for the combined gradation, the material represented by that test for this sieve will be considered non-complying. Price adjustments will be assessed based on Coarseness/Workability Factors as described in Article DS-23027.07, E.

2. Concrete Tests.

Take corrective action when an individual test result approaches the control limits. Notify the Engineer whenever an individual test result exceeds the control limits.

D. Acceptable Field Adjustments.

- All mix changes must be mutually agreed upon between the Contractor and Engineer. Document all mix changes on the QM-C Mix Adjustment form. Determine batch weights using a basic water cement ratio of 0.40. When the water cement ratio varies more than ±0.03 from the basic water cement ratio, adjust the mix design to unit volume of 1.000. A change in the source of materials or an addition of admixtures or additives requires a new CDM. The following are small adjustments that may be made without a new CDM being required:
 - Increase cementitious content.
 - Decrease fly ash substitution rate.
 - Aggregate proportions may be adjusted from CDM proportions by a maximum of ± 4% for each aggregate.
 - Change water reducer to water reducer retarder.
 - Adjustment in water reducer or water reducer retarder admixture dosage.
 - Change in source of fly ash.
 - Change in source of sand, provided target gradation limits are met.

- 2. When circumstances arise, such as a cement plant breakdown, that create cement supply problems, a change in cement source may be allowed with the Engineer's approval. Consult the District Materials Engineer for approval of other changes to the mix design. A set of three beams for 28 day flexural strength testing may be required to document the changes.
- 3. Should conditions beyond the Contractor's control prevent completion of the work with the CDM, a Class C mix, or a mix based on Class C mix proportions using project materials, will be allowed, at no additional cost to the Contracting Authority. Mutual agreement between the Contractor and Engineer is required. When Class C mix, or mix based on Class C mix proportions using project materials is allowed it will not be considered in the coarseness and workability lot evaluation.

E. Hand Finished Pavement.

Use project materials based on Class C or Class M concrete mix proportions. With approval of the Engineer, the Contractor's CDM may be used for hand finished pavement. Quality control, as required in this specification, will not apply to hand finished pavement.

23027.06 METHOD OF MEASUREMENT.

Measurement will be as follows:

- A. Standard or Slip-Form Portland Cement Concrete Pavement, QM-C. Square yards shown in the contract documents.
- B. Portland Cement Concrete Overlay, QM-C, Furnish Only. <u>Article 2310.04, A</u>, of the Standard Specifications applies.
- C. Portland Cement Concrete Overlay, QM-C, Placement Only. <u>Article 2310.04, B</u>, of the Standard Specifications applies.

D. Hand Finished Pavement.

Square yards of Standard or Slip-Form Portland Cement Concrete Pavement, QM-C, constructed using Class C or Class M mixtures. For overlays, the Engineer will compute the number of:

- Square yards of Portland Cement Concrete Overlay, QM-C, Placement Only, constructed using Class C or Class M mixtures, and
- Cubic yards of Class C and Class M mixtures used.

23027.07 BASIS OF PAYMENT.

The cost for furnishing labor, equipment, and materials for the work required by the Contractor to design, test, and provide process control for production of QM-C shall be included in the contract unit price for QM-C bid items. Payment will be the contract unit prices as follows:

A. Standard or Slip Form Portland Cement Concrete Pavement, QM-C.

Contract unit price for Standard or Slip-Form Portland Cement Concrete Pavement, QM-C, per square yard.

B. Portland Cement Concrete Overlay, QM-C, Furnish Only.

<u>Article 2310.05, A</u>, of the Standard Specifications applies. Average coarseness and workability factor for each lot will be determined according to <u>Materials I.M. 530</u>.

C. Portland Cement Concrete Overlay, QM-C, Placement Only.

<u>Article 2310.05, B</u>, of the Standard Specifications applies. Average coarseness and workability factor for each lot will be determined according to <u>Materials I.M. 530</u>.

D. Hand Finished Pavement.

1. Standard or Slip-Form Portland Cement Concrete Pavement, QM-C: per square yard.

- 2. Portland Cement Concrete Overlay, QM-C, Placement Only: per square yard.
- **3.** Portland Cement Concrete Overlay, QM-C, Furnish Only: per cubic yard.

E. Price Adjustment

Failure to provide an optimized gradation within Zone II, when required, will result in the following price adjustments.

Gradation Zone (Materials I.M. 532)	Price Adjustment Per Lot
IV	2%
	5%

Table DS-23027.07-1: Price Adjustments

DS-23034 (New)



DEVELOPMENTAL SPECIFICATIONS FOR HIGH PERFORMANCE CONCRETE FOR STRUCTURES

Effective Date October 17, 2023

THE STANDARD SPECIFICATIONS, SERIES 2023, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

23034.01 DESCRIPTION.

- **A.** Develop and provide high performance concrete (HPC) for bridge substructures and decks when called for in the contract documents. HPC is defined as a concrete mix providing the following:
 - Desired workability.
 - Maximum 28 day permeability of 2000 coulombs for the substructure (or greater than 20 K ohm-cm surface resistivity by Wenner probe) and 1500 coulombs for the deck (or greater than 30 K ohm-cm surface resistivity by Wenner probe), as a target.
- **B.** Apply <u>Sections 2403</u>, <u>2412</u>, and <u>Division 41</u> of the Standard Specifications with the following modifications.

23034.02 MATERIALS.

Contractor may use other mixes than those described below provided they meet the requirements of this specification and are approved by the District Materials Engineer.

A. Substructure.

- **1.** Apply the following conditions for substructure HPC mixes:
 - Coarse aggregate meeting Class 3i durability.
 - Basic water to cementitious material (w/c) ratio of 0.42, with a maximum w/c ratio of 0.45.
- 2. HPC mix for substructure may be a HPC-S or CV-HPC-S. Apply the following conditions:
 - a. Use one of the following cement combinations:
 - Type IS, IP or IT.
 - Type I, II or IL with a minimum of 30% weight substitution with GGBFS.
 - b. Fly ash substitution not to exceed 20% by weight of the cement.
 - **c.** Maximum total substitution of 50%
 - **d.** A high range water reducer may be used with a maximum allowable slump of 8 inches and target air content of $7.5\% \pm 2.0\%$.

B. Deck.

1. Apply the following conditions for deck HPC mixes:

- **a.** Use coarse aggregate meeting Class 3i durability.
- **b.** Basic w/c ratio of 0.40, with a maximum w/c ratio of 0.42.
- 2. The HPC mix for the deck may be a HPC-D or a CV-HPC-D. Apply the following conditions:
 - **a.** Use one of the following cement combinations:
 - Type IS, IP or IT.
 - Type I, II or IL with a minimum of 30% weight substitution with GGBFS.
 - **b.** Fly ash substitution not to exceed 20% by weight of the cement.
 - c. Maximum total substitution of 50%.
 - d. Combined aggregate gradation optimized in Zone II according to Materials I.M. 532.

C. Contractor Designed HPC.

Other mixes meeting the above requirements may be approved by the District Materials Engineer.

23034.03 CONSTRUCTION.

A. Production Concrete.

- 1. Notify the Engineer at least 48 hours prior to placement of production concrete. Use only approved HPC mixes for production concrete. If a mix other than mix described in Article DS-23034.02, A or B is to be used, ensure it has same materials, proportions, and properties (including slump, air content, and w/c ratio) as approved by the District Materials Engineer.
- 2. District Materials Engineer will obtain random verification strength samples on a minimum of one deck placement. Strength samples will be tested at District Materials Laboratory according to AASHTO T 22. A set of four cylinders will be cast, cured, and handled according to <u>Materials I.M. 315</u>. Three cylinders will be tested for strength at 28 days. One cylinder will be tested for permeability on a random basis by Central Materials Laboratory or Wenner probe resistivity testing by the District Materials Engineer. Permeability testing will not be evaluated on footings or drilled shafts.

B. Placing Concrete.

For the deck, placing of concrete floors shall not begin if the theoretical rate of evaporation exceeds 0.1 pounds per square foot per hour. Monitor theoretical evaporation rate at a maximum interval of every three hours during placement at a location as near the deck as possible. If the rate exceeds 0.15 pounds per square foot per hour cease placement at next location acceptable to Engineer.

C. Curing.

1. Substructure.

- a. Leave forms in place for 96 hours of curing.
- **b.** Apply curing protection to exposed surfaces of concrete in accordance with <u>Article</u> <u>2403.03, E, 4, b</u>. Leave curing protection in place for 96 hours.

2. Deck.

- a. Leave forms in place for 168 hours of curing.
- **b.** Apply water to the burlap covering for 168 hours of continuous wet sprinkling system curing.
- c. Do not place curing compound on floor.
- **d.** Use burlap that is prewetted by fully saturating, stockpiling to drain, and covering with plastic to maintain wetness prior to placement. Place two layers of prewetted burlap on floor immediately after artificial turf drag or broom finish with a maximum time limit of 10 minutes after final finishing. Apply water to burlap covering for entire curing period by means of a continuous wet sprinkling system that is effective in keeping burlap wet during moist curing period.

e. Use evaporation retardant only in situations where equipment and/or labor delays, or environmental conditions, prevent adequate protection of concrete until prewetted burlap is in place. Have an evaporation retardant, including Confilm, Conspec Acquafilm, Evapre, or Sure Film, readily available during placement for application as directed by the Engineer. Do not work evaporation retardant into concrete surface or use as a finishing aid.

D. Cold Weather Protection.

- 1. Monitor surface temperature of concrete continuously during curing period using electronic recording type thermometers capable of recording a minimum of one reading per hour. Furnish results to Engineer in electronic format as required.
- 2. If supplemental housing and heating is used, locate temperature monitors in the concrete at the furthest and closest point from heat source. Verify maximum temperature at monitor point closest to heat source does not exceed 150°F.
- **3.** After required curing period, gradually reduce temperature of air surrounding concrete to outside air temperature according to <u>Article 2403.03, I</u>, of the Standard Specifications.
 - a. Substructure.

Ensure concrete and its surface temperature are maintained at a temperature of no less than 50° F for the first 120 hours after placing. Curing time will not be counted if concrete temperature falls below 50° F.

- b. Deck.
 - 1) Covering with plastic will not be allowed as a substitute for continuous wet sprinkling system curing.
 - 2) Ensure concrete and its surface temperature are maintained at a temperature of no less than 50°F for 168 hours of continuous wet sprinkling system curing. Curing time will not be counted if the concrete temperature falls below 50°F.

23034.04 METHOD OF MEASUREMENT.

Measurement for High Performance Concrete will be the cubic yards shown in the contract documents.

23034.05 BASIS OF PAYMENT.

Payment for High Performance Concrete will be at the contract unit price per cubic yard. Payment includes cost for testing production concrete.

APPENDIX F COMPUTER MIX DESIGN

QMC Mix Design Problem

You are responsible for designing and proportioning a QMC paving mix for a federally funded Iowa DOT interstate paving project. As a designer you must ensure you meet all specification requirements while providing the most economical mix design.

The project cover page, typical cross section, and bid items have been provided. This information can be used to identify the location of the project, pavement width/depth/cross slope, quantity, and aggregate quality.

With the location of the project and aggregate quality known use the provided T203, aggregate map, and production gradations to select individual aggregates and then optimize their combined grading using the mix design spreadsheet. There are multiple aggregates provided for coarse, intermediate, and fine. Base your selection on proximity to the project as well as the maximum nominal aggregate top size and the ability to optimize the combined aggregate gradation. The average production gradations are provided at the bottom of each production gradation sheet and should be used when optimizing. If your selection of individual aggregates proves difficult to optimize do not be afraid to switch an aggregate out for another.

When you have completed optimizing the combined aggregate gradation, have it reviewed by the instructor. Once it is reviewed and approved you then will need to select other component materials to complete the mix design and develop proportions. Component materials can be selected directly on the mix design spreadsheet using the pull downs. When determining what component materials to use, consider the time of year (temperature) the project will be constructed at, contractor plant/equipment capabilities, paver/plant accessibility, and economics.

Make the following assumptions:

- Central mix batch plant capable of using up to three cementitious materials and three aggregates
- Pavement will be placed by slip-form paver and delivered by dump truck
- Paving will be in late July through late August
- Shoulder area exists to provide a haul road so opening time is not as critical
- Maturity will be used for opening
- Per specification, the maximum allowable substitution rates for fly ash and GGBFS are 20 and 35 percent respectively, with a total substitution limit of 40 percent
- Fly ash is 15 percent and GGBFS is 5 percent cheaper than cement
- Chemical admixtures are equal in cost and should be selected on compatibility

When you have selected component materials and completed the mix design and proportions, have it reviewed by an instructor.





Bid Items

TEM NO.	ITEM CODE	ITEM	UNIT	TOTAL	AS BUILT
1	2102-0425070	SPECIAL BACKFILL	TON	12041	14.410
2	2102-2713070	EXCAVATION, CL 13, RDWY+BORROW	CY	28103	26913
3	2111-81/4100	GRANULAR SUBBASE	SY	86972	87863.
	2212-5070310	PATCH FINI-DEPTU REPAIR	SY	38050	36,711.
6	2212-5070320	PATCH. PARTIAL-DEPTH REPAIR		1092	720.
7	2212-5070330	PATCH BY COUNT (REPAIR)	EACH	143	1. 71
8	2301-1004115	STD/S-F PCC PAV'T, QM-C CL 31, 11.5"	SY	74127	67891
9	2301-6911722	PCC PAY'T SAMPLE	LS ·	1	\$ 3000.
10	2301-9090000	IQUALITY MANAGEMENT - CONCRETE	CY	24709	22,599.
12	2399-5145000	DETOUR PAV'T	LS	1	\$1200
13	2417-1007000	CORR PIPE CULV. 15" Roadway	JF	234	1923.
14	2417-5895000	BEVELED PIPE+GUARD	EACH	2	400.
15	2510-6745850	RMVL OF PAV'T	SY	113792	93,290.
16	2518-6910000	SAFETY CLOSURE	EACH	12	17
1/	2520-3350010	IF IELD LABURATURY	EACH	1	\$3500.
18	2527-9263005		LS	1	\$30,900.
20	2527-9263111	PAINTED PAV'T MARK, WATERBORNE	CTA	910	1266
21	2527-9263130	REMOVABLE TAPE MARK	STA	2103	2872.
.22	2527-9263139	PAINTED SYMBOL+LEGEND, WATERBORNE	EACH	16	16
23	2527-9263180	PAV'T MARK RMVD	STA	1125	1576.
- 24	2527-9263190	SYMBOL+LEGEND RMVD	EACH	16	16
25	2528-6765001	MUNITUR W/INCIDENT RESPONSE	CDAY	120	169
-27	2528-8400042	TEMP ATTENIATOR SAND-FILLED BARREL -RE-73	EACH	2	2
28	2528-8400047	TEMP BARRIER RAIL		500	300
-29	2528-8400157	TEMP FLOODLIGHTING LUMINAIRE	FACH	8	300
3D	2528-8445110	TRAFFIC CONTROL	LS	1	\$74625.
31	2528-8445112	FLAGGER	DAY	10	48
32	2529-5070110	PAICH, FULL-DEPTH FINISH, BY AKEA	SY	187	880.
34	2529-8174010	SUBRASE (PATCH) (ITEM NAT USED)	IEACH	15	86
35	2533-4980005	MOBILIZATION	51	862	0
. 36	2601-2634100	MULCH	ACRE	10.8	- A13 /000.
37	2601-2636041	SEED+FERTILIZE	ACRE	10.0	30.
-38	2601-2640350	SPECIAL DITCH CONTROL, WOOD EXCELSION MAT (ITEM NOT USED)	SQ	78	0
39	2601-2642100	STABILIZE CROP - SEED+FERTILIZE (ITEM NOT USED)	ACRE	11	0
40	2602-0000020	WATER-SUD/SPEC DITCH UNIL/SLUPE PRUTECT (TTEM NOT USED)	MGAL	3.9	0
42	2602-0000030	SILT FENCE-DITCH CHECKS		2500	2295.0
43	2602-0000060	RMVL OF SILT FENCE (ITEM NOT USED)		2400	1522.0
44	2602-0000070	RMVL OF SILT FENCE-DITCH CHECK (ITEM NOT USED)	LF	2000	. 0
44.5		PATCH, PARTIAL-DEPTH PCC FINISH	SF	1246.130	1581.1
45.		TRACH, PARTIAL-DEPTH PCC FINISH BY COUNT	EACH	186	183
45.5		CARRICATED PIPE CULVERT IS IN	LS		\$935.0
465		BEVELED PIPE & GUARD IS IN	LF FACU	188	188
47		CULVERT, CONCRETE ROWY, PIPE 24"	LACH		
47.5		REMOVE & REPLACE 24" RCP APRON	EACH	0	
48		TRAFFIC CONTROL - MEDIAN CROSSOVERS	LS		\$10500.0
48.5		MOBILIZATION-CROSSOVERS	LS		\$10,000.0
49.5		MOBILIZATION - PCC REMOVAL	LS	1	\$ 3,500.0
50	<u> </u>	REMOVE & REINSTALL DELINEATORS	EACH	3	3
505		SAWCUT	EACH	. 90	105
51		INSTALL & REMOVE TRAFFIC SIGNS		1380	1378
51.5		REPLACEMENT OF CMP	LS	1	\$214317
52		RELOCATE OUTLET	LS	i	# 841.
52.5	.	PIPE EXTENSIONS	LS	1	\$5,316.5
53.5		HOLL LOLD WEATHER PROTECTION	SY	11,006.667	11,006.6
54		AVEMENT SMOOTHNESS INCENTINE	SY	125.444	125.4
54.5	<u></u>	PIPE REPLACEMENT	EACH	37,600.000	37,600.0
55	· · · · · · · · · · · · · · · · · · ·	DM-C PCCP INCENTIVE	5y	67881307	17800
55.5		SPECIAL BACKFILL	TON	5428 000	54780
56		TRAFFIC CONTROL	LS.	1	\$9740.0
565		PCC PAVEMENT THICKNESS INCENTIVE	SY	67,891.796	67.891.7
. 5/	/	UN-LUFITLYING I KAFFIC CONTROL	EACH	- 750.000	-750.0
		ೆ. ಮೆ. ಇದ ಇಗ			
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October 18, 2005 Supersedes April 19, 2005

Matls. IM T203

		RECENTLY ACTIV	E AGGREC	GATE	SOURC	ES	BULK	DUR		FR	ICT		N O
CODE	OPERATOR	SOURCE NAME	LOC	ATIO	N		SSD SpGr	PCC CA	FA	HM A	IA B	BEDS	T E
38	GRUNDY DIST 1	SAND & GRAVEL						1				1	an 20 da 10
A38504	CARLSON MATERIALS CO	HERONIMOUS	SE	35	TO88	R17W	2.63		X			1	
39	GUTHRIE DIST 4	SAND & GRAVEL									•••••••	4	
A39502	BECKER GRAVEL CO	HEILAND	SW	29	TO79	R30W				4	4		
A39506	BUTTLER CONST CO	BAYARD	NE	22	TO81	R32W				4	4		
40	HAMILTON DIST 1	CRUSHED STONE											
A40006	MARTIN MARIETTA	GRANDGEORGE	SE	18	TO89	R25W							
A40512	BECKER GRAVEL CO	ANDERSON		12	T087	P26W							+
A 4				ک (1007	112000						a the barrow of	-
41 A41002	BASIC MATERIALS CORP	GARNER NORTH	SE	11	T-005	DOWN	0.77	2:0				1 1	+
	5/10/0 /// 2/ // 20 00/1	CARLER HORTH	0L		1035	112411	2.77	3i		4	4	6	
A41004	BASIC MATERIALS CORP	GARNER SOUTH-WIELAND	NW	13	TO95	R24W	2.77	3iB		4	4	1 - 4	
		CAND & ODANCI					2.77	3i		4	4	6	
A41504	HANCOCK COUNTY	HUTCHINS	F2	27	TOOG	DOGW	-					├	╀
A41506	HANCOCK COUNTY	KLEMME	L2	26	TO90	R24W					4		
A41510	NUCKOLL'S CONCRETE	BRITT		34	TO96	R26W	DWU	2		3	3		
	SERVICES INC						DWU		Хļ				
A41518	HANCOCK COUNTY	AUSTIN	NE	11	TO97	R25W							
42	HARDIN DIST 1	CRUSHED STONE											
A42002	MARTIN MARIETTA	ALDEN	NW	20	TO89	R21W	2.56	31		4	4	0, 1, 3	
A42004	GERHKE QUARRIES INC	GIFFORD	NW	04	TO86	R19W		3			5	0,1	
		SAND & GRAVEL		0-1	1000	1(1011					5		
A42502	WELDON BROS CONST CO	IOWA FALLS	NW	20	TO89	R20W	2.65	2		4	4		T
A42510	MARTIN MARIETTA	JANSSEN	SE	3/		P20W	2.68		хI	А	A		
		5/4COLIV	UL	04	1000	112011	2.65		хI	4	4		
A42512	HARDIN AGGREGATES INC	GIFFORD	SW	31	TO87	R19W				4	4		
40504			05		TOOS	D (O) (2.66		хΙ	-	-		
A42524	BECKER GRAVEL CO	GRIFFEL	SE	31 04	1089 T086	R19W	DWU			3	3		
				04	1000	1/12/4	סיים	1		4	4	1	

Aggregate Map

Production	
se Aggregate I	ations
Coar	Grad

											I.
Material Source	D67 Con Alden	crete Stor	Ð	2004 (Certified	Aggrega	fe				
Producer	Martin M	arietta 1 1/2"] ‡	"V/E	1/7"	3/8"	VĦ	8#	000#		
Date	Lab #	37.5	- 25	10	12.5	9.5 mm ₄	4.75 mm 2	.36 mm	75 µm	Complies	
			100	100 90		55 20	<u></u> 000	υO	1.5 0		
30-Mar	15	100	100	100	62	29	2.3	0.3	0.3	>	
31-Mar	16	100	100	100	99	40	7.7	0.8	0.7	~ ~	
12-Apr	17	100	100	66	56	24	2.4	0.3	0.3	~ ~	
13-Apr	18	100	100	100	49	21	1.9	0.3	0.3	- >	
14-Apr	19	100	100	66	49	22	2.2	0.3	0.3	Y	
16-Apr	20	100	100	66	54	26	2.2	0.3	0.8	Y	
27-May	42	100	100	98	45	24	2.0	0.6	0.5	Y	
28-May	43	100	100	96	55	27	3.6	0.4	0.3	Х	
1-Jun	44	100	100	97	52	29	3.5	0.4	0.4	Z	
3-Jun	45	100	100	98	45	23	2.6	0.4	0.3	У	
4-Jun	46	100	100	95	42	22	1.2	0.3	0.2	У	
6-Jun	73	100	100	96	42	20	0.8	0.4	0.3	У	
ղոր-շ	74	100	100	95	40	20	1.0	0.5	0.4	Y	
12-Jun	75	100	100	96	41	21	0.9	0.5	0.4	Y	
lul-9	76	100	100	97	43	23	1.0	0.4	0.3	У	
րե-շ	77	100	100	96	44	24	0.9	0.3	0.3	Z	
3-Sep	153	100	100	97	49	28	2.7	0.2	0.2	Y	
8-Sep	154	100	100	66	54	28	4.7	0.6	0.4	Y	
9-Sep	155	100	100	97	53	25	3.2	0.5	0.4	Z	
29-Sep	156	100	100	66	58	34	1.8	0.2	0.2	Y	
30-Sep	157	100	100	66	54	g	2.6	0.2	0.2	Y	
1-Oct	166	100	100	98	58	35	2.3	0.2	0.2	У	
4-Oct	167	100	100	66	55	33	2.5	0.2	0.2	Z	
11-Oct	168	100	100	66	55	31	3.2	0.2	0.2	Z	
12-Oct	169	100	100	98 0	54	34	3.7	0.3	0.3	У	
1-Dec	188	100	100	98	54	26	1.2	0.2	0.2	Z	
2-Dec	189	100	100	96	45	22	1.4	0.2	0.2	Y	
3-Dec	190	100	100	98	51	28	1.4	0.2	0.1	У	
4-Dec	191	100	100	98	52	23	0.9	0.2	0.2	У	
6-Dec	192	100	100	100	50	27	2.5	0.4	0.3	У	
Crsr here	_										
Average-		√ 100	100	98	51	27	2.3	0.3	0.3	\downarrow	
Std. Devia	ition	0	0	1.48	6.28	5.01	1.39	0.15	0.15		_
Minimum		100	100	95	40	20	0.8	0.2	0.1		
Maximum		100	100	100	99	40	7.7	0.8	0.8		

Coarse Aggregate Production Gradations

Material Source	1" D57 (Alden	Concrete	Stone	2004	Certified	Aggregate	e			
Producer	Martin M	larietta								
		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#200	
Date	Lab #	37.5	25	19	12.5	9.5 mm 4	4.75 mm	2.36 mm	75 µm	Complies
Limits			100		60		10.0	5.0	1.5	
		100	95		25		0.0	0.0	0.0	
25-Mar	6R	100	100	74	29	13	2.0	0.8	0.8	Y
25-Mar	7R	100	99	73	32	15	2.0	1.0	0.8	Y
25-Mar	8R	100	100	75	34	18	2.7	1.0	0.8	Y
8-Apr	26	100	98	76	34	16	2.0	0.7	0.7	Y
26-Apr	27	100	99	73	32	14	1.8	0.4	0.6	Y
27-Apr	28	100	99	70	30	14	1.4	0.4	0.3	Y
20-May	29	100	99	78	30	18	1.7	0.4	0.3	Y
25-May	30	100	99	79	37	17	1.1	0.3	0.3	Y
26-May	31	100	98	76	30	12	1.0	0.4	0.4	Y
7-Jun	32	100	99	78	44	23	2.8	0.4	0.2	Y
18-Jun	33	100	98	75	39	19	1.5	0.2	0.2	Y
9-Jun	50	100	98	79	44	. 22	2.9	0.4	0.3	Y
11-Jun	51	100	98	79	41	22	2.4	0.4	0.2	Y
14-Jun	52	100	99	81	37	18	1.2	0.3	0.3	Y
15-Jun	53	100	99	80	34	15	0.9	0.3	0.3	Y
29-Jun	54	100	99	81	30	14	0.8	0.4	0.4	Y
30-Jun	55	100	99	82	28	12	0.9	0.3	0.3	Y
9-Jul	56	100	99	81	31	12	0.6	0.3	0.3	Y
12-Jul	57	100	100	73	42	20	0.5	0.4	0.6	Y
13-Jul	128	100	98	81	35	16	1.6	0.3	0.3	Y
14lul	129	100	99	79	29	15	0.8	0.2	0.2	Y
31-Jul	130	100	99	77	35	18	1.8	0.4	0.4	Ý
2-Aug	131	100	99	81	29	15	11	0.3	0.3	Ý
10-Aug	132	100	100	87	44	15	14	0.3	0.3	Ŷ
11_Aug	132	100	90	81	33	10	15	0.3	0.3	Ý
17_Aug	134	100	qq	76	26	12	0.9	0.4	0.3	Ŷ
18_Aug	135	100	97	76	32	17	17	0.3	0.3	Ŷ
- 31_Δuα	145	100	100	83	44	25	3.8	0.5	0.3	Ŷ
1_Son	1/16	100	100	81	42	22	3.2	0.3	0.3	Ŷ
2-Sen	140	100	100	84	54	37	5.7	0.7	0.6	Ŷ
2-00p 3-80n	148	100	98	68	28	15	1.3	0.6	0.2	Ý
10-Sen	140	100	100	83	43	26	4.6	0.7	0.4	Ŷ
13_Son	150	100	90. 98	78	33	16	17	0.3	0.3	Ŷ
14-Sen	151	100	98	, 0 72	31	15	1.5	0.4	0.3	Ŷ
16-Sen	152	100	99	72	35	18	1.5	0.3	0.3	Ŷ
27-Sen	152	100	100	81		16	1.8	0.3	0.2	Ŷ
28-Sen	159	100	99	78	33	18	2.1	0.4	0.3	Ŷ
18_Oct	160	100	100	82	47	30	57	1.1	0.4	Ŷ
19-Oct	160	100	100	77	33	15	1.8	0.4	0.3	Ý
20-Oct	162	100	99	80	32	14	1.0	0.3	0.3	Ý
20-000 21-Oct	163	100	qq	76	31	14	1.9	0.3	0.3	Ý
28-0ct	160 H	100	100	75	27	15	13	0.3	0.3	Ý
20-00	165	100	100	77	36	17	21	0.0	0.0 0.4	Ý
20-000 1_Nov	100	100	001	יי 70	· 20	16	2.1 1 R	0. 4 1 3	0.4 0.2	Ý
2 Nov	193	100	100	70	. 23	16	1.0	0.0 N 3	0.Z	Ý
	194	100	100	00	. 29	10	1.0	0.0 0.2	0.4 0.7	v
	- 190 - 10e	100	99	70	21	10	י.י ה ה	0.0 0.0	0.2 0.2	Ý
	, 190 . 107	100	59 00	10	, 04) /1	10 01	17	0.2	0.2 0.3	V
Crsr here	to insert	100	99	02	. 41	۲ ک	1.7	0.5	0.0	
<u></u>										
Average	Dec 1 1	100	99	78	35	17	1.9	0.4	0.4	
Standard	Deviation	1 0.00	0.75	3.95	5.98	4.69	1.12	0.20	0.16	

*

	40		Complies	-	1	ר י	У	Y	У	У	Y	Y	Y	Y	Y	У	У	Y	Y	Y	Y	Y	Y	Y	Y		\checkmark
	14013-		75 µm (1.5	0.0	0.4	0.2	0.3	0.2	0.4	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.5	0.3	0.4	0.3		0.3
Production	Carlson M-35-6(94)	α #	#0 2.36 mm	5.0	0.0	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.5	0.5	0.3	0.2	0.3	0.3	0.3	0.5	0.5	0.6	0.5		0.4
ggregate IS		V #	75 mm	7.0	0.0	1.6	1.7	1.9	1.8	2.1	0.8	1.1	1.2	1.3	2.0	2.4	2.4	1.4	2.0	1.7	1.6	1.9	1.9	2.8	2.0		1.8
Coarse A Gradation	Aggregate	"0/C		21	11	14	11	12	13	16	1			14	12	13	14	13	12	-	1	15	16	18	15		13
	Certified A	"C/ F	112.5	33	23	26	23	24	25	28	24	23	23	25	23	23	25	26	27	24	23	29	28	32	29		26
	2003 (шV/С	19 19	 65	55	63	59	60	59	61	56	59	55	56	56	09	58	60	60	59	56	61	62	65	59		59
	Stone	= T	- 25	88	78	83	82	79	81	81	78	82	81	78	78	82	81	83	81	78	79	78	79	85	79		80
	al Conc.	tta 4 4 0"	1 1/2 37 5		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		100.0
	'2" Speci en	tin Marie	#	Ŧ		121	122	123	124	125	126	127	128	181	182	183	184	185	186	187	188	207	208	209	210		\wedge
	Material 11/ Source Ald	Producer Mai	Date Lab	Limits		6-Jun	6-Jun	9-Jun	12-Jun	24-Jun	25-Jun	26-Jun	28-Jun	29-Jun	30-Jun	1-Jul	2-Jul	4-Aug	5-Aug	6-Aug	7-Aug	15-Sep	16-Sep	17-Sep	18-Sep	Insert Here	Average —

Intermediate Aggregate Production Gradations

		#200	75 µm			0.5	0.5	
		#100	150 µm					
		#50	300 µm					
		#30	600 µm					
		#16	1.18 mm					
		8#			د النظرية ال	1.3	1.7	
		TH	.75 mm 2			17.2	27	
		"a/s	9.5 mm 4	,		86	86	
Monitor		1/0"	12.5			100	100	
2006	A42002	ш <i>V</i> /С	19					
3" Washed Chips	len	artin Marietta	p #		برجا والمحالية و	20	40	
al 3/5	Alc	er Ma	La			lav	ep	
Materia	Source	Produc	Date	LIMITS		16-M	11-S	

Insert

							ampees withing surpressing			
Averade	10//10	100	86	22	1.5	#DIV/0	#DIV/IC# i0//IC#	10/V	0.5 🗸	
Standard Deviation	i0//ID#	0.00	0.00	4.90	0.20	#DIV/0	NIC# i0//NIC# i0//NIC#	0 i0//	00.	r
Maximum	0	100	86	27	1.7	0	0	0	0.5	
Minimum	0	100	86	17.2	1.3	0.0	0	0	0.5	

	1		Complies		>	- >	~ ~	· >	У	Y	> :	> >	~ >	~ ~	~	У	> :	> >	~ >	~ >	, >	~ ~	Υ	7	7	> :	~ >	~ >	. >	У	Y	Y	> :	~ :	~ >	~ >	- >	` >	, Y		\bigvee
		000#	75 µm	1.5 0	0.3	0.4	0.3	0.5	0.5	0.4	0 0 4 v	0 C	0.3	0.2	0.3	0.4	0.2	0.0		0.0	0.4	0.4	0.3	0.3	0,4	0.0	4 G 9 C	0.3	0.4	0.4	0.3	0.3	0.0 4. 7		7.0	0.3	0.5	0.5	0.4		0.4
egate ions		#100	202		0 4	0.5	0.4	0.7	0.7	0.5	0.7	0.0 0	0.4	0.3	0.4	0.5	0.3	0 C		0.5	0.5	0.5	0.4	0.5	0.7	4.00		0.4	0.5	0.6	0.4	0.5	0.7		0 C	0.0	0.6	0.7	0.6		. 0.5
e Aggre Gradat	3-40	450			0.5	0.7	0.5	0.9	0.9	0.6	20.0 0	0.0 0	0.6	0.5	0.5	0.6	0.5	0.0 E	0.0	0.7	0.6	0.6	0.6	0.0		0.5	- - -	0.5	0.7	0.8	0.5	0.0	0.1		- - -	0.5	0.7	0.9	0.8		0.7
ediate ction (J1401	08#			0.6	0.8	0.6	1.1	1.1	0.7	0.9	D. C	0.0	0.7	0.6	0.9	0.7	7.0	- a 0	0.0	0.7	0.8	0.7	0.8	1.3	9.0 0	5 r 7 r	0.6	0.8	1.0	0.7	0.7		- c 4. u	0.0	0.6	0.8	<u>.</u> ,	1.0		0.8
Interm Produ	M-35-6(5 Carlson	410			- 20	0.9	0.7	1.3	1.2	0.8	0.1	- + υ ⊂	0,0	0.9	0.7	1.2	0.9	20 C	0. r	0.9	0.8	1.0	0.8	 .	1.7	80. v 0. v	- u	- C	1.0	1.4	0.9	0.8	1.7	ר. ה היי		0.0	0.9	1.5	1.4		1.0
	_ U	8#	2.36 mm	۲ 0		10	0.8	1.5	1.9	4.	 4 1	- r - r	- + 5 4		0.9	2.1	1.7	0. 6	- <u>+</u> 	+ C	1.0	1.3	1.0	1.5	2.5	0.1	- u v	4 7 4	1.3	2.0	1.7	1.6	5 5 7	7.7		0.0	1.5	2.1	1.9		1.5
		¥	.75 mm	20 10		14	12	13	8	15	15	7 7	<u>5</u> 6	10	11	20	17	10	= ¥	<u>5</u> ±	12	13	11	13	19		<u>;</u>	<u>+</u> +	10	15	17	16	17	9		<u>+</u> 5	5 4	18	17		4
	Aggregate	"0/6	9.5 mm 4	89 79		2 7 7 7 7 7	85 85	83	86	82	85	81 70	81	79	79	85	82	6/	20	40 79	19	80	79	79	84	62	2 G	5 č	79	79	81	80	84 1	6 S	00 85	32	8	82	85		81
	certified /	"C/ F	12.5	100 94	100	00	100	66	100	100	100	66 6	0 0 0 0 0	86	97	98	66	97	0000	6 6 6	98 86	66	98	66	00	88	000	8 8	98 86	98	66	66	66	55 55	200	100	86	66	66		66
	2003 C	" V / C	19	100		80	001	100	100	100	100	00 00 00 00 00 00 00 00 00 00 00 00 00	80	100	100	100	100	100		80	100	100	100	100	100	100	36		100	100	100	100	100	001	36	001	100	100	100		V 100
	c. Chipe	arietta			30	60 70	4	42	43	44	45	130	132	133	134	135	136	137	-44	140 144	145	146	147	148	149	164	100	167	168	169	170	171	211	212	0 0 7	יד דיר דיר	216	217	218		Υ
	1/2"Conc Alden	Martin M	Lab #																																					to insert	
	Material Source	Producer	Date	Limits	14 An	15-Anr	17-Apr	21-Apr	23-Apr	24-Apr	25-Apr	2-Jun	unt-c	7-Jun	unC-6	10-Jun	11-Jun	24-Jun	unr-07	78-Jun	29-Jun	30-Jun	1-Jul	2-Jul	3-Jul	lul-7	10-9 1-1-01	Inc-01	21-Jul	22-Jul	23-Jul	24-Jul	28-Jul	29-Jul	30-Jui	0119-1 C	15-Sen	16-Sep	17-Sep	Crsr here	Average

Fine Aggregate Production Gradations

Material	Concrete Sand	2005									1
Source	Welden Pit		_								
Frounder	welden Agylegale	3/8"	7#7	8#	#16	02#	#50	#100	#200		
Date	Lab #	9.5 mm	4.75 mm 2	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm	Complies	
Limits			100	100		50		•	1.5		
		100	06	20		10			0		
6-Mč	ay WA-1-05	100	96	82	64	41	15	1.8	0.7	У	
18-Ai	ig WA-2-05	100	96	62	61	39	13	1.8	0.5	Y	
26-Au	ig WA-3-05	100	96	79	59	37	12	2.0	0.9	У	
2-Se	p WA-4-05	100	96	80	62	39	14	2.2	0.9	Y	
9-26	p WA-5-05	100	96	80	60	36	12	1.0	0.3	У	
16-Se	p WA-6-05	100	96	80	61	36	12	1.2	0.4	У	
23-St	p WA-7-05	100	97	83	65	42	14	1.6	0.6	У	
23-St	p WA-8-05	100	97	62	54	27	6.5	1.6	0.9	У	
12-O	ct WA-9-05	100	96	81	63	41	13	1.7	0.7	У	
31-0	ct WA-10-05	100	96	81	63	41	13	1.4	0.5	~	
· 15-N	ov WA-11-05	100	96	80	61	37	12	1.5	0.8	У	
Crsr Here to inser						****					
Average		10 10	96	80	61	38	12	1.6	0.7		╉
Standard Deviatio	-	0	0.39	1.23	2.82	4.00	2.10	0.33	0.20	1	1
Maximum		100	97	83	65	42	15	2.2	0.9		
Minimum		100	96	62	54	27	6.5	-	0.3		
Range		0	-	4	1	15	8.5	1.2	0.6		
Middle of Range		100	97	81	60	35	1	1.6	0.0		
% Range of Avera	ge	0.0	1.0	5.0	18.0	39.7	68.5	74.2	91.7		
Range to Std. Dev			2.6	3.3	3.9	3.8	4.1	3.7	3.0		

Fine Aggregate Production Gradations

2004 Certified

Concrete Sand

Material

Source	Jansse	Ļ					~				
Producer	Martin I	Marietta									
		3/8"	#4	#8	#16	#30	#50	#100	#200		
Date	Lab#	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm	Complies	
Limits			100	86	68	46	17	3.9	1.5		
		100	92	78	60	38		0	0		
	J1	100	98	85	62	34	10.0	1.3	0.5	×	
25-Mar	J2	100	98	88	69	44	11	1.6	0.9	У	
5-Aug		1 100	98	86	66	41	12	1.1	0.6	Y	
5-Aug	. 1	2 100	98	88	68	45	14	2.1	0.8	Х	
Crsr Here to	insert										
Averade		100	98		99	41	11.8	1.5	0.7≪		
Standard Dev	viation	0	00.0	1.50	3.10	4.97	1.71	0.45	0.18		1
Maximum		100	98	. 88		45	14	2.1	0.9		
Minimum		100	98	85	62	34	10	1.1	0.5		

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Fine Aggregate Production Gradations

Material Source	Concrete S Heronimus	and	Certified / 2004	Aggregate						
Producer	Carlson Ma	itls.								
		3/8"	#4	#8	#16	#30	#50	#100	#200	
Date	Lab #	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm	
			100		80	50			1	
Limits		100	90		10	10			0	
 12-May	RC-04-01	100	95	84	68	42	13.0	1.6	0.6	
12-May	RC-04-02	100	96	89	74	44	10	1.2	0.6	
12-May	RC-04-03	. 100	97	89	74	45	12	1.6	0.8	
12-May	RC-04-04	100	97	89	74	44	11	0.9	0.5	
12-May	RC-04-05	100	95	85	69	43	9.6	1.0	0.6	
Crsr here to i	nsert									
Average		100	96	87	72	44	11 1	1.3	0.6	/
Standard Dev	viation	0100	0.80	2.23	2 71	1 02	1 26	0.29	0.0 4	and the second sec
Maximum	viation	100	97	2.20	74	45	13	16	0.10	
Minimum		100	95	84	68	42	9.6	0.9	0.5	