IOWA | DOT

PORTLAND CEMENT CONCRETE LEVEL III

INSTRUCTION MANUAL

2025

TECHNICAL TRAINING AND CERTIFICATION PROGRAM

DOT CONTACT INFORMATION

Wesley Musgrove	Construction & Materials Bureau Director	515-239-1843
John Hart	Bituminous Materials Engineer	515-239-1547
Brian Johnson	Bituminous Field Engineer	515-290-3256
Bob Dawson	Chief Geologist	515-239-1339
Kevin Merryman	Contract Administration Engineer	515-239-1848
Melissa Serio	Earthwork Engineer	515-239-1280
Cedric Wilkinson	E-Construction Program Administrator	563-391-2750
Jennifer Strunk	FieldManager/FieldBook/Doc Express	641-344-0044
Desiree McClain	Foundations Field Engineer	515-233-7906
Jeff DeVries	Materials Testing Engineer	515-239-1237
Chris Brakke	Pavement Design Engineer	515-239-1882
Todd Hanson	PCC Materials Engineer	515-239-1226
Elijah Gansen	PCC Field Engineer	515-233-7865
Mahbub Khoda	Prestressed & Precast Concrete Engineer	515-239-1649
Kyle Frame	Structures Group Engineer	515-239-1619
Curtis Carter	Senior Structures Field Engineer	515-239-1185
Jesse Peterson	Structures Field Engineer	515-239-1159
Brian Worrel	Traffic Safety Engineer	515-239-1471
Mike Lauritsen	District 1 Materials Engineer	515-357-4350
Robert Welper	District 2 Materials Engineer	641-422-9421
Vacant	District 3 Materials Engineer	712-202-0809
Timothy Hensley	District 4 Materials Engineer	712-243-7629
Allen Karimpour	District 5 Materials Engineer	515-815-1405
Shane Neuhaus	District 6 Materials Engineer	319-366-0446

ORGANIZATIONS CONTACT INFORMATION

Asphalt Paving Association of Iowa
1606 Golden Aspen Drive Ste 102
Ames, IA 50010
Mike Kvach 515-450-8166
www.apai.net

Iowa Concrete Paving Association
360 SE Delaware Ave.
Ankeny, Iowa 50021
Greg Mulder 515-963-0606
www.concretestate.org

Iowa Prestress Association
Dennis Drews 402-291-0733

Iowa Limestone Producers Association
4438 114th St
Urbandale, IA 50322
Randy Olson 515-262-8668
www.limestone.org

Iowa Ready Mix Concrete Association
380 SE Delaware Ave.
Ankeny, Iowa 50021
Greg Mulder 515-965-4575
www.iowareadymix.org

TECHNICAL TRAINING AND CERTIFICATION PROGRAM
CONTACT INFORMATION

CONTACT PERSON	ADDRESS	PHONE #
Brian Squier - TTCP Coordinator brian.squier@iowadot.us	Technical Training & Certification Program and District 1 Materials 800 Lincoln Way Ames, Iowa 50010	515-233-7915
Hope Arthur - TTCP Coordinator hope.arthur@iowadot.us		515-509-8302
Jon Kleven jon.kleven@iowadot.us	District 2 Materials 428 43rd Street SW Mason City, Iowa 50401	641-422-9428
Alex Crosgrove alex.crosgrove@iowadot.us	District 3 Materials 6409 Gordon Drive Sioux City, Iowa 51106	712-239-4713
Mike Magers michael.magers@iowadot.us	District 4 Materials 2310 E. Seventh St. Atlantic, Iowa 50022	712-243-7649
Helen Bailey helen.bailey@iowadot.us	District 5 Materials 205 E. 227th St. Fairfield, Iowa 52556	319-759-5408
Tammy Siebert tammy.siebert@iowadot.us	District 6 Materials 5455 Kirkwood Blvd. SW Cedar Rapids, Iowa 52404	319-364-0235

Des Moines Area Community College (DMACC)
Boone Campus
1125 Hancock Drive
Boone, Iowa 50036

Kelli Bennett
Phone number: 515-433-5232
Email: kabennett@dmacc.edu

or

Renee White
Phone number: 515-433-5056
Email: crwhite@dmacc.edu

1. Table of Contents

CHAPTER 1

INTRODUCTION

1. Introduction

1.1. *Introductions*

1.2. *Schedule*

Day 1

9-10:30	Chapter 1 Introduction
10:30-11:30	Chapter 2 Cementitious Materials
11:30-12:30	Lunch
12:30-2:00	Chapter 3 Chemical Admixtures
2:00-3:30	Chapter 4 Aggregate

Day 2

9:00-11:30	Chapter 4 Aggregate
11:30-12:30	Lunch
12:30-2:30	Chapter 5 Mix Design
2:30-3:30	Chapter 6 Mix Design Approaches

Day 3

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

Day 4

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

- John Hart
  515 -239-1494
  john.hart@iowadot.us

- Todd Hanson
  515-239-1226
  todd.hanson@iowadot.us

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

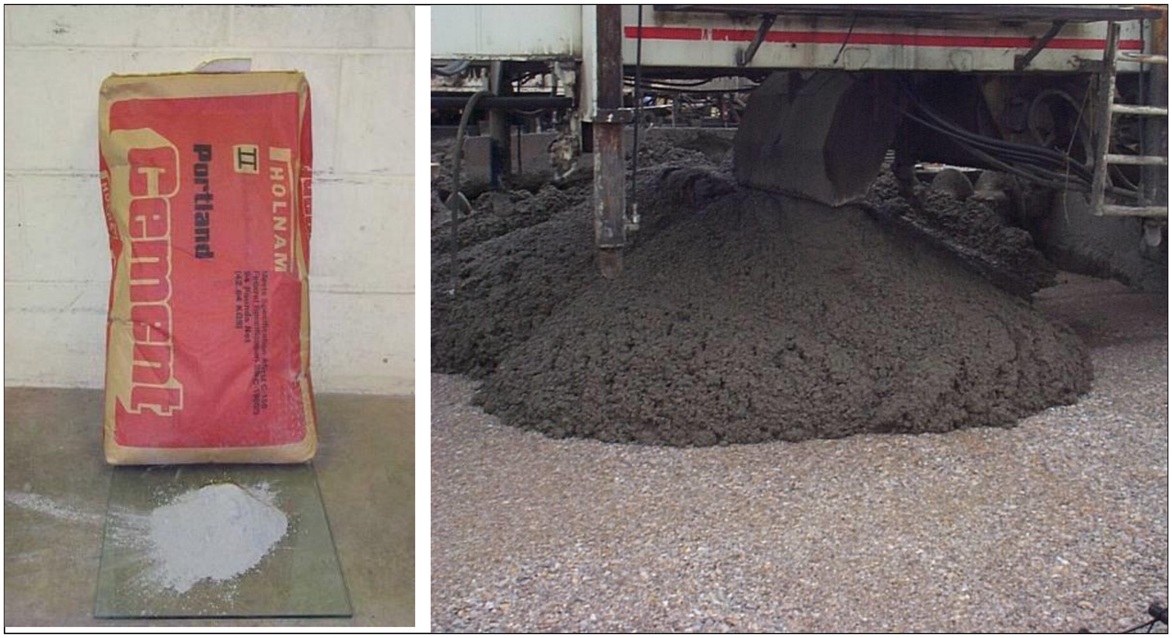
1.7. Course Objectives

- 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:
    - Iowa DOT I.M. 529
    - ACI 211.1
    - Iowa DOT QM-C
    - Iowa DOT BR
    - Iowa DOT HPC structural
    - Iowa DOT HPC overlay
    - Iowa DOT mass concrete
    - Iowa 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
    - 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 NOT cement

Figure 1-1 Cement versus concrete



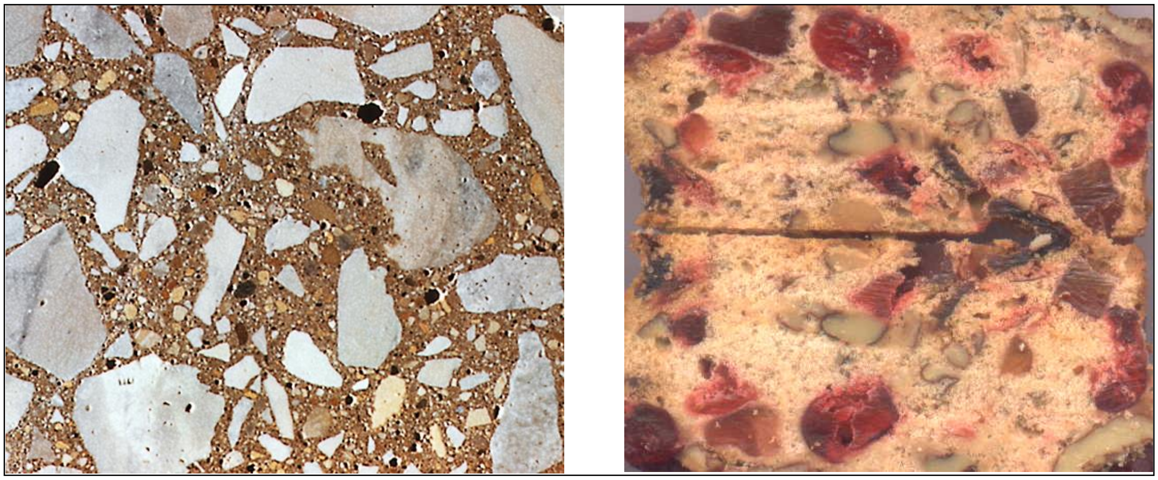
- Composite materials
    - Main categories are aggregate and paste
    - Aggregate is an economic filler that provides dimensional stability and wear resistance
    - Paste glues, bonds, adheres, ties, attaches, joins, links and holds the aggregate together
    - Other concrete composite materials can 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 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	Epoxy	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
    - Goal of a mix designer is to identify and understand observer needs and best satisfy them

Table 1-2 Quality concrete for different observers and applications

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

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
     - 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
    - Kiln is fueled from lower end with powdered coal, oil, gas, and or waste materials where the temperatures can reach 2600 to 3000 °F
    - Limestone ($CaCO_3$) converts to CaO releasing carbon dioxide (CO_2)
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

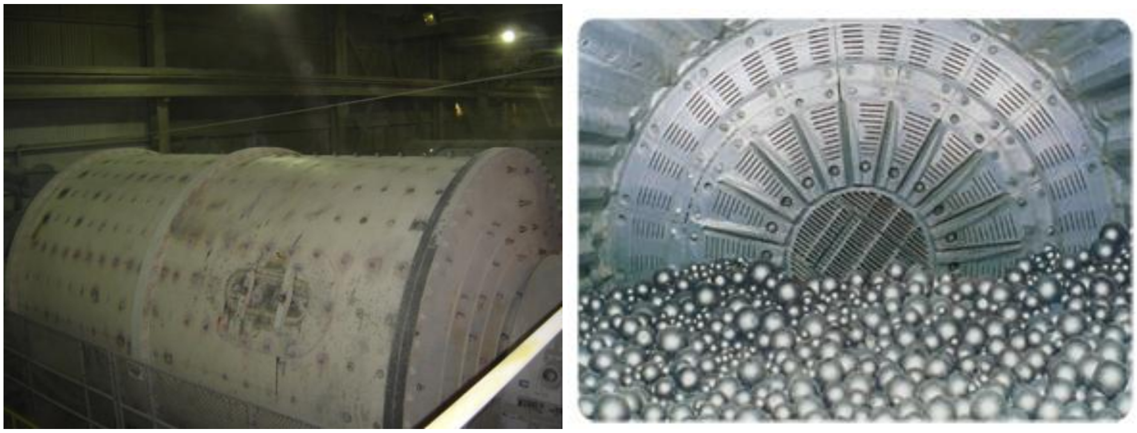
Figure 2-5 Quarry operations for cement production

Figure 2-6 Bins used for blending operation

Figure 2-7 Kiln for cement production

Figure 2-8 Clinker and gypsum

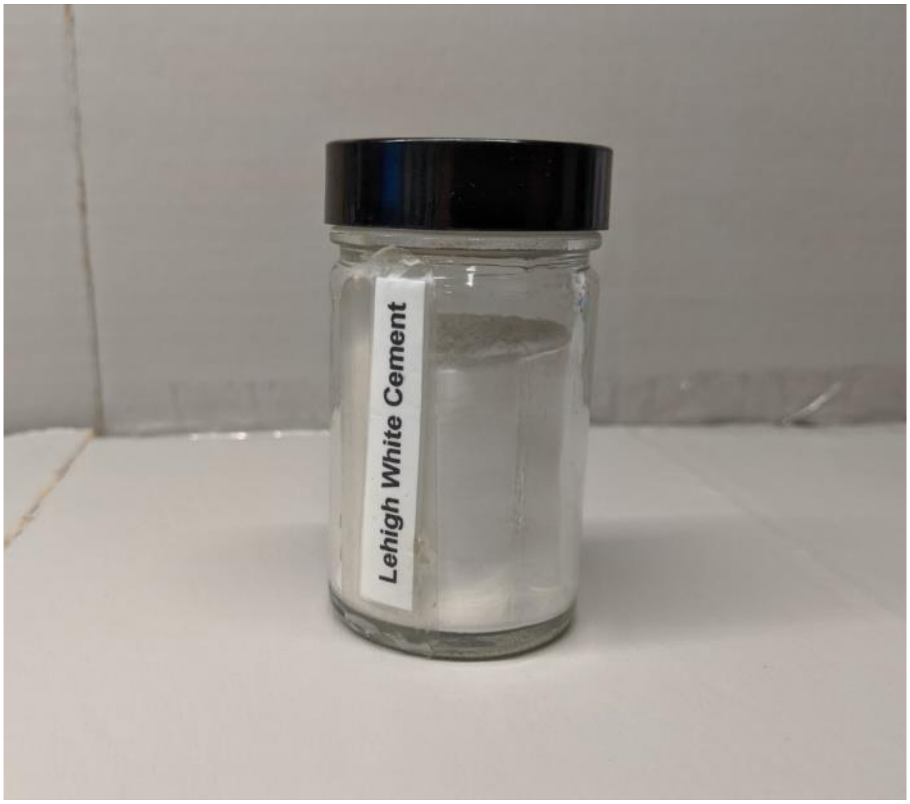
Figure 2-9 Ball mill for grinding cement clinker



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 ($3CaO \bullet SiO_2$ = $\mathbf{C_3S}$)
     - Temperature rise during hydration
     - Contributes to early strength
  2. Dicalcium Silicate ($2CaO \bullet SiO_2$ = $\mathbf{C_2S}$)
     - Similar reaction as C_3S but much slower
     - Contributes to long term strength
  3. Tricalcium Aluminate ($3CaO \bullet Al_2O_3$ = $\mathbf{C_3A}$)
     - Can cause early stiffening without proper gypsum
     - Temperature rise during initial hydration
     - Contributes little to strength
  4. Tetracalcium Aluminoferrite ($4CaO \bullet Al_2O_3 \bullet Fe_2O_3$ = $\mathbf{C_4AF}$)
     - Fairly inert
     - Reduces clinkering temperatures
     - Fe_2O_3 gives cement gray color
     - White cement limits Fe_2O_3 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

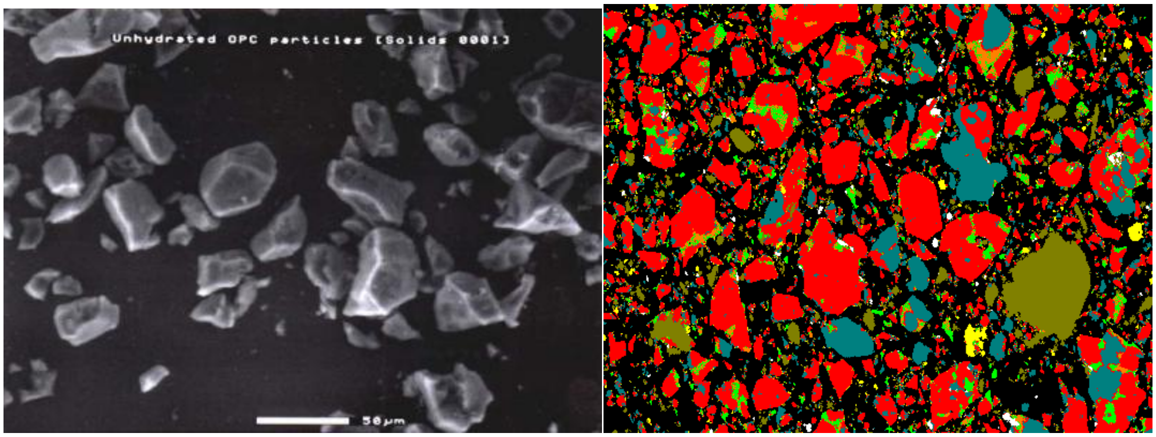
Table 2-1 Five major cement types and their characteristics ASTM C150

Cement Type	Use	Characteristic
I	Normal use	> 8% C_3A
II	Moderate sulfate resistance	< 8% C_3A
III	High early strength	Fine ground type I
IV	Low heat of hydration	< 35% C_3S
V	High sulfate resistance	< 5% C_3A

Table 2-2 Blended cements and their composition ASTM C595

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 (C_3S), Blue (C_2S), Lime Green (C_3A), Orange (C_4AF), 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

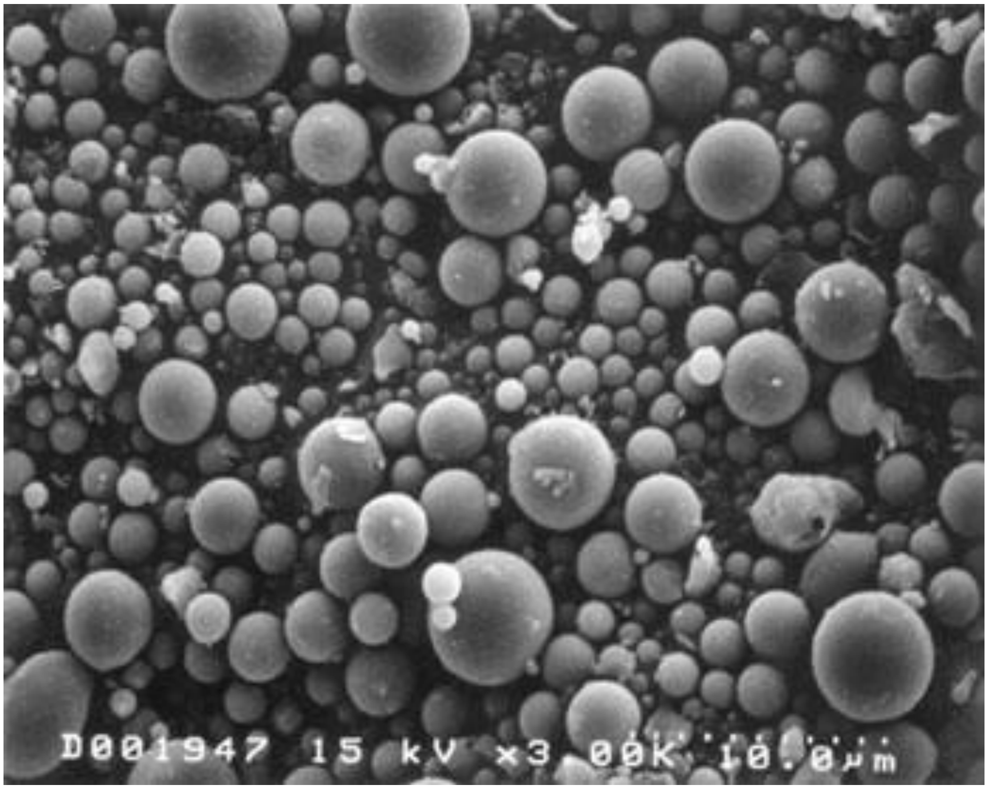


Figure 2-13 Typical coal burning electric power generating station

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

Class	Characteristic
C	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

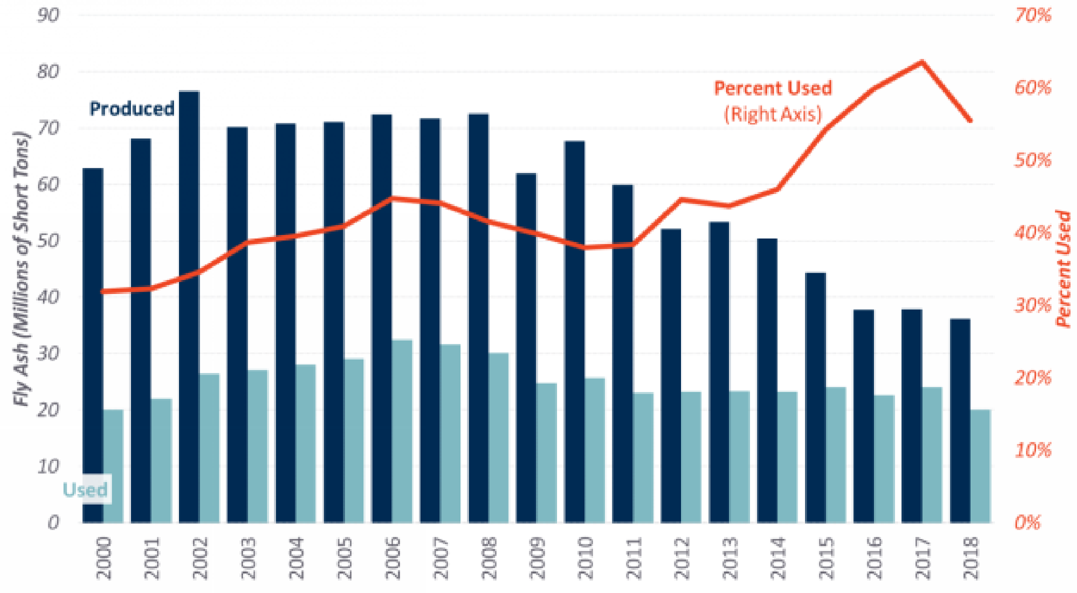
2.2.5. Disadvantages

- 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 (Al), 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 2-16 GGBFS byproduct generation

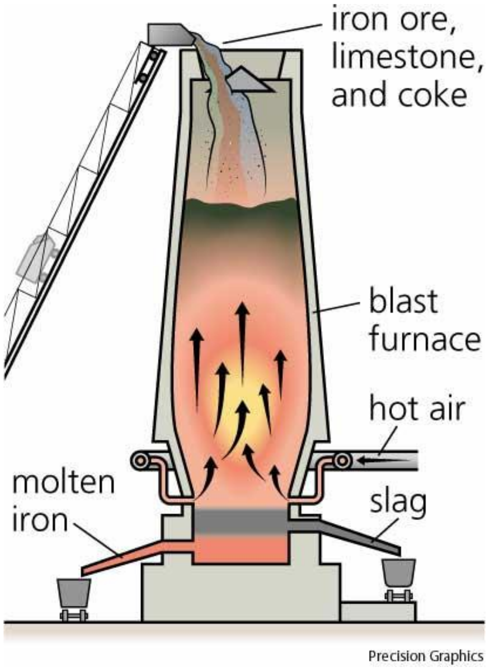
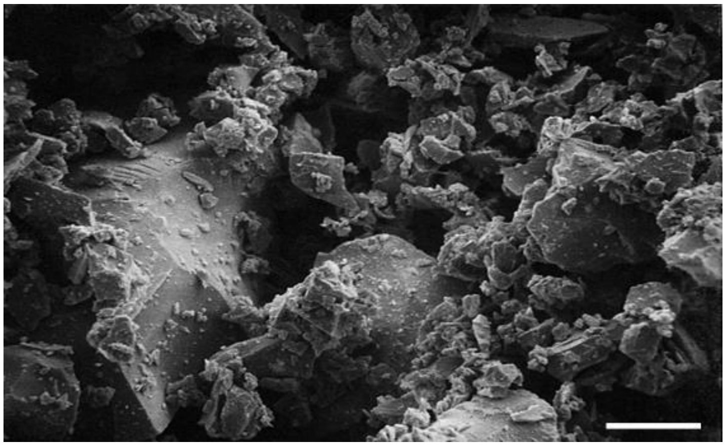


Figure 2-17 Granulated slag and GGBFS

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

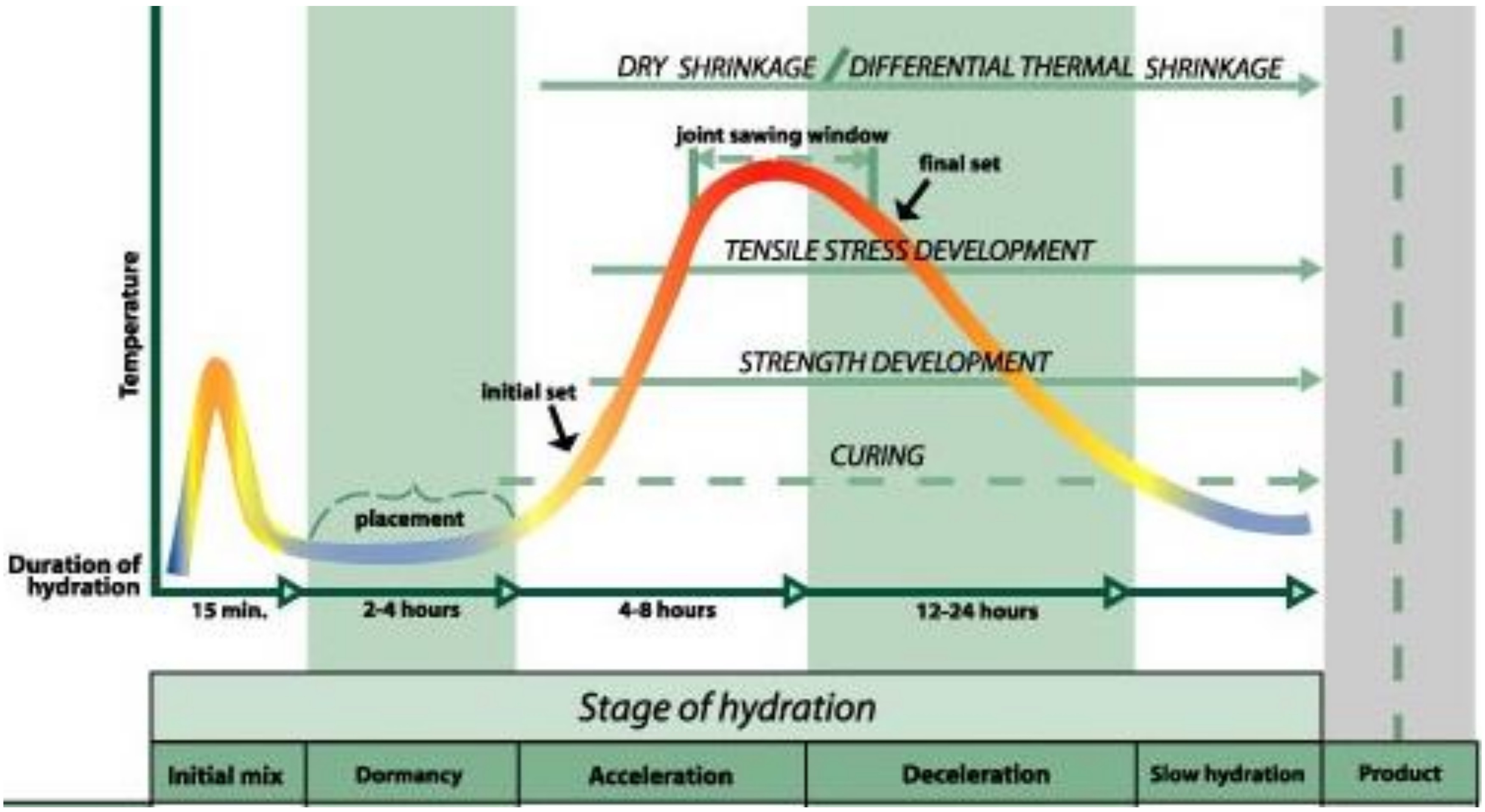
- Calcining is the process of using high temperature to drive off moisture and alter materials (clay and shale) to form a pozzolan
- After calcining the pozzolans are ground to the proper fineness
- Metakaolin is a calcined clay produced from a high purity kaolin clay
- Calcined shale contains calcium 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

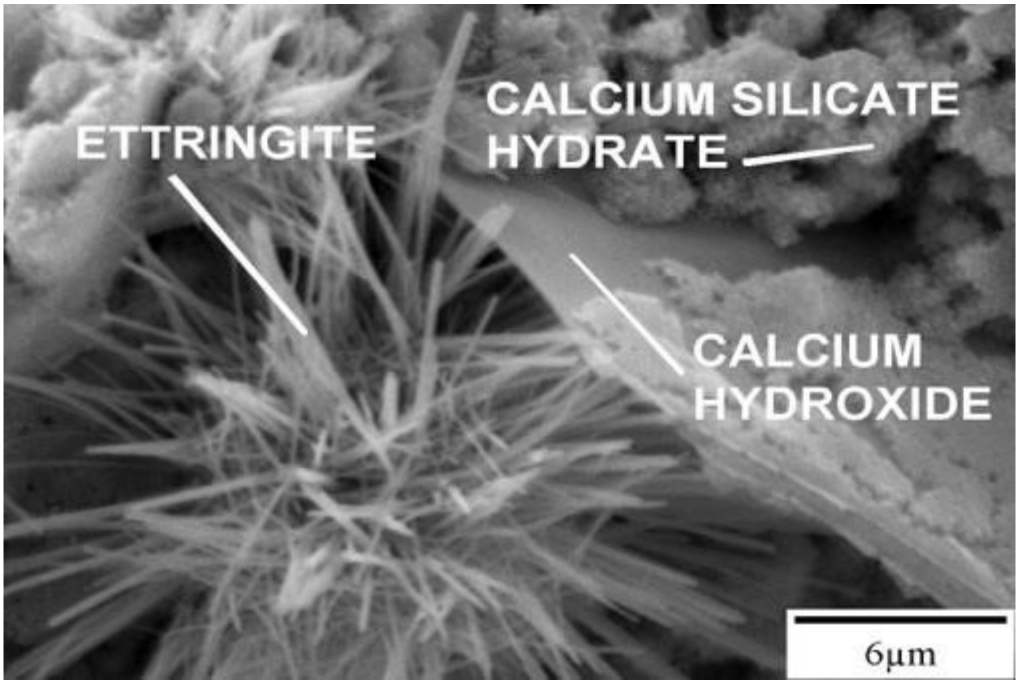
- Portland cement is combined with water to produce a glue or the paste
- Hydration reaction is exothermic, meaning heat is released
- Basic hydration reactions
  - Calcium Silicates + Water => Calcium Silicate Hydrate (CSH) Gel + Calcium Hydroxide (CH)
  - Calcium Aluminates + Gypsum + Water => Ettringite
- Initial set occurs when temperature rises as the C_3S 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



- 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

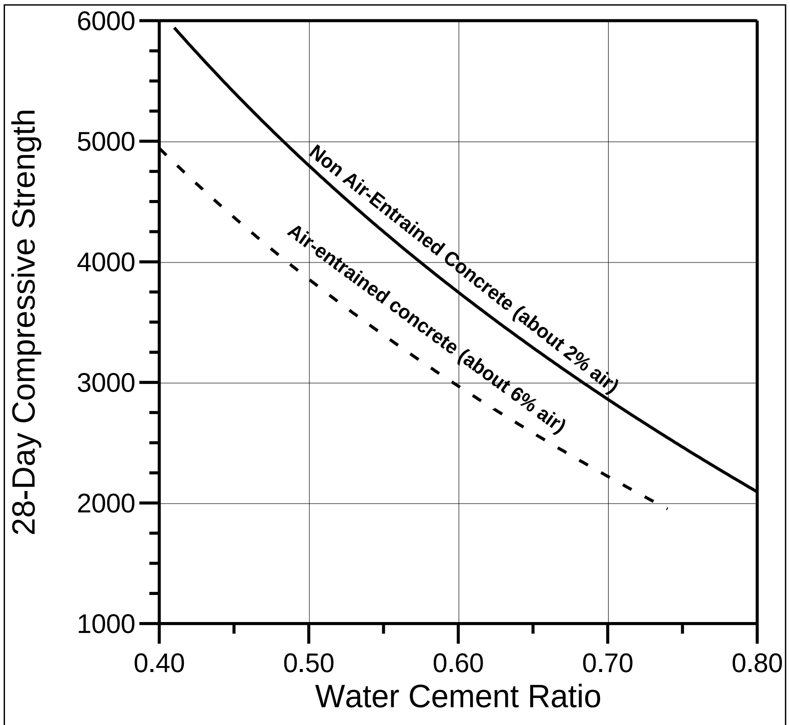
2.7. *Effect of w/c Ratio on Strength and Permeability*

- 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

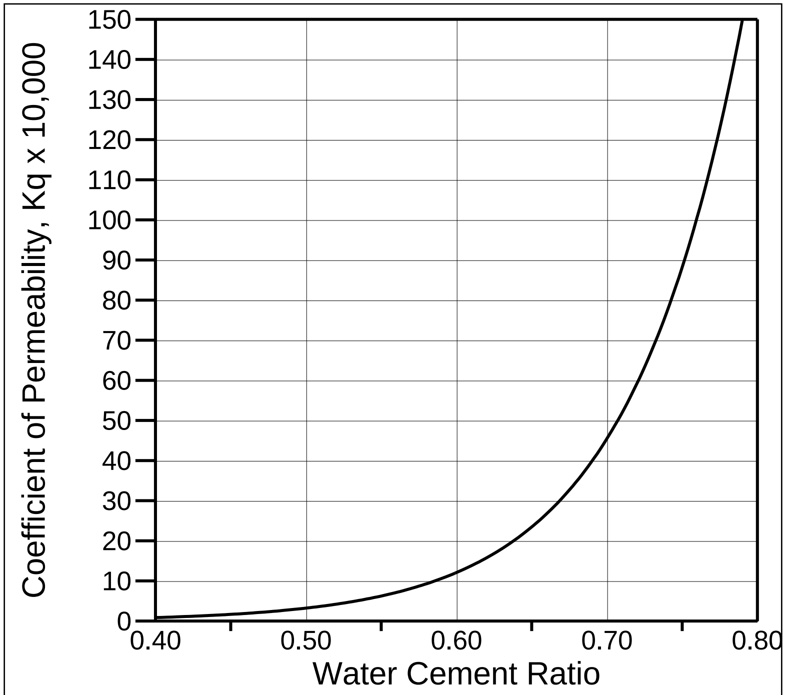
Figure 2-22 Graphical representation of low and high w/c ratio

- 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



Approximate 28-Day Compressive Strength
as a function of Water/Cement Ratio.
Adapted from ACI 211.1-91, Table 6.3.4(a)



Permeability as a function of Water/Cement Ratio.
Data from Bureau of Reclamation Concrete Manual,
8th Edition, 1975, Figure 17, page 37.

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
  - Optimizing cement content for aggregate gradation and size
  - Replacement of cement with SCMs like GGBFS and class F ash
- An acceptable initial mix temperature may be estimated using the following

$$\boldsymbol{Temperature\ rise = 0.16°F\ X\ (C + 0.5\ X\ FA + 0.8\ X\ CA + 1.2\ X\ SF + F\ X\ S)}$$

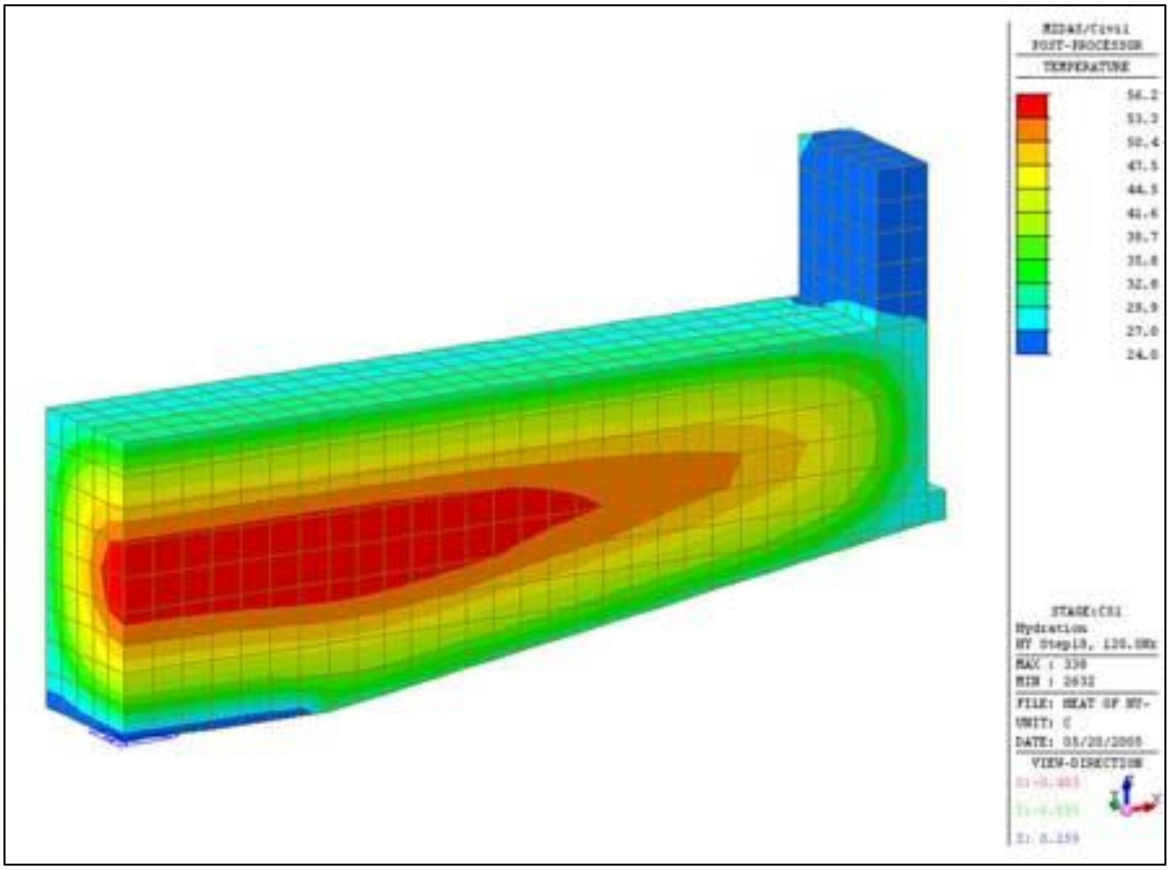
0.16°F rise per 1lb/yd^3 equivalent cement
C is Type I/II cement, lbs/yd^3
FA is Class F fly ash, lbs/yd^3
CA is Class C fly ash, lbs/yd^3
SF is silica fume or metakaolin, lbs/yd^3
F is the equivalent cement factor based on the percent GGBFS replacement
S is GGBFS, lbs/yd^3

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

$$\boldsymbol{Initial\ temperature\ °F = Maximum\ temperature\ °F - Temperature\ rise\ °F}$$

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 CO_2 in the atmosphere and CH which decomposes into calcium carbonate

Figure 2-25 Relative magnitudes of different types of shrinkage

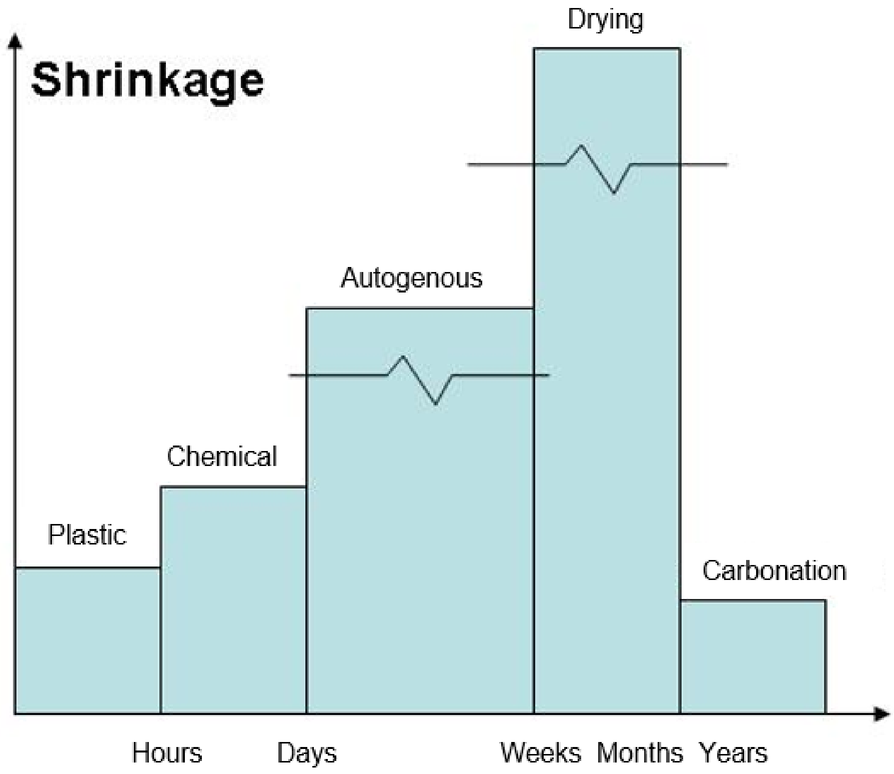
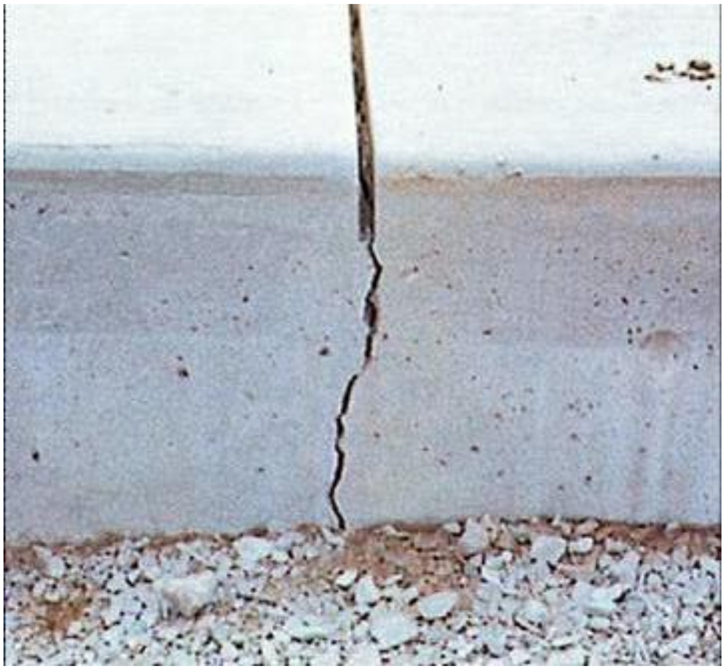


Figure 2-26 Plastic shrinkage cracks form perpendicular to wind direction

- Mitigation methods:
  1. 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

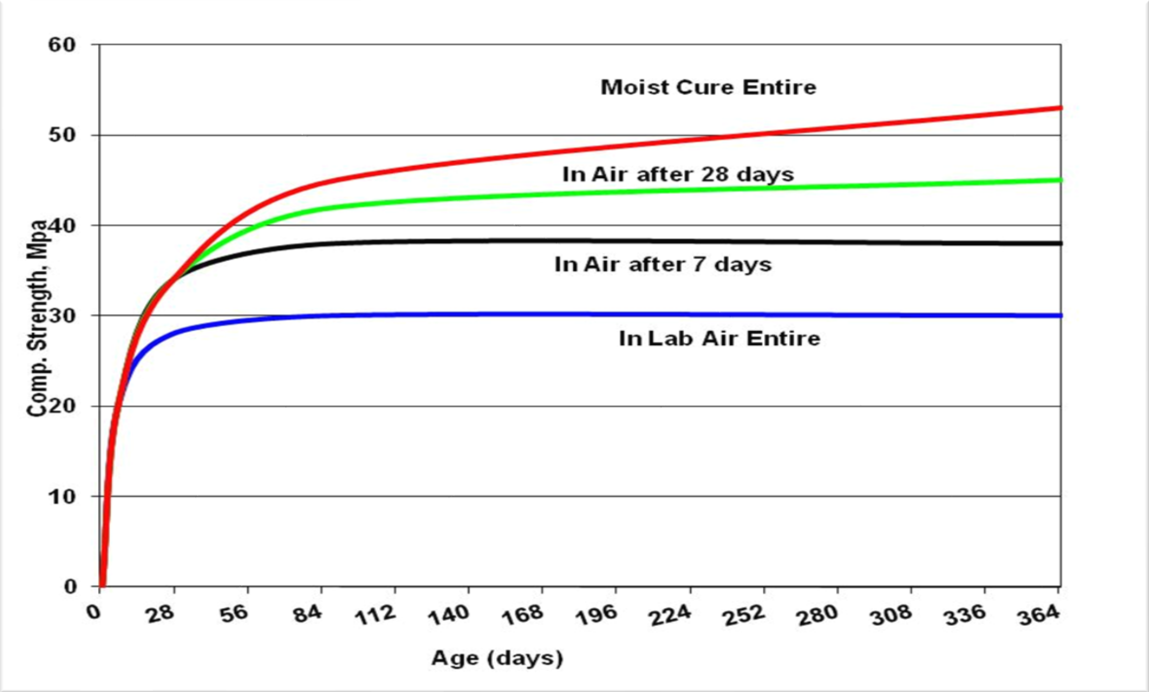
- Cement content should be optimized to provide the needed workability for the placement technique and element being constructed while maintain the desired w/c ratio for adequate strength and permeability
- Perfect optimization of cement allows paste (cement and water) to coat all particles and fill 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/yd^3 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/yd^3 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/yd^3
- 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

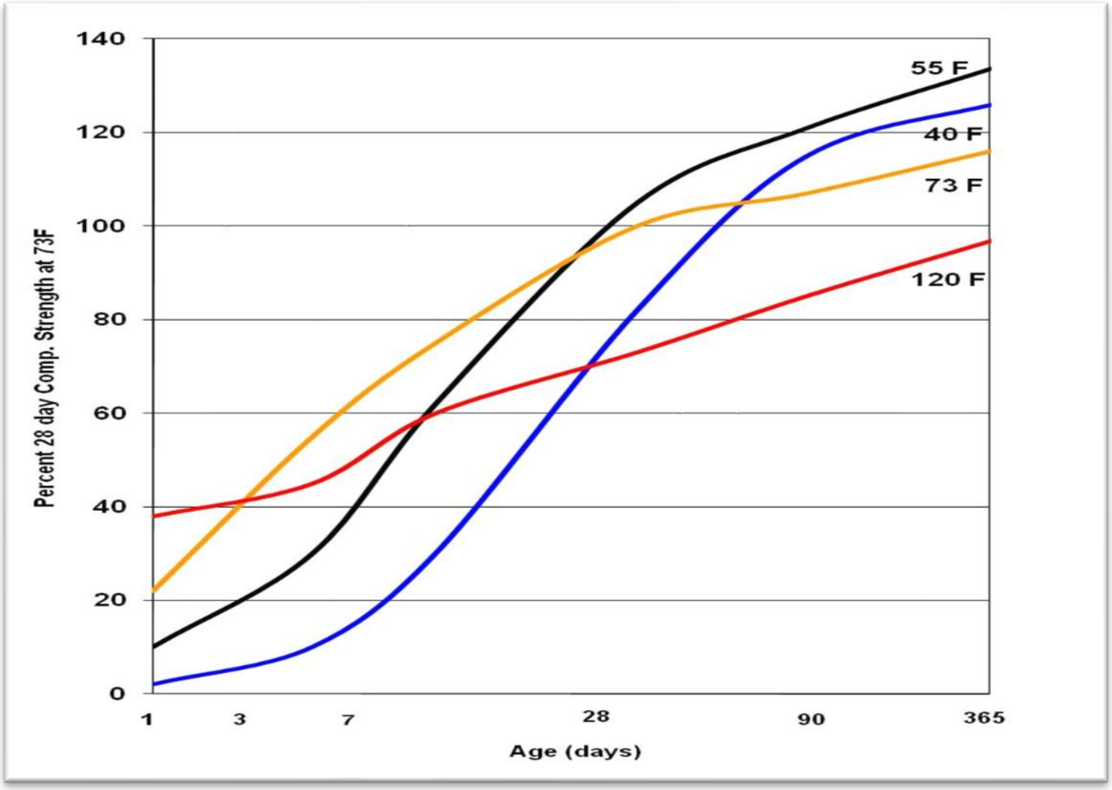
- Proper curing of concrete ensures adequate moisture and temperatures are maintained at early ages for continued hydration and development of strength, resistance to freezing, volume stability, and scaling resistance
- Air dried concrete hydrates for a short amount of time resulting in reduced strengths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

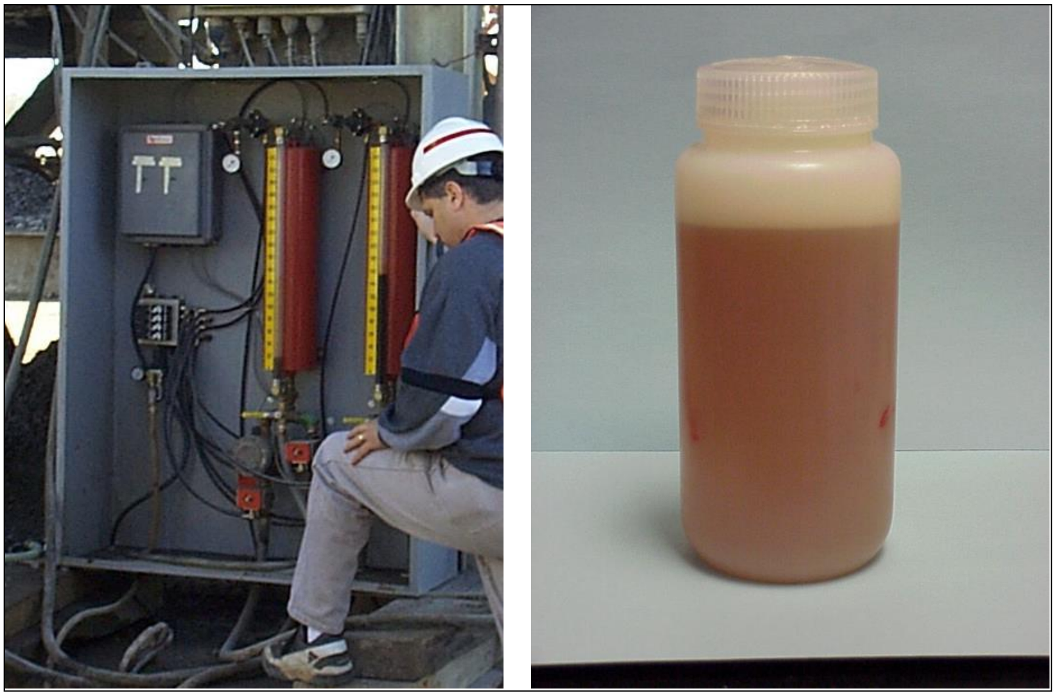
3. Chemical Admixtures

- 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

Table 3-1 I.M. 403 Appendix summary

Appendix	Admixture	Intent	Application
A	Air entraining	Entrain air	All
B	Retarding and water reducing	Retard and reduce water demand for extended working time	Bridge decks and drilled shafts
C	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

Figure 3-1 Chemical admixture and dispensing equipment

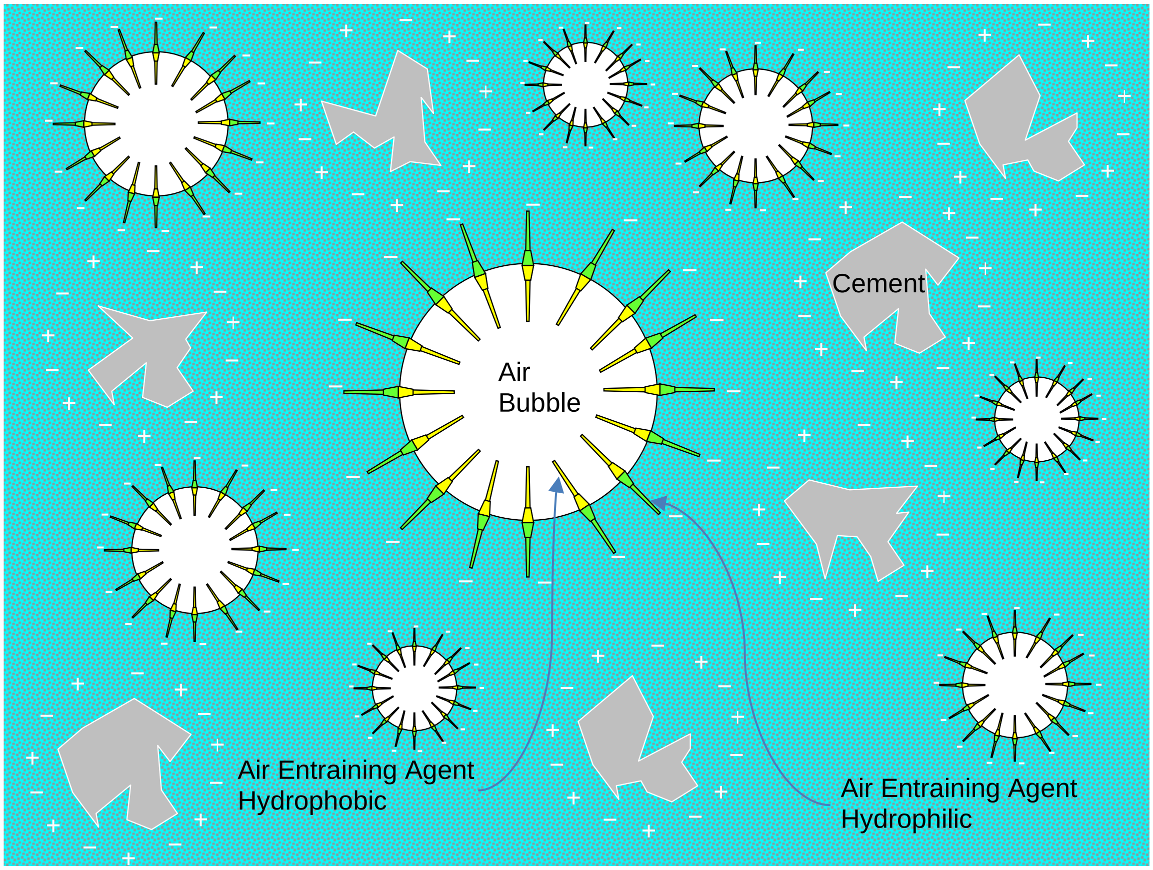


3.1. Air Entraining

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

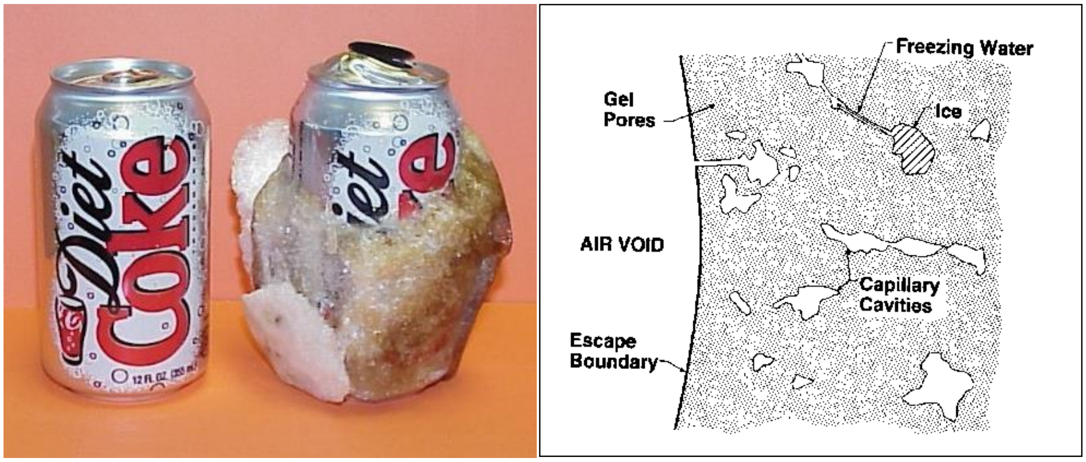
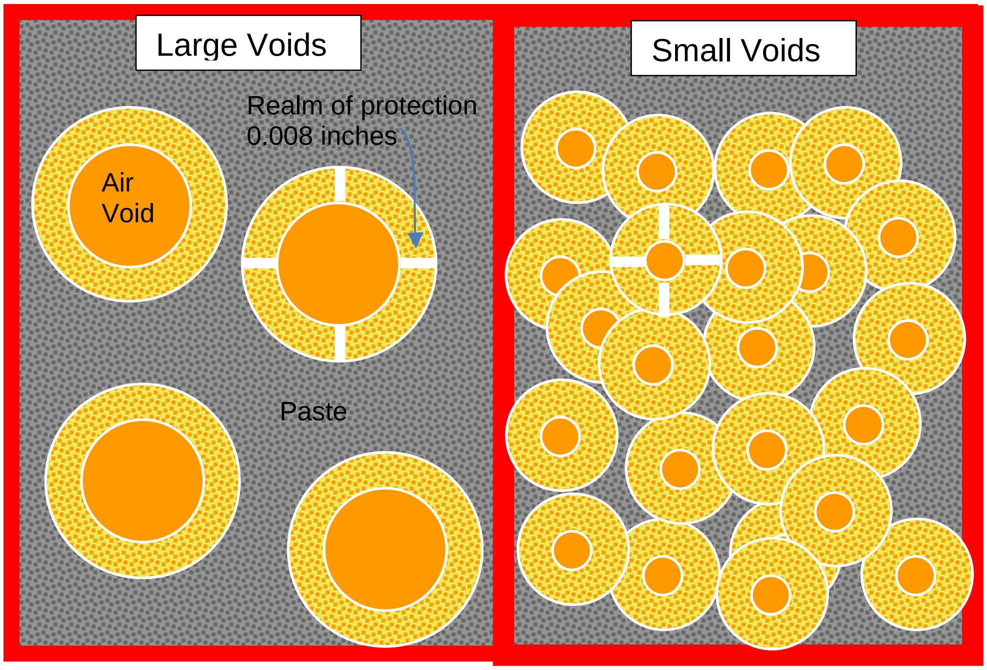


Figure 3-4 Example of freeze thaw damage on five-year-old pavement

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 in-place 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

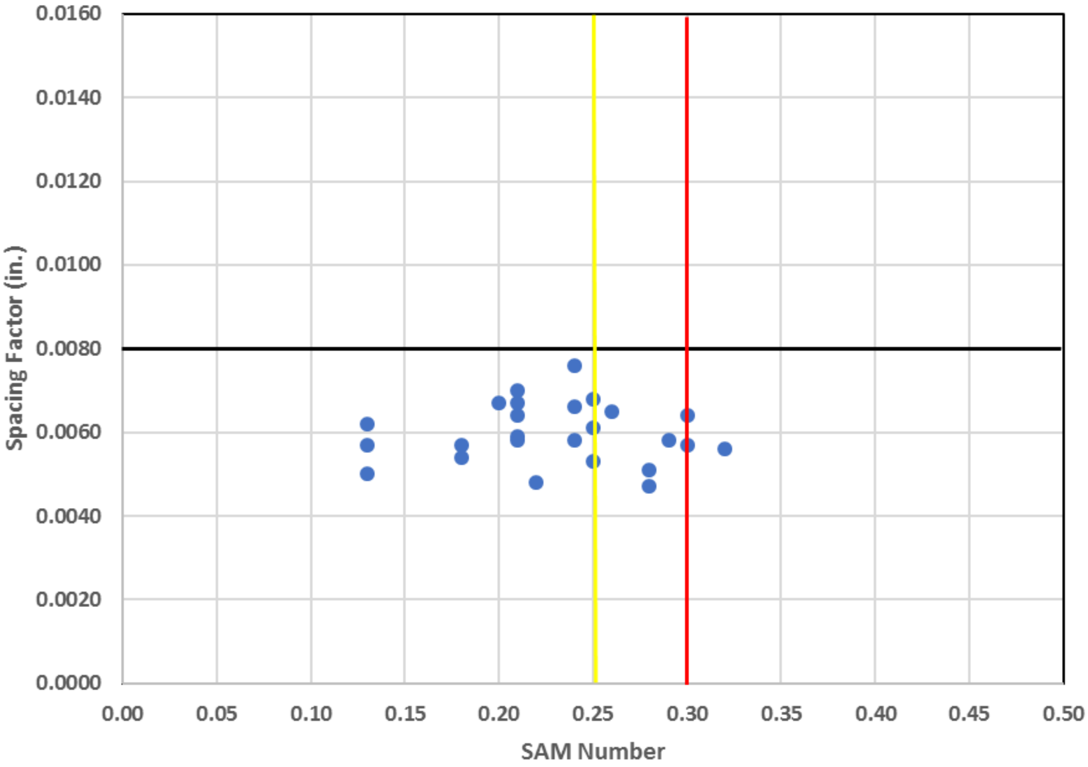
Figure 3-5 Air size distribution effect on paste protection



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

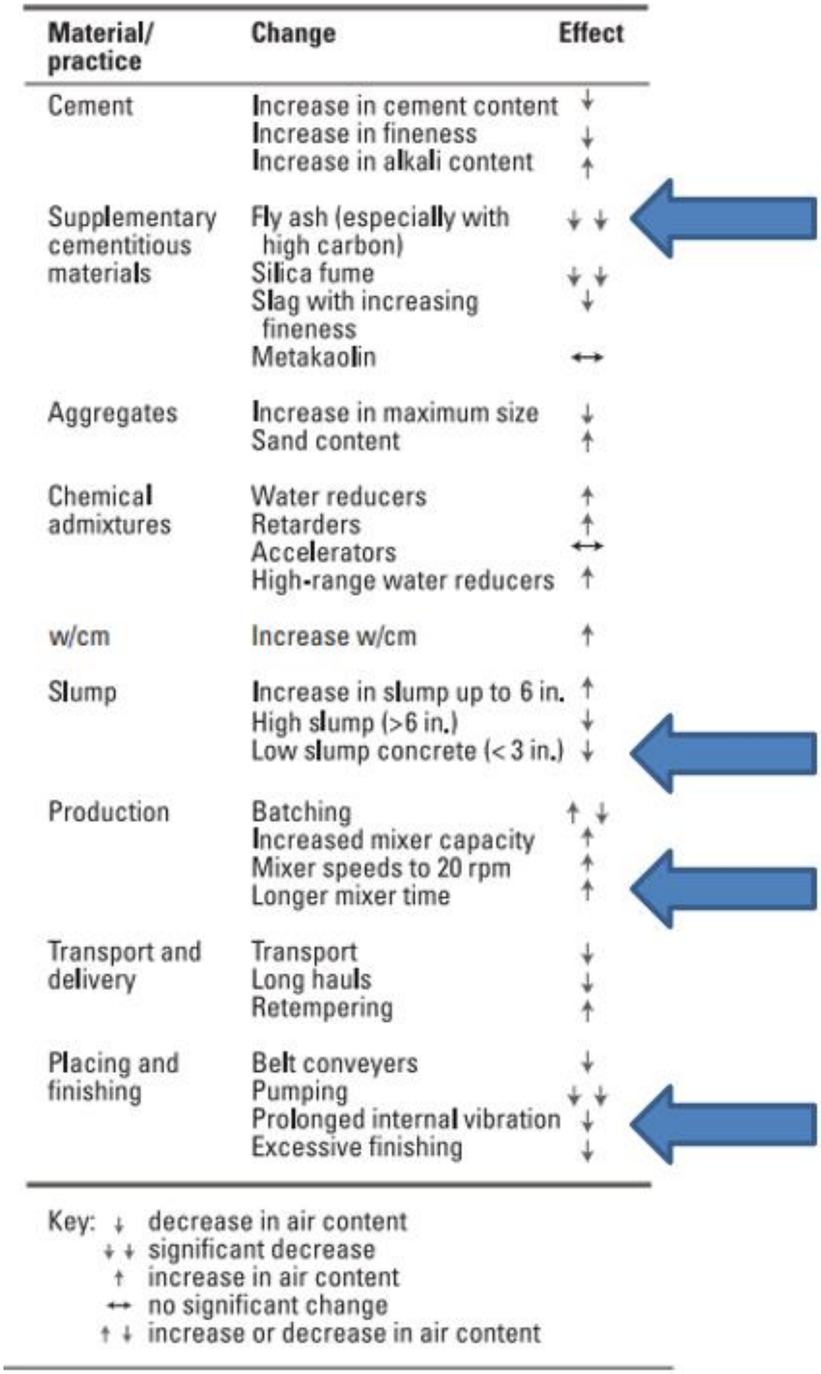
Figure 3-6 Spacing factor versus SAM number Iowa DOT Q-MC mix



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	↑
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	↑
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	↑
Placing and finishing	Belt conveyers	↓
	Pumping	↓ ↓
	Prolonged internal vibration	↓
	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

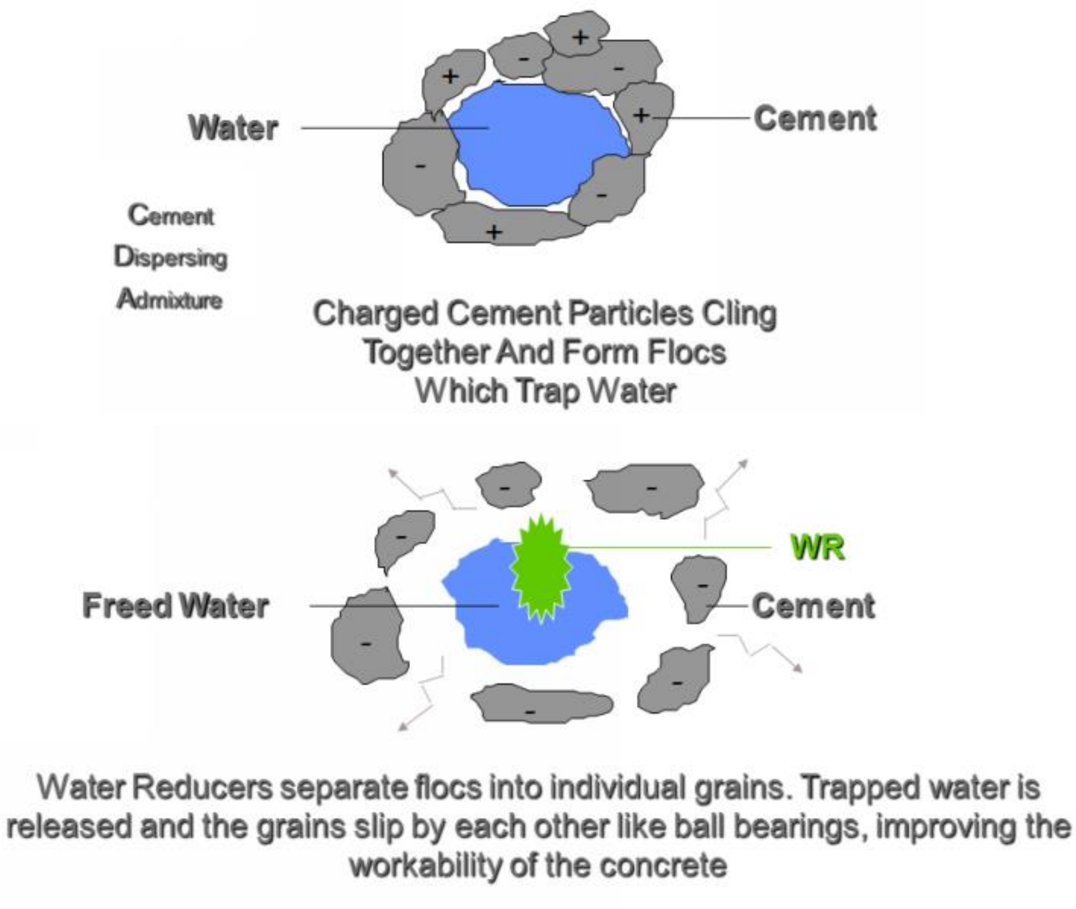
- Reduce the quantity of water required to achieve a given degree of workability
- Can be used in three ways:
    1. Same amount of cement but a reduced amount of water
        - Water reducing
        - W/C ratio reduced and workability remains the same
        - Improved concrete quality
    2. Cement and water are reduced by same proportion
        - Cost reducing
        - W/C ratio and workability are maintained
        - 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

Type	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



Charged Cement Particles Cling Together And Form Flocs Which Trap Water

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

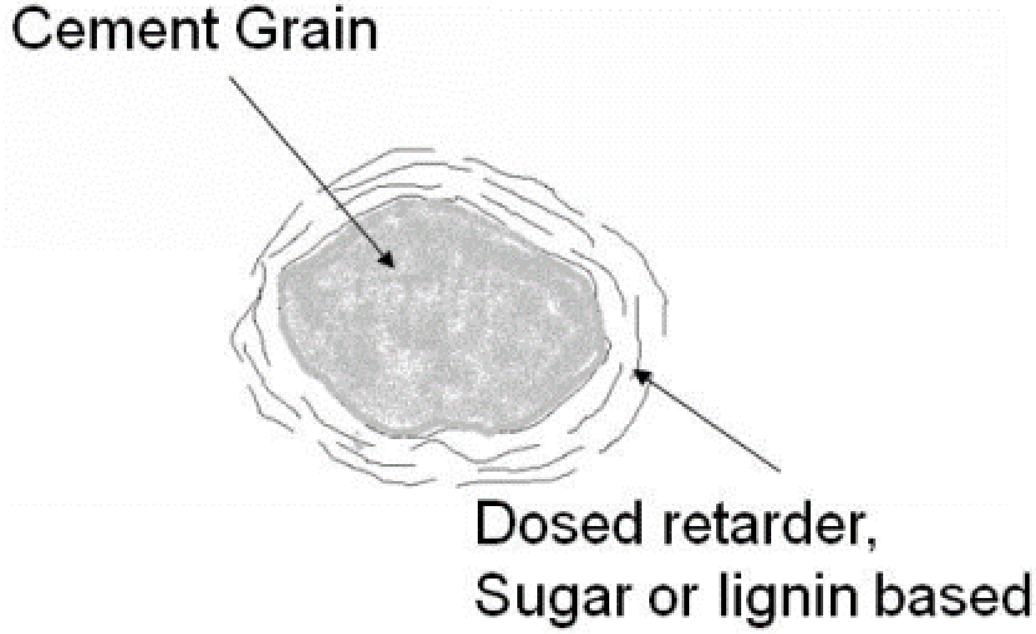
- Multiple effects of water reducers include increased air content and retardation of hydration
- High range water reducers may entrain larger bubbles and cause air instability
- ASTM C 494 specification requirements

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 ($CaCl_2$), 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 (C_3S) reacts with water
- Increased C_3S 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
    - Liquid or powder pigments in the desired color

CHAPTER 4

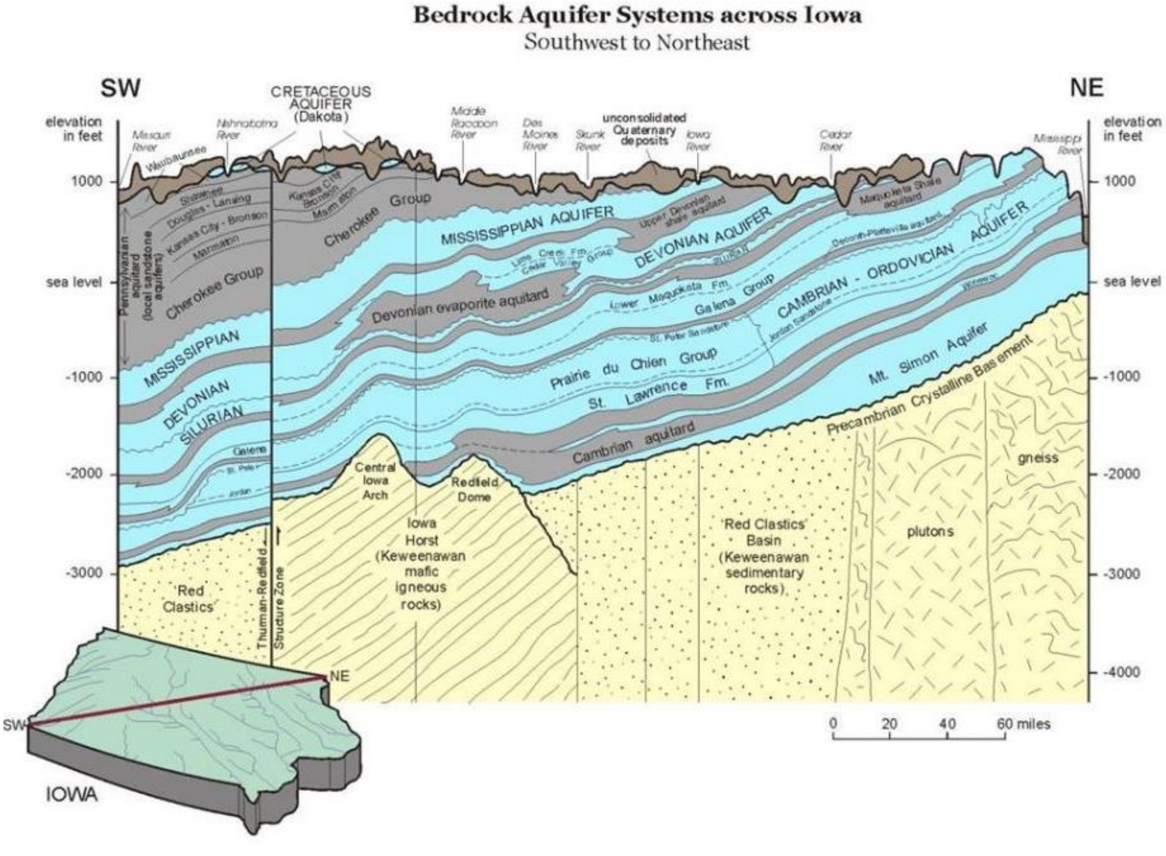
AGGREGATE

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 Iowa



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 ½ 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 ½ 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

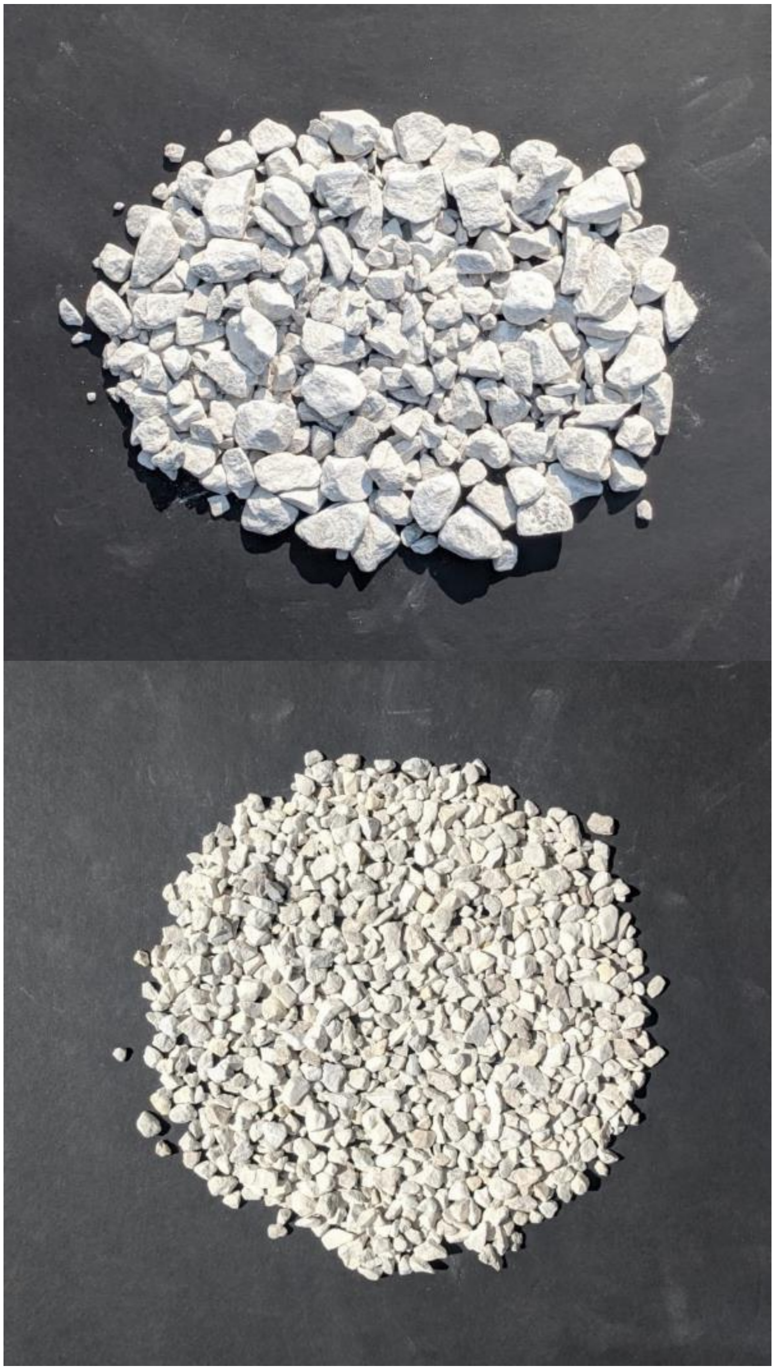
- For normal strengths concrete, the ideal aggregate shape and texture for optimizing paste content while providing the desired workability is smooth and rounded
- Relationships between texture and shape and paste required to provide a desired workability is more critical for intermediate aggregate due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

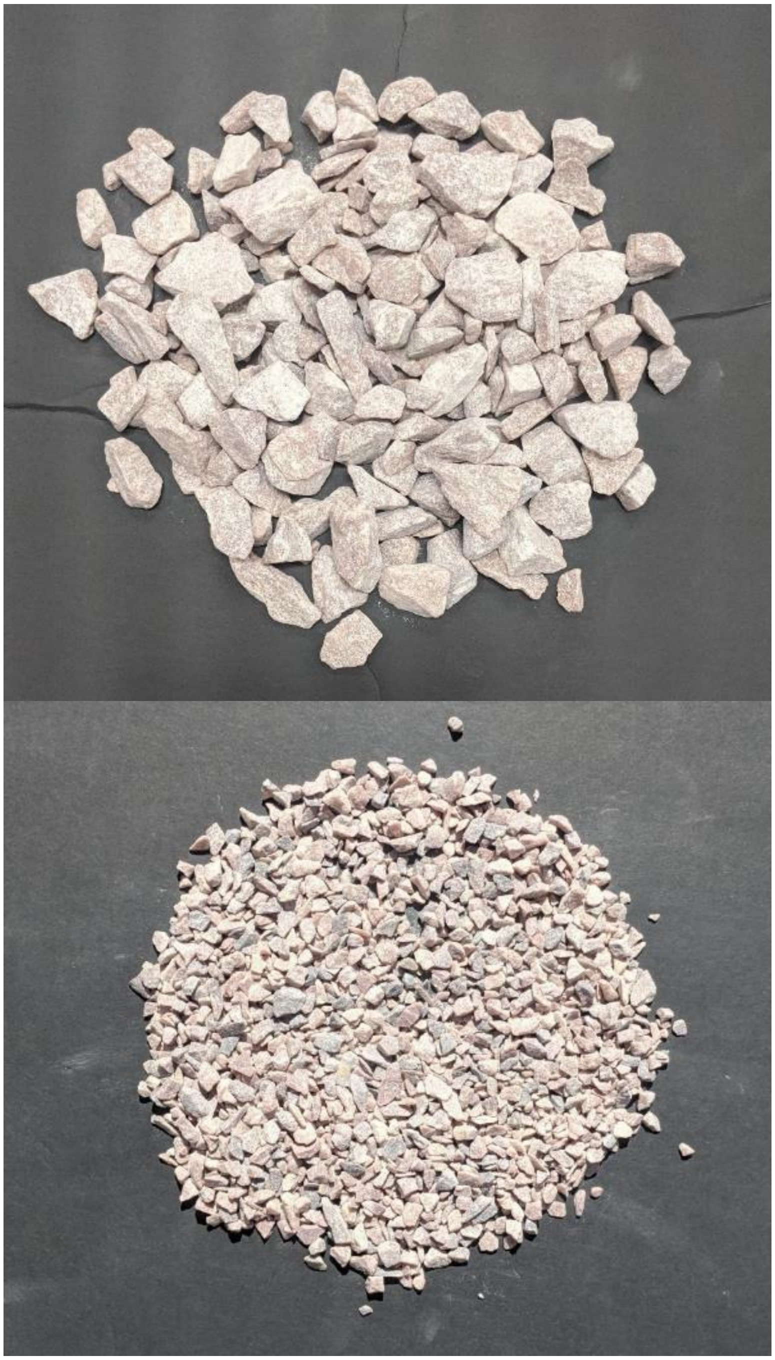
- Slightly rough and cubical particles will require more paste to be coated and fill void space between adjoining particles while providing workability
- Crushed limestone is typically slightly rough and cubical

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)

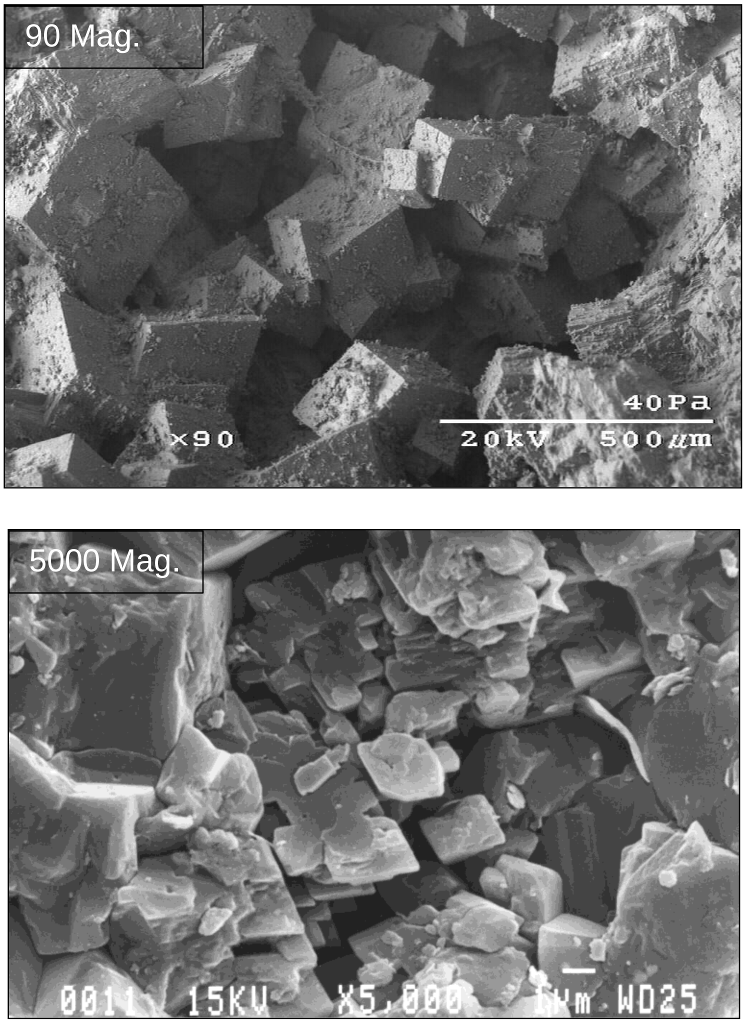


Figure 4-7 D-cracking deterioration

4.2.6. Deleterious Materials

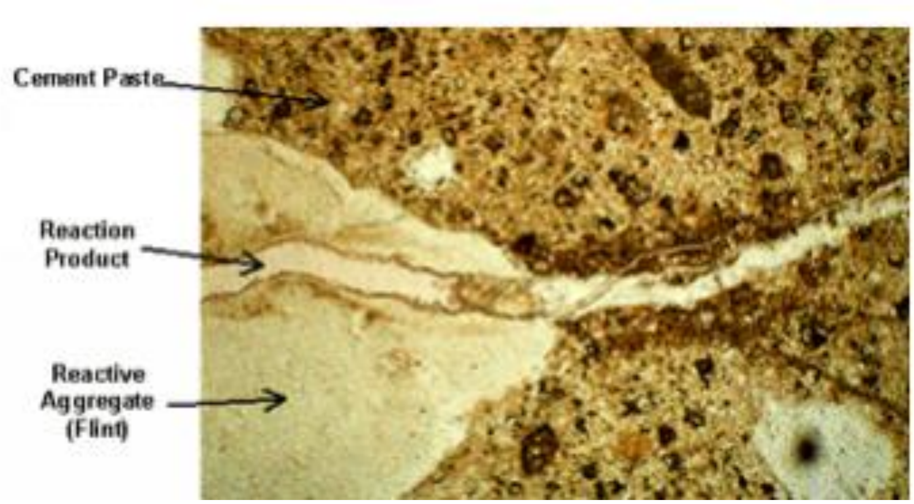
- Aggregate impurities that adversely affect concrete performance and/or appearance
- Coal, shale, chert, and other organic materials are the primary deleterious materials
- Readily absorb moisture and degraded or experience disruptive expansion when freezing in a moist state
- Coal and shale are light 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
- Iowa 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

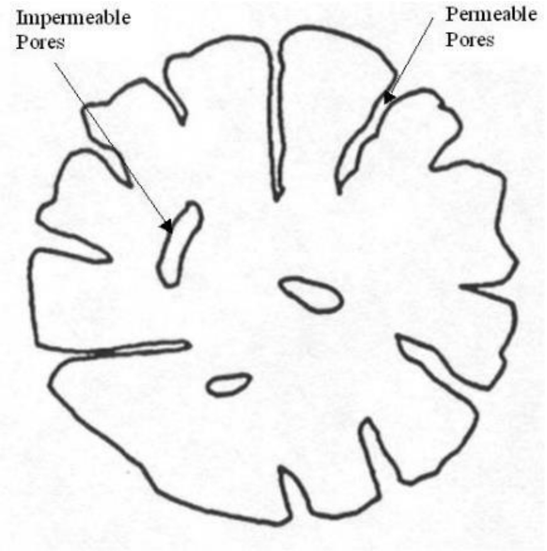
- Classes are assigned based on physical and chemical testing
- Physical testing includes the Iowa Pore Index test
- Chemical testing includes X-ray fluorescence and diffraction for mineralogy makeup and X-ray fluorescence for clay content
- Physical and chemical test results are used to calculate a 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

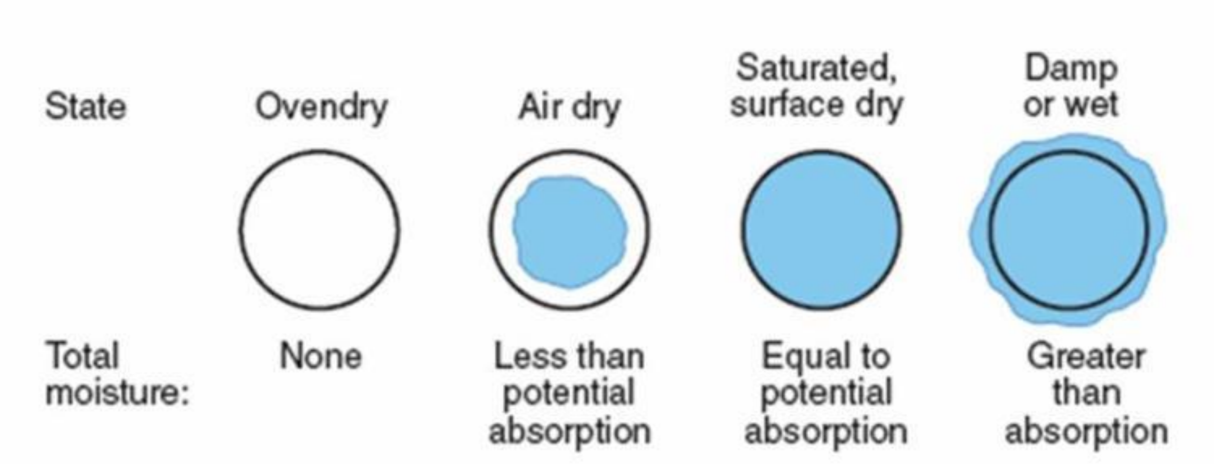
Figure 4-10 Porous aggregate with permeable and impermeable pores



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

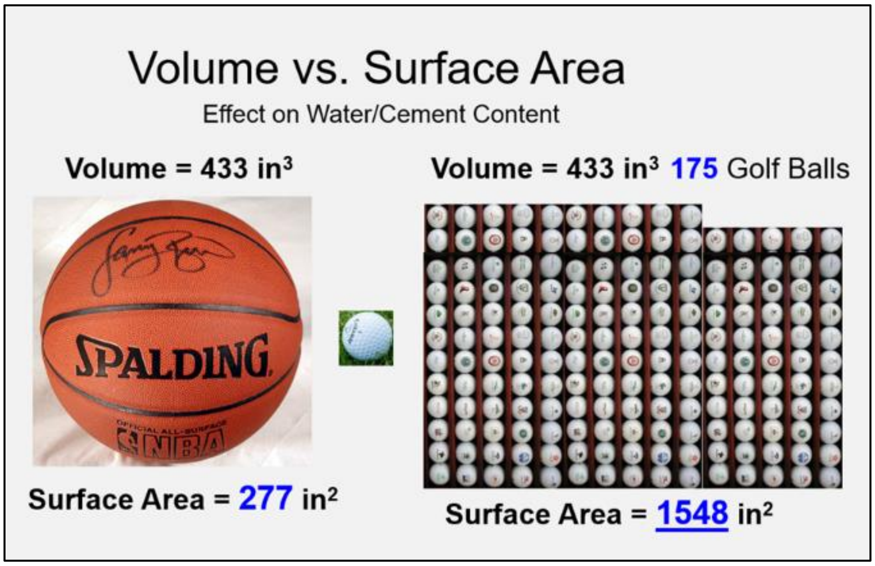
4.4.2. Nominal Maximum Aggregate Size

- 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



Volume vs. Surface Area

Effect on Water/Cement Content

Volume = 433 in^3

Volume = 433 in^3 **175** Golf Balls

Surface Area = 277 in^2

Surface Area = 1548 in^2

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

Example: FM calculation

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		**2.83**

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 (Iowa 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)
    - 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

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

Sieve Size	ASTM #57 Iowa DOT No. 3	ASTM #67 Iowa DOT No. 5	ASTM	Iowa DOT No. 1
	Coarse	**Coarse**	**Fine**	**Fine**
1.5”	100			
1.0”	95 to 100	100		
¾”		90 to 100		
½”	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	

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

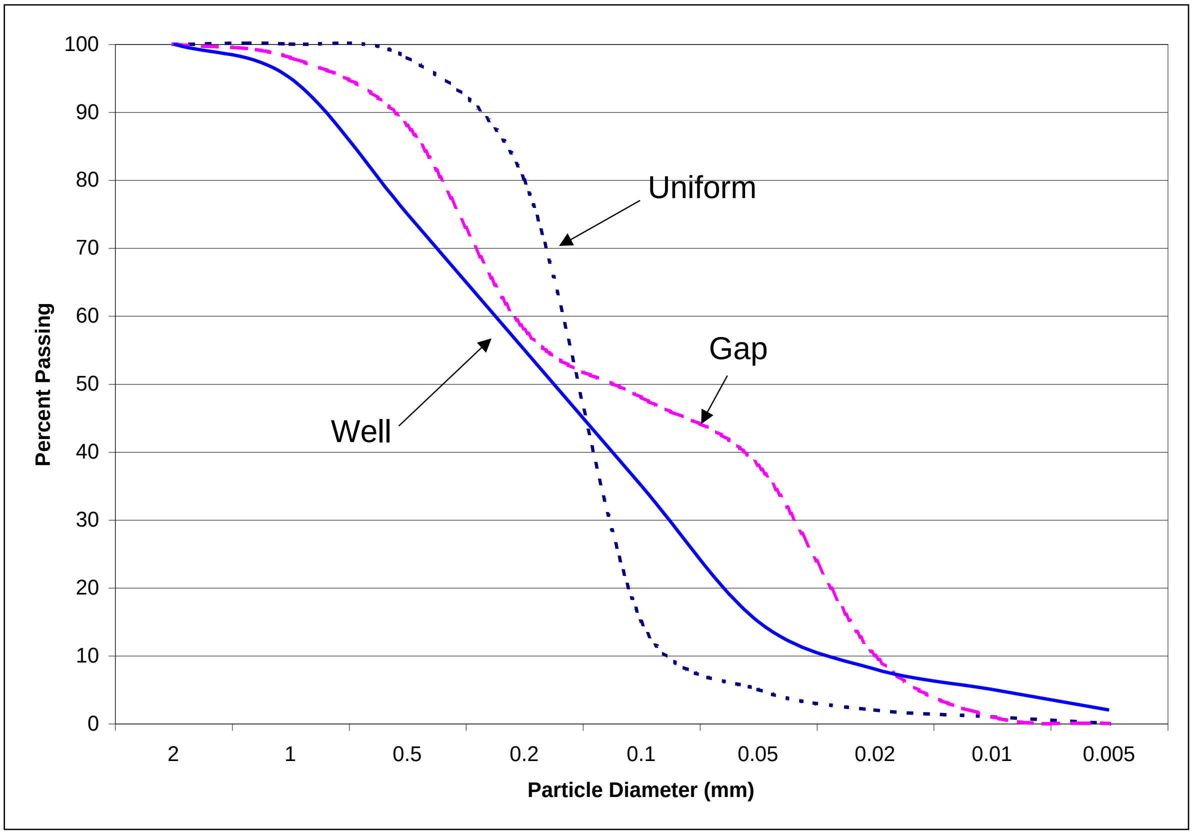
4.4.7.2. Gap graded

- 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

Example: mathematically combined grading

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
¾”	75.0	100.0	100.0	88.0	99-88 = 11.0
½”	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 = 11.3
#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

Combined percent passing calculations
1 ½”   100x0.48 + 100x0.12 + 100x0.40 = 100
1”   98x0.48 + 100x0.12 + 100x0.40 = 99.0
¾”   75x0.48 + 100x0.12 + 100x0.40 = 88.0
½”   38x0.48 + 100x0.12 + 100x0.40 = 70.2
3/8”   21x0.48 + 86x0.12 + 100x0.40 = 60.4
#4   4.0x0.48 + 21x0.12 + 92x0.40 = 41.2
#8   1.8x0.48 + 4.1x0.12 + 82x0.40 = 34.2
#16   1.6x0.48 + 3.7x0.12 + 66x0.40 = 27.6
#30   1.5x0.48 + 3.3x0.12 + 42x0.40 = 17.9
#50   1.3x0.48 + 2.9x0.12 + 14x0.40 = 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
- Tarantula curve, percent retained, and 0.45 power curve may be used to identify issues with individual sieves

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

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

$$\textbf{\textit{Workability factor}} = \textit{Combined percent pas} \sin g \;\; \#8 \; \textit{Sieve}$$

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**
¾”	75.0	100.0	100.0	88.0	**11.0**
½”	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**	**7.0**
#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

$$\text{Coarseness factor} = \frac{\mathbf{0+1+11+17.8+9.8}}{\mathbf{0+1+11+17.8+9.8+19.2+7.0}} \text{ X } 100$$

$$= \frac{\mathbf{39.6}}{\mathbf{65.8}} \text{ X } 100$$

$$= \underline{\underline{60.2}}$$

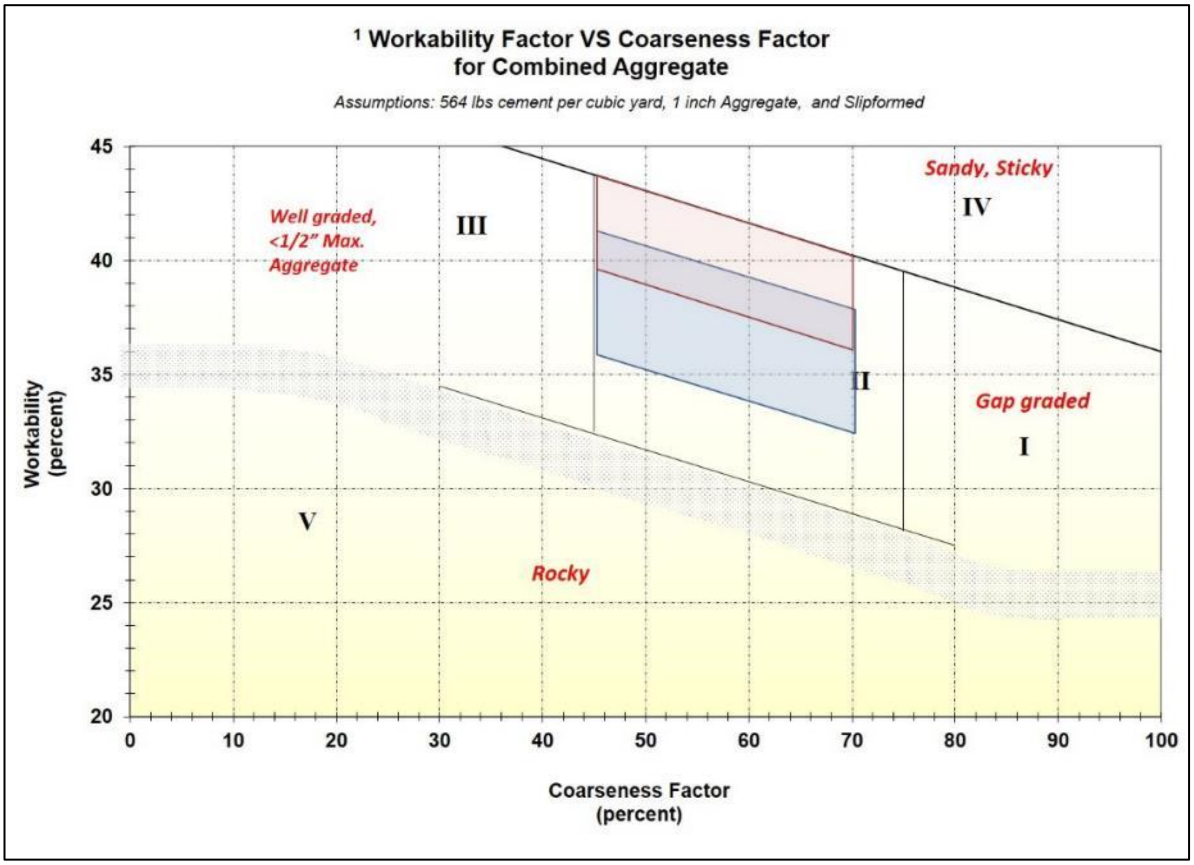
$$\text{Workability factor} = \underline{\underline{34.2}}$$

4.4.11. Shilstone CW Chart

- Assumptions
    - Cementitious content is 564 lbs/yd^3
        - For every 94 lbs of cementitious below or above 564 lbs/yd^3 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
    - 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 ¾” to 1 ½” 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 ½”
- 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 nominal maximum aggregate sizes of 1 ½”, 1”, and ¾”
- 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
- Gradation line may fall between two maximum density lines, means top size between. Acceptable as long as 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

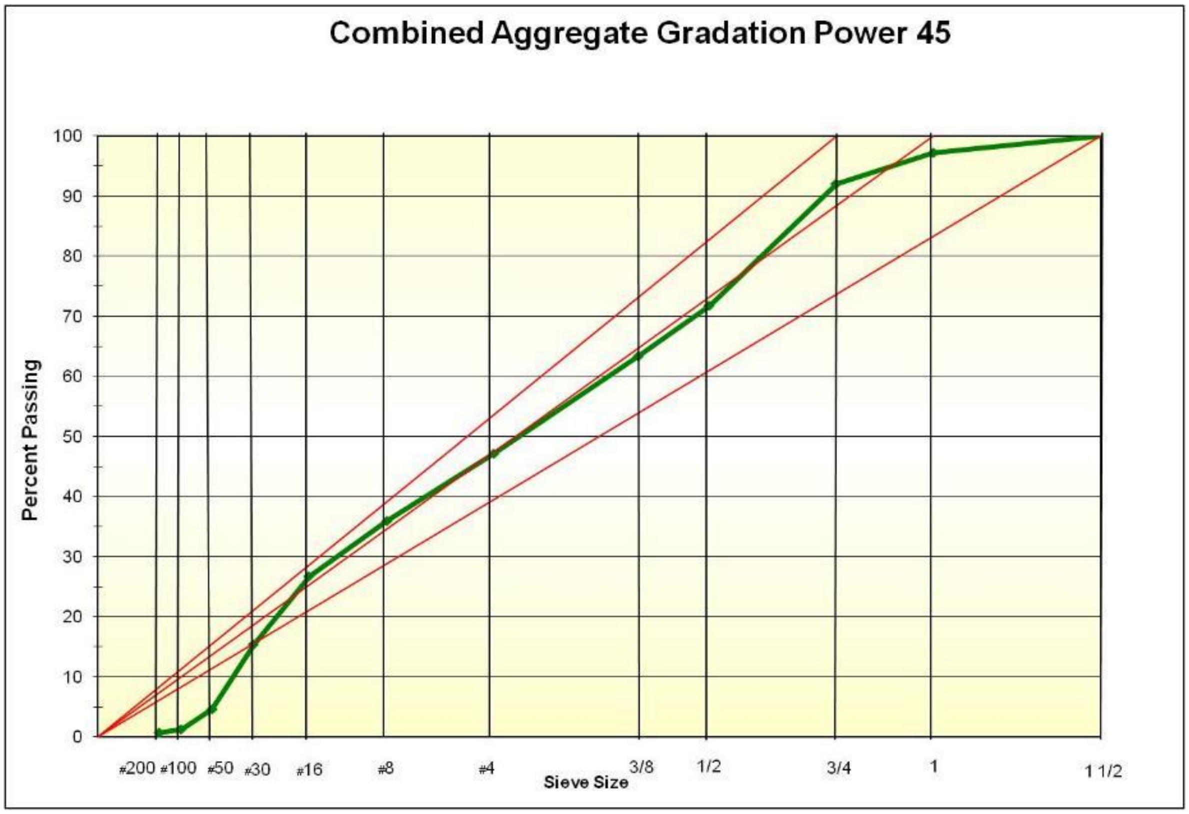
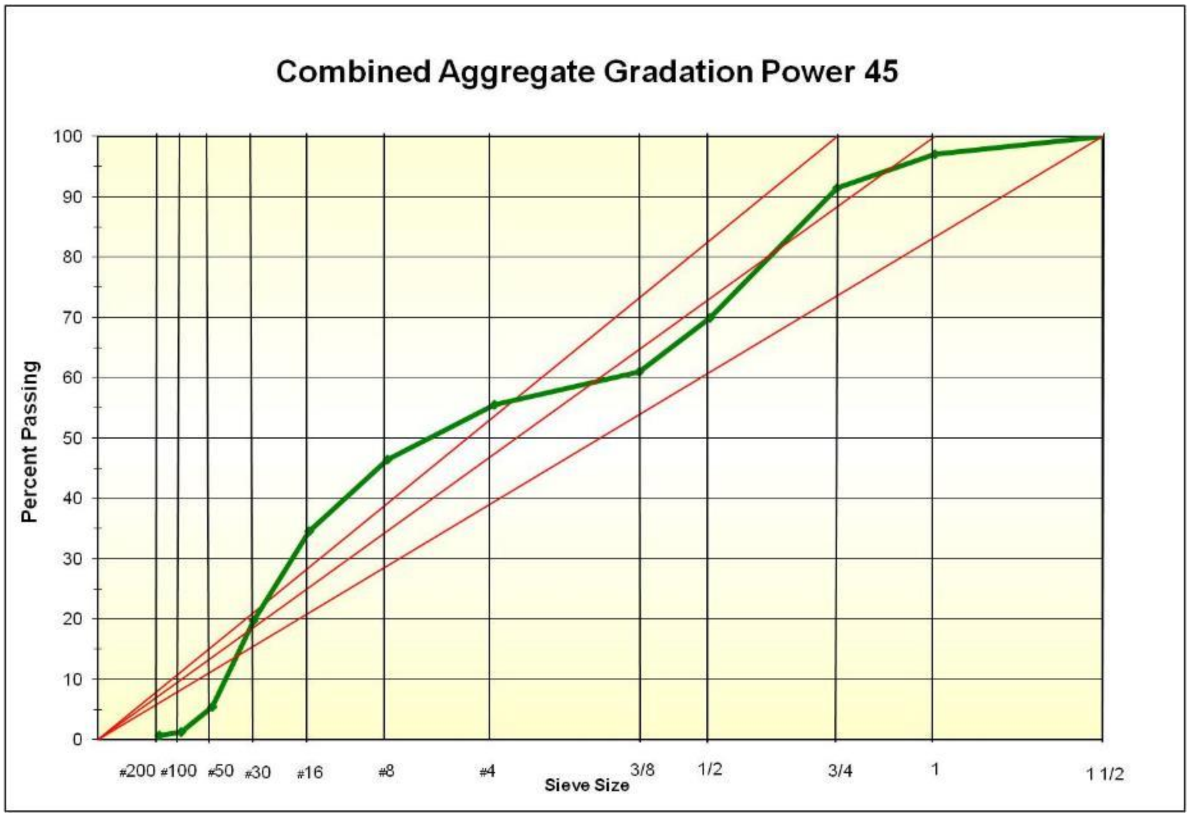


Figure 4-16 0.45 power curve for a gap graded combined aggregate



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

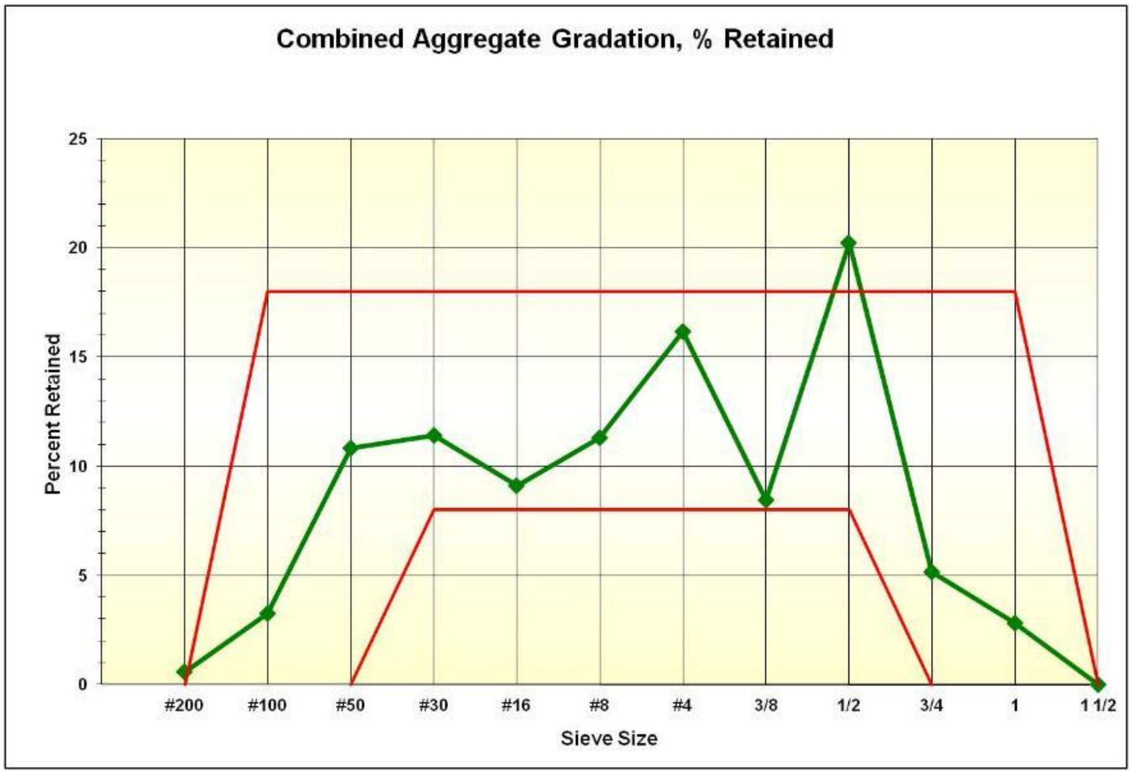
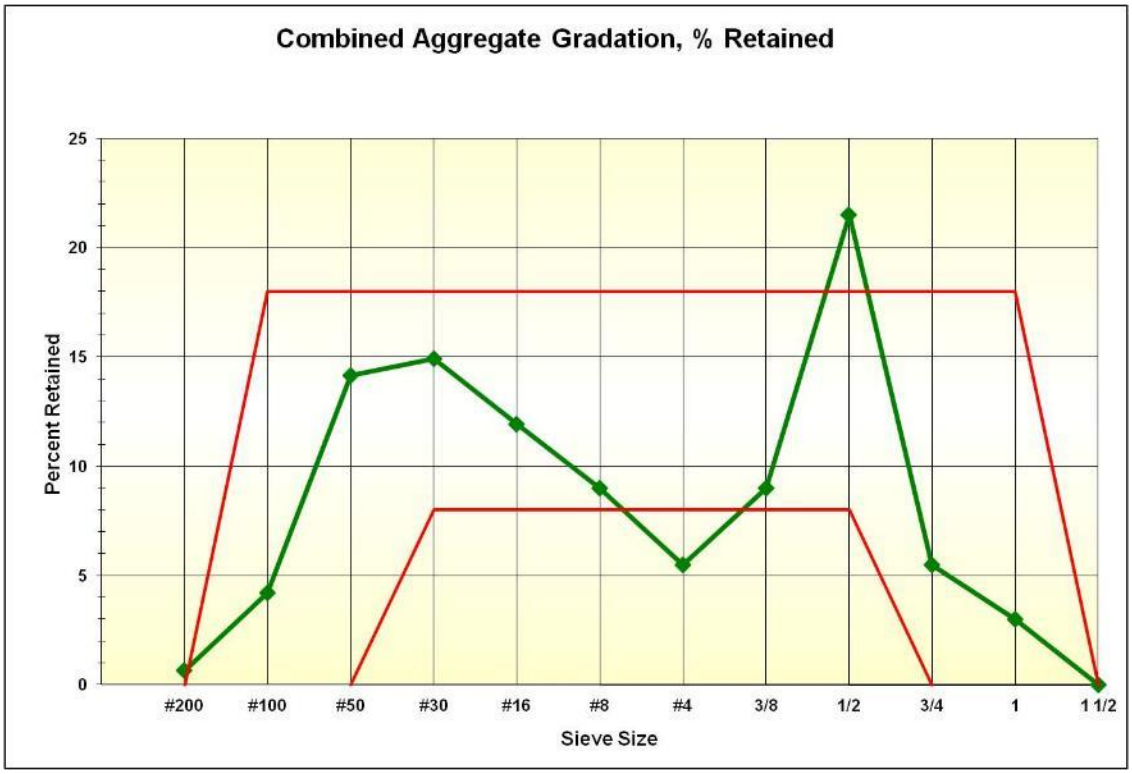


Figure 4-18 Percent retained chart for a gap graded combined aggregate



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

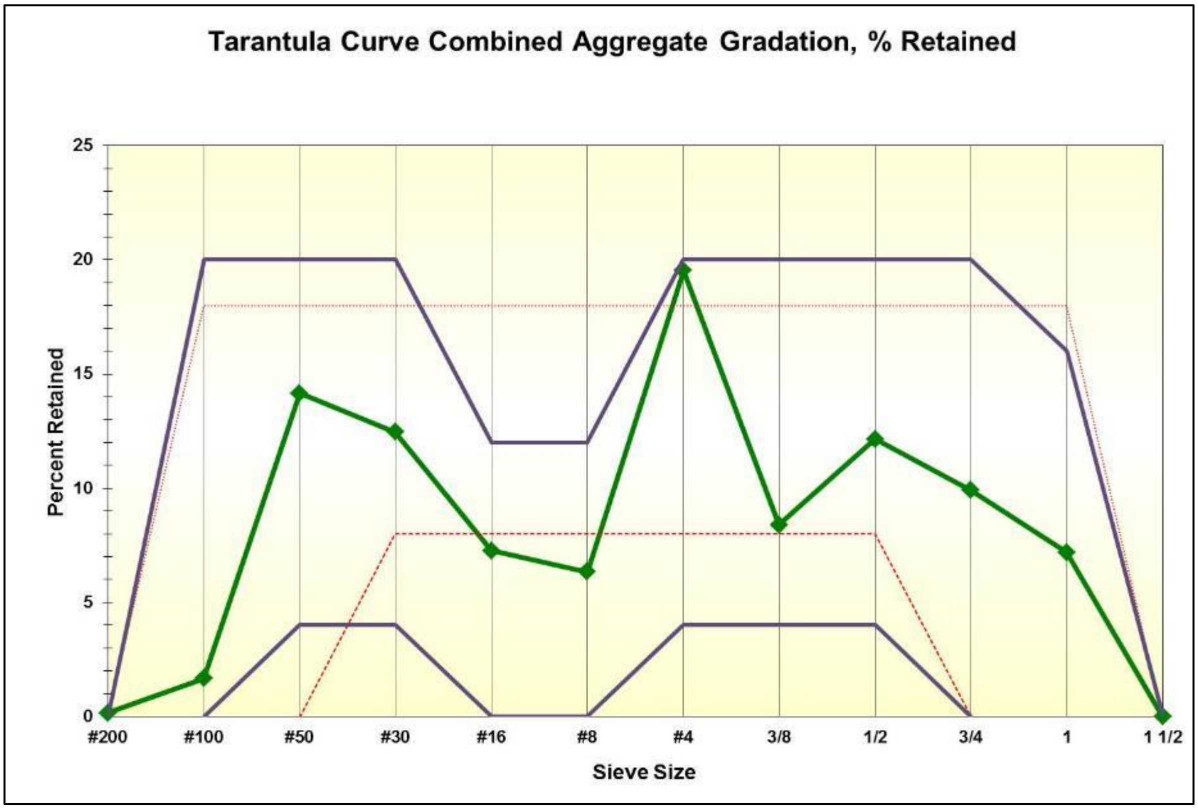
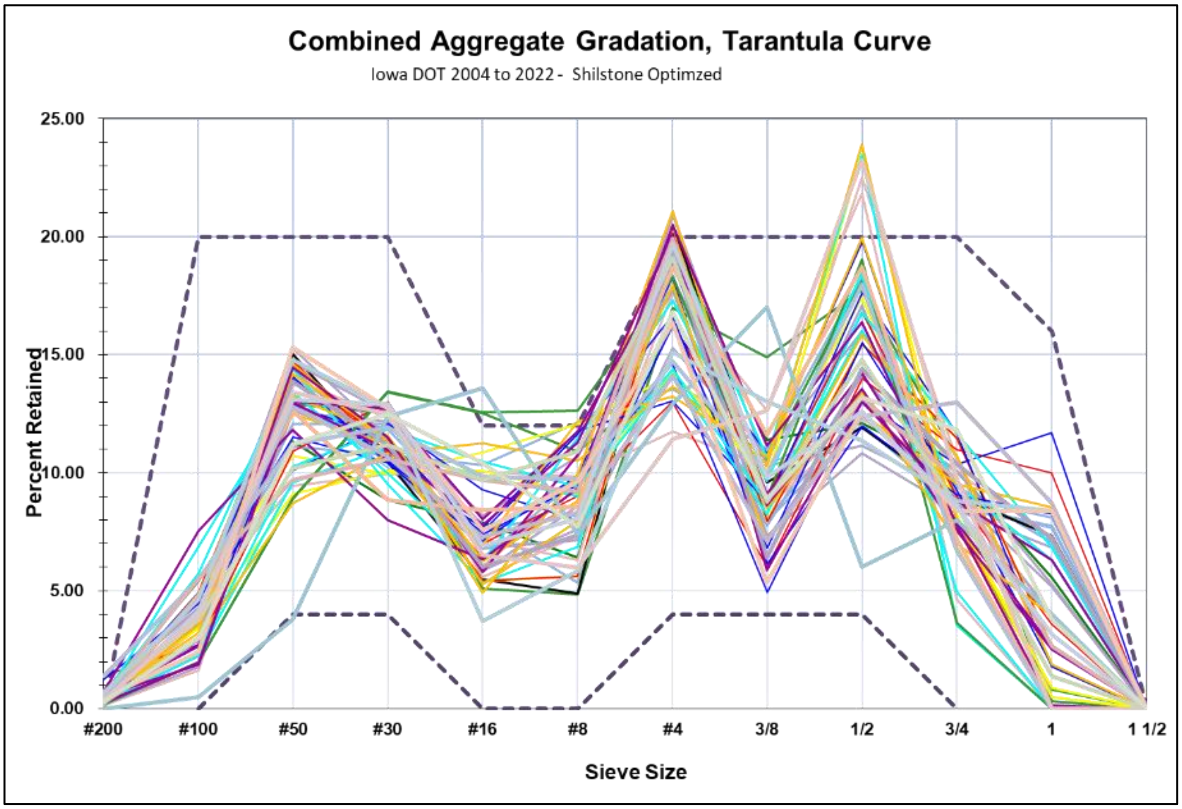


Figure 4-20 Tarantula curve - QMC Mixes 2004-2022



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 4-21 CW chart midpoint gradation C-2 through C-6

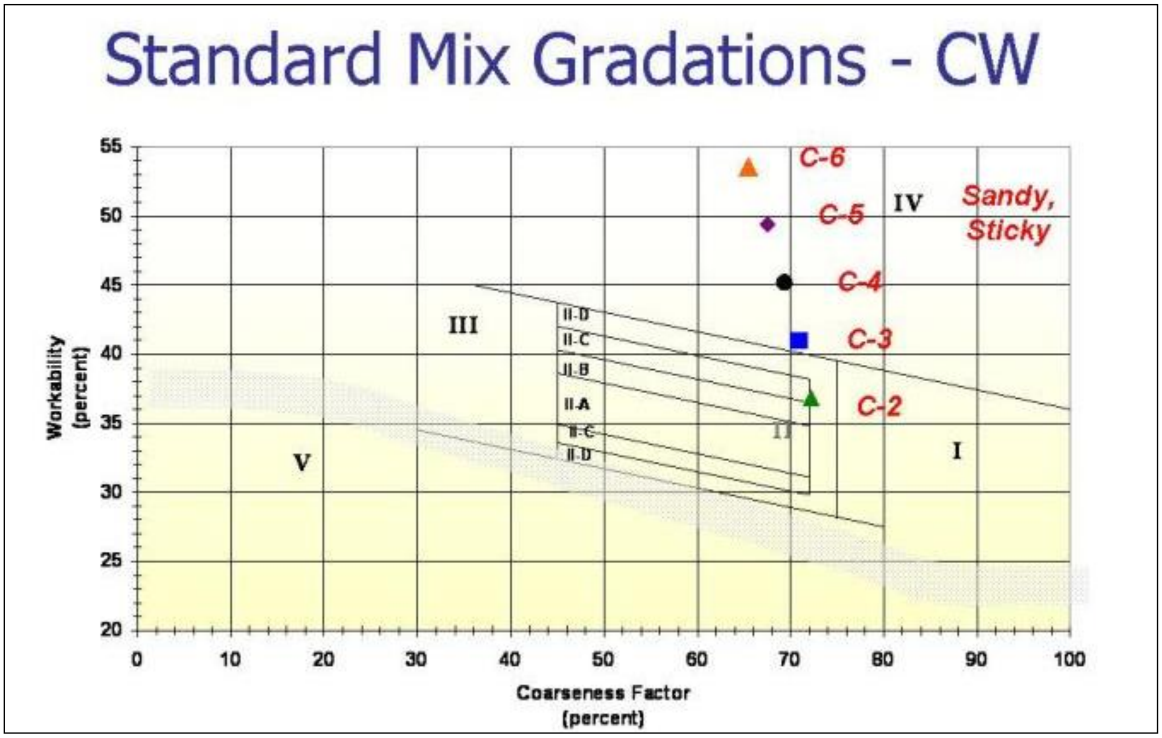


Figure 4-22 0.45 power curve midpoint gradation C-2 through C-6

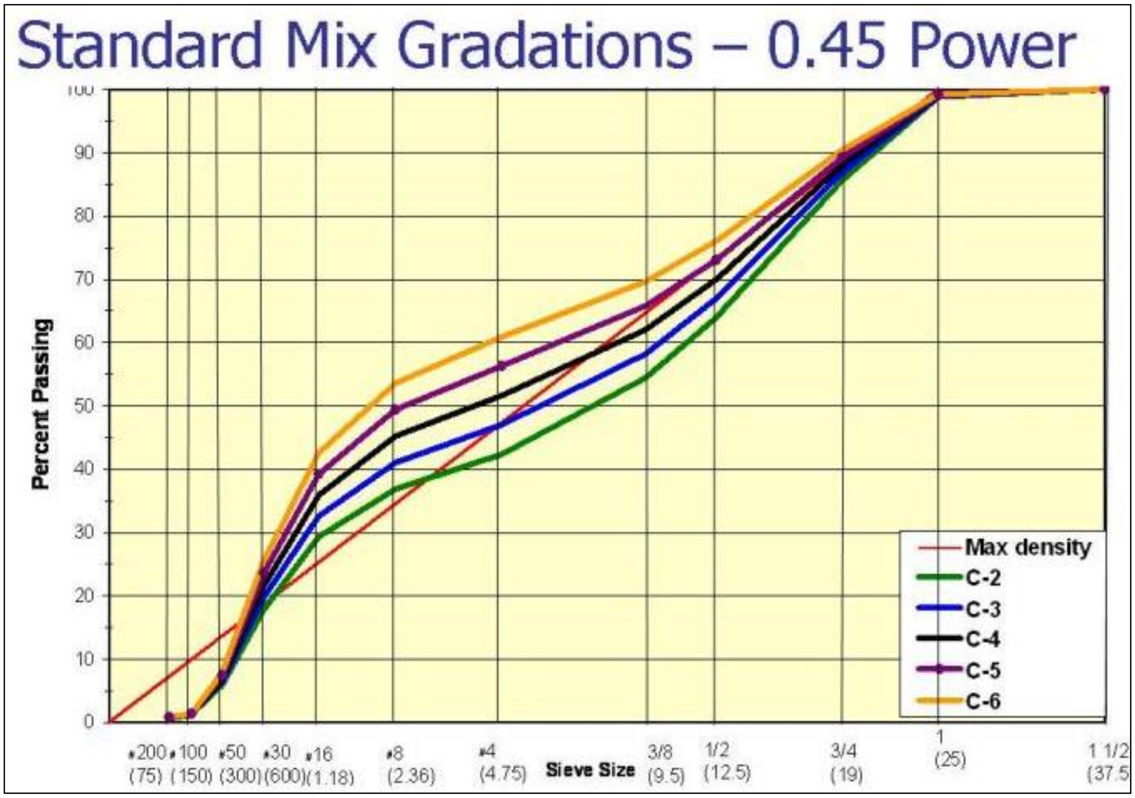
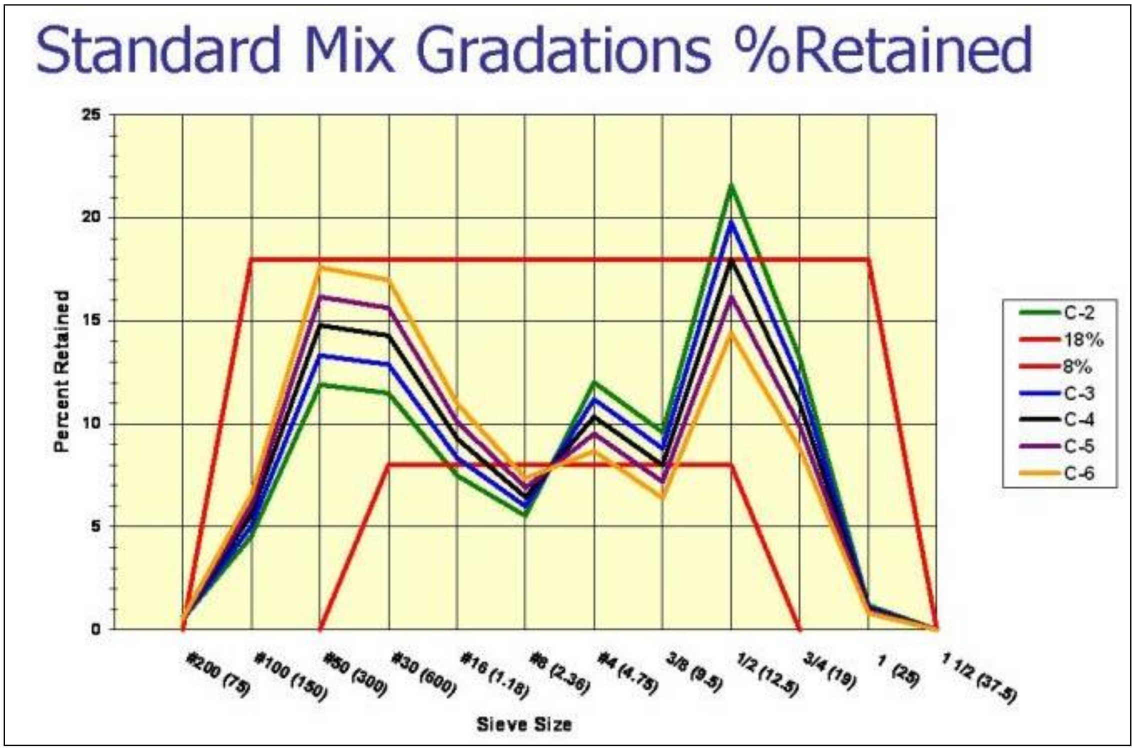


Figure 4-23 Percent retained midpoint gradation C-2 through C-6



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

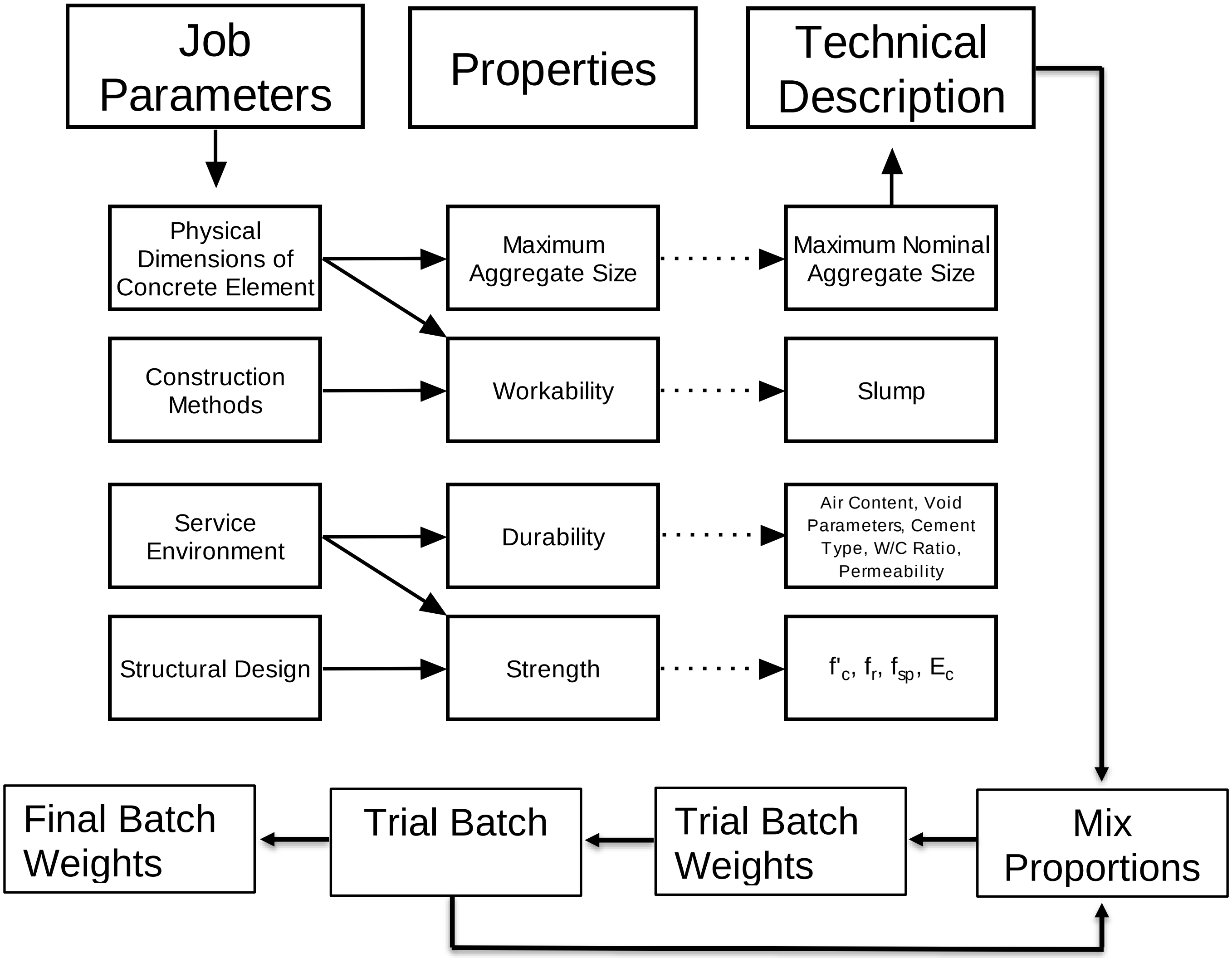
Table 5-1 Times and concrete properties for life stages

Life Stage	**Fresh**	**Transition**	**Hardened**
Time	Mixer, transport, placement	Placement, end product	End product
Properties	Placeability Workability Slump and consistency Air content and stability Segregation Response to vibration Finishability Bleeding Temperature Yield	Rate of slump loss Initial and final set time Rate of strength gain Time to freeze resistance Rate of evaporation Plastic shrinkage Drying shrinkage	Strength Air void system Frost resistance ASR resistance Sulfate resistance Permeability Abrasion resistance Shrinkage Aesthetics 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 yd^3 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 Iowa 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

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

- 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/ft^3
- Water has a constant particle density of 62.4 lbs/ft^3

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

$$\boldsymbol{SPG = \frac{Weight\ of\ solid\ material\ of\ known\ volume}{Weight\ of\ water\ of\ equal\ volume}}$$

or

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

Example: specific gravity calculation

Given 1.0 ft^3 of solid material weighs 172 lbs, what is the specific gravity?

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

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/ ft^3
- 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/ft^3

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

Example: unit weight calculations

Given 0.5 ft^3 of coarse aggregate weighs 47 lbs, what is the dry rodded unit weight?

$$\text{Unit weight} = \frac{47\ \text{lbs}}{0.5\ \text{ft}^3} = \underline{\underline{94.0\ \ \text{lbs/ft}^3}}$$

Given 0.25 ft^3 of concrete weighs 34.8 lbs, what is the unit weight?

$$\text{Unit weight} = \frac{34.8\ \text{lbs}}{0.25\ \text{ft}^3} = \underline{\underline{139.2\ \ \text{lbs/ft}^3}}$$

5.9.4. Individual Aggregate Gradations

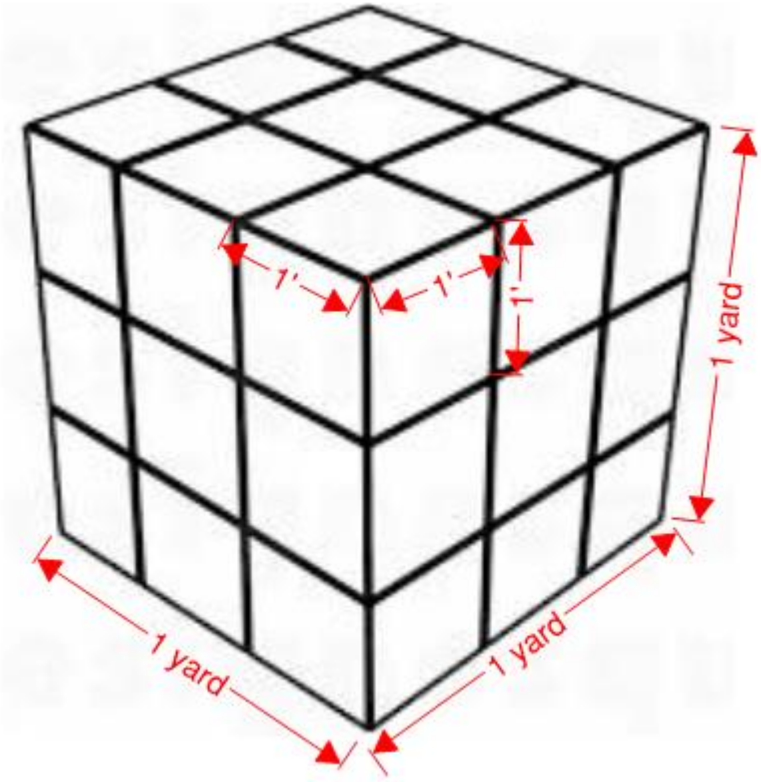
- Need to be known for the Iowa DOT QM-C, BR, and HPC-D mix design approaches so that a combined grading can be optimized
- Need to know for ACI 211.1 mix design to verify nominal maximum aggregate size for coarse aggregate and calculate the FM for fine aggregate
- Average production gradations provided 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 ft^3 is equal to a 1 foot by 1 foot by 1 foot cube
- 1 yd^3 is equal to a 1 yard by 1 yard by 1 yard cube
- Conversion between ft^3 and yd^3 is **27 ft^3 = 1 yd^3**
- Concrete is batched by weight and sold by cubic yard

Figure 5-2 1 yd^3 volume made of 27 individual 1 ft^3 volumes



Example: volume conversions

8.5 ft^3 is equal to how many yd^3 ?

$$8.5\ \mathrm{ft}^3\ \mathrm{X}\frac{1\mathrm{yd}^3}{27\mathrm{ft}^3} = \underline{\underline{0.315\ \mathrm{yd}^3}}$$

0.114 yd^3 is equal to how many ft^3 ?

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

5.10.2. Absolute and Bulk Volume

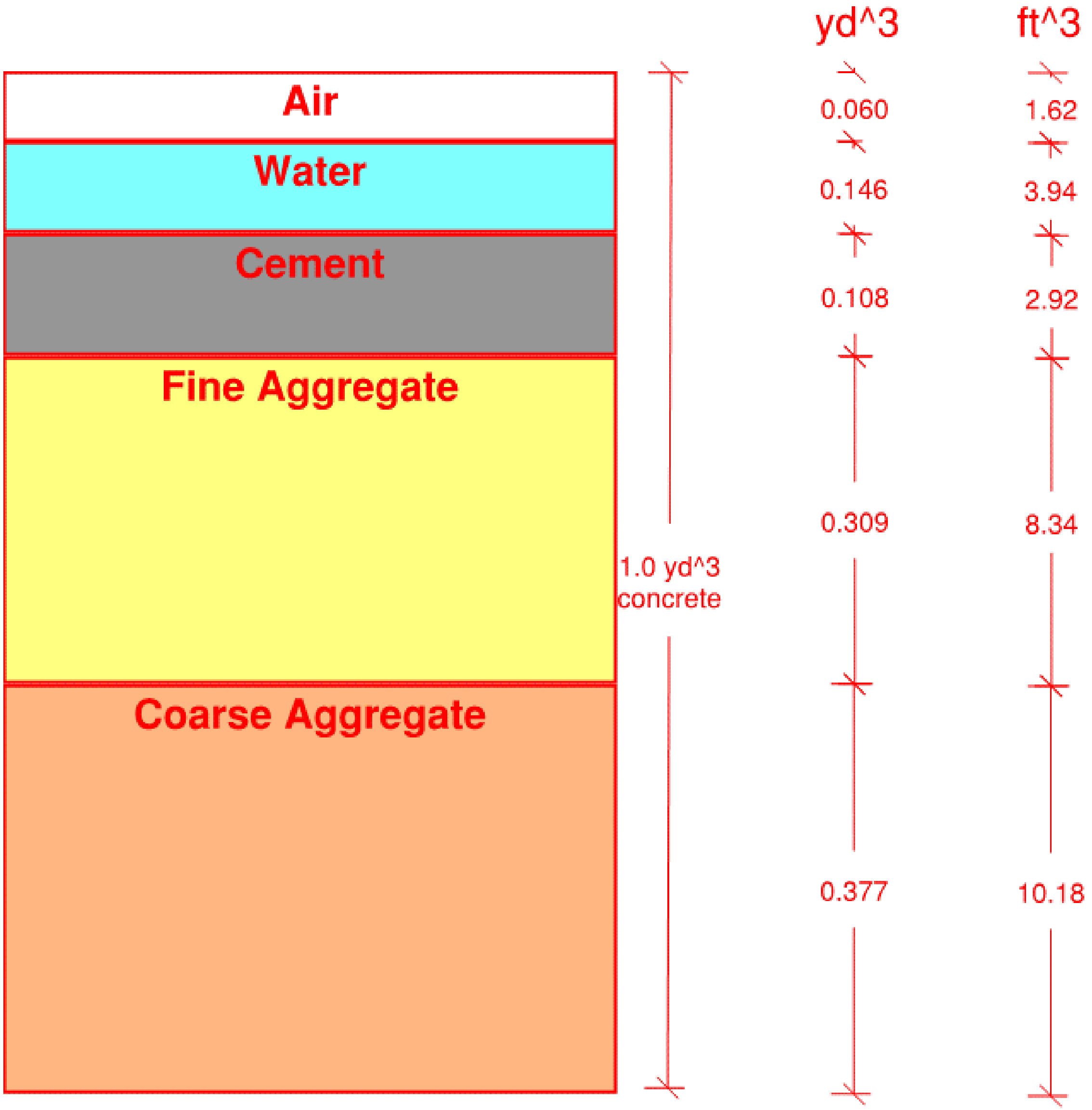
- Absolute volume is the volume of solid matter in particles not including the void spaces
- Bulk volume is the volume of solid mater in particles as well as the void spaces separating the solid particles
- Void spaces included in the bulk volume will be filled with other mix ingredients

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 1yd^3 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 yd^3 when determining the volumes of component materials
- ACI 211.1 mix design approach uses ft^3 when determining the volumes of component materials
- The arbitrary selection of 1 yd^3 results in units for component materials of ft^3/yd^3, yd^3/yd^3, and lbs/yd^3
- Absolute volumes should be calculated to three decimal places when in yd^3/yd^3 and two decimals when in ft^3/yd^3
- Batch weights should be rounded to the nearest whole number

Figure 5-4 Absolute volume of concrete and component materials



$$Abs. Vol.\ \frac{yd^3}{yd^3} = \frac{Weight\ lbs}{SPG\ X\ 62.4\frac{lbs}{ft^3}\ X\ 27\frac{ft^3}{yd^3}}$$

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

$$\boldsymbol{Weight\,\frac{lbs}{yd^3} = Abs.Vol.\ \frac{yd^3}{yd^3}\ X\ SPG\ X\ 62.4\,\frac{lbs}{ft^3}\ X\ 27\,\frac{ft^3}{yd^3}}$$

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

Example: absolute volume calculations

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

$$\text{Abs. Vol. } \frac{\text{yd}^3}{\text{yd}^3} = \frac{593\,\frac{\text{lbs}}{\text{yd}^3}}{3.14 \text{ X } 62.4\,\frac{\text{lbs}}{\text{ft}^3} \text{ X } 27\,\frac{\text{ft}^3}{\text{yd}^3}} = \underline{\underline{0.112\,\frac{\text{yd}^3}{\text{yd}^3}}}$$

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

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

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

$$\text{Weight}\,\frac{\text{lbs}}{\text{yd}^3} = 0.325\ \frac{\text{yd}^3}{\text{yd}^3} \text{ X } 2.59 \text{ X } 62.4\,\frac{\text{lbs}}{\text{ft}^3} \text{ X } 27\,\frac{\text{ft}^3}{\text{yd}^3} = \underline{\underline{1{,}418\,\frac{\text{lbs}}{\text{yd}^3}}}$$

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

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

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 23
- 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 **1 gallon = 8.33 lbs**

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

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

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

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.

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

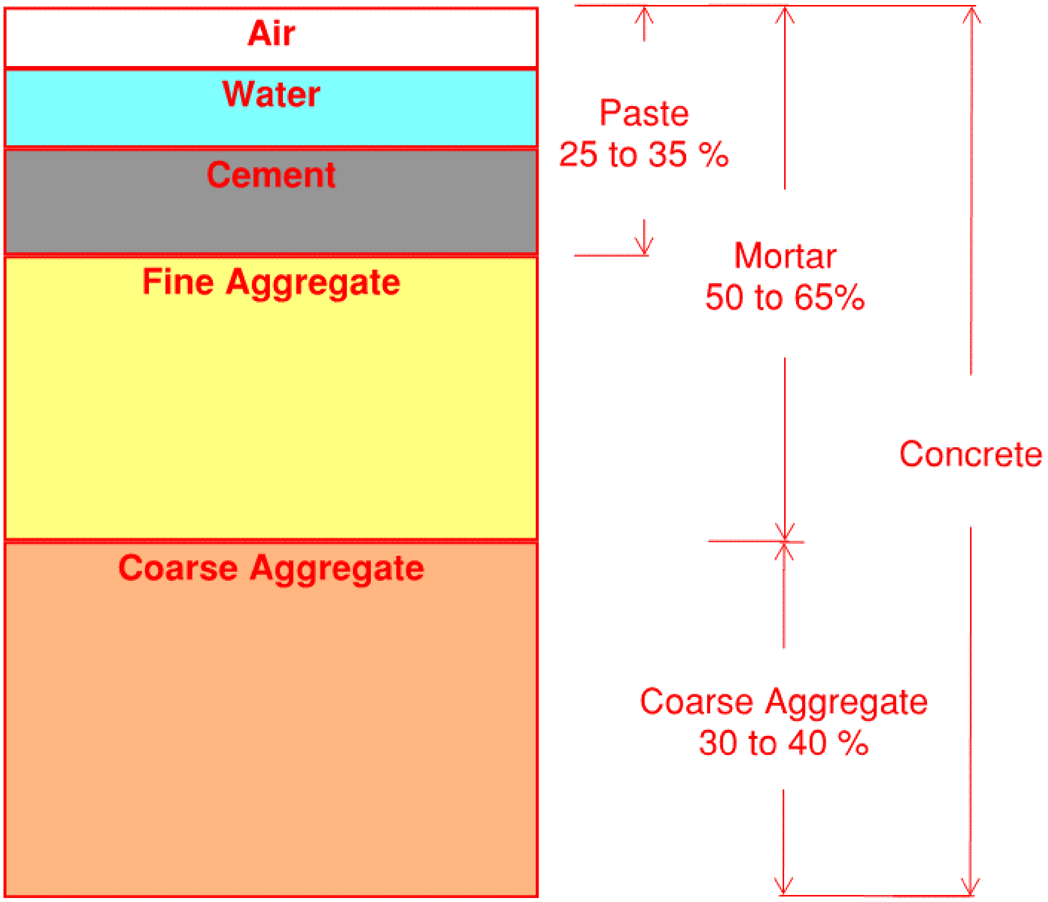
Determine the weight of water given 482 lbs cement, 121 lbs fly ash and a w/c ratio of 0.400.

$$\mathrm{Total\ water\ weight\ lbs} = (482\ \mathrm{lbs} + 121\ \mathrm{lbs})\ \ \mathrm{X}\ \ 0.400 = \underline{\underline{241\ \mathrm{lbs}}}$$

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
  - Concrete quality depends substantially on the quality of paste
  - Higher paste results in higher potential for shrinkage, increased heat, and increased costs, see page 29
- 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
  - 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

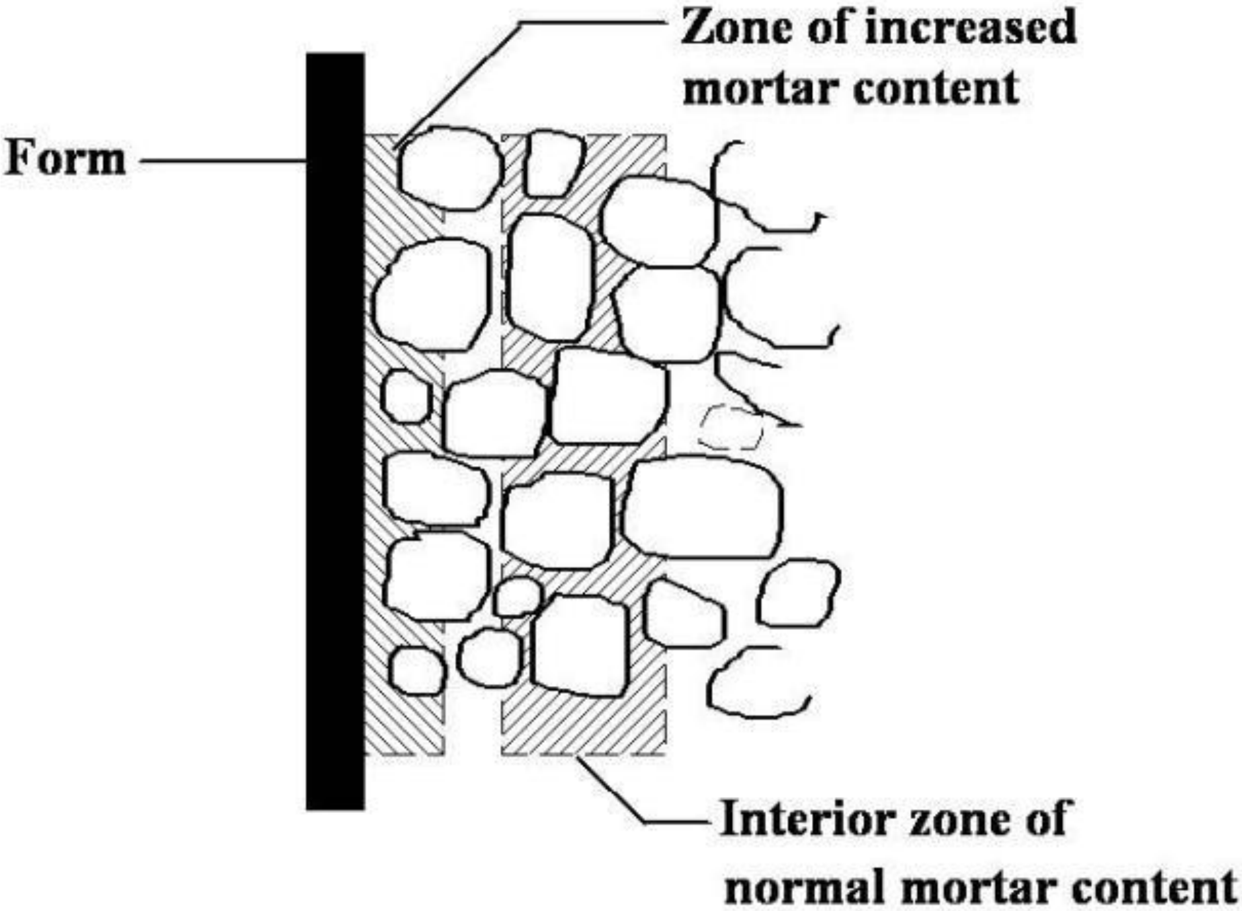


Figure 5-7 Bugholes and honeycombing at wall effected zone

Table 5-3 Percent mortar required for different placement methods

Class	Description	Approximate Percent Mortar Required
1	Placed by steep sided bottom-drop bucket, conveyor, or paving machine.	48 to 50
2	Placed by bottom drop bucket or chute in open vertical construction.	50 to 52
3	Placed by chute, buggy, or conveyor in an 8 in. (200 mm) or deeper slab.	51 to 53
4	Placed by 5 in. (125 mm) or larger pump for use in vertical construction, thick flat slabs and larger walls, beams, and similar elements.	52 to 54
5	Placed by 5 in. (125 mm) pump for pan joist slabs, thin or small castings, and high reinforcing steel density.	53 to 55
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 mm).	58 to 60
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.

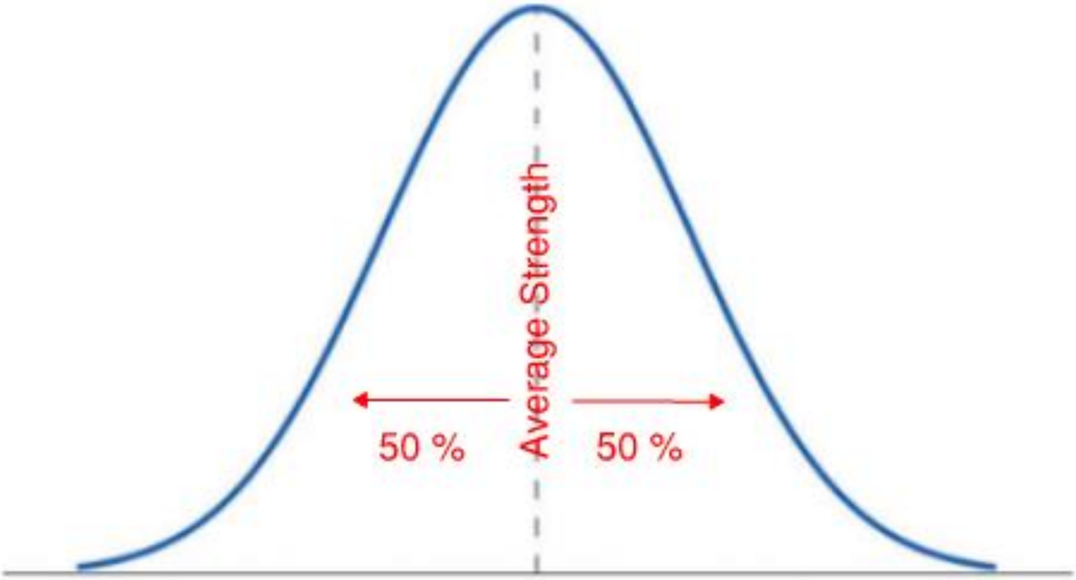
5.10.7. Producer Capabilities

- 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

     $$f'_{cr} = f'_c + (2.33\ S - 500)$$

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

     $$f'_{cr} = f'_c + (1.34\ S)$$

- 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

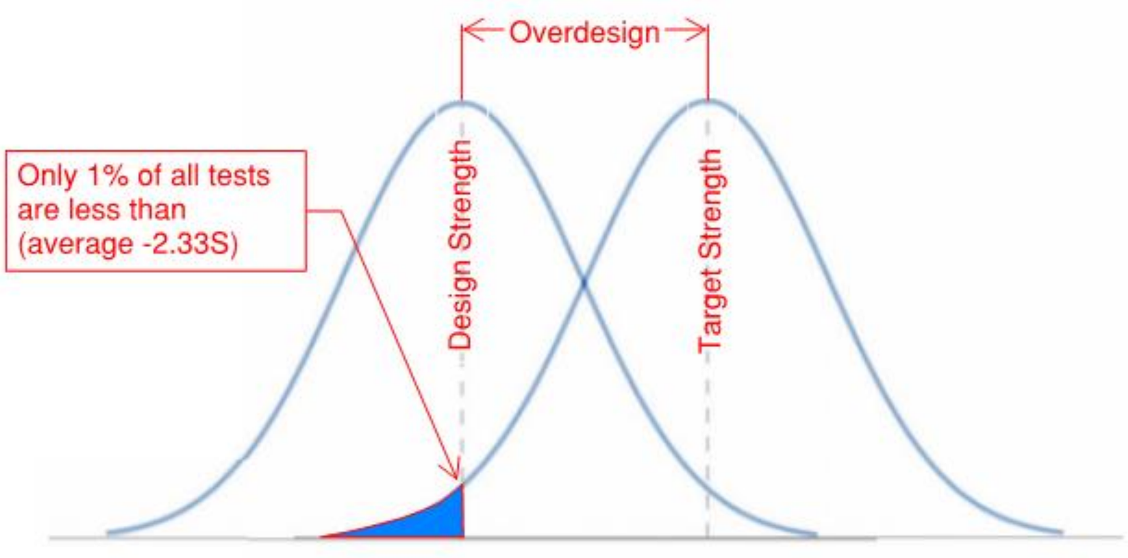
Table 5-4 Factor to increase S when less than 30 tests

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 Special equations for required target strength

Design Strength, f'_c (psi)	Target Strength, f'_{cr} (psi)
Less than 3000	f'_c + 1000 psi
3000 to 5000	f'_c + 1200 psi
Over 5000	1.1 x f'_c + 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
- Developmental Specification Structural Concrete (4500 psi or greater)

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 ½ the mix water and air agent and one with ½ 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 ½ 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 admixture
12. 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
  - ACI 211.1
  - British DoE
  - 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 Iowa 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 yd^3, 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 yd^2
- Uses Shilstone principles to provide and optimized combined aggregate gradation, see page 61
- 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 specific concrete mixture constraints in the QMC DS

Table 6-1 Concrete mixture constraints

Technical Description	**Requirement**
Nominal maximum coarse aggregate size	Greater than or equal to I inch
Combined gradation	CW factor plots in zone II
Cementitious content	560 lbs/yd^3 * (Abs. Vol. = 0.106)
W/C ratio	Basic 0.40, maximum 0.435
Air content	Design absolute volume 0.060 yd^3, 6 ± 1%,
Third point 28-day flexural strength	Minimum 640 psi
* 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 yd^3. If cement other than Type I/II is used, use an absolute volume of 0.106 yd^3 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

1. 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
  - 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

Table 6-2 Quality control testing

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

- 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

Table 6-3 Combined aggregate working ranges

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

- 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 Iowa 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 Verification testing

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
    - Adjust aggregate proportions ±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%
I	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 61
- 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
- Submit mix design to the District Materials Engineer 7 calendar days prior to placement for approval
- All batch weights are in SSD condition
- Strength testing not required, however these mixes have historically exceeded design strengths of 4000 psi
- Durability is addressed by specifying w/c ratio limits, air contents, and coarse aggregate durability classes
- Contractor may use synthetic fibers at an addition rate and using batching recommendations provided by manufacturer
- Calculations are the same as a QM-C mix, see page 98

Table 6-6 BR 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 20% fly ash	March 16 to October 15
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 6-8 Target strength and permeability for HPC substructure and deck mixes

Target	Substructure	Deck
Compressive strength (psi)	4,000 to 5,000	4,000 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 61
- 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 yd^3 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
  - Submit mix design 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 96
- Calculations for the deck are the same as a QM-C mix, see page 98

Table 6-9 HPC substructure and deck mix requirements

	Requirement	
Technical Description	**Substructure**	**Deck**
Coarse and intermediate aggregate durability	3i	3i
Individual gradation	Meet division 41	Meet division 41
Combined gradation	NA	CW factor plots in zone II
Cement type	Type IS, IP, or IT Type I/II or IL with a minimum of 30% weight replacement with GGBFS	Type IS, IP, or IT Type I/II or IL with a minimum of 30% weight replacement with GGBFS
Fly ash substitution	20% maximum	20% maximum
Maximum SCM substitution	50%	50%
W/C ratio	Basic 0.42, maximum 0.45	Basic 0.40, maximum 0.435
Air content	Design absolute volume 0.060 yd^3	Design absolute volume 0.060 yd^3

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 96

Table 6-10 HPC-O mix requirements

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, IP, or IT Type I/II or IL with a minimum of 25% weight replacement with GGBFS
Fly ash substitution	20% maximum
Air content	Design absolute volume 0.060 yd^3

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 6-11 Tier 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 Iowa
- 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 96

Table 6-12 Mass concrete mix requirements

	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

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

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

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

6.9. Iowa DOT SCC

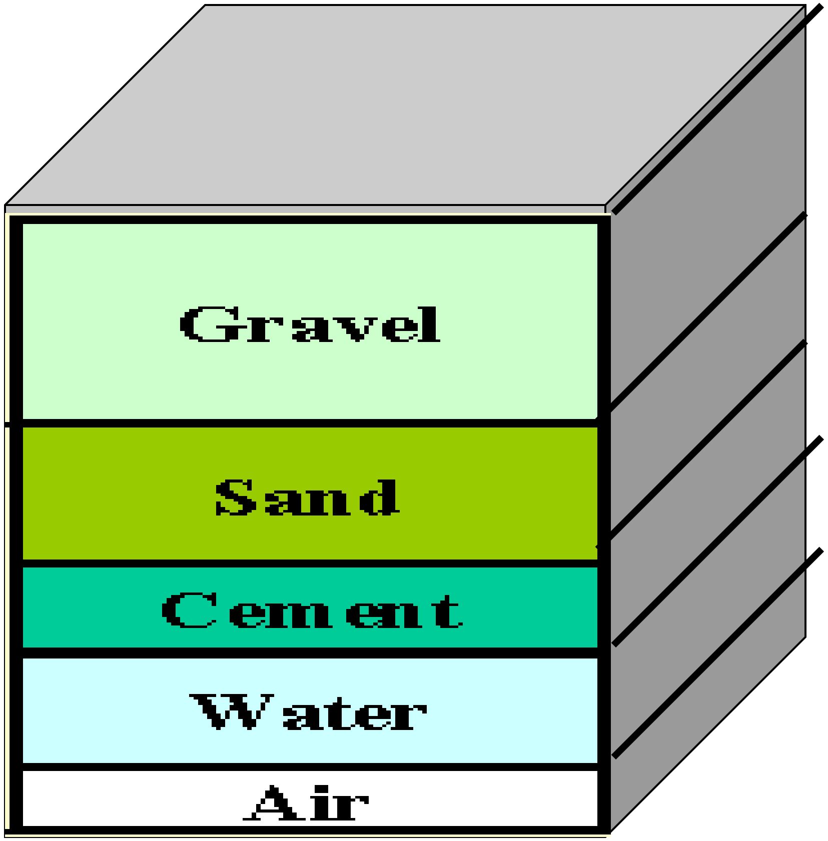
- Highly flowable and non-segregating concrete used for structural concrete placements that are complex in shape, congested with reinforcement, and/or inaccessible to placement and vibration
- Developed to optimize flow and stability using the following typical characteristics
    - Well graded combined grading
    - ¾ 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 yd^3 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 98

Table 6-14 SCC mix requirements

Technical Description	Requirement
Nominal maximum aggregate size	No larger than 1/3rd 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

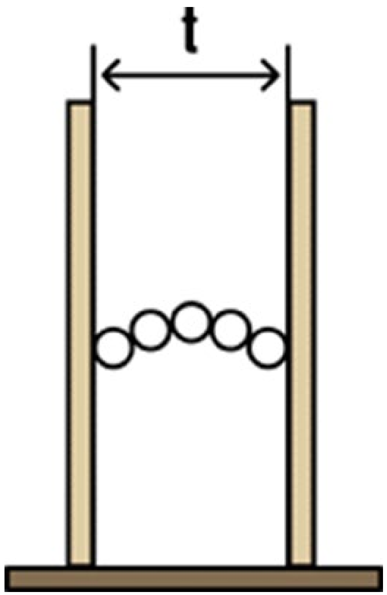
APPENDIX A
ACI 211 MIX DESIGN

ACI Mix Design



ACI Mix Design Example Problem

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



ACI Mix Design Example Problem

Specifications

- A minimum compressive strength of 3500 psi.
- Assume a standard deviation of 370 psi.
- A maximum w/c ratio of 0.50

ACI Mix Design Example Problem

- The maximum aggregate size available is ¾”.
- Mid range water reducer shall be used
  - Assume a 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

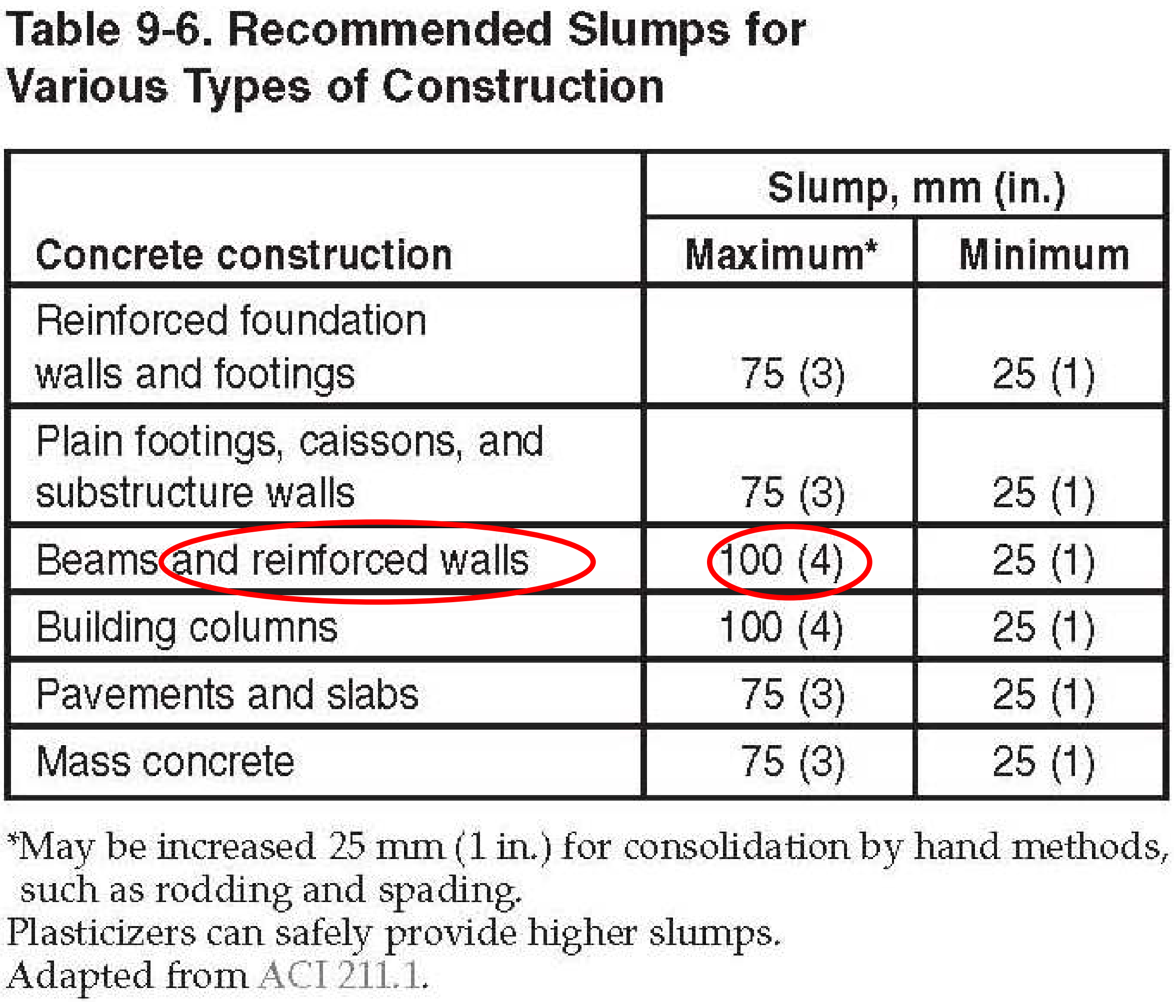


Table 9-6. Recommended Slumps for Various Types of Construction

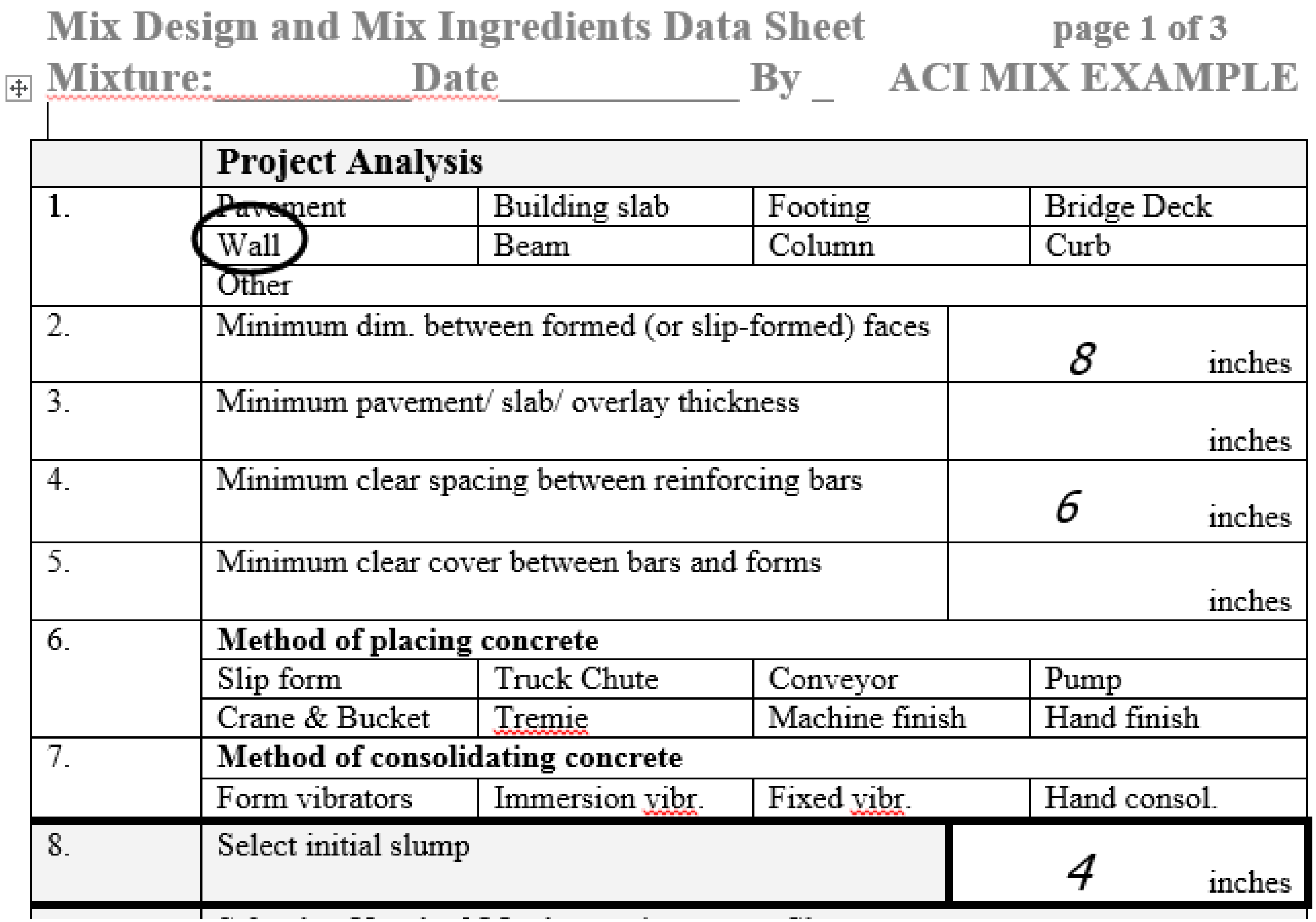
Concrete construction	Slump, mm (in.)	
	Maximum*	Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

*May be increased 25 mm (1 in.) for consolidation by hand methods, such as rodding and spading.

Plasticizers can safely provide higher slumps.

Adapted from ACI 211.1.

Select Slump

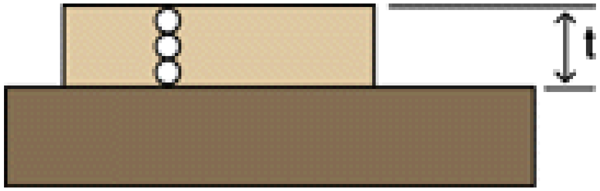


Mix Design and Mix Ingredients Data Sheet **page 1 of 3**

Mixture:__________ Date__________ By _ ACI MIX EXAMPLE

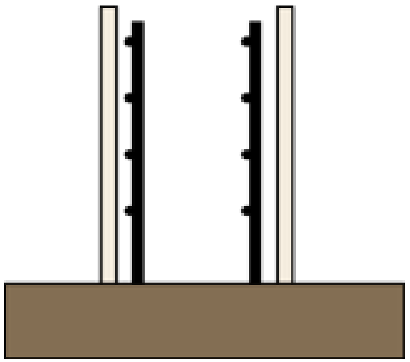
	Project Analysis			
1.	Pavement	Building slab	Footing	Bridge Deck
	[✓ Wall]	Beam	Column	Curb
	Other			
2.	Minimum dim. between formed (or slip-formed) faces		8 inches	
3.	Minimum pavement/ slab/ overlay thickness		inches	
4.	Minimum clear spacing between reinforcing bars		6 inches	
5.	Minimum clear cover between bars and forms		inches	
6.	**Method of placing concrete**			
	Slip form	Truck Chute	Conveyor	Pump
	Crane & Bucket	Tremie	Machine finish	Hand finish
7.	**Method of consolidating concrete**			
	Form vibrators	Immersion vibr.	Fixed vibr.	Hand consol.
8.	Select initial slump		4 inches	

Select Max. Aggregate Size



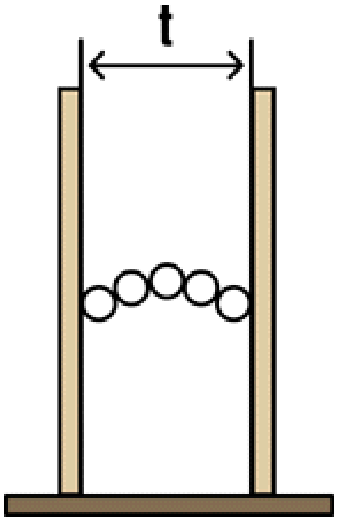
1/3 slab thickness

N/A



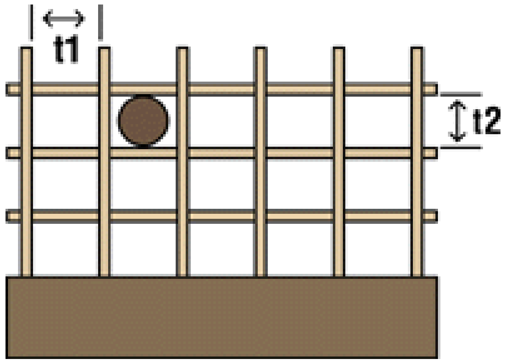
0.75 clear
cover between
form & rebars

N/A



1/5 formed surfaces

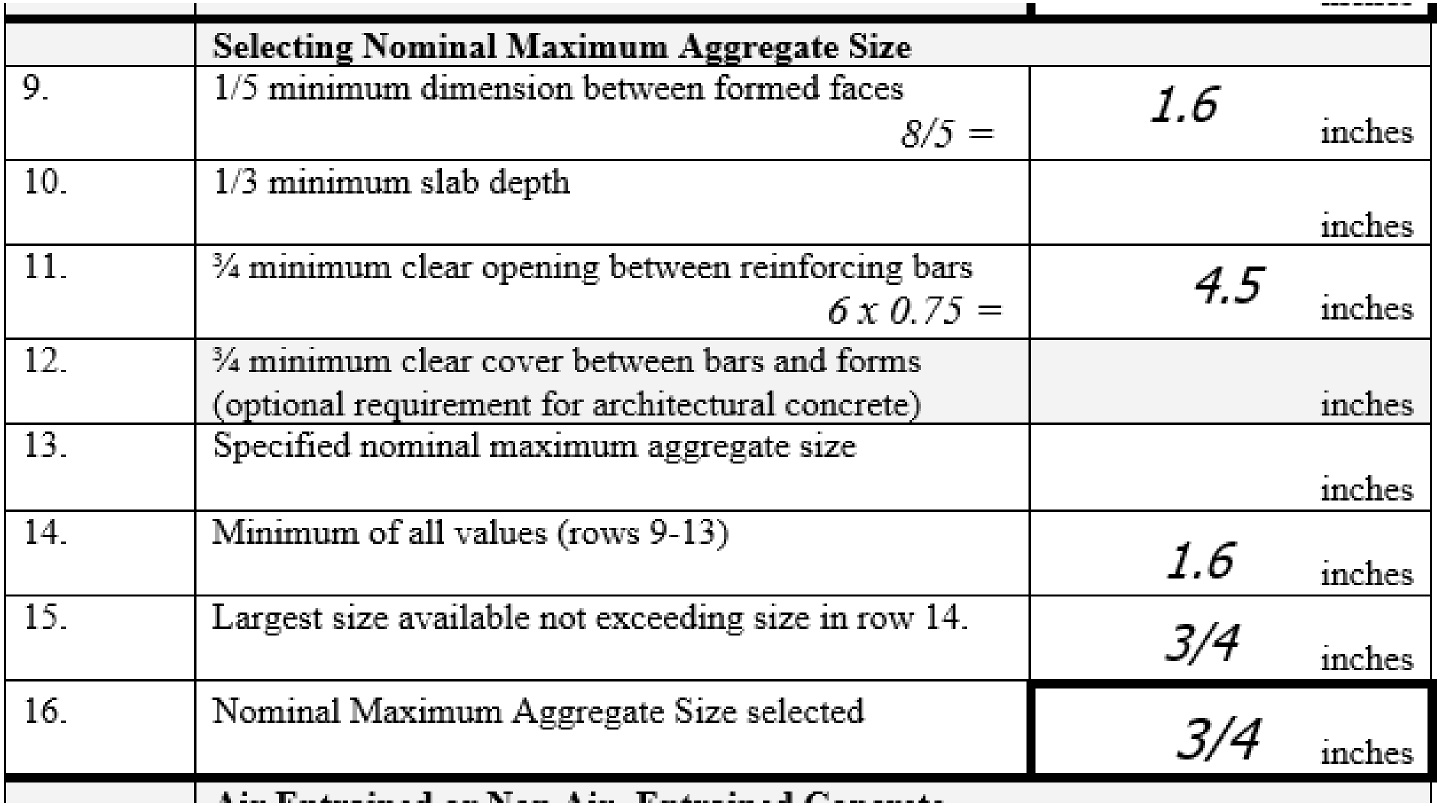
8/5 = 1.6 in.



0.75 clear space between rebars

6 X 0.75 = 4.5 in.

Select Max. Aggregate Size



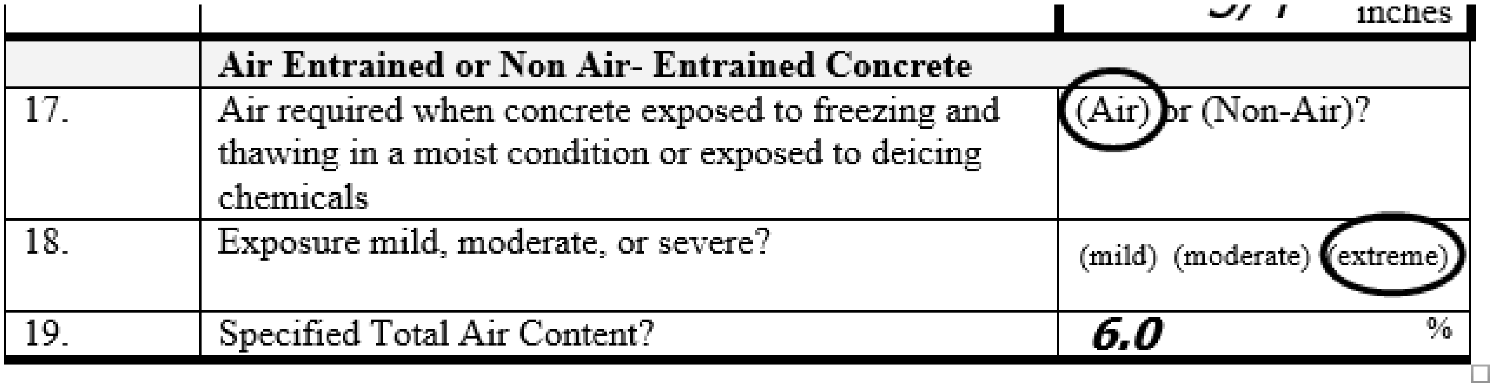
	Selecting Nominal Maximum Aggregate Size	
9.	1/5 minimum dimension between formed faces *8/5 =*	1.6 inches
10.	1/3 minimum slab depth	inches
11.	¾ minimum clear opening between reinforcing bars *6 x 0.75 =*	4.5 inches
12.	¾ minimum clear cover between bars and forms (optional requirement for architectural concrete)	inches
13.	Specified nominal maximum aggregate size	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

Nominal maximum aggregate size, in inches.	Air content, as a percentage of total concrete volume.	
9% mortar air for Severe F/T	**Severe Exposure**	**Moderate Exposure**
3/8	7.5	6
1/2	7	5.5
3/4	6	5
1	6	4.5
1-1/2	5.5	4.5
2	5	4
3	4.5	3.5

Increasing Paste Content

Select Air Content



		inches
	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)] or (Non-Air)?
18.	Exposure mild, moderate, or severe?	(mild) (moderate) [✓ (extreme)]
19.	Specified Total Air Content?	**6.0** %

Select minimum w/c ratio - Durability

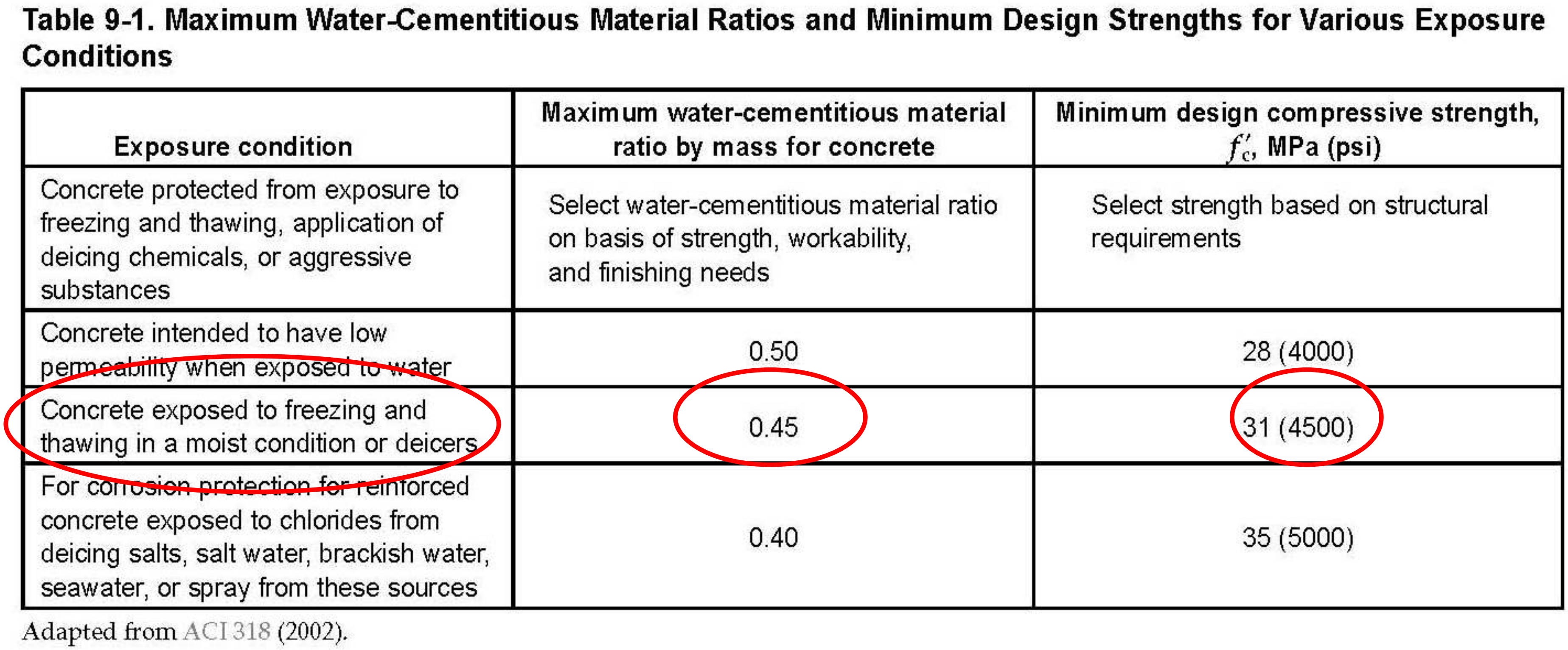
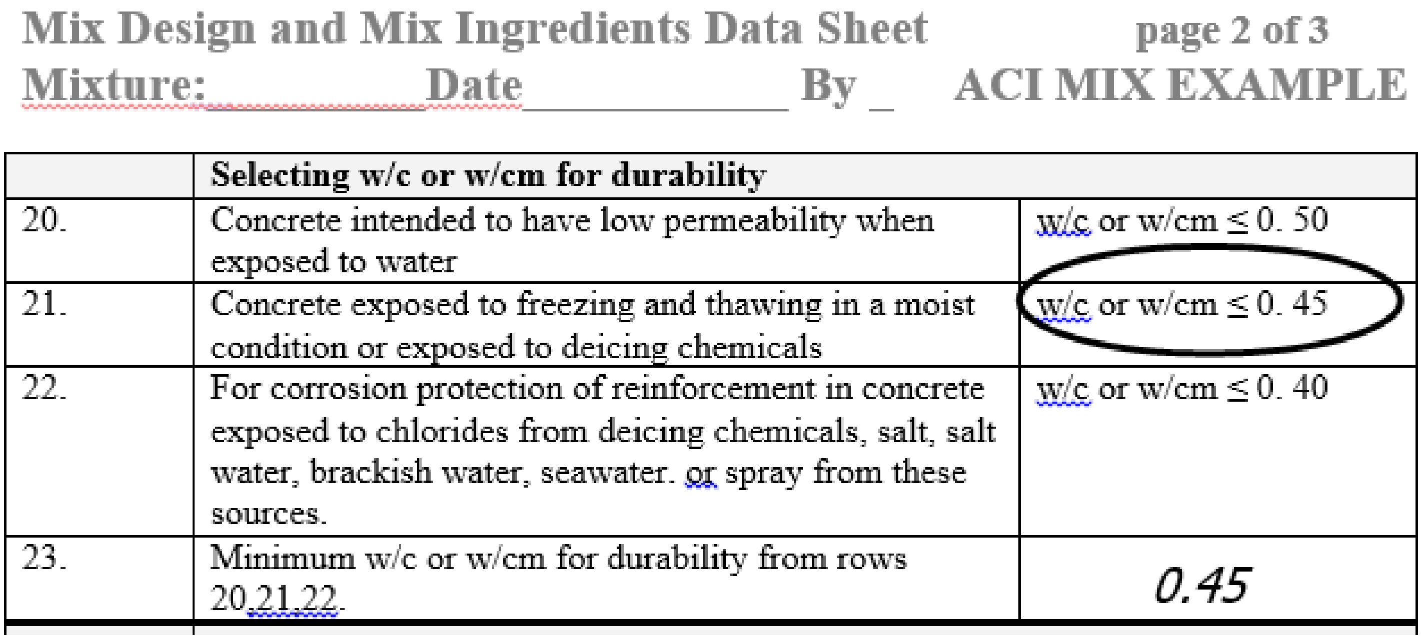


Table 9-1. Maximum Water-Cementitious Material Ratios and Minimum Design Strengths for Various Exposure Conditions

Exposure condition	Maximum water-cementitious material ratio by mass for concrete	Minimum design compressive strength, f'_c, MPa (psi)
Concrete protected from exposure to freezing and thawing, application of deicing chemicals, or aggressive substances	Select water-cementitious material ratio on basis of strength, workability, and finishing needs	Select strength based on structural requirements
Concrete intended to have low permeability when exposed to water	0.50	28 (4000)
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45	31 (4500)
For corrosion protection for reinforced concrete exposed to chlorides from deicing salts, salt water, brackish water, seawater, or spray from these sources	0.40	35 (5000)

Adapted from ACI 318 (2002).

Select minimum w/c ratio - Durability



Mix Design and Mix Ingredients Data Sheet **page 2 of 3**

Mixture:____________Date_______________ By _ ACI MIX EXAMPLE

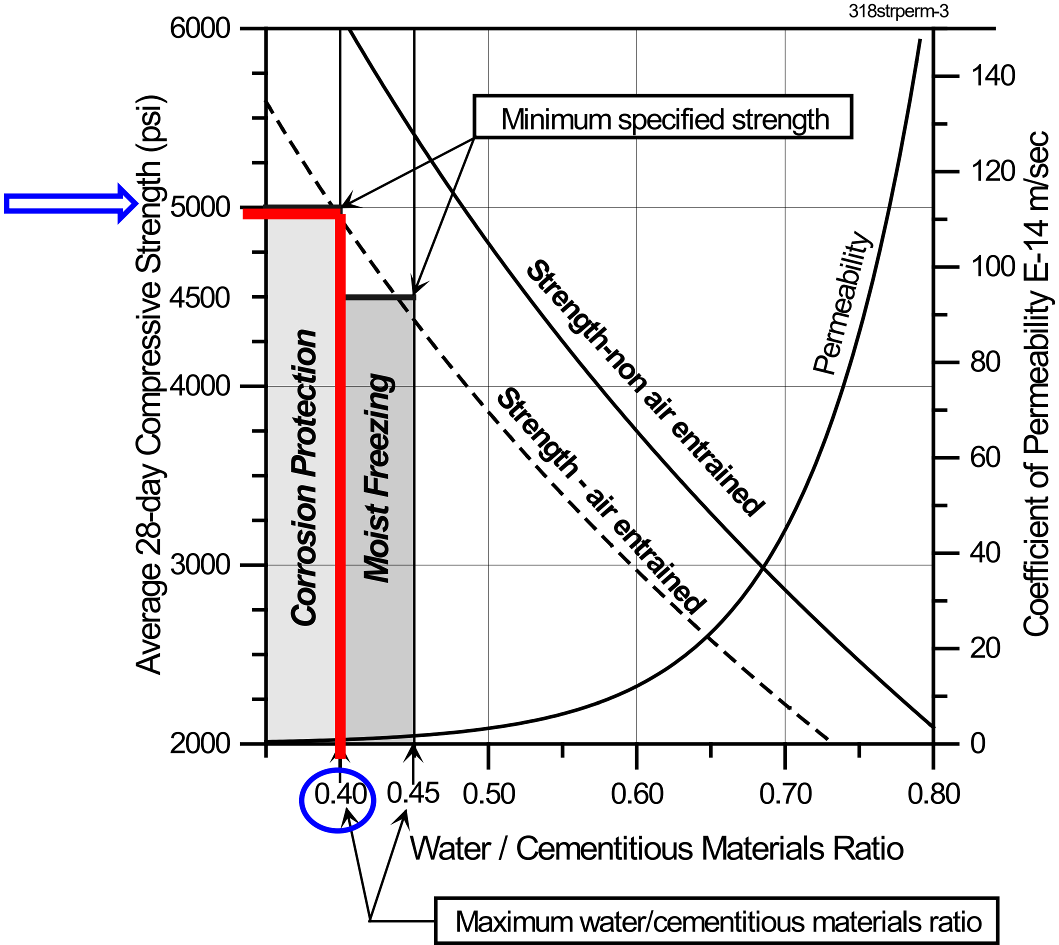
	Selecting w/c or w/cm for durability	
20.	Concrete intended to have low permeability when exposed to water	w/c or w/cm ≤ 0. 50
21.	Concrete exposed to freezing and thawing in a moist condition or exposed to deicing chemicals	w/c or w/cm ≤ 0. 45
22.	For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater. or spray from these sources.	w/c or w/cm ≤ 0. 40
23.	Minimum w/c or w/cm for durability from rows 20,21,22.	0.45

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 370) - 500 = 4862
    - ☐ 4500 + (1.34 X 370) = 4991 ~ 5000 psi

Select minimum w/c ratio

ACI 318-99 Building Code Requirements for Durable Concrete (Section 4.2.2)



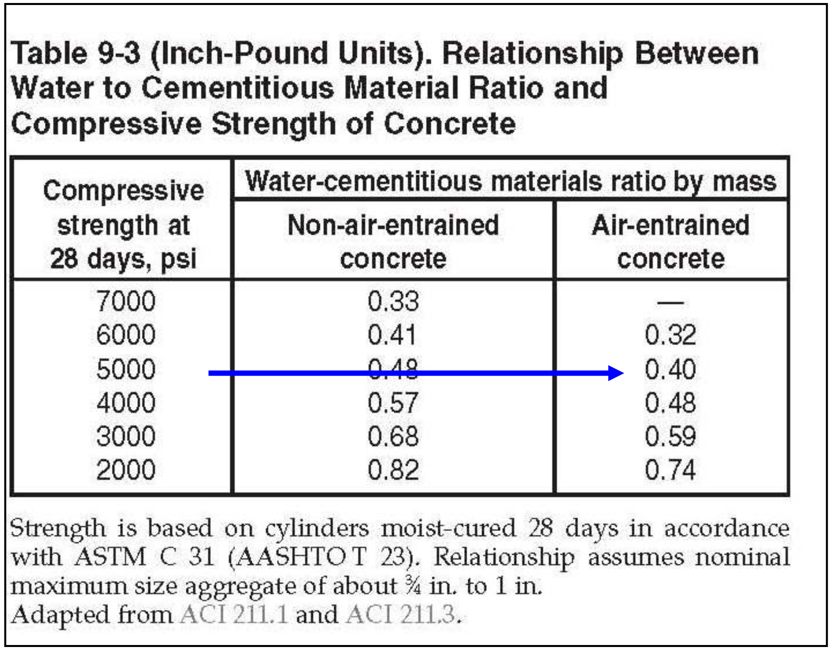


Table 9-3 (Inch-Pound Units). Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

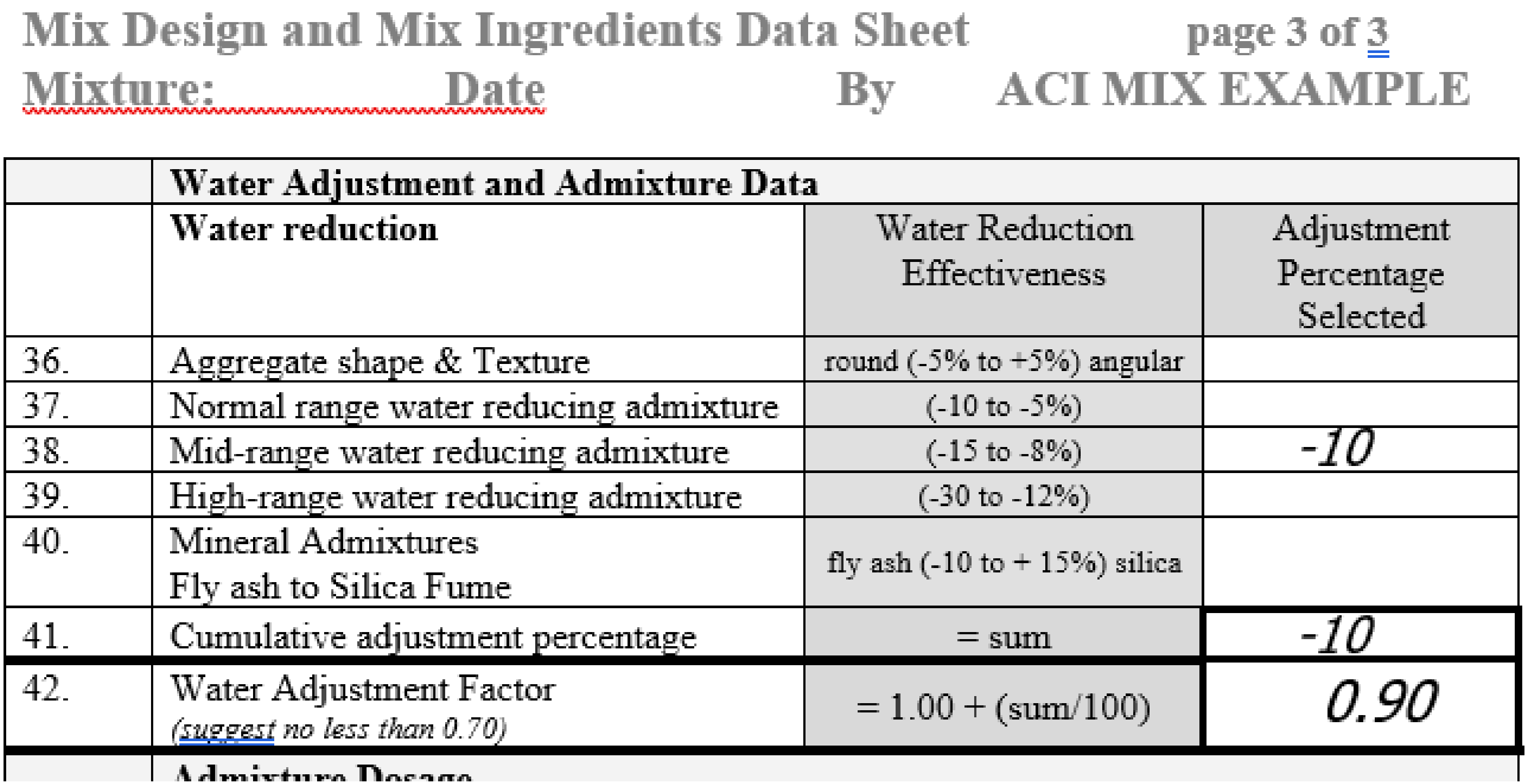
Compressive strength at 28 days, psi	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
7000	0.33	—
6000	0.41	0.32
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Strength is based on cylinders moist-cured 28 days in accordance with ASTM C 31 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about ¾ in. to 1 in.
Adapted from ACI 211.1 and ACI 211.3.

Select minimum w/c ratio - Strength

	Selecting w/c or w/cm for strength	
24.	If concrete intended to have low permeability when exposed to water, f'_c min. = 4000 psi.	f'_c minimum =
25.	If concrete exposed to freezing and thawing in moist condition or exposed to deicers, f'_c min. = 4500 psi.	f'_c minimum = *4500*
26.	If conc. is reinforced and exposed to chlorides from deicers, salt, salt water, brackish water, seawater. or spray from these sources, f'_c min.= 5000 psi.	f'_c minimum =
27.	Specified 28-day compressive strength, f'_c	f'_c = *3500* psi
28.	Maximum of rows 24-27.	f'_c* = *4500* psi
29.	Producer's standard deviation, S, for similar mix (index of producer's precision)	***S*** = *370* psi
30.	f'_c* + 2.33 ***S*** – 500 psi	*4862* psi
31.	f'_c* + 1.34 ***S*** psi	*4996* psi
32.	***Mix design target strength, f'_{cr}*** = Larger of two values in rows 30 and 31.	f'_{cr} = ***5000*** psi
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 = Minimum value from rows 23(durability), 33(strength), and 34(specifications)	***0.40***

Water Adjustment



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

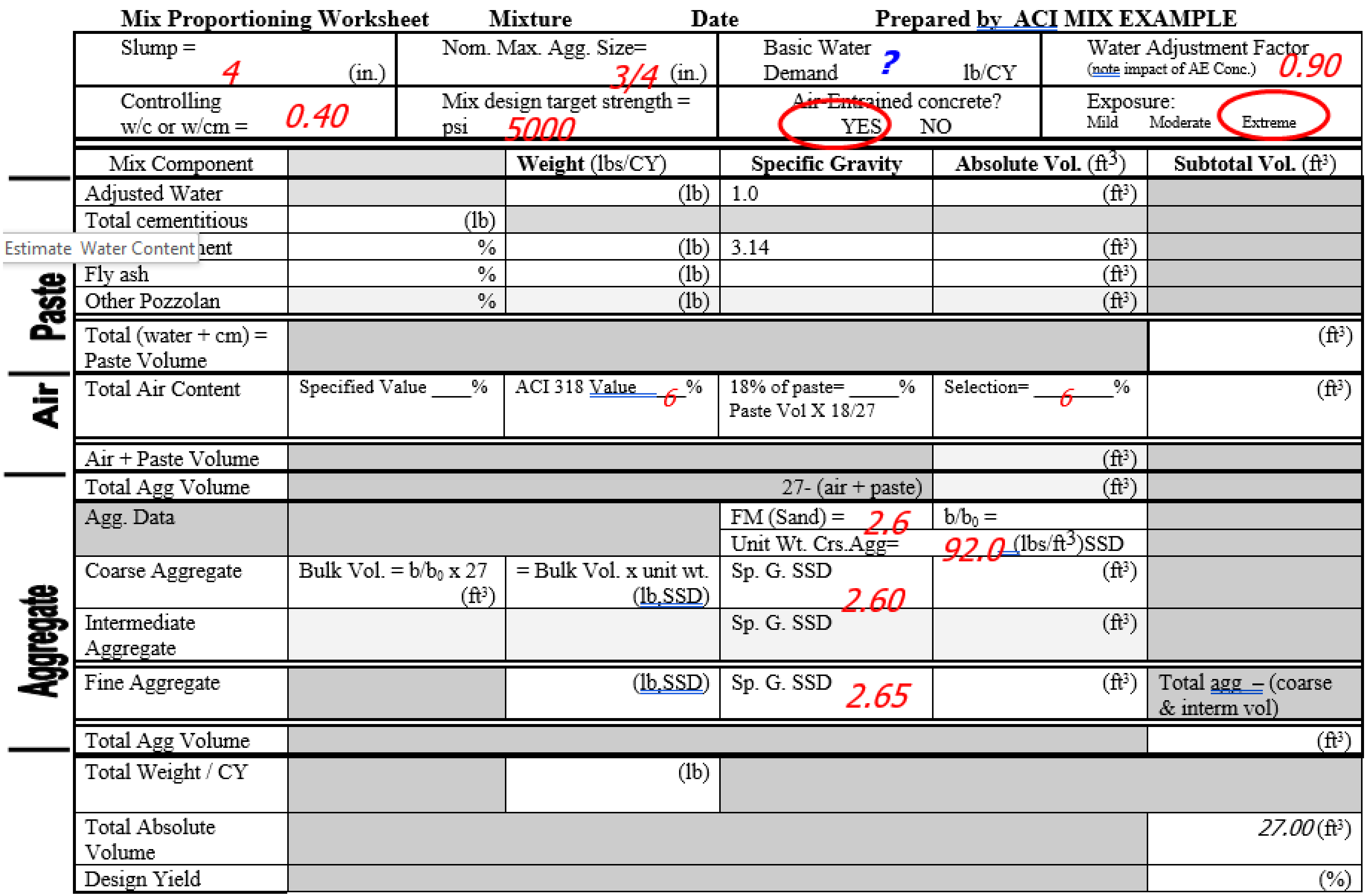
	Water Adjustment and Admixture Data		
	Water reduction	Water Reduction Effectiveness	Adjustment Percentage Selected
36.	Aggregate shape & Texture	round (-5% to +5%) angular	
37.	Normal range water reducing admixture	(-10 to -5%)	
38.	Mid-range water reducing admixture	(-15 to -8%)	-10
39.	High-range water reducing admixture	(-30 to -12%)	
40.	Mineral Admixtures Fly ash to Silica Fume	fly ash (-10 to + 15%) silica	
41.	Cumulative adjustment percentage	= sum	-10
42.	Water Adjustment Factor *(suggest no less than 0.70)*	= 1.00 + (sum/100)	0.90
	Admixture Dosage		

Water Content & Aggregate Shape

Aggregate Shape	Water Reduction (pounds per cubic yard)
Crushed stone (angular)	0
Crushed stone (subangular)	20
Gravel (some crushed)	35
Gravel (well rounded)	45

This illustrates the need for trial batch testing of local materials, as each aggregate source is different and can influence concrete properties differently.

Enter Known Data on Mix Proportioning Worksheet



Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand ? lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

Estimate Water Content

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		(lb)	1.0	(ft^3)	
	Total cementitious	(lb)				
	ment	%	(lb)	3.14	(ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					(ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= ____% Paste Vol X 18/27	Selection= 6 %	(ft^3)
	Air + Paste Volume				(ft^3)	
	Total Agg Volume			27- (air + paste)	(ft^3)	
Aggregate	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b_0 = 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 (ft^3)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Estimate Water Content

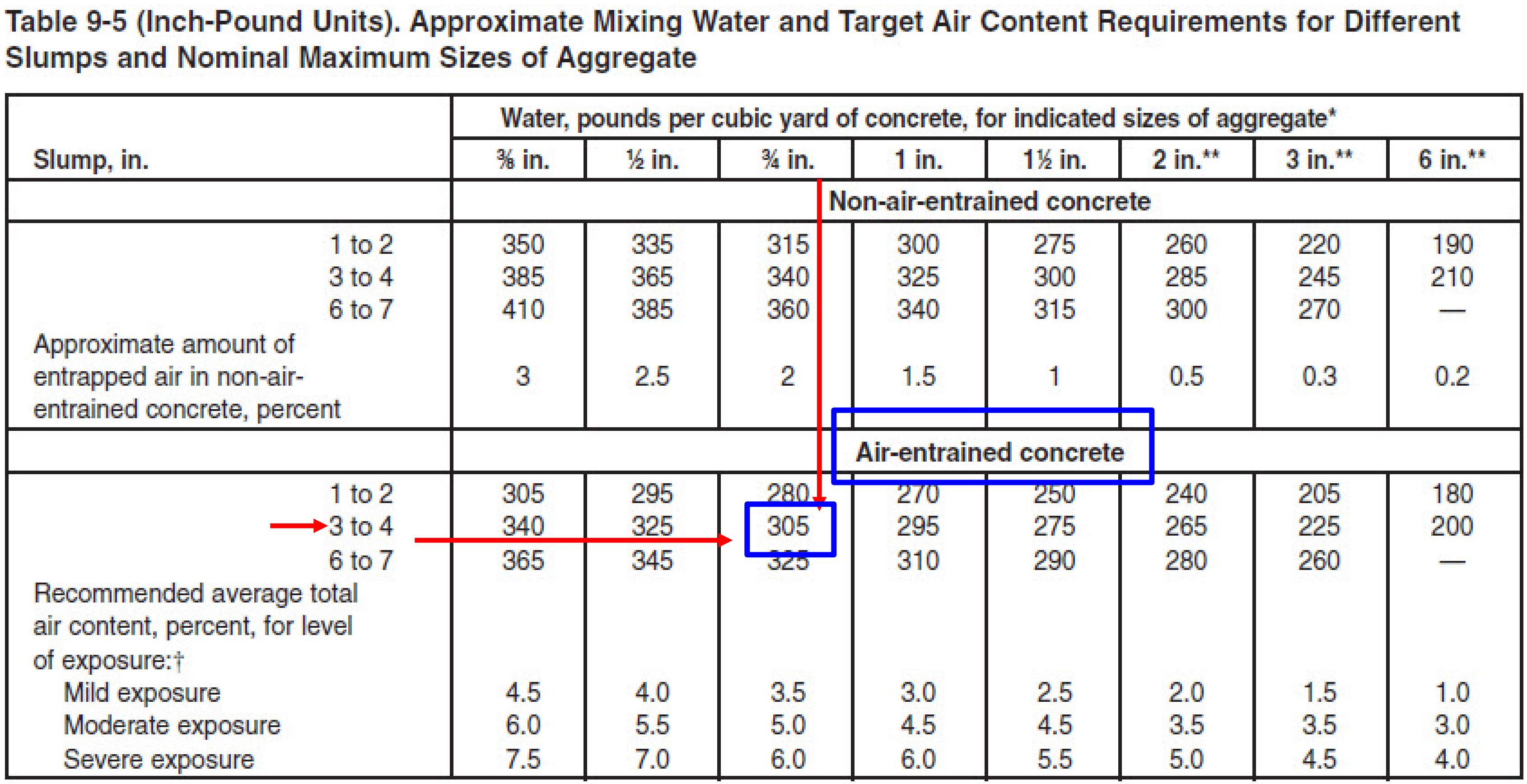
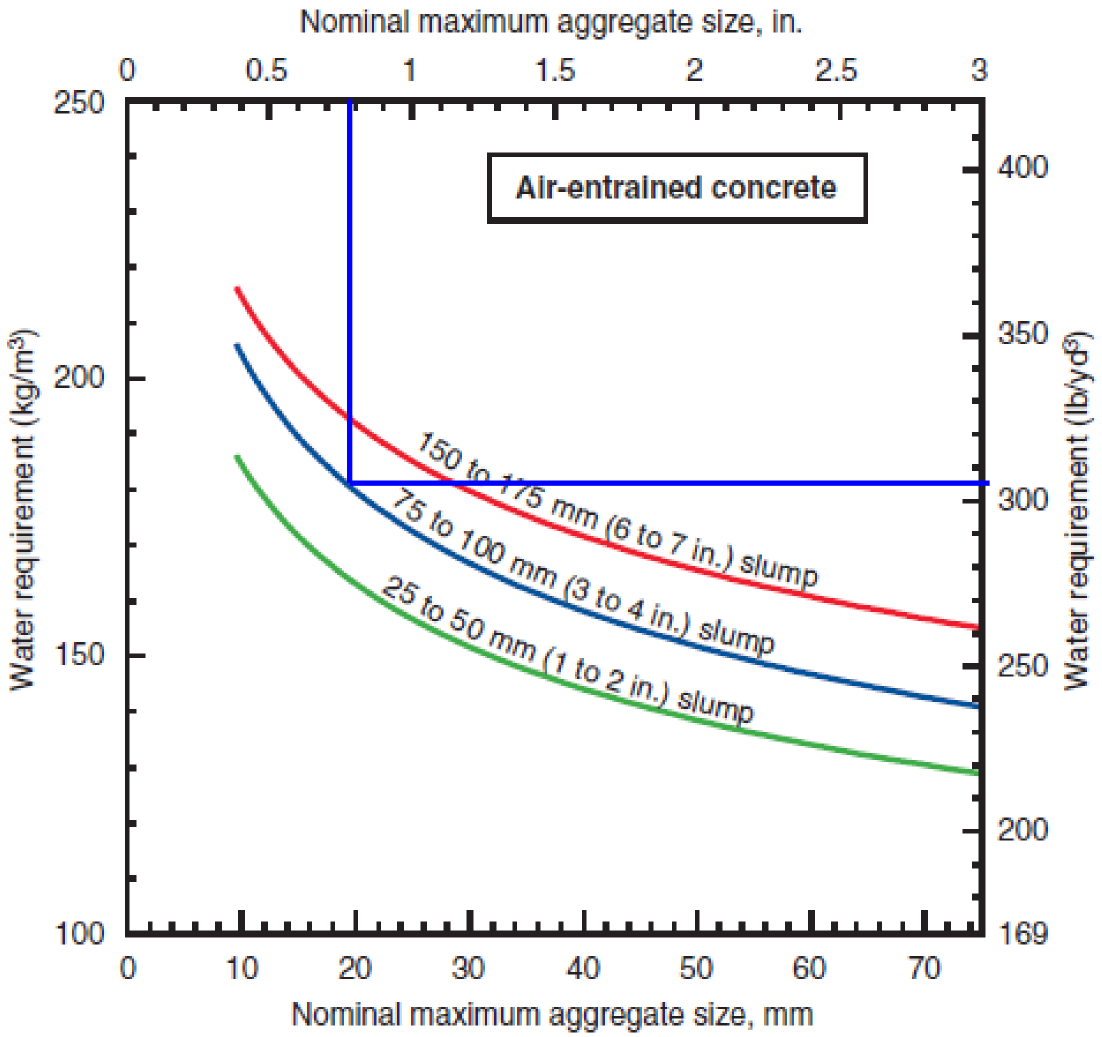


Table 9-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	⅜ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
Recommended average total air content, percent, for level of exposure:†								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Estimate Water Content



305 lbs/cy

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		(lb)	1.0	(ft^3)	
	Total cementitious	(lb)				
	Portland Cement	%	(lb)	3.14	(ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					(ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= ____% Paste Vol X 18/27	Selection= 6 %	(ft^3)
	Air + Paste Volume				(ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	(ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b_0 = 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 (ft^3)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Determine
Paste Volume

Calculate Batch Proportions & Volumes

Water Adjustment = 305 lbs X 0.90 = 275 lbs

Cement Content = 275 lbs / 0.40 = 688 lbs

Abs Vol. (ft^3)

Water = 275 lbs / (62.4 lbs/ft3 X 1.00) = 4.41 ft^3

Cement = 688 lbs / (62.4 lbs/ft3 X 3.14) = $\underline{3.51 \text{ ft}^3}$

Volume of Paste = 7.92 ft3

Mix Proportioning Worksheet Mixture Date Prepared by ACI MIX EXAMPLE

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft^3)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					7.92 (ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= ____% Paste Vol X 18/27	Selection= 6 %	(ft^3)
	Air + Paste Volume				(ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	(ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b$_0$ = 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b$_0$ x 27 (ft^3)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Determine
Air Volume

Calculate Batch Volumes

Air must be minimum of 18% of paste volume.

7.94 ft^3 X 0.18 = 1.43 ft^3 air volume in paste

1.43 ft^3 /27 ft^3 X 100 = 5.3% air

6% required by ACI Select highest

Air Vol = 0.06 X 27 ft^3 = 1.62 ft^3

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft³)	**Subtotal Vol.** (ft³)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft³)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft³)	
	Fly ash	%	(lb)		(ft³)	
	Other Pozzolan	%	(lb)		(ft³)	
	Total (water + cm) = Paste Volume					7.92 (ft³)
Air	Total Air Content	Specified Value ___%	ACI 318 Value 6 %	18% of paste= 5.3 % Paste Vol X 18/27	Selection= 6 %	1.62 (ft³)
	Air + Paste Volume				(ft³)	
	Total Agg Volume			27- (air + paste)	(ft³)	
Aggregate	Agg. Data			FM (Sand) = 2.6	b/b₀ =	
				Unit Wt. Crs.Agg= 92.0 (lbs/ft³)SSD		
	Coarse Aggregate	Bulk Vol. = b/b₀ x 27 (ft³)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft³)	
	Intermediate Aggregate			Sp. G. SSD	(ft³)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft³)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft³)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft³)
	Design Yield					(%)

Determine

Paste + Air Volume

Aggregate Volume

Calculate Batch Volumes

Volume of Paste = 7.92 ft3

Volume of Air = 1.62 ft^3

Volume of Paste + Air = 9.54 ft3

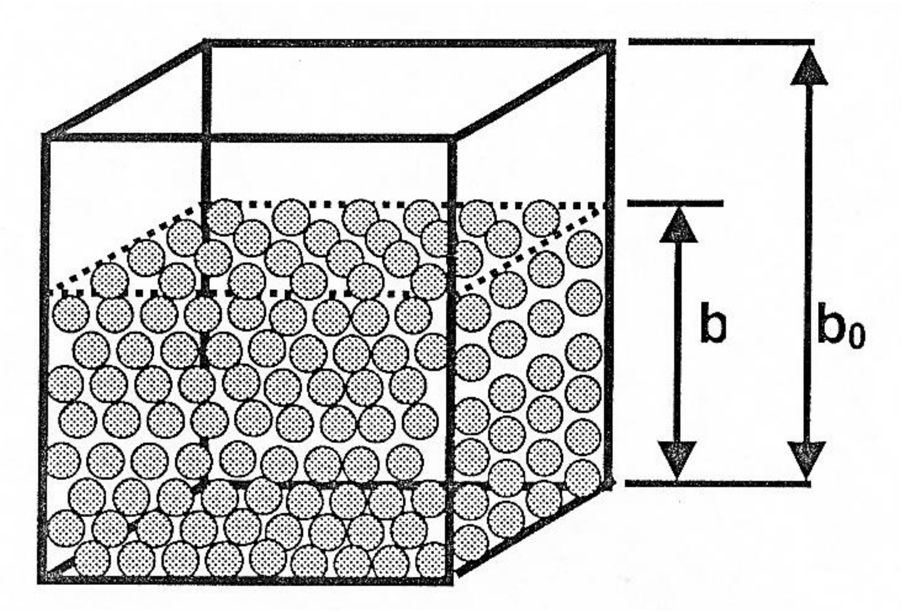
Volume of Aggregate = 27ft3 - 9.56 ft3 = 17.46 ft3

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

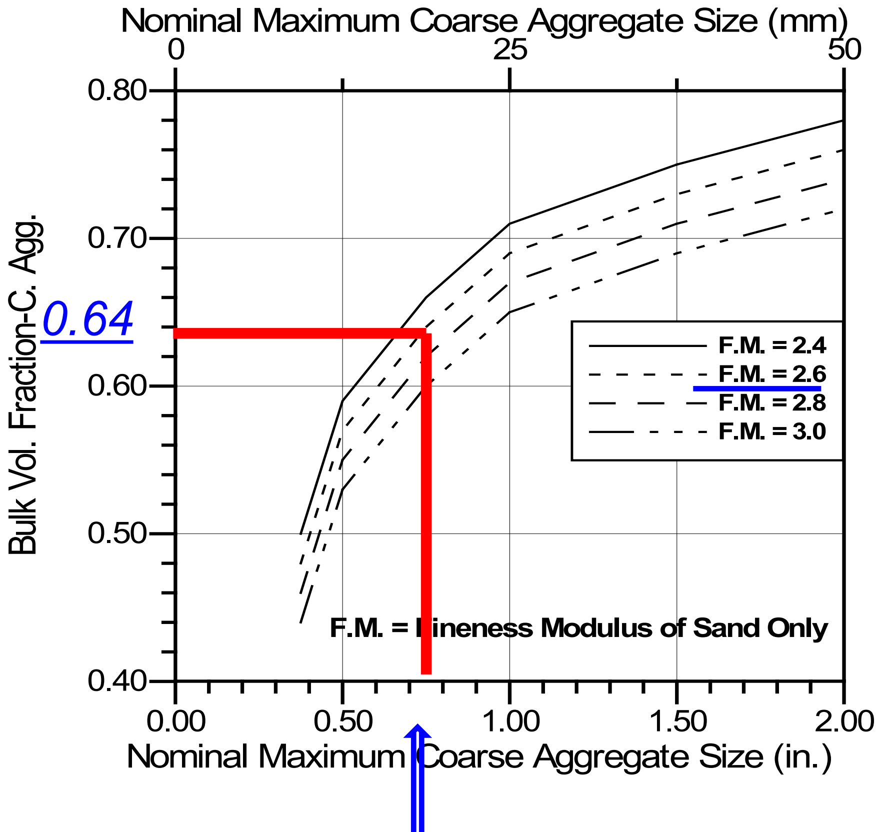
	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft^3)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					7.92 (ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= 5.3 % Paste Vol X 18/27	Selection= 6 %	1.62 (ft^3)
	Air + Paste Volume				9.54 (ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	17.46 (ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b_0 = 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 (ft^3)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Estimate Aggregate Proportions



- Bulk volume of coarse aggregate (b/b_0) is the percent of loosely packed (dry rodded) volume the coarse aggregate occupies in one cubic yard

Estimate Aggregate Proportions



Bulk Volume of Coarse Aggregate as a Fraction of Total Concrete Volume. Data from Table 6.3.6 ACI 211.1-91.

BBO00.GRF

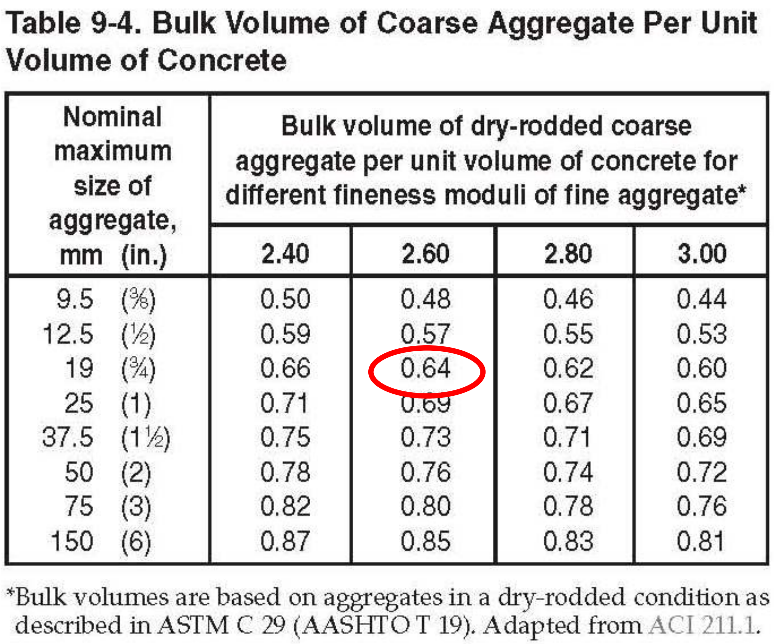


Table 9-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

Nominal maximum size of aggregate, mm (in.)	Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate*			
	2.40	2.60	2.80	3.00
9.5 (⅜)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
19 (¾)	0.66	0.64	0.62	0.60
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

*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.

Determine
Coarse Aggregate Volume

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft^3)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					7.92 (ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= 5.3 % Paste Vol X 18/27	Selection= 6 %	1.62 (ft^3)
	Air + Paste Volume				9.54 (ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	17.46 (ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg= 92.0 (lbs/ft^3)SSD	b/b_0 = 0.64	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 (ft^3)	= Bulk Vol. x unit wt. (lb,SSD)	Sp. G. SSD 2.60	(ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Calculate Aggregate Batch Proportions

Coarse Aggregate

Bulk Volume (b/b_0) = 0.64 X 27 ft^3 = 17.28 ft^3

Weight (lbs) = 17.28 ft^3 X 92.0 lbs/ft3 = 1590 lbs

Abs. Vol.(ft^3)=1590 lbs/(62.4 lbs/ft3 X 2.60)= 9.80ft^3

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft^3)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					7.92 (ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= 5.3 % Paste Vol X 18/27	Selection= 6 %	1.62 (ft^3)
	Air + Paste Volume				9.54 (ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	17.46 (ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b_0 = 0.64 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 17.28 (ft^3)	= Bulk Vol. x unit wt. 1590 (lb,SSD)	Sp. G. SSD 2.60	9.80 (ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		(lb,SSD)	Sp. G. SSD 2.65	(ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					(ft^3)
	Total Weight / CY		(lb)			
	Total Absolute Volume					27.00 (ft^3)
	Design Yield					(%)

Determine
Fine Aggregate Volume

Calculate Aggregate Batch Proportions

Fine Aggregate

Abs. Vol.(ft^3) = 17.46 ft^3 - 9.80 ft^3 = 7.66 ft^3

Weight (lbs) = 7.66 ft^3 X 62.4 lbs/ft3 X 2.65=1267 lbs

Mix Proportioning Worksheet **Mixture** **Date** **Prepared by ACI MIX EXAMPLE**

Slump = 4 (in.)	Nom. Max. Agg. Size= 3/4 (in.)	Basic Water Demand 305 lb/CY	Water Adjustment Factor (note impact of AE Conc.) 0.90
Controlling w/c or w/cm = 0.40	Mix design target strength = psi 5000	Air-Entrained concrete? [✓ YES] NO	Exposure: Mild Moderate [✓ Extreme]

	Mix Component		**Weight** (lbs/CY)	**Specific Gravity**	**Absolute Vol.** (ft^3)	**Subtotal Vol.** (ft^3)
Paste	Adjusted Water		275 (lb)	1.0	4.41 (ft^3)	
	Total cementitious	688 (lb)				
	Portland Cement	100 %	688 (lb)	3.14	3.51 (ft^3)	
	Fly ash	%	(lb)		(ft^3)	
	Other Pozzolan	%	(lb)		(ft^3)	
	Total (water + cm) = Paste Volume					7.92 (ft^3)
Air	Total Air Content	Specified Value ____%	ACI 318 Value 6 %	18% of paste= 5.3 % Paste Vol X 18/27	Selection= 6 %	1.62 (ft^3)
	Air + Paste Volume				9.54 (ft^3)	
Aggregate	Total Agg Volume			27- (air + paste)	17.46 (ft^3)	
	Agg. Data			FM (Sand) = 2.6 Unit Wt. Crs.Agg=	b/b_0 = 0.64 92.0 (lbs/ft^3)SSD	
	Coarse Aggregate	Bulk Vol. = b/b_0 x 27 17.28 (ft^3)	= Bulk Vol. x unit wt. 1590 (lb,SSD)	Sp. G. SSD 2.60	9.80 (ft^3)	
	Intermediate Aggregate			Sp. G. SSD	(ft^3)	
	Fine Aggregate		1267 (lb,SSD)	Sp. G. SSD 2.65	7.66 (ft^3)	Total agg – (coarse & interm vol)
	Total Agg Volume					17.46 (ft^3)
	Total Weight / CY		3820 (lb)			
	Total Absolute Volume					27.00 (ft^3)
	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		**2.67**

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.

Mathematical Combined Aggregate Gradation, by Weight

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		
¾”	76.0	100.0	100.0		
½”	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		

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.

Mathematical Combined Aggregate Gradation, by Weight

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
¾”	76.0	100.0	100.0	89.2	99.1-89.2 = 9.9
½”	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

Combined %Passing
1 ½” 100x0.45 + 100x0.15 + 100x0.40 = 100
1” 98x0.45 + 100x0.15 + 100x0.40 = 99.1
¾” 76x0.45 + 100x0.15 + 100x0.40 = 89.2
½” 38x0.45 + 100x0.15 + 100x0.40 = 72.1
3/8” 21x0.45 + 86x0.15 + 100x0.40 = 62.8
#4 4.8x0.45 + 21x0.15 + 92x0.40 = 42.1
#8 1.8x0.45 + 4.1x0.15 + 84x0.40 = 35.0
#16 1.7x0.45 + 3.7x0.15 + 66x0.40 = 27.7
#30 1.6x0.45 + 3.4x0.15 + 42x0.40 = 18.0
#50 1.5x0.45 + 2.9x0.15 + 14x0.40 = 6.7
#100 1.4x0.45 + 2.5x0.15 + 1.4x0.40 = 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*
¾"	76.0	100.0	100.0	89.2	*9.9*
½"	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	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*
¾”	76.0	100.0	100.0	89.2	*9.9*
½”	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*

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

$$= \frac{0 + 0.9 + 9.9 + 17.1 + 9.3}{0 + 0.9 + 9.9 + 17.1 + 9.3 \quad +20.7 + 7.1}\ \text{X}\ 100$$

$$= \frac{37.2}{65}\ \text{x}\ 100 = 57.2$$

$$\text{Workability factor} = \textit{Combined Percent Passing \#8 Sieve}$$

$$= 35.0$$

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

4. 8.0 ft^3 = ______ yd^3

5. 0.118 yd^3 = _______ ft^3

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

7. What is the absolute volume (yd^3) of 235 lbs of water?

8. Determine the unit weight of 0.25 ft^3 of concrete that weighs 35.7 lbs?

9. 1.0 ft^3 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 **yd^3** per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd^3 ?

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

13. What is the weight of material (lbs/yd^3) given an absolute volume of 0.330 and a specific gravity of 2.65? What is the weight in (lbs/ft^3) ?

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

300 lbs cement
90 lbs fly ash
210 lbs ggbfs

200 lbs water at plant
10 lbs from coarse aggregate
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 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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 ft^3 = ______ yd^3

8.0 ft^3 ÷ 27 ft^3 / yd^3 = 0.296 yd^3

5. 0.118 yd^3 = _______ ft^3

0.118 yd^3 × 27 ft^3/ yd^3 = 3.186 ft^3

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

(6.8 gal) × (8.33 lbs)/gal. = 56.64 lbs

7. What is the absolute volume (yd^3) of 235 lbs of water?

Abs Vol (yd^3) = 235 lbs ÷ (1.00 x 62.4 lbs/ ft^3 x 27 ft^3 yd^3)

235 lbs ÷ 1684.8 lbs/yd^3 = 0.139 yd^3

8. Determine the unit weight of 0.25 ft^3 of concrete that weighs 35.7 lbs?

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

9. 1.0 ft^3 of a material weighs 167 lbs. Determine the specific gravity (SPG).

$$SPG = \frac{\text{Unit wt of material}}{\text{Unit wt of water}} = 167.4\ lbs/ft^3 \div 62.4\ lbs/ft^3 = 2.68$$

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

0.06 yd^3/yd^3 × 27 ft^3/yd^3 = 1.62 ft^3

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

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

12. What is the absolute volume of cement **<u>ft³</u>** per cubic yard, given the SPG is 3.14 and there are 709 lbs/yd^3 ?

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

13. What is the weight of material (lbs/yd^3) given an absolute volume of 0.330 and a specific gravity of 2.65? What is the weight in (lbs/ft^3) ?

Weight lbs/yd^3 = 0.330 x 2.65 x 62.4 ft^3/yd^3 x 27 ft^3/yd^3 = 1473 lbs/yd^3

Weight lbs/ ft^3 = 1473 lbs/yd^3 ÷ 27 ft^3/yd^3 = 54.57 lbs/ft^3

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

300 lbs cement
90 lbs fly ash
210 lbs ggbfs

200 lbs water at plant
10 lbs from coarse aggregate
30 lbs from fine aggregate
2 gallons water per yd^3 added on truck

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

15. Given that a concrete mix is designed on the basis of 1 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. The **w/c ratio** is given as **0.45**.

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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 ft^3
c) 561 X 0.45 = 252.45 lbs
d) 252.45 ÷ (1.00 X 62.4 X 27) = 0.150 yd^3
e) 0.150 X 27 = 4.05 ft^3
f) 10.6 ÷ 27 = 0.393 yd^3
g) 1.000 – 0.393 – 0.150 – 0.106 = 0.351 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:

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

Assume the following aggregate Proportions:

- Coarse = 0.48

- Intermediate = 0.12

- Fine = 0.40

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Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: Problem 16

County : Any

Mix No.: QMC

Abs Vol. Cement: 0.1059

Type: I/II

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.:

Adjusted lbs. Cement: 448

Total Cementitious 560

Total % Replacement = 20

IM T203	Fine Aggregate Source:	Army Post East	Sp. Gr.:	2.65
IM T203	Interm. Aggregate Source:	Ames Mine	Sp. Gr.:	2.68
IM T203	Coarse Agregate Source:	Ames Mine	Sp. Gr.:	2.68

Basic w/c 0.400

Max w/c 0.435

Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 224

Max. Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 244

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.:

% In. Agg.:

% CA Agg.:

Fine Aggregate (1.000 - Subtotal) X % In Mix =

Interm. Aggregate (1.000 - Subtotal) X % In Mix =

Coarse Aggregate (1.000 - Subtotal) X % In Mix =

Aggregate Total = 0.697

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/cy)
Fly Ash (lbs/cy)
Slag (lbs/cy)
Water (lbs/cy)
Fine Agg. (lbs/cy)
Interm. Agg. (lbs/cy)
Coarse Agg. (lbs/cy)

Distribution: ___ Materials, ___ DME, ___ Proj. Engr., ___ Contractor

Example 16 Answer

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Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Form E820150E

Project No.: Problem 16

County : Any

Mix No.: QMC

Abs Vol. Cement: 0.1059

Type: I/II

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.:

Adjusted lbs. Cement: 448

Total Cementitious 560

Total % Replacement = 20

IM T203 Fine Aggregate Source: Army Post East Sp. Gr.: 2.65
IM T203 Interm. Aggregate Source: Ames Mine Sp. Gr.: 2.68
IM T203 Coarse Agregate Source: Ames Mine Sp. Gr.: 2.68

Basic w/c 0.400
Max w/c 0.435

Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 224
Max. Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 244

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.: 40 Fine Aggregate (1.000 - Subtotal) X % In Mix = 0.278
% In. Agg.: 12 Interm. Aggregate (1.000 - Subtotal) X % In Mix = 0.084
% CA Agg.: 48 Coarse Aggregate (1.000 - Subtotal) X % In Mix = 0.335
Aggregate Total = 0.697

Aggregate Weights

Fine Aggregate (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 Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27 = 1513

Summary

Cement	448	(lbs/cy)
Fly Ash	112	(lbs/cy)
Slag	0	(lbs/cy)
Water	224	(lbs/cy)
Fine Agg.	1241	(lbs/cy)
Interm. Agg.	379	(lbs/cy)
Coarse Agg.	1513	(lbs/cy)

Distribution: ___ Materials, ___ DME, ___ Proj. Engr., ___ Contractor

APPENDIX C

WORKSHEETS

PCC Level III Basic Equations

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

Abs. Vol. (ft3/yd3) = weight (lbs) ÷ SpG ÷ 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 cement 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

Standard Deviation

$f'_{cr} = f'_{c} + (2.33 \text{ X } S - 500)$

$f'_{cr} = f'_{c} + (1.34 \text{ X } S)$

f'_{cr} = *Targetstrength*
f'_{c} = *design strength*
S = standard deviation

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

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”					
¾”					
½”					
3/8”					
#4					
#8					
#16					
#30					
#50					
#100					
#200					

Rev 05/09

Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: ______________________ **County :** __________

Mix No.: __________ **Abs Vol. Cement:** ________ **Type:** __________

Cement (IM 401): __________ **lbs** **Source:** ______________ **Sp. Gr.:** __________

%

Fly Ash (IM 491.17): __________ ☐ **Source:** ______________ **Sp. Gr.:** __________

Slag (IM 491.14): __________ ☐ **Source:** ______________ **Sp. Gr.:** __________

Adjusted lbs. Cement: ☐

Total Cementitious __________ **Total % Replacement =** __________

IM T203 **Fine Aggregate Source:** ______________ **Sp. Gr.:** __________

IM T203 **Interm. Aggregate Source:** ______________ **Sp. Gr.:** __________

IM T203 **Coarse Agregate Source:** ______________ **Sp. Gr.:** __________

Basic w/c __________ **Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) =** __________

Max w/c __________ **Max. Water (lbs/cy) = 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** = __________

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/cy)**
Fly Ash __________ **(lbs/cy)**
Slag __________ **(lbs/cy)**
Water __________ **(lbs/cy)**
Fine Agg. __________ **(lbs/cy)**
Interm. Agg. __________ **(lbs/cy)**
Coarse Agg. __________ **(lbs/cy)**

Distribution: ___ **Materials,** ___ **DME,** ___ **Proj. Engr.,** ___ **Contractor**

Rev 05/09 Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: ____________ **County :** ____________

Mix No.: ____________ **Abs Vol. Cement:** ____________ **Type:** ____________

Cement (IM 401): ____________ **lbs** **Source:** ____________ **Sp. Gr.:** ____________

%

Fly Ash (IM 491.17): ____________ ____________ **Source:** ____________ **Sp. Gr.:** ____________

Slag (IM 491.14): ____________ ____________ **Source:** ____________ **Sp. Gr.:** ____________

Adjusted lbs. Cement: ____________

Total Cementitious ____________ **Total % Replacement =** ____________

IM T203 **Fine Aggregate Source:** ____________ **Sp. Gr.:** ____________
IM T203 **Interm. Aggregate Source:** ____________ **Sp. Gr.:** ____________
IM T203 **Coarse Agregate Source:** ____________ **Sp. Gr.:** ____________

Basic w/c ____________ **Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) =** ____________
Max w/c ____________ **Max. Water (lbs/cy) = 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 =** ____________
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 = ____________

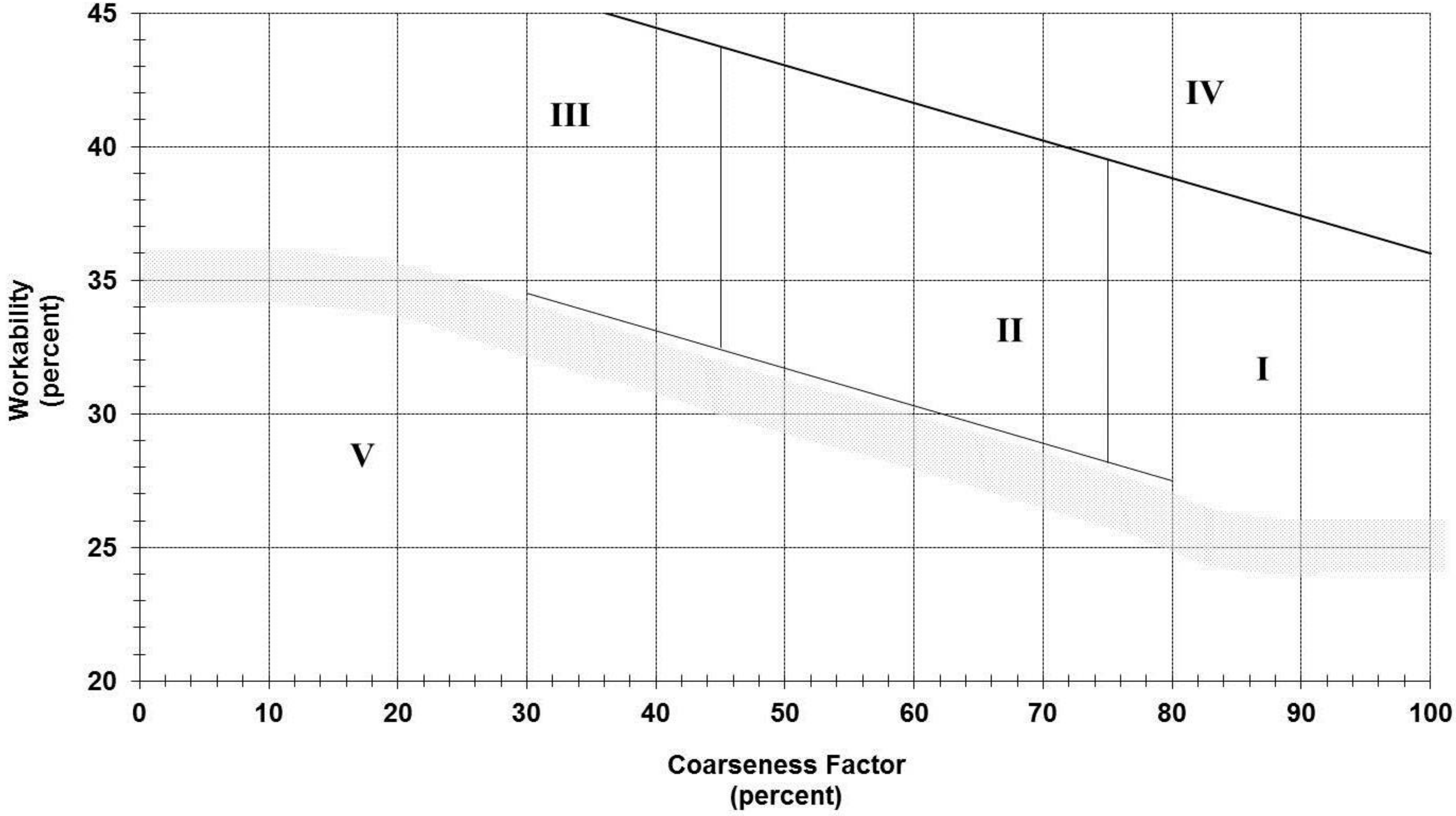
Summary

Cement ____________ **(lbs/cy)**
Fly Ash ____________ **(lbs/cy)**
Slag ____________ **(lbs/cy)**
Water ____________ **(lbs/cy)**
Fine Agg. ____________ **(lbs/cy)**
Interm. Agg. ____________ **(lbs/cy)**
Coarse Agg. ____________ **(lbs/cy)**

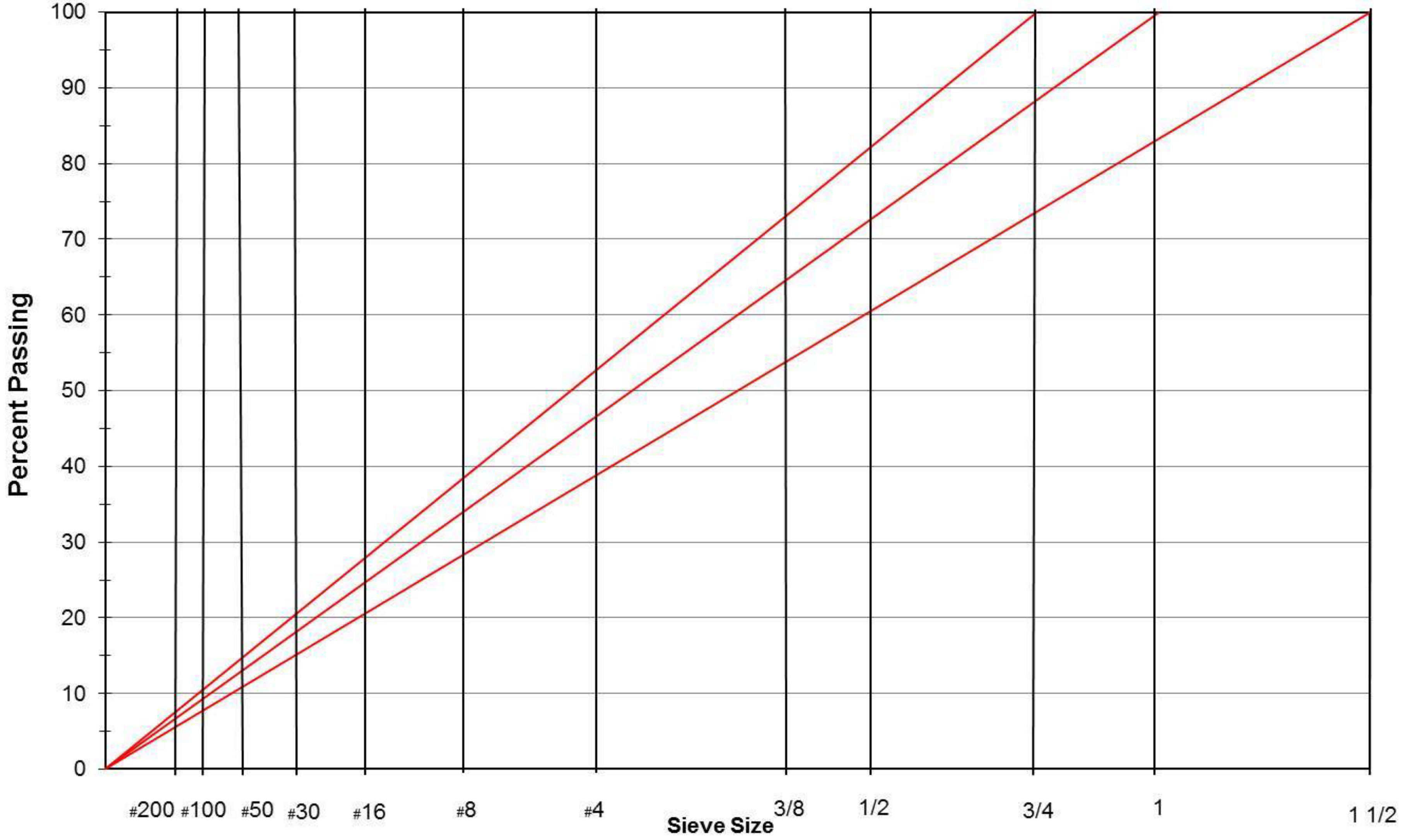
Distribution: ___ **Materials,** ___ **DME,** ___ **Proj. Engr.,** ___ **Contractor**

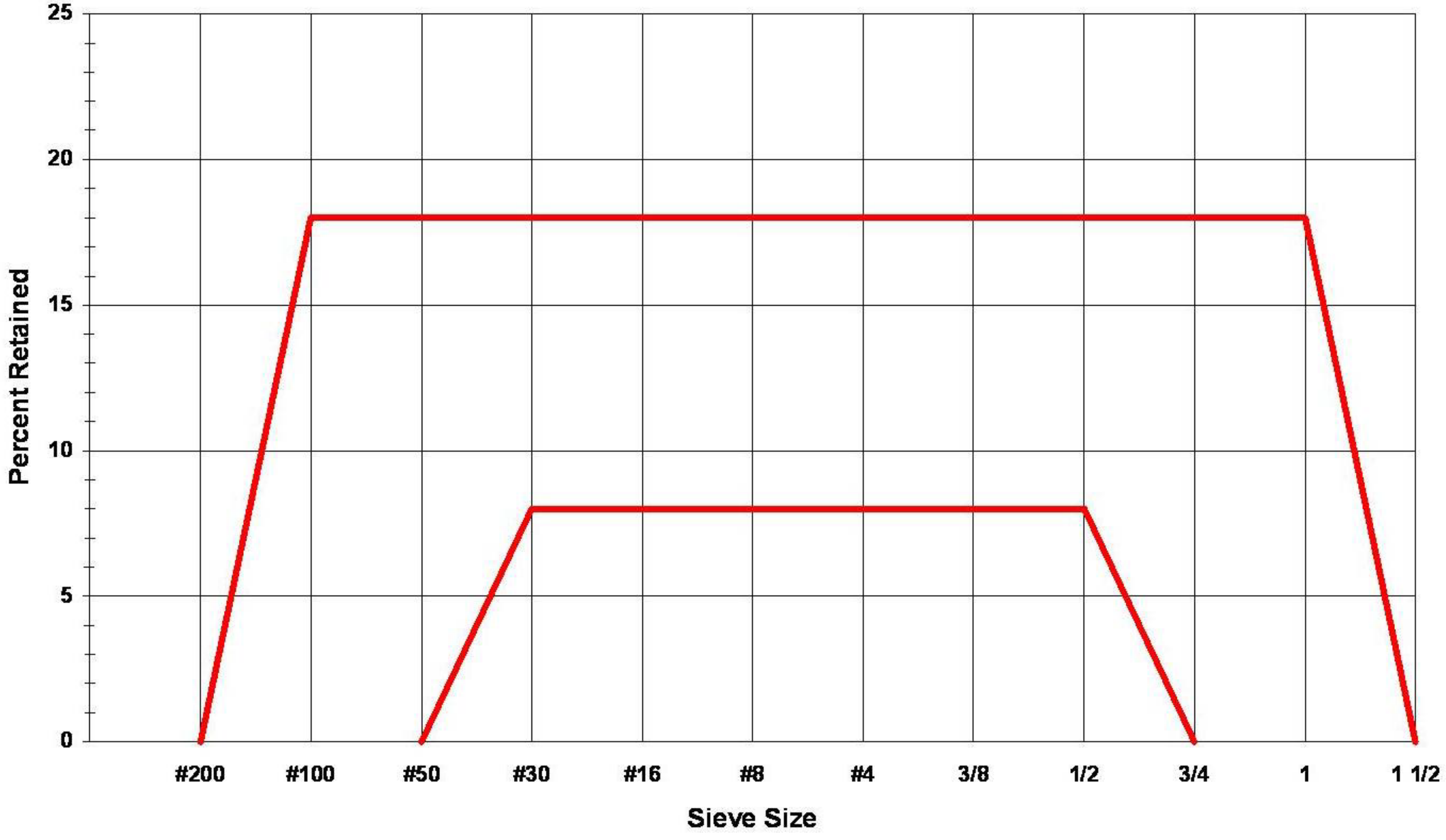
[1] Workability Factor VS Coarseness Factor for Combined Aggregate

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



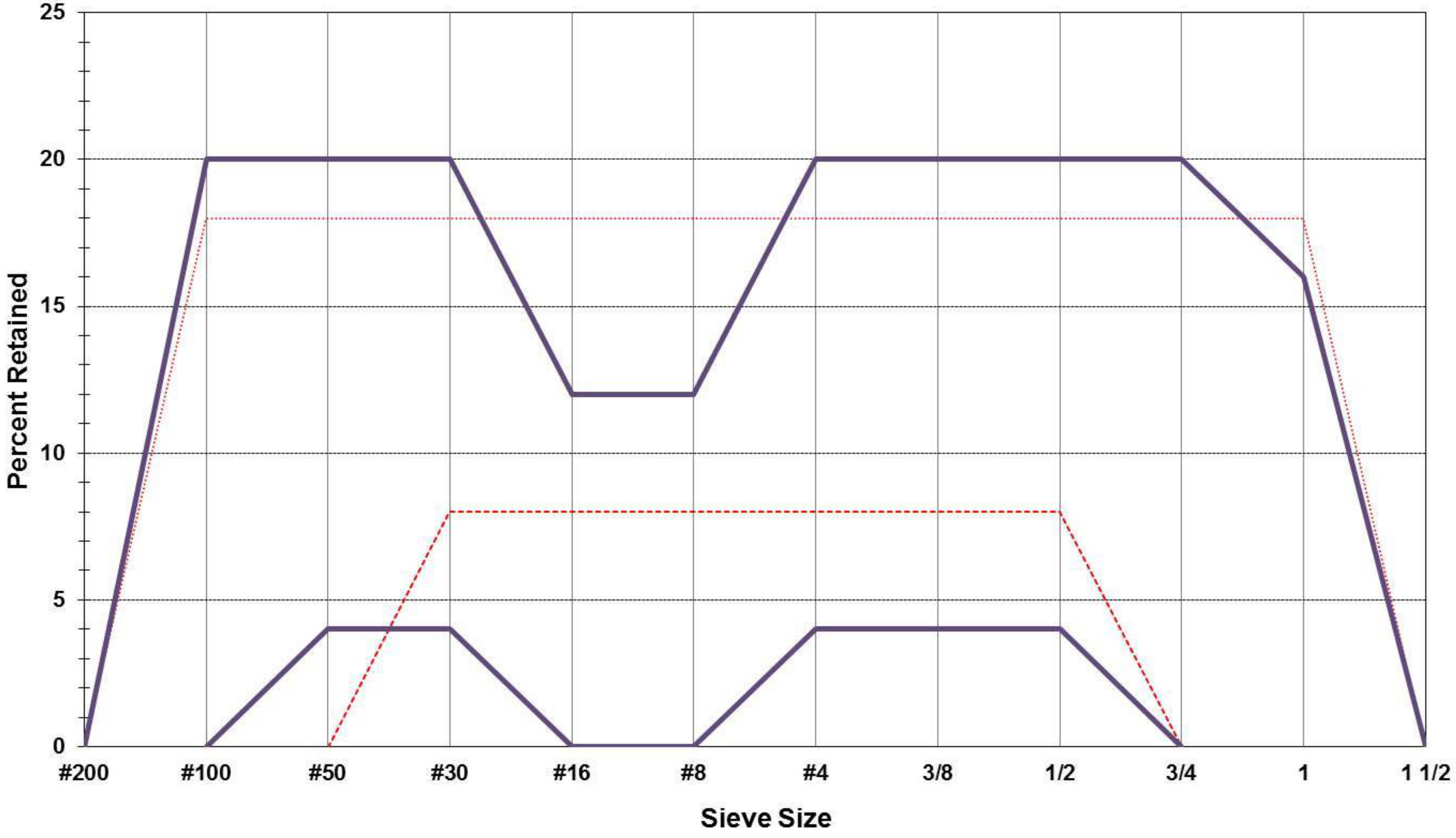
Combined Aggregate Gradation Power 45 Scale





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. 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 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?
    1. All admixtures are designed to improve only one concrete property
    2. An admixture may be used to enhance a poor mix design and improve placement
    3. **Admixtures should be used to enhance the properties of a good mix design**
    4. 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?
    1. **Many small bubbles spaced relatively close to each other provides the maximum freeze thaw protection**
    2. A few large bubbles spaced as close as possible will provide adequate freeze thaw protection
    3. Freeze thaw protection is not a concern in Iowa because the concrete remains frozen for an extended time
    4. 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?
    1. Water reducers aid in air entrainment as well as reduce water for a given slump
    2. Retarders provide water reduction as well as retard the set
    3. Air entrainment improves workability and improves F/T resistance
    4. **All of the above**
    5. None of the above

4. Water reducers can be used in which of the following manners to achieve various effects?
    1. Use same cement and reduce the water
    2. Reduce cement and water the same reduce cost
    3. Cement and water remain the same increase workability
    4. **All of the above**
    5. 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

5. Calculate the FM for the following 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	
#4	12	
#8	17	
#16	16	
#30	23	
#50	10	
#100	7	
Pan	5	NA
Sum		
Calculation		
FM		

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
¾"	84.0	100.0	100.0	92.8	6.8
½"	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

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

Sieve Size	Passing Coarse	Passing Intermediate	Passing Fine	Passing (Combined Agg)	Retained (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

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
    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

5. Calculate the FM for the following 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		**3.87**

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
¾"	84.0	100.0	100.0	92.8	6.8
½"	44.0	100.0	100.0	74.8	18.0
3/8"	15.0	100.0	100.0	**61.8**	**13.0**
No. 4	2.4	38.0	98.0	**46.6**	**15.2**
No. 8	1.2	5.2	84.0	**35.7**	**10.9**
No. 16	1.1	4.3	65.0	**27.8**	**7.9**
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" 0.45x15 + 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

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

	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

WF = 36

$$CF = \frac{0+0 + 7.1 + 16.8 + 11}{0+ 0 + 7.1 + 16.8 + 11 + 18.8 + 10.2} \times 100 = \frac{34.9}{63.9} \times 100 = 54.6$$

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
    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. ______ $ft^3 = 0.118\ yd^3$

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

6. What is the weight of water (lbs/yd^3), if the w/c ratio is 0.40 and the cement content is 448 lbs/yd^3 and fly ash content is 112 lbs/yd^3?

7. What is the absolute volume(ft^3) of cement if the SPG is 3.14 and there are 625lbs/yd^3?

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 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. w/c=0.40

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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. ______ $ft^3 = 0.118\ yd^3$

$0.118\ yd^3 \times (27\ ft^3 / 1\ yd^3) = 3.186\ ft^3$

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

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

6. What is the weight of water (lbs/yd^3), if the w/c ratio is 0.40 and the cement content is 448 lbs/yd^3 and fly ash content is 112 lbs/yd^3?

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

7. What is the absolute volume(ft^3) of cement if the SPG is 3.14 and there are 625lbs/yd^3?

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 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. The w/c ratio is given as 0.45.

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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 yd^3/yd^3 x 27 ft^3/yd^3 = 4.29 ft^3/yd^3
b) 0.159 yd^3/yd^3 x 27 ft^3/yd^3 x 62.4 lbs/ft^3 x 1.00 = 268 lbs/yd^3
c) w/c = 0.45 0.45 = 268/c c = 268 / 0.45 = 596 lbs/yd^3
d) 596 lbs/yd^3 / (27 ft^3/yd^3 x 62.4 lbs/ft^3 x 3.14) = 0.113 yd^3/yd^3
e) 0.113 yd^3/yd^3 x 27 ft^3/yd^3 = 3.05 ft^3/yd^3
f) 9.45 ft^3/yd^3 / 27 ft^3/yd^3 = 0.350 yd^3/yd^3
g) 1.000yd^3/yd^3 -0.113yd^3/yd^3 -0.159yd^3/yd^3-0.350yd^3/yd^3 = 0.378 yd^3/yd^3
h) 0.378 yd^3/yd^3 x 27 ft^3/yd^3 = 10.21 ft^3/yd^3
i) 596 + 268 + 1650 + 1560 = 4074 lbs/yd^3

Check totals

0.113 + 0.159 + 0.350 + 0.378 = 1.000 yd^3/yd^3
4.29 + 3.05 + 10.21 + 9.45 = 27.0 ft^3/yd^3

11. Given that a concrete mix is designed on the basis of 1 yd^3 (27 ft^3) provide the correct answer in each box so that ALL of the missing information in the following table is completed. w/c = 0.40

Component Material	Absolute Volume (yd^3/yd^3)	Absolute Volume (ft^3/yd^3)	Weight (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 yd^3/yd^3 x 27 ft^3/yd^3 = 3.19 ft^3/yd^3
b) 0.118 yd^3/yd^3 x 27 ft^3/yd^3 x 62.4 lbs/ft^3 x 3.14 = 624 lbs/yd^3
c) w/c = 0.40 0.40 = w/624 lbs w = 624 X 0.40 = 250 lbs/yd^3
d) 250 lbs/yd^3 / (27 ft^3/yd^3 x 62.4 lbs/ft^3 x 1.00) = 0.148 yd^3/yd^3
e) 0.148 yd^3/yd^3 X 27 ft^3/yd^3 = 4.00 ft^3/yd^3
f) 0.335 yd^3/yd^3 x 27 ft^3/yd^3 = 9.05 ft^3/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 yd^3/yd^3 x 27 ft^3/yd^3 = 10.77 ft^3/yd^3
i) 624 lbs/yd^3 + 250 lbs/yd^3 + 1550 lbs/yd^3 + 1625 lbs/yd^3 = 4049 lbs/yd^3

Check totals

0.118 + 0.148 + 0.335 + 0.399 = 1.000 yd^3/yd^3
3.19 + 4.00 + 9.05 + 10.77 = 27.0 ft^3/yd^3

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) = 4991 psi
f'_{cr} = 4000 + 1.34 X 640 = 4858 psi
Select the largest value 4991 and round to the next highest 10 psi
Target =5000 psi

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.

Sieve Size	**% Passing Coarse**	**% Passing Intermediate**	**% Passing Fine**	**% Passing** (Combined Agg)	**% Retained** (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

Rev 05/09

Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: ____________________ **County :** ____________

Mix No.: ____________ **Abs Vol. Cement:** __________ **Type:** ____________

Cement (IM 401): ____________ **lbs** **Source:** ____________________ **Sp. Gr.:** ____________

%

Fly Ash (IM 491.17): ____________ ☐ **Source:** ____________________ **Sp. Gr.:** ____________

Slag (IM 491.14): ____________ ☐ **Source:** ____________________ **Sp. Gr.:** ____________

Adjusted lbs. Cement: ☐

Total Cementitious ____________ **Total % Replacement =** ____________

IM T203 **Fine Aggregate Source:** ____________________ **Sp. Gr.:** ____________
IM T203 **Interm. Aggregate Source:** ____________________ **Sp. Gr.:** ____________
IM T203 **Coarse Agregate Source:** ____________________ **Sp. Gr.:** ____________

Basic w/c ____________ **Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) =** ____________
Max w/c ____________ **Max. Water (lbs/cy) = 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** **=** ____________
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/cy)**
Fly Ash __________ **(lbs/cy)**
Slag __________ **(lbs/cy)**
Water __________ **(lbs/cy)**
Fine Agg. __________ **(lbs/cy)**
Interm. Agg. __________ **(lbs/cy)**
Coarse Agg. __________ **(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

Project No.: NHSX-020 **County :** Any

Mix No.: QMC **Abs Vol. Cement:** 0.106 **Type:** I/II

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.:**

Adjusted lbs. Cement: 448

Total Cementitious 560 **Total % Replacement =** 20

IM T203	**Fine Aggregate Source:**	Emmetsburg	**Sp. Gr.:**	2.64
IM T203	**Interm. Aggregate Source:**	Emmetsburg	**Sp. Gr.:**	2.71
IM T203	**Coarse Agregate Source:**	Moore	**Sp. Gr.:**	2.62

Basic w/c 0.400 **Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) =** 224

Max w/c 0.435 **Max. Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) =** 244

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.:		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	=	
		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	448	(lbs/cy)
Fly Ash	112	(lbs/cy)
Slag	0	(lbs/cy)
Water	224	(lbs/cy)
Fine Agg.		(lbs/cy)
Interm. Agg.		(lbs/cy)
Coarse Agg.		(lbs/cy)

Distribution: ___ Materials, ___ DME, ___ Proj. Engr., ___ Contractor

Chapter 6 - Mix Design Answers

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?
   0.45 from table 4.2.2 or mix datasheet

2. 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?

   $0.06\ yd^3/yd^3 \times 27\ ft^3/yd^3 \qquad = 1.62\ ft^3$

4. What are the mix design requirements for an HPC-D mix design?
   Basic w/c ratio = 0.40, Maximum w/c ratio = 0.435.
   Type IP, IS, IT cement.
   Type I/II or IL cement with a minimum of 30% replacement with GGBFS.
   Maximum fly ash replacement not to exceed 20%
   Maximum total replacement of 50% by weight (mass) of the cement.

QMC Mix Design Example 6A Answer Key

	%	%	%	%	%	%
	Passing	**Passing**	**Passing**	**Passing**	**Passing**	**Retained**
Sieve Size	**Coarse**	**Intermediate**	**Fine**	**Paste**	(Combined Agg)	(Combined Agg)
1 1/2"	100.0	100.0	100.0	100.0	100.0	0.0
1"	93.0	100.0	100.0	100.0	96.7	3.3
3/4"	75.0	100.0	100.0	100.0	88.3	8.5
1/2"	38.0	100.0	100.0	100.0	70.9	17.4
3/8"	20.0	100.0	100.0	100.0	62.4	8.5
#4	4.0	40.0	99.0	100.0	48.5	14.0
#8	1.5	3.1	84.0	100.0	37.1	11.3
#16	1.4	2.5	59.0	100.0	26.3	10.9
#30	1.3	2.0	32.0	100.0	14.6	11.7
#50	1.1	1.4	10.0	100.0	5.0	9.6
#100	1.0	0.9	2.1	100.0	1.5	3.5
#200	0.9	0.3	0.6	100.0	0.7	0.8

WF = 37.1

$$CF = \frac{0 + 3.3 + 8.5 + 17.4 + 8.5}{0 + 3.3 + 8.5 + 17.4 + 8.5 + 14 + 11.3} \text{ x } 100 = \frac{37.7}{63.0} \text{ x } 100 = 59.8$$

Rev 05/09

Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: Exercise 6A

County : Any

Mix No.: QMC

Abs Vol. Cement: 0.106

Type: 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.:**	

Adjusted lbs. Cement: 442

Total Cementitious 553

Total % Replacement = 36

IM T203	Fine Aggregate Source:	Saylorville	Sp. Gr.:	2.66
IM T203	Interm. Aggregate Source:	Ames Mine	Sp. Gr.:	2.68
IM T203	Coarse Agregate Source:	Ames Mine	Sp. Gr.:	2.68

Basic w/c 0.400

Max w/c 0.435

Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 221

Max. Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 241

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) = 0.131

Air 0.060

Subtotal = 0.301

1.000 - Subtotal = 0.699

Total = 1.000

% FA Agg.:	43	Fine Aggregate (1.000 - Subtotal) X % In Mix	= 0.300
% In. Agg.:	10	Interm. Aggregate (1.000 - Subtotal) X % In Mix	= 0.070
% CA Agg.:	47	Coarse Aggregate (1.000 - Subtotal) X % In Mix	= 0.329
		Aggregate Total	= 0.699

Aggregate Weights

Fine Aggregate (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 Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27 = 1486

Summary

Cement	442	(lbs/cy)
Fly Ash	111	(lbs/cy)
Slag	0	(lbs/cy)
Water	221	(lbs/cy)
Fine Agg.	1344	(lbs/cy)
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

Form E820150E

Iowa Department Of Transportation
Office Of Materials
PORTLAND CEMENT CONCRETE

Project No.: NHSX-020

County : Any

Mix No.: QMC

Abs Vol. Cement: 0.106

Type: I/II

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.:

Adjusted lbs. Cement: 448

Total Cementitious 560

Total % Replacement = 20

IM T203	Fine Aggregate Source:	Emmetsburg	Sp. Gr.:	2.64
IM T203	Interm. Aggregate Source:	Emmetsburg	Sp. Gr.:	2.71
IM T203	Coarse Agregate Source:	Moore	Sp. Gr.:	2.62

Basic w/c 0.400

Max w/c 0.435

Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 224

Max. Water (lbs/cy) = Design w/c (wt. cement + wt Fly Ash +Slag) = 244

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 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 Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	1330
	Intermediate Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	384
	Coarse Aggregate (abs vol.) X Sp. Gr. X 62.4 X 27	=	1386

Summary

	Cement	448	(lbs/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	(lbs/cy)

Distribution: ___ Materials, ___ DME, ___ Proj. Engr., ___ Contractor

APPENDIX E

QMC DS & IMs

April 15, 2025 Construction & Materials Bureau Matls. IM 529
Supersedes October 15, 2024

PORTLAND CEMENT (PC) CONCRETE PROPORTIONS

GENERAL

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%.

Example: 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:

1. Fly Ash and GGBFS used in concrete mixtures shall meet the requirements of Section 4108. Fly Ashes for use in concrete mixtures shall be included on the list of approved sources (Materials IM 491.17). GGBFS for use in concrete mixtures shall be included on the list of approved sources (Materials IM 491.14).

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 Section 4103 and shall be included on the list of Approved Sources of Water Reducing Admixtures (Materials IM 403, Appendix C). The dosage shall be as described in IM 403.

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 IM 401. The cement type shall be documented on all reports pertaining to a project.

5. The fine aggregates other than Class V (Section 4117) and Class L (Section 4111) shall meet the requirements of Section 4110 of the current specifications. The coarse aggregates for mixtures using aggregates, other than Class V aggregates, shall meet the requirements of Articles 4115.01 through 4115.04 of the current specifications. The coarse aggregates for Class O or Class HPC-O concrete mixtures shall meet the requirements of 4115.05 of the current specifications, for overlays (Article 2413). Intermediate aggregates used for QMC, BR, or HPC-D mixes shall meet 4112.

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 Appendix A.

A-MIX

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.

C-MIX

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 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.

M-MIX

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.

O-MIX

O-Mixes are specified for low slump concrete, primarily for use in bridge deck overlays. The water-cement 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 IM 403. O-Mixes require coarse aggregate specifically intended for repair and overlay. See Article 4115.05. 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).

X-MIX

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 Article 2405.05 for limits on water usage.

QMC

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 0.435 ~~0.42~~.

BR

BR mixes are used in slip form barrier rail in accordance with Section 2513. 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.

HPC

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.

CLASS V

Class V is an aggregate classification, specified in Section 4116. The fine limestone aggregates in concrete mixes using Class V aggregate with/without fly ash shall meet the requirements of Article 4116.03 of the current specifications. Allowable cements and substitutions shall meet the requirements of Article 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.

~~CLASS L~~

~~Class L is an aggregate classification, specified in Section 4111. 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. IM 527 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-for-pound 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) X 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 X 0.90 = 356 lbs. Portland cement
396 X 0.10 = 40 lbs. inter-ground limestone

Total replacement of Portland cement
((57 + 113 + 40) / 566) X 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 X 0.90 = 395 lbs. Portland cement
439 X 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 Article 4110 and 4115 Aggregates
Basic Absolute Volumes of Materials Per Unit Volume of Concrete

A MIXES Basic w/c = 0.474 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 MIXES 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 = 0.430 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 = 0.423 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 = 0.328 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 = 0.327 Max w/c = ------

Mix No.	Cement	Water	Air	Fine	Coarse
O-4WR	0.156	0.160	0.060	0.312	0.312

HPC-O MIXES 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 MIXES 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 Max w/c =0.435

Mix No.	Cement	Water	Air	Fine	Coarse
HPC-D	0.118	0.148	0.060	*	*

QMC MIXES Basic w/c = 0.400 Max w/c =0.435~~0.420~~

Mix No.	Cement	Water	Air	Fine	Coarse
QMC	0.106	0.133	0.060	*	*

MCM MIXES 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 = 0.423 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 IM 401.
*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-V47BP[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 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	0.435
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.

[1] When Type IP or IL cement is used. See Section 4116 for requirements when Type IL used.
[2] M-V47B mix shall use Type I/II or IL cements for patching projects.
[3] When Type IS or IT 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~~

~~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 IM 401.~~

Proportion Table 34
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 IM 401. *These mixes require optimized aggregate proportioning in accordance with the specifications.

Using Class V Aggregates (4116) 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	Air	Class V.	Coarse Limestone
CV-SUD	0.114	0.135	0.060	0.379	0.311

Above mixture is based on Type IP, IS, or IT 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 Sections 2403, 2412, and Division 41 of the Standard Specifications with the following modifications.

Typically, aggregates are well graded with a maximum top size of ¾” 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.

Materials

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

- Use a high range water reducer (HRWR) from Material IM 403 Appendix D.
- 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 IM 389. 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 IM 389. 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 IM 315, IM 316, IM 318, and IM 340 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 IM 315.

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.

Testing

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 IM 318, except place SCC in one layer, without consolidation or tapping. Cast cylinders in accordance with Materials IM 315, except place SCC in one layer, without consolidation or tapping.

The Engineer will perform air content testing at sampling at testing rate described in IM 204. The contractor will perform quality control testing of slump flow in accordance with IM 389 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 I.M. 315. 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 IM 390.

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.

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 Iowa 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 (IM 532, Appendix A). 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 Iowa DOT prior to the start of the work and prior to regular monitoring during the progress of the work. Use standard Iowa DOT forms. Batch tickets and gradation data shall be documented in accordance with Iowa 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 (IM 530, Appendix A). 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	IM 340
Gradation (Individual aggr., % passing)	Sample 1/day if production >500 yd3 Test 1st/day, then twice per week	IM 302
Flexural Strength, Third Point Loading - 28 days *	1/10,000 cu. yd. Maximum of three sets	IM 328
Air Content Unconsolidated Concrete	1/700 cu. yd.	IM 318
Water/Cement Ratio	None	IM 527
Vibration Frequency	1/week	IM 384

*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 IM 216. If the air tests are outside the tolerance, both air meters should be calibrated in accordance with 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 Article 2301.04C 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 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 Proportions		New Mix Proportions	
	Source	SSD Weight or Dosage	Source	SSD Weight 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

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-in., 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.

METHOD A

Multiply relative percentage by the percent passing and sum all aggregates 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 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.

Sieve	Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Theoretical Combined Gradation % Passing	Theoretical Combined Gradation % 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
½ inch Intermediate Aggregate (Limestone Chip)	0.100
1½ 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:

Aggregate	Proportion Volume	Specific Gravity	Weight	Proportion 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

Sieve	% Retained	Relative Volume	Adjusted % 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:

Sieve	Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Theoretical Combined Gradation % Retained	Theoretical Combined Gradation % 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.

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 CHART[1]

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.

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

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.

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[1] Shilstone, J. Sr., ”Concrete Mixture Optimization”, Concrete International, June 1990

Zone II is considered well graded for ¾” to 1 ½” 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 IM 531. 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 IM 531. 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 Ley[2] 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.

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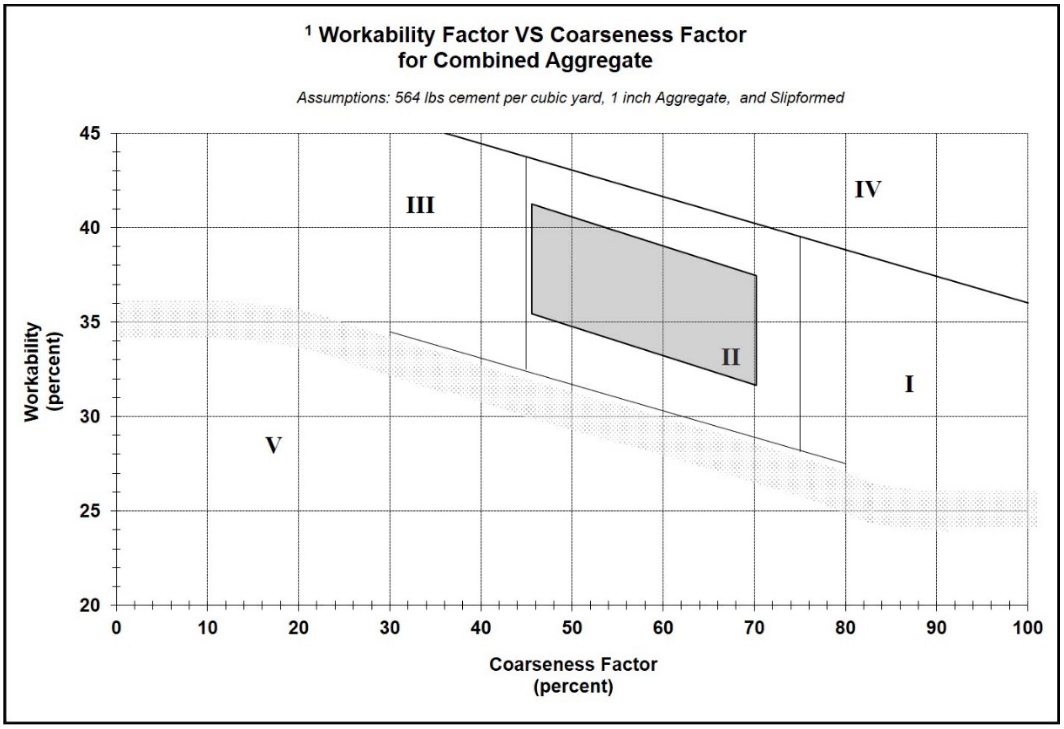
[2] Cook D, Seader N, Ley T, Russell B. *Investigation of Optimized Graded Concrete for Oklahoma- Phase* 2. FHWA-OK-15-07. Oklahoma City, OK: Oklahoma Department of Transportation; 2015

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.

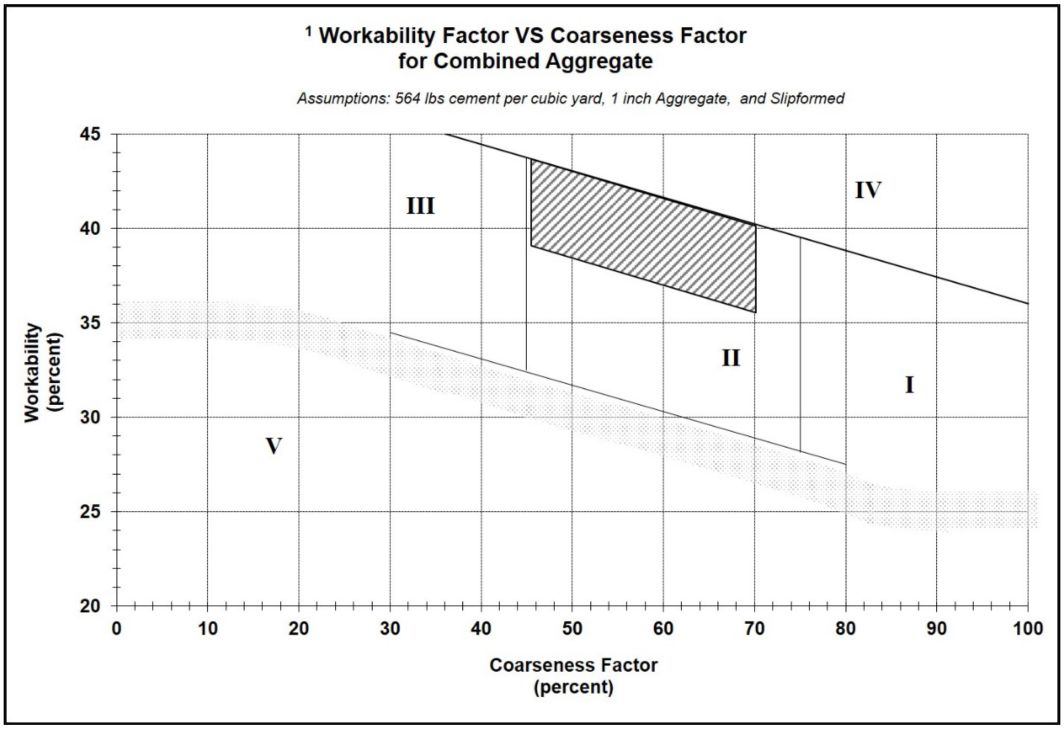


FIGURE 1

[1] Workability Factor VS Coarseness Factor for Combined Aggregate

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

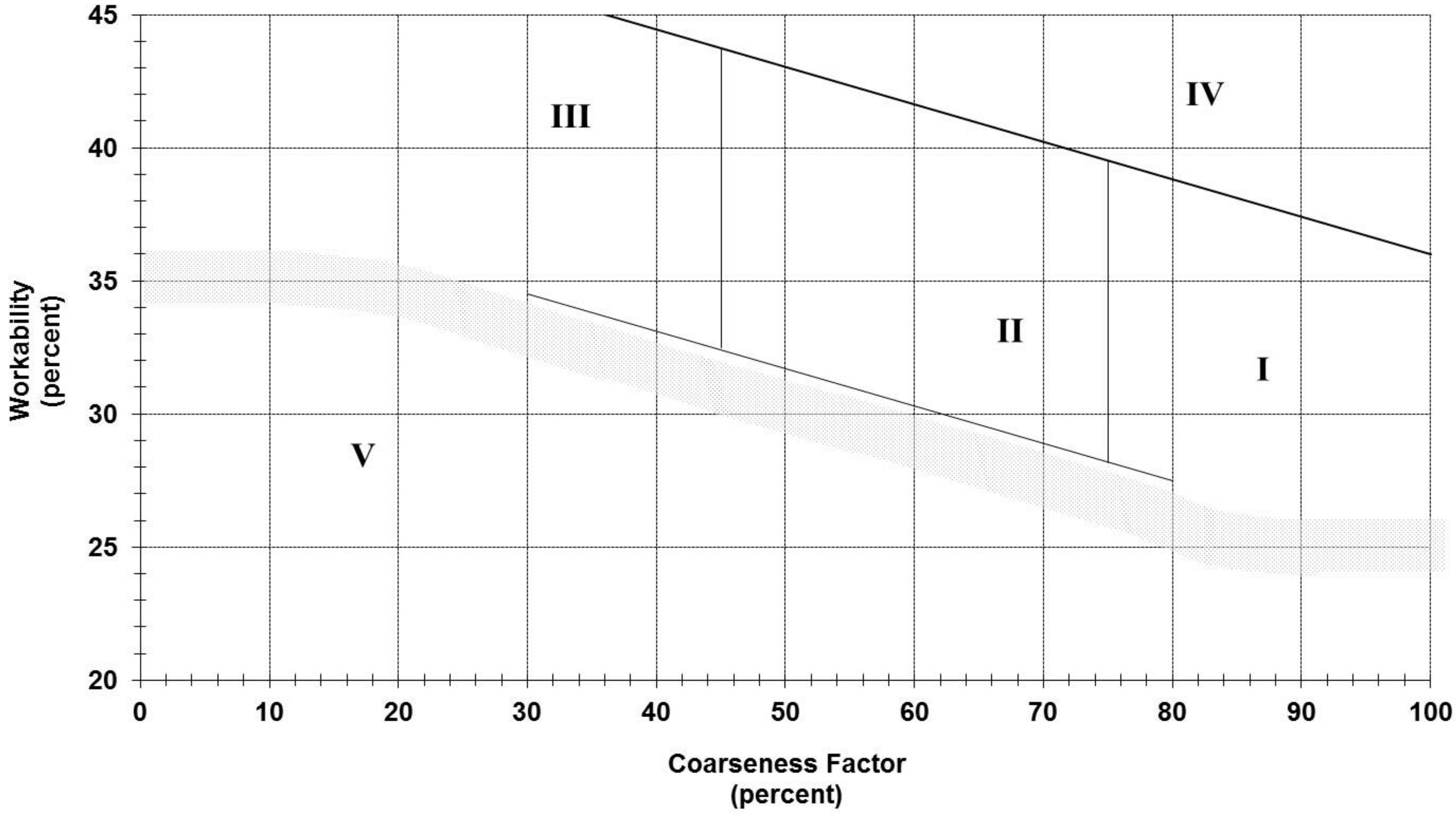


FIGURE #2

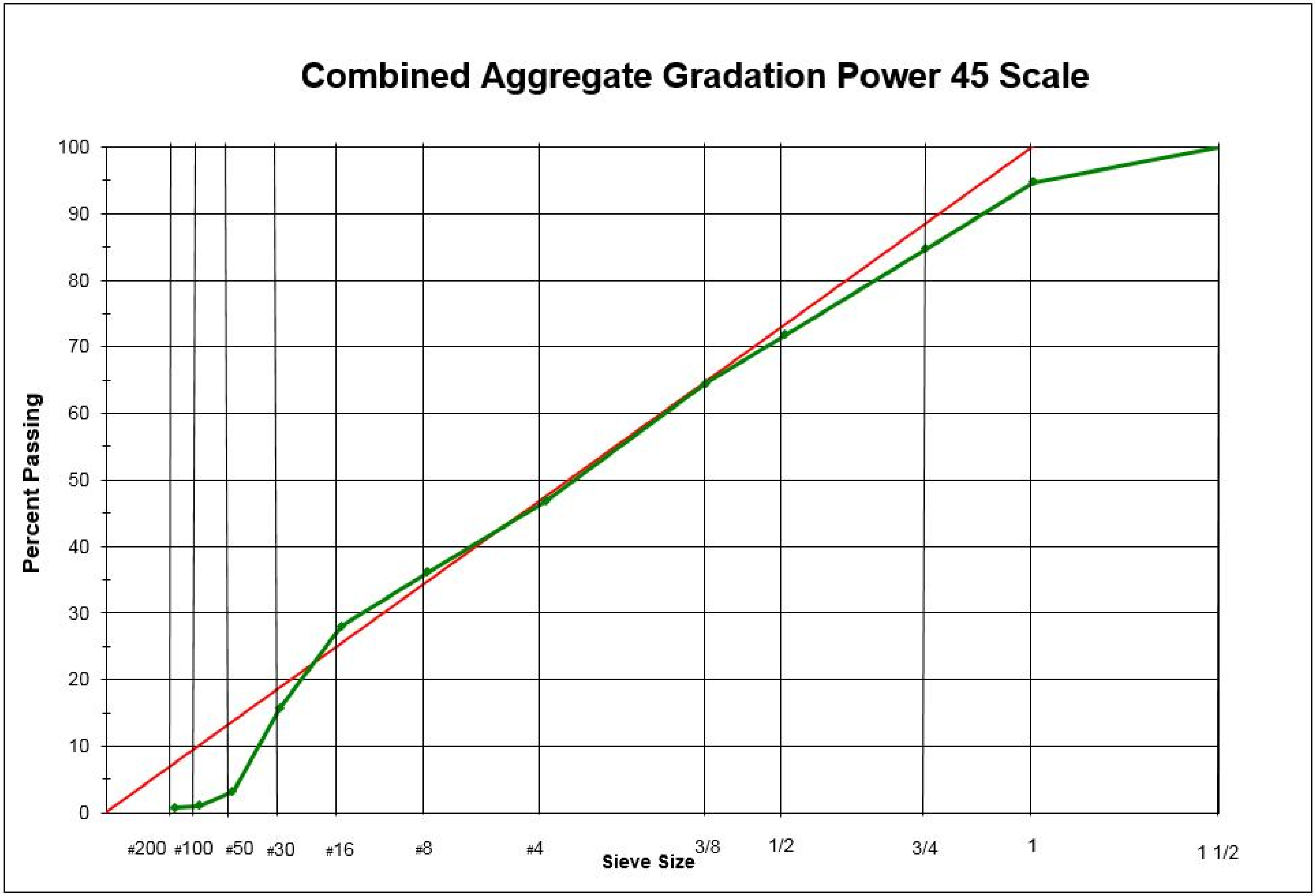

Combined Aggregate Gradation Power 45 Scale
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
#200
#100
#50
#30
#16
#8
#4
3/8
1/2
3/4
1
1 1/2
Sieve Size

FIGURE 3

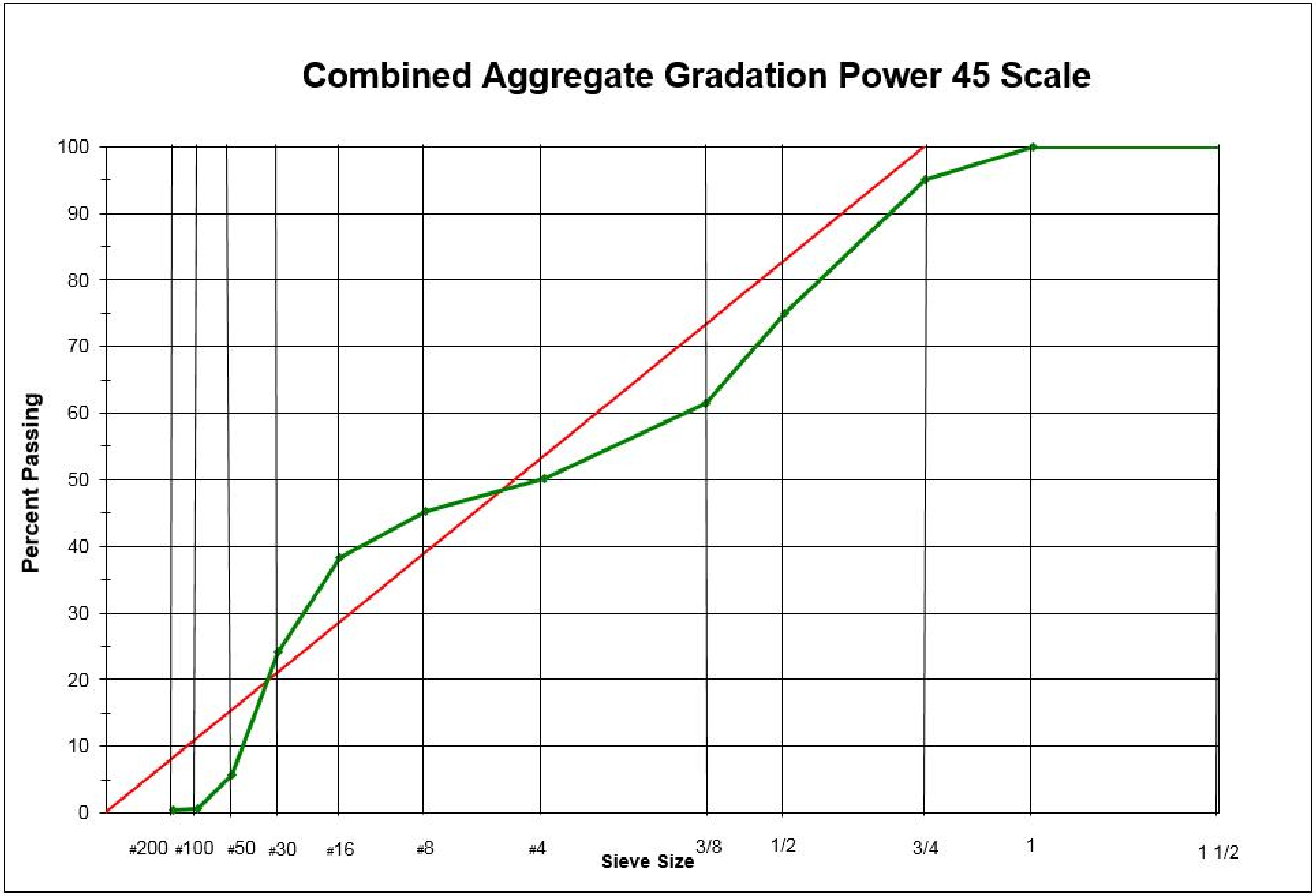

Combined Aggregate Gradation Power 45 Scale
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
#200
#100
#50
#30
#16
#8
#4
Sieve Size
3/8
1/2
3/4
1
1 1/2

FIGURE 4

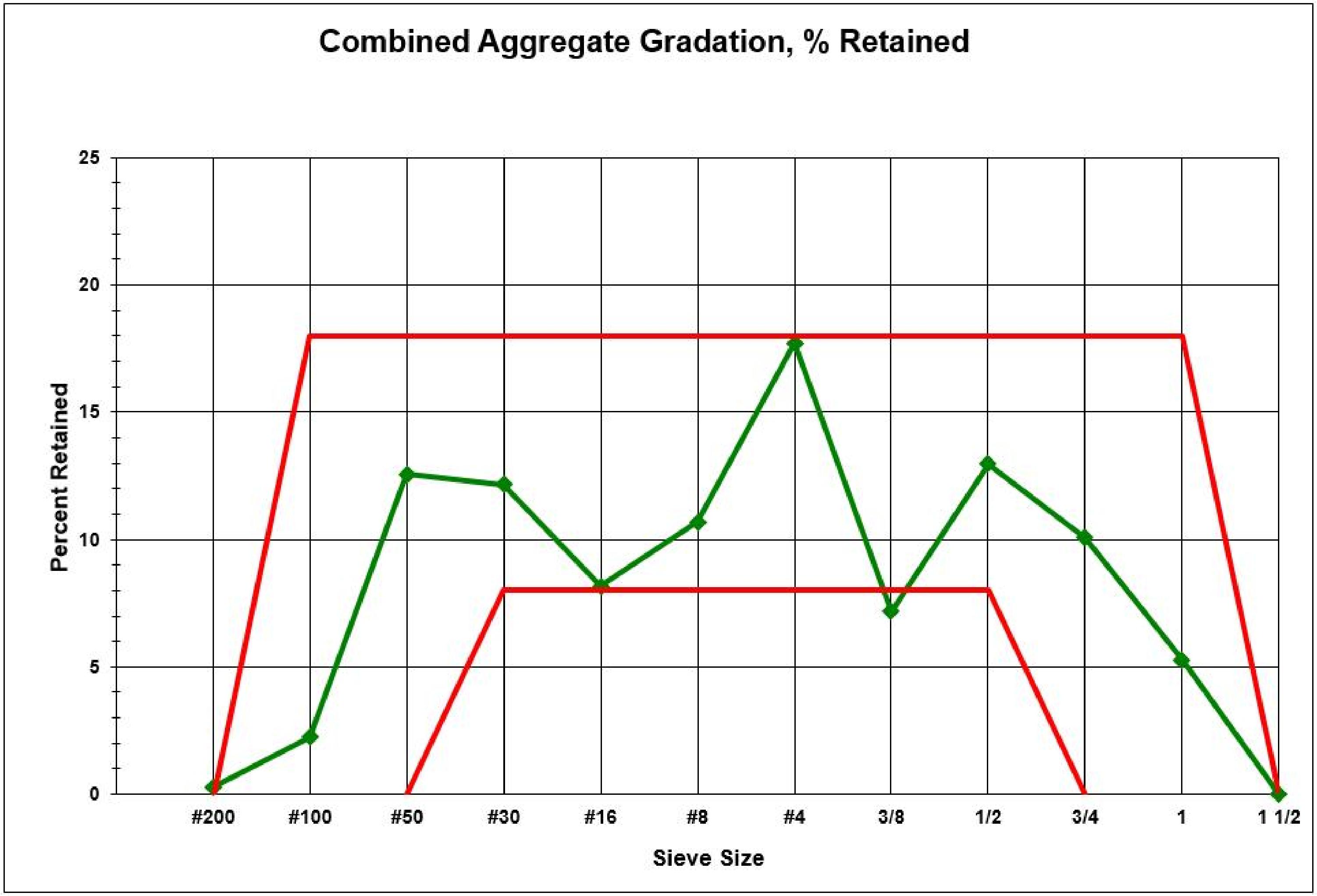

Combined Aggregate Gradation, % Retained
Percent Retained
25
20
15
10
5
0
#200
#100
#50
#30
#16
#8
#4
3/8
1/2
3/4
1
1 1/2
Sieve Size

FIGURE 5

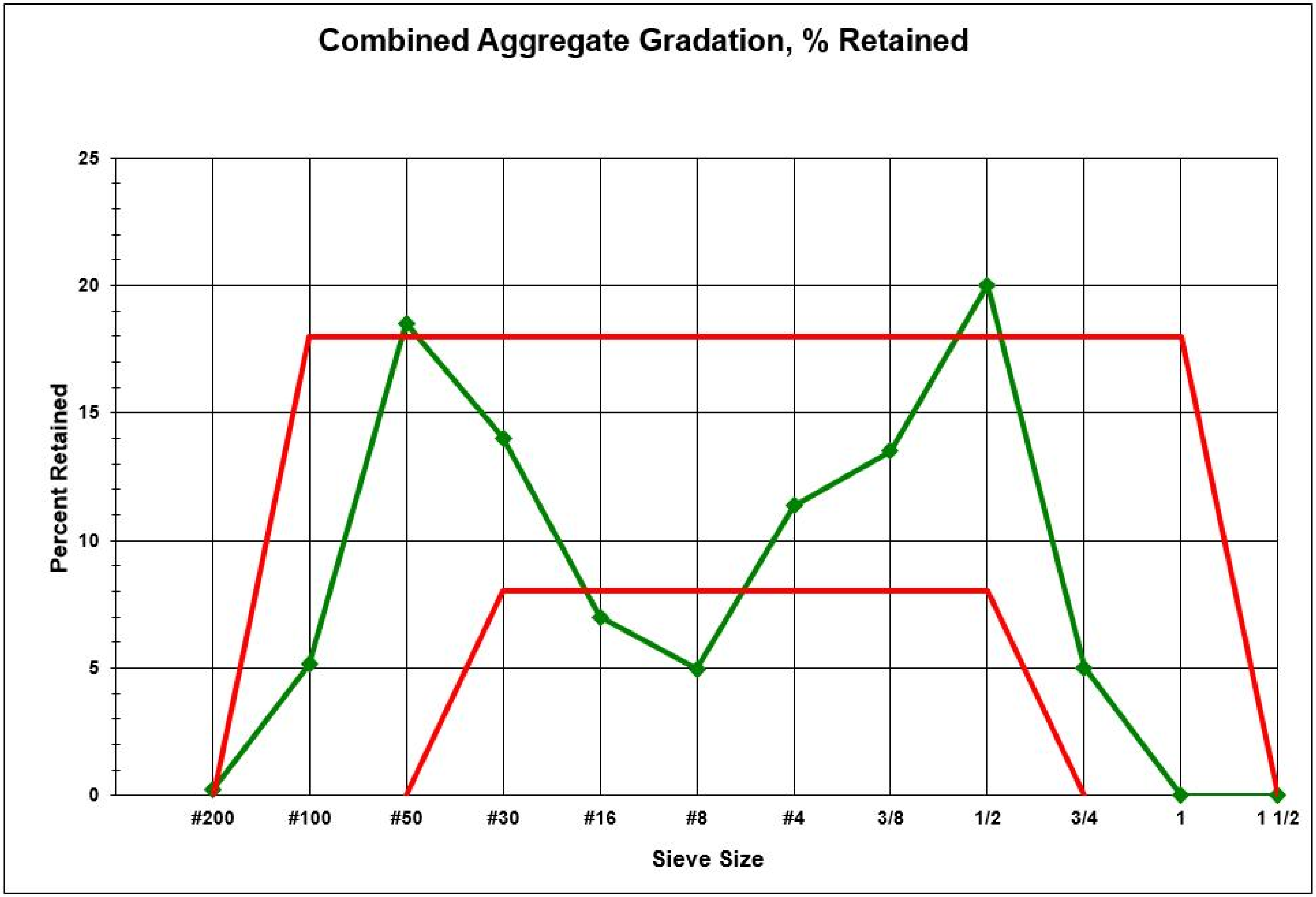
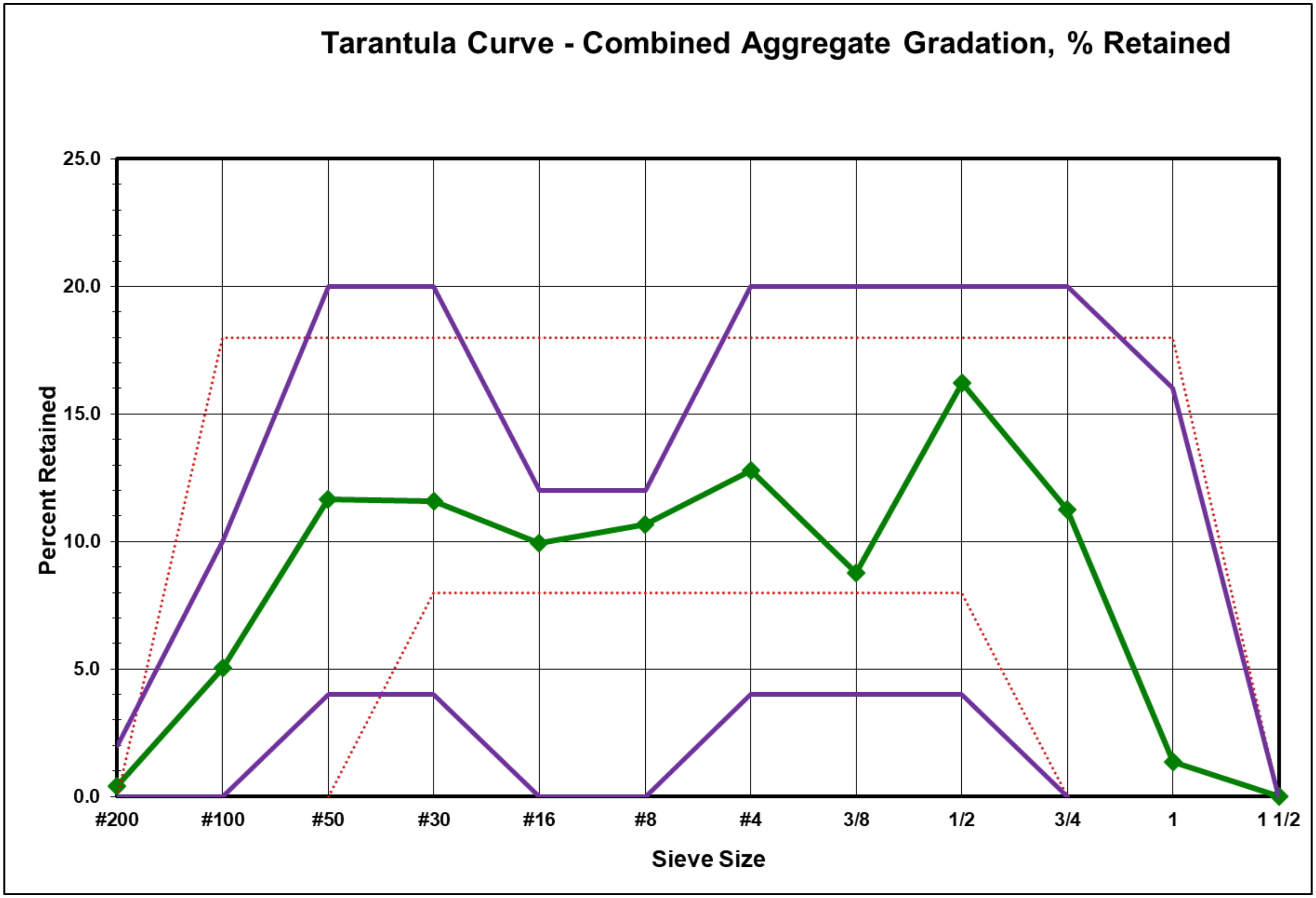

Combined Aggregate Gradation, % Retained
Percent Retained
25
20
15
10
5
0
#200
#100
#50
#30
#16
#8
#4
3/8
1/2
3/4
1
1 1/2
Sieve Size

FIGURE 6


Tarantula Curve - Combined Aggregate Gradation, % Retained
Percent Retained
25.0
20.0
15.0
10.0
5.0
0.0
#200
#100
#50
#30
#16
#8
#4
3/8
1/2
3/4
1
1 1/2
Sieve Size

Form 955QMC

Iowa Department of Transportation

Highway Division-Office of Materials
Proportion & Production Limits For Aggregates

County :
Project No.:
Date:
Project Location:
Mix 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		

Individual Aggregates Sieve Analysis - % Passing (Target)

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

Preliminary Target Gradation

* Upper Toleranc	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 Toleranc	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.

Signed: ______________________________
Producer

Check(X)
Coarse ☐
Interm. ☐
Interm. ☐
Fine ☐

Signed: ______________________________
Contractor

Signed: ______________________________
Producer

Signed: ______________________________
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:

Table DS-23027.03-1: Concrete Mixture Constraints

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

* 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 Section 4109, 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.

1. 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 Materials I.M. 530. 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:

Table DS-23027.05-1: Quality Control Table

	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	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 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 2301.03, A, 3, a, 6, a	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:

Table DS-23027.05-2: CDM Target Gradations

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

C. Corrective Action.

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

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.

1. 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.
Article 2310.04, A, of the Standard Specifications applies.

C. Portland Cement Concrete Overlay, QM-C, Placement Only.
Article 2310.04, B, 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.
Article 2310.05, A, of the Standard Specifications applies. Average coarseness and workability factor for each lot will be determined according to Materials I.M. 530.

C. Portland Cement Concrete Overlay, QM-C, Placement Only.
Article 2310.05, B, of the Standard Specifications applies. Average coarseness and workability factor for each lot will be determined according to Materials I.M. 530.

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.

Table DS-23027.07-1: Price Adjustments

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

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 Sections 2403, 2412, and Division 41 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% ± 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 Materials I.M. 315. 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 Article 2403.03, E, 4, b. 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 150ºF.

3. After required curing period, gradually reduce temperature of air surrounding concrete to outside air temperature according to Article 2403.03, I, of the Standard Specifications.

- **a. Substructure.**
  Ensure concrete and its surface temperature are maintained at a temperature of no less than 50ºF for the first 120 hours after placing. Curing time will not be counted if concrete temperature falls below 50ºF.
- **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 50ºF for 168 hours of continuous wet sprinkling system curing. Curing time will not be counted if the concrete temperature falls below 50ºF.

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.

Project Cover Page

LETTING DATE
4-30-02

PCC PAVEMENT- REPLACEMENT (NB & SB)
IM-35-6(94)140-13-40

HAMILTON CO.

STANDARD ROAD PLANS

105-4
12-03-96

The following Standard Road Plans shall be considered applicable to construction work on this project.

NUMBER	DATE	NUMBER	DATE	NUMBER	DATE
RC-5	04-27-99	RH-55	10-02-01	RS-65B	09-21-99
RC-16A	10-28-98	RH-56	10-02-01	RS-66(1)	04-30-02
RC-16B	09-21-99	RR-2	04-30-02	RS-66(2)	04-30-02
RE-73	04-25-00	RR-4	04-30-02	RS-68A	10-02-01
RH-410	10-02-01	RR-6	04-30-02	RS-68B	10-02-01
RH-42	10-02-01	RS-61	10-27-98	RS-72	04-30-96
RH-50	04-27-99	RS-62	01-12-99	RS-73	09-21-99
RH-51	04-30-02	RS-63A	04-30-02	RS-74	04-30-96
RH-52	08-20-96	RS-63B	04-30-02	RV-4	04-30-02
RH-53	04-03-01	RS-65A	04-30-96	RV-5	04-30-02

Form 520003 12-97

ROY A. GELHAUS 13158

I hereby certify that this project was constructed in accordance with the contract documents, the "as-built" plans were prepared under my supervision, and that I am a duly licensed Professional Engineer under the laws of the State of Iowa.

Project Engineer — Date: Feb. 25, 2005

My license renewal date is December 31, 2006

Year: 2003 — Contractor: Fred Carlson Co., Inc. — Project Inspector: Joseph W. Cook

Iowa Department of Transportation
Highway Division

PLANS OF PROPOSED IMPROVEMENTS ON THE

INTERSTATE ROAD SYSTEM
HAMILTON COUNTY
PCC PAVEMENT - REPLACEMENT (NB & SB)

ON I-35, FROM 1 MILES N. OF CO. RD D-41 N. TO CO. RD. D-25,
INCLUDES PATCHES IN STORY COUNTY FROM MP. 106.10 TO MP 123.60.

SCALES: As Noted

The Iowa Department of Transportation Standard Specifications for Highway and Bridge Construction, series of 2001, plus current Supplemental Specifications and Special Provisions shall apply to construction work on this project.

Value Engineering Saves. Refer to Standard Notation 203-4 on Sheet C.03

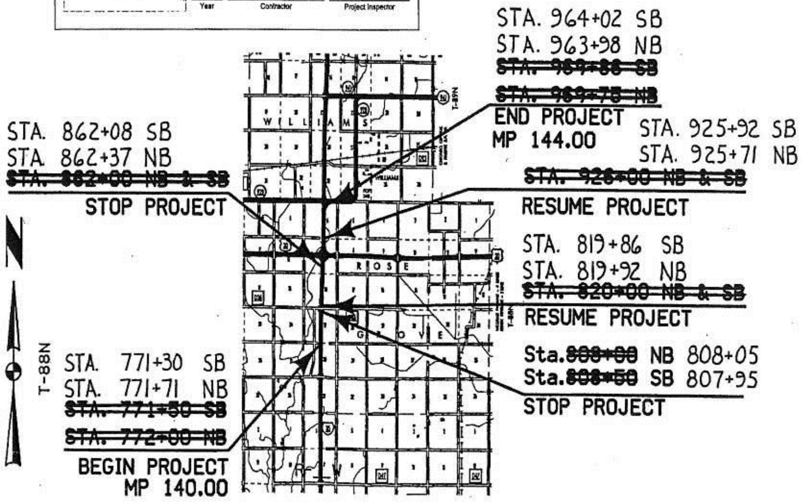
PROJECT NUMBER
IM-35-6(94)140-13-40
R.O.W. PROJECT NUMBER
PROJECT IDENTIFICATION NUMBER
01-40035-020

TOTAL 35

INDEX OF SHEETS

105-3
07-21-87

NO.	DESCRIPTION
A.01	Title Sheet
A.02	Strip Map
B.01-B.07	Typical Cross Sections
C.01-C.06	~~Estimate of~~ Quantities and General Information
D.01-D.08	Existing Plan, Profile, and Typical Sheets
J.01-J.03	Traffic Control Layouts
U.01-U.09	500 Detail Series, Modified Standards and Special Details



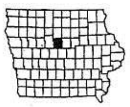
MILEAGE SUMMARY

105-1
09-27-94

DIV.	LOCATION	LIN. FT.	MILES
1	Rural: Hamilton NB		
	Sta. ~~772+00.00~~ 771+71 to Sta. ~~808+00.00~~ 808+05	3634.00 ~~3600.00~~	
	Sta. ~~820+00.00~~ 815+92 to Sta. ~~862+00.00~~ 862+37	4245.00 ~~4200.00~~	
	Sta. ~~926+00.00~~ 925+71 to Sta. ~~969+75.00~~ 963+98	3827.00 ~~4375.00~~	
	Total North Bound	11706.00 ~~12175.00~~	2.217 ~~2.306~~
	Rural: Hamilton SB		
	Sta. ~~771+50.00~~ 771+30 to Sta. ~~808+50.00~~ 807+95	3665.00 ~~3700.00~~	
	Sta. ~~820+00.00~~ 815+86 to Sta. ~~862+00.00~~ 862+08	4222.00 ~~4200.00~~	
	Sta. ~~926+00.00~~ 925+92 to Sta. ~~969+86.00~~ 964+02	3810.00 ~~4386.00~~	
	Total South Bound	~~12288.00~~ 11697.00	~~2.327~~ 2.215
	Total Length of Project	23403.00 ~~24461.00~~	4.432 ~~4.633~~

Includes patches in Story and Hamilton County

REVISIONS



EDC
168

R-23E

LOCATION MAP SCALE
0 2 4 6
Miles

156

04-30-02 101-4

DESIGN DATA RURAL

1998	AADT	19,441	V.P.D.
2018	AADT	27,631	V.P.D.
20	DHV		V.P.H.
TRUCKS		24	%
Total Design ESALs		76,994,700	

INDEX OF SEALS

SHEET NO.	NAME	TYPE
A.01	John R. Abrams	Primary Signature Block

John R. Abrams 07229

I hereby certify that this plan was prepared by me or under my direct personal supervision and that I am a duly licensed Professional Engineer under the laws of the State of Iowa.

Signature — Date

John R. Abrams
Printed or Typed Name

My license renewal date is December 31, 2002

Pages or sheets covered by this seal:
A.01 - A.02, B.01 - B.07, C.01 - C.06, D.01 - D.08,
J.01 - J.03, U.01 - U.09

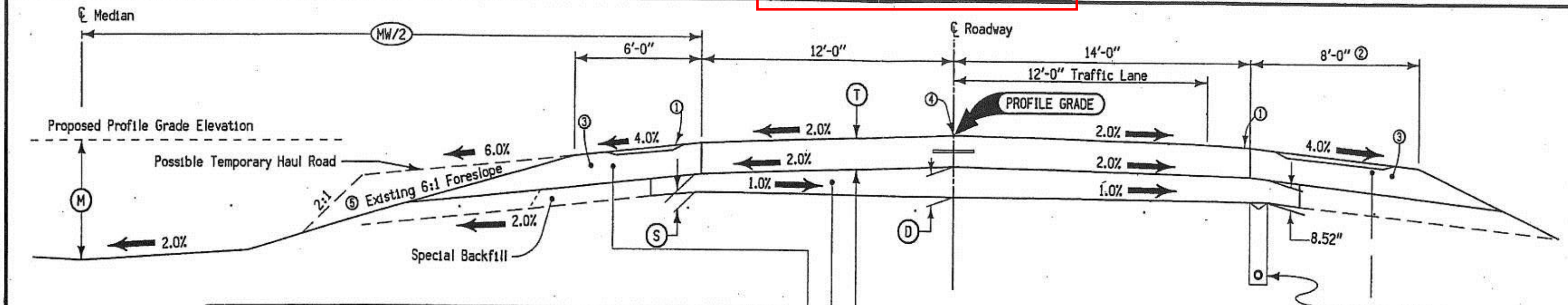
DESIGN TEAM ABRAMS/CLEM/BLIVEN/GOLIBER/JENSEN

HAMILTON COUNTY

PROJECT NO. IM-35-6(94)140-13-40

SHEET NO. A.01

Typical Cross Section



3213
MODIFIED

Notes:

Normal sections shown may be modified appropriately in areas of superelevated curves or other locations specifically designated by the Engineer.

① Rumble Strip required. Refer to RH-41D details sheets located elsewhere in this plan.

② See Typical MC-1

③ Refer to Typical Section 7115 for details of paved shoulder.

④ 'L-2', or 'KT-2' Joints, see Standard Road Plan RH-51.

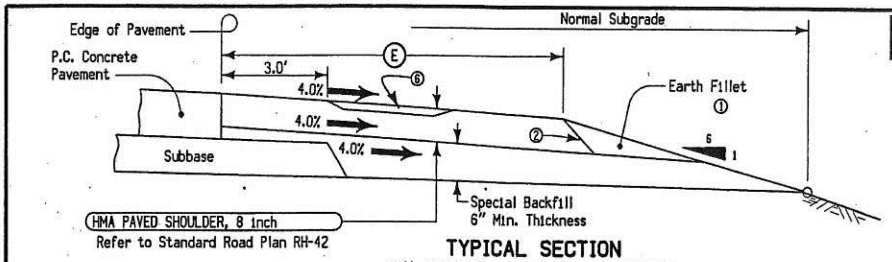
⑤ Foreslope to be returned to 6:1 when complete.

TYPICAL CROSS SECTION 4-LANE DIVIDED ROADWAY PCC RECONSTRUCTION WITH PAVED SHOULDERS

LOCATION			Ⓣ	Ⓢ	Ⓓ	MW	Ⓜ
ROAD IDENTIFICATION	STATION TO STATION		Inches	Inches	Inches	Feet	Feet
I-35 NB	771+71 ~~772+00~~	808+~~00~~ 05	11.5	6	10.32	50	UAC
I-35 SB	771+~~50~~ 30	807+95 ~~808+50~~	11.5	6	10.32	50	UAC
I-35 NB ~~& SB~~	819+92 ~~820+00~~	862+~~00~~ 37	11.5	6	10.32	50	UAC
I-35 NB	925+71 ~~926+00~~	963+98 ~~969+75~~	11.5	6	10.32	50	UAC
I-35 SB	925+92 ~~926+00~~	964+02 ~~969+88~~	11.5	6	10.32	50	UAC
I-35 SB	819+86	862+08	11.5	6	10.32	50	UAC

UAC = USE AS CONSTRUCTED

7115
MODIFIED



TYPICAL SECTION 8" THICK PAVED SHOULDER Adjacent to PCC Pavement

LOCATION			Ⓔ	SIDE	QUANTITIES③				
ROAD IDENTIFICATION	STATION TO STATION		Feet		SURFACE④ AREA Sq. Yds.	TYPE 'B' HMA BASE Tons	TACK COAT Gals.	ASPHALT BINDER Tons	SPECIAL④ BACKFILL Tons
I-35 NB	771+63 ~~772+00~~	808+~~00~~ 15	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 NB	771+63 ~~772+00~~	808+~~00~~ 10	6	IN	66.666	30.608	4.02	1.84	17.11
I-35 SB	771+~~50~~ 30	~~808+50~~ 807+95	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 SB	771+~~50~~ 30	~~808+50~~ 807+95	6	IN	66.666	30.608	4.02	1.84	17.11
I-35 NB	819+92 ~~820+00~~	862+~~00~~ 37	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 NB	819+92 ~~820+00~~	862+~~00~~ 37	6	IN	66.666	30.608	4.02	1.84	17.11
I-35 SB	819+86 ~~820+00~~	862+~~00~~ 08	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 SB	819+86 ~~820+00~~	862+~~00~~ 08	6	IN	66.666	30.608	4.02	1.84	17.11
I-35 NB	925+71 ~~926+00~~	~~969+75~~ 964+00	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 NB	925+71 ~~926+00~~	~~969+75~~ 962+00	6	IN	66.666	30.608	4.02	1.84	17.11
I-35 SB	925+92 ~~926+00~~	~~969+88~~ 956+91	8	OUT	88.889	38.685	5.00	2.34	21.65
I-35 SB	925+92 ~~926+00~~	~~969+88~~ 956+89	6	IN	66.666	30.608	4.02	1.84	17.11

① Refer to appropriate Detail Drawing.

② Approximately 1:1 Slope

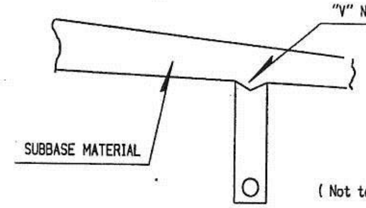
③ Per side per station. See Standard Road Plan RH-42 for basis of estimate.

④ Bid Items

⑤ Qunatities are based on a design weight of 140 lbs. per cubic foot.

⑥ See RH-41D

V NOTCH



(Not to Scale)

LONGITUDINAL SUBDRAIN TRENCH CLEANING ALL LOCATIONS

OFFICE OF DESIGN • CADD • PRODUCED	STATE OF IOWA	FHWA REGION 7	FISCAL YEAR	HAMILTON COUNTY	PROJECT NUMBER IM-35-6(94)140-13-40	SHEET NUMBER B.01

25-JAN-2002 11:38 mclem v:\Projects\4003502001\Design\k40035094.B01

Bid Items

~~ESTIMATED~~ PROJECT QUANTITIES

100-1A
07-15-97

ITEM NO.	ITEM CODE	ITEM	UNIT	TOTAL	AS BUILT QUAN.
1	2102-0425070	SPECIAL BACKFILL	TON	12041	14,410.789
2	2102-2713070	EXCAVATION, CL 13, RDWY+BORROW	CY	28103	26,913.450
3	2111-8174100	GRANULAR SUBBASE	SY	86972	82,863.110
4	2122-5500080	PAVED SHLD, HMA, 8"	SY	38050	36,711.779
5	2212-5070310	PATCH, FULL-DEPTH REPAIR	SY	1092	720.021
6	2212-5070320	PATCH, PARTIAL-DEPTH REPAIR	SY	44	7.998
7	2212-5070330	PATCH BY COUNT (REPAIR)	EACH	143	71
8	2301-1004115	STD/S-F PCC PAV'T, QM-C CL 3I, 11.5"	SY	74127	67,891.796
9	2301-6911722	PCC PAV'T SAMPLE	LS	1	$3000.00
10	2301-9090000	QUALITY MANAGEMENT - CONCRETE	CY	24709	22,599.000
11	2303-6911000	HMA PAV'T SAMPLE	LS	1	$1200.00
12	2399-5145000	DETOUR PAV'T	SY	3122	7929.094
13	2417-1007000	CORR PIPE CULV, 15", Roadway	LF	234	468.000
14	2417-5895000	BEVELED PIPE+GUARD	EACH	2	4
15	2510-6745850	RMVL OF PAV'T	SY	113792	93,290.865
16	2518-6910000	SAFETY CLOSURE	EACH	12	17
17	2520-3350010	FIELD LABORATORY	EACH	1	$3500.00
18	2526-8285000	CONSTRUCTION SURVEY	LS	1	$30,900.00
19	2527-9263005	RAISED PAV'T MARKER	EACH	910	1266
20	2527-9263111	PAINTED PAV'T MARK, WATERBORNE	STA	2163	2892.936
21	2527-9263130	REMOVABLE TAPE MARK	STA	31	71.190
22	2527-9263139	PAINTED SYMBOL+LEGEND, WATERBORNE	EACH	16	16
23	2527-9263180	PAV'T MARK RMVD	STA	1125	1576.474
24	2527-9263190	SYMBOL+LEGEND RMVD	EACH	16	16
25	2528-4983200	MONITOR W/INCIDENT RESPONSE	CDAY	120	169
26	2528-6765001	RMV+REINSTALL CROSSOVER BARRICADE	EACH	2	2
27	2528-8400042	TEMP ATTENUATOR,SAND-FILLED BARREL;RE-73	EACH	2	6
28	2528-8400047	TEMP BARRIER RAIL	LF	500	300
29	2528-8400157	TEMP FLOODLIGHTING LUMINAIRE	EACH	8	12
30	2528-8445110	TRAFFIC CONTROL	LS	1	$74,625.00
31	2528-8445112	FLAGGER	DAY	10	48
32	2529-5070110	PATCH, FULL-DEPTH FINISH, BY AREA	SY	187	880.675
33	2529-5070120	PATCH, FULL-DEPTH FINISH, BY COUNT	EACH	15	86
34	2529-8174010	SUBBASE, (PATCH) (ITEM NOT USED)	SY	862	0
35	2533-4980005	MOBILIZATION	LS	1	$197,000.00
36	2601-2634100	MULCH	ACRE	10.8	30.520
37	2601-2636041	SEED+FERTILIZE	ACRE	11	30.520
38	2601-2640350	SPECIAL DITCH CONTROL,WOOD EXCELSIOR MAT (ITEM NOT USED)	SQ	78	0
39	2601-2642100	STABILIZE CROP - SEED+FERTILIZE (ITEM NOT USED)	ACRE	11	0
40	2601-2643110	WATER-SOD/SPEC DITCH CNTL/SLOPE PROTECT (ITEM NOT USED)	MGAL	3.9	0
41	2602-0000020	SILT FENCE	LF	2500	2295.000
42	2602-0000030	SILT FENCE-DITCH CHECKS	LF	2400	1522.800
43	2602-0000060	RMVL OF SILT FENCE (ITEM NOT USED)	LF	2400	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	1581.194
45		PATCH, PARTIAL-DEPTH PCC FINISH BY COUNT	EACH	186	183
45.5		TRAFFIC CONTROL - PARTIAL DEPTH PATCHING	LS	1	$935.00
46		CORRUGATED PIPE CULVERT, 18 IN.	LF	188	188
46.5		BEVELED PIPE & GUARD, 18 IN.	EACH	1	1
47		CULVERT, CONCRETE RDWY. PIPE, 24"	LF	8	8
47.5		REMOVE & REPLACE 24" RCP APRON	EACH	1	1
48		TRAFFIC CONTROL - MEDIAN CROSSOVERS	LS	1	$10,500.00
48.5		MOBILIZATION-CROSSOVERS	LS	1	$10,000.00
49		MOBILIZATION- PCC REMOVAL	LS	1	$3,500.00
49.5		EF JOINT ASSEMBLY	EACH	3	3
50		REMOVE & REINSTALL DELINEATORS	EACH	90	105
50.5		SAWCUT	LF	1380	1378
51		INSTALL & REMOVE TRAFFIC SIGNS	LS	1	$1,100.00
51.5		REPLACEMENT OF CMP	LS	1	$21,431.73
52		RELOCATE OUTLET	LS	1	$841.50
52.5		PIPE EXTENSIONS	LS	1	$5,316.53
53		PCC COLD WEATHER PROTECTION	SY	11,006.667	11,006.667
53.5		SHOULDER REPAIR	SY	125.444	125.444
54		PAVEMENT SMOOTHNESS INCENTIVE	EACH	37,600.000	37,600.000
54.5		PIPE REPLACEMENT	LS	1	$1,980.00
55		QM-C PCCP INCENTIVE	SY	67,881.307	67,881.307
55.5		SPECIAL BACKFILL	TON	5,428.000	5,428.000
56		TRAFFIC CONTROL	LS	1	$9,240.00
56.5		PCC PAVEMENT THICKNESS INCENTIVE	SY	67,891.796	67,891.796
57		NON-COMPLYING TRAFFIC CONTROL	EACH	-750.000	-750.000

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19-MAR-2002 11:01 rschoen v:\Projects\4003502001\Design\k40035094.C01

T203

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION				BULK SSD SpGr	DUR PCC		FRICT HMA		BEDS	NOTE
								CA	FA	A	B		
38	**GRUNDY DIST 1**	**SAND & GRAVEL**											
A38504	CARLSON MATERIALS CO	HERONIMOUS	SE	35	TO88	R17W	2.63		X				
39	**GUTHRIE DIST 4**	**SAND & GRAVEL**											
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							
		SAND & GRAVEL											
A40512	BECKER GRAVEL CO	ANDERSON		12	TO87	R26W							
41	**HANCOCK DIST 2**	**CRUSHED STONE**											
A41002	BASIC MATERIALS CORP	GARNER NORTH	SE	11	TO95	R24W	2.77	3iB		4	4	1 - 4	
							2.77	3i		4	4	6	
A41004	BASIC MATERIALS CORP	GARNER SOUTH-WIELAND	NW	13	TO95	R24W	2.77	3iB		4	4	1 - 4	
							2.77	3i		4	4	6	
		SAND & GRAVEL											
A41504	HANCOCK COUNTY	HUTCHINS	E2	27	TO96	R26W					4		
A41506	HANCOCK COUNTY	KLEMME		26	TO95	R24W					4		
A41510	NUCKOLL'S CONCRETE	BRITT		34	TO96	R26W	DWU	2		3	3		
	SERVICES INC						DWU		X				
A41518	HANCOCK COUNTY	AUSTIN	NE	11	TO97	R25W							
42	**HARDIN DIST 1**	**CRUSHED STONE**											
A42002	MARTIN MARIETTA	ALDEN	NW	20	TO89	R21W	2.56	3i		4	4	0, 1, 3	
							DWU	3				0, 1	
A42004	GERHKE QUARRIES INC	GIFFORD	NW	04	TO86	R19W					5		
		SAND & GRAVEL											
A42502	WELDON BROS CONST CO	IOWA FALLS	NW	20	TO89	R20W	2.65	2		4	4		
							2.68		X				
A42510	MARTIN MARIETTA	JANSSEN	SE	34	TO89	R20W	2.65			4	4		
							2.65		X				
A42512	HARDIN AGGREGATES INC	GIFFORD	SW	31	TO87	R19W				4	4		
							2.66		X				
A42524	BECKER GRAVEL CO	GRIFFEL	SE	31	TO89	R19W				3	3		
A42528	BECKER GRAVEL CO	LLOYD		04	TO86	R19W	DWU			4	4		

Aggregate Map

Coarse Aggregate Production Gradations

Material D67 Concrete Stone 2004 Certified Aggregate
Source Alden
Producer Martin Marietta

		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#200	
Date	Lab #	37.5	25	19	12.5	9.5 mm	4.75 mm	2.36 mm	75 µm	Complies
				100		55	10	5	1.5	
			100	90		20	0	0	0	
30-Mar	15	100	100	100	62	29	2.3	0.3	0.3	y
31-Mar	16	100	100	100	66	40	7.7	0.8	0.7	y
12-Apr	17	100	100	99	56	24	2.4	0.3	0.3	y
13-Apr	18	100	100	100	49	21	1.9	0.3	0.3	y
14-Apr	19	100	100	99	49	22	2.2	0.3	0.3	y
16-Apr	20	100	100	99	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	y
1-Jun	44	100	100	97	52	29	3.5	0.4	0.4	y
3-Jun	45	100	100	98	45	23	2.6	0.4	0.3	y
4-Jun	46	100	100	95	42	22	1.2	0.3	0.2	y
6-Jun	73	100	100	96	42	20	0.8	0.4	0.3	y
7-Jun	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
6-Jul	76	100	100	97	43	23	1.0	0.4	0.3	y
7-Jul	77	100	100	96	44	24	0.9	0.3	0.3	y
3-Sep	153	100	100	97	49	28	2.7	0.2	0.2	y
8-Sep	154	100	100	99	54	28	4.7	0.6	0.4	y
9-Sep	155	100	100	97	53	25	3.2	0.5	0.4	y
29-Sep	156	100	100	99	58	34	1.8	0.2	0.2	y
30-Sep	157	100	100	99	54	33	2.6	0.2	0.2	y
1-Oct	166	100	100	98	58	35	2.3	0.2	0.2	y
4-Oct	167	100	100	99	55	33	2.5	0.2	0.2	y
11-Oct	168	100	100	99	55	31	3.2	0.2	0.2	y
12-Oct	169	100	100	98	54	34	3.7	0.3	0.3	y
1-Dec	188	100	100	98	54	26	1.2	0.2	0.2	y
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	y
4-Dec	191	100	100	98	52	23	0.9	0.2	0.2	y
6-Dec	192	100	100	100	50	27	2.5	0.4	0.3	y
Crsr here t										
Average →		100	100	98	51	27	2.3	0.3	0.3	←
Std. Deviation		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	66	40	7.7	0.8	0.8	

Coarse Aggregate Production Gradations

Material 1" D57 Concrete Stone 2004 Certified Aggregate
Source Alden
Producer Martin Marietta

Date	Lab #	1 1/2" 37.5	1" 25	3/4" 19	1/2" 12.5	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#200 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
14-Jul	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	Y
2-Aug	131	100	99	81	29	15	1.1	0.3	0.3	Y
10-Aug	132	100	100	87	44	15	1.4	0.3	0.3	Y
11-Aug	133	100	99	81	33	17	1.5	0.3	0.3	Y
17-Aug	134	100	99	76	26	12	0.9	0.4	0.3	Y
18-Aug	135	100	97	76	32	17	1.7	0.3	0.3	Y
31-Aug	145	100	100	83	44	25	3.8	0.5	0.3	Y
1-Sep	146	100	100	81	42	22	3.2	0.3	0.3	Y
2-Sep	147	100	100	84	54	37	5.7	0.7	0.6	Y
3-Sep	148	100	98	68	28	15	1.3	0.6	0.2	Y
10-Sep	149	100	100	83	43	26	4.6	0.7	0.4	Y
13-Sep	150	100	98	78	33	16	1.7	0.3	0.3	Y
14-Sep	151	100	98	72	31	15	1.5	0.4	0.3	Y
16-Sep	152	100	99	72	35	18	1.5	0.3	0.3	Y
27-Sep	158	100	100	81	34	16	1.8	0.3	0.2	Y
28-Sep	159	100	99	78	33	18	2.1	0.4	0.3	Y
18-Oct	160	100	100	82	47	30	5.7	1.1	0.4	Y
19-Oct	161	100	100	77	33	15	1.8	0.4	0.3	Y
20-Oct	162	100	99	80	32	14	1.6	0.3	0.3	Y
21-Oct	163	100	99	76	31	14	1.9	0.3	0.3	Y
28-Oct	164	100	100	75	27	15	1.3	0.3	0.3	Y
29-Oct	165	100	100	77	36	17	2.1	0.4	0.4	Y
1-Nov	193	100	99	72	29	16	1.8	0.3	0.2	Y
2-Nov	194	100	100	72	29	16	1.8	0.3	0.4	Y
7-Dec	195	100	99	80	37	18	1.1	0.3	0.2	Y
8-Dec	196	100	99	78	34	16	0.6	0.2	0.2	Y
10-Dec	197	100	99	82	41	21	1.7	0.3	0.3	Y
Crsr here to insert										
Average		100	99	78	35	17	1.9	0.4	0.4	
Standard Deviation		0.00	0.75	3.95	5.98	4.69	1.12	0.20	0.16	

Coarse Aggregate Production Gradations

Material 1 1/2" Special Conc. Stone 2003 Certified Aggregate Carlson
Source Alden IM-35-6(94)140--13-40
Producer Martin Marietta

		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#200	
Date	Lab #	37.5	25	19	12.5	9.5 mm	4.75 mm	2.36 mm	75 µm	Complies
Limits			88	65	33	21	7.0	5.0	1.5	
		100	78	55	23	11	0.0	0.0	0.0	
6-Jun	121	100	83	63	26	14	1.6	0.3	0.4	y
6-Jun	122	100	82	59	23	11	1.7	0.3	0.2	y
9-Jun	123	100	79	60	24	12	1.9	0.4	0.3	y
12-Jun	124	100	81	59	25	13	1.8	0.3	0.2	y
24-Jun	125	100	81	61	28	16	2.1	0.4	0.4	y
25-Jun	126	100	78	56	24	11	0.8	0.3	0.2	y
26-Jun	127	100	82	59	23	11	1.1	0.3	0.2	y
28-Jun	128	100	81	55	23	11	1.2	0.4	0.3	y
29-Jun	181	100	78	56	25	14	1.3	0.4	0.3	y
30-Jun	182	100	78	56	23	12	2.0	0.5	0.4	y
1-Jul	183	100	82	60	23	13	2.4	0.5	0.3	y
2-Jul	184	100	81	58	25	14	2.4	0.3	0.3	y
4-Aug	185	100	83	60	26	13	1.4	0.2	0.2	y
5-Aug	186	100	81	60	27	12	2.0	0.3	0.2	y
6-Aug	187	100	78	59	24	11	1.7	0.3	0.2	y
7-Aug	188	100	79	56	23	11	1.6	0.3	0.2	y
15-Sep	207	100	78	61	29	15	1.9	0.5	0.5	y
16-Sep	208	100	79	62	28	16	1.9	0.5	0.3	y
17-Sep	209	100	85	65	32	18	2.8	0.6	0.4	y
18-Sep	210	100	79	59	29	15	2.0	0.5	0.3	y
Insert Here										
Average	→	100.0	80	59	26	13	1.8	0.4	0.3	←

Intermediate Aggregate
Production Gradations

Material 3/8" Washed Chips 2006 Monitor
Source Alden A42002
Producer Martin Marietta

Date	Lab #	3/4" 19	1/2" 12.5	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#16 1.18 mm	#30 600 µm	#50 300 µm	#100 150 µm	#200 75 µm
LIMITS											
16-May	20		100	86	17.2	1.3					0.5
11-Sep	40		100	86	27	1.7					0.5
Insert											
Average		#DIV/0!	100	86	22	1.5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.5
Standard Deviation		#DIV/0!	0.00	0.00	4.90	0.20	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.00
Maximum		0	100	86	27	1.7	0	0	0	0	0.5
Minimum		0	100	86	17.2	1.3	0.0	0	0	0	0.5

Intermediate Aggregate Production Gradations

IM-35-6(94)140--13-40
Carlson

Material 1/2"Conc. Chip 2003 Certified Aggregate
Source Alden
Producer Martin Marietta

Date	Lab #	3/4" 19	1/2" 12.5	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#16	#30	#50	#100	#200 75 µm	Complies
Limits			100	89	20	7					1.5	
		100	94	79	10	0					0	
14-Apr	39	100	100	82	12	1.0	0.7	0.6	0.5	0.4	0.3	y
15-Apr	40	100	99	85	14	1.0	0.9	0.8	0.7	0.5	0.4	y
17-Apr	41	100	100	85	12	0.8	0.7	0.6	0.5	0.4	0.3	y
21-Apr	42	100	99	83	13	1.5	1.3	1.1	0.9	0.7	0.5	y
23-Apr	43	100	100	86	8	1.9	1.2	1.1	0.9	0.7	0.5	y
24-Apr	44	100	100	82	15	1.4	0.8	0.7	0.6	0.5	0.4	y
25-Apr	45	100	100	85	15	1.4	1.0	0.9	0.8	0.7	0.4	y
2-Jun	130	100	99	81	12	1.7	1.3	1.0	0.8	0.6	0.4	y
5-Jun	131	100	98	79	13	1.3	1.0	0.8	0.7	0.6	0.4	y
6-Jun	132	100	98	81	16	1.4	1.0	0.8	0.6	0.4	0.3	y
7-Jun	133	100	98	79	10	1.1	0.9	0.7	0.5	0.3	0.2	y
9-Jun	134	100	97	79	11	0.9	0.7	0.6	0.5	0.4	0.3	y
10-Jun	135	100	98	85	20	2.1	1.2	0.9	0.6	0.5	0.4	y
11-Jun	136	100	99	82	17	1.7	0.9	0.7	0.5	0.3	0.2	y
24-Jun	137	100	97	79	10	1.0	0.8	0.7	0.6	0.4	0.3	y
26-Jun	142	100	98	79	11	1.3	0.9	0.7	0.5	0.4	0.3	y
27-Jun	143	100	99	84	15	1.4	1.0	0.8	0.6	0.4	0.3	y
28-Jun	144	100	99	79	11	1.2	0.9	0.8	0.7	0.5	0.4	y
29-Jun	145	100	98	79	12	1.0	0.8	0.7	0.6	0.5	0.4	y
30-Jun	146	100	99	80	13	1.3	1.0	0.8	0.6	0.5	0.4	y
1-Jul	147	100	98	79	11	1.0	0.8	0.7	0.6	0.4	0.3	y
2-Jul	148	100	99	79	13	1.5	1.1	0.8	0.6	0.5	0.3	y
3-Jul	149	100	99	84	18	2.5	1.7	1.3	1.0	0.7	0.4	y
7-Jul	164	100	98	79	11	1.0	0.8	0.6	0.5	0.4	0.3	y
9-Jul	165	100	98	79	15	2.1	1.1	0.9	0.6	0.4	0.2	y
10-Jul	166	100	98	81	14	2.5	1.6	1.3	1.0	0.8	0.6	y
11-Jul	167	100	99	81	14	1.4	0.8	0.6	0.5	0.4	0.3	y
21-Jul	168	100	98	79	10	1.3	1.0	0.8	0.7	0.5	0.4	y
22-Jul	169	100	98	79	15	2.0	1.4	1.0	0.8	0.6	0.4	y
23-Jul	170	100	99	81	17	1.7	0.9	0.7	0.5	0.4	0.3	y
24-Jul	171	100	99	80	16	1.6	0.8	0.7	0.6	0.5	0.3	y
28-Jul	211	100	99	84	17	2.3	1.7	1.3	1.0	0.7	0.4	y
29-Jul	212	100	99	79	16	2.7	1.9	1.4	1.1	0.7	0.4	y
30-Jul	213	100	99	80	11	0.7	0.6	0.5	0.4	0.3	0.2	y
31-Jul	214	100	99	85	14	0.9	0.8	0.7	0.6	0.5	0.4	y
7-Aug	215	100	100	84	10	0.8	0.7	0.6	0.5	0.4	0.3	y
15-Sep	216	100	98	80	14	1.5	0.9	0.8	0.7	0.6	0.5	y
16-Sep	217	100	99	82	18	2.1	1.5	1.1	0.9	0.7	0.5	y
17-Sep	218	100	99	85	17	1.9	1.4	1.0	0.8	0.6	0.4	y
Crsr here to insert												
Average		100	99	81	14	1.5	1.0	0.8	0.7	0.5	0.4	

Fine Aggregate Production Gradations

Material Concrete Sand 2005
Source Welden Pit
Producer Welden Aggregate

Date	Lab #	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#16 1.18 mm	#30 600 µm	#50 300 µm	#100 150 µm	#200 75 µm	Complies
Limits			100	100		50			1.5	
		100	90	70		10			0	
6-May	WA-1-05	100	96	82	64	41	15	1.8	0.7	y
18-Aug	WA-2-05	100	96	79	61	39	13	1.8	0.5	y
26-Aug	WA-3-05	100	96	79	59	37	12	2.0	0.9	y
2-Sep	WA-4-05	100	96	80	62	39	14	2.2	0.9	y
9-Sep	WA-5-05	100	96	80	60	36	12	1.0	0.3	y
16-Sep	WA-6-05	100	96	80	61	36	12	1.2	0.4	y
23-Sep	WA-7-05	100	97	83	65	42	14	1.6	0.6	y
23-Sep	WA-8-05	100	97	79	54	27	6.5	1.6	0.9	y
12-Oct	WA-9-05	100	96	81	63	41	13	1.7	0.7	y
31-Oct	WA-10-05	100	96	81	63	41	13	1.4	0.5	y
15-Nov	WA-11-05	100	96	80	61	37	12	1.5	0.8	y
Crsr Here to insert										
Average		100	96	80	61	38	12	1.6	0.7	
Standard Deviation		0	0.39	1.23	2.82	4.00	2.10	0.33	0.20	
Maximum		100	97	83	65	42	15	2.2	0.9	
Minimum		100	96	79	54	27	6.5	1	0.3	
Range		0	1	4	11	15	8.5	1.2	0.6	
Middle of Range		100	97	81	60	35	11	1.6	0.6	
% Range of Average		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

Material	Concrete Sand
Source	Janssen
Producer	Martin Marietta

Date	Lab #	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#16 1.18 mm	#30 600 µm	#50 300 µm	#100 150 µm	#200 75 µm	Complies
Limits			100	86	68	46	17	3.9	1.5	
		100	95	78	60	38	11	0	0	
25-Mar	J1	100	98	85	62	34	10.0	1.3	0.5	y
25-Mar	J2	100	98	88	69	44	11	1.6	0.9	y
5-Aug	1	100	98	86	66	41	12	1.1	0.6	y
5-Aug	2	100	98	88	68	45	14	2.1	0.8	y
Crsr Here to insert										
Average		100	98	87	66	41	11.8	1.5	0.7	
Standard Deviation		0	0.00	1.50	3.10	4.97	1.71	0.45	0.18	
Maximum		100	98	88	69	45	14	2.1	0.9	
Minimum		100	98	85	62	34	10	1.1	0.5	

Fine Aggregate Production Gradations

Material Concrete Sand Certified Aggregate
Source Heronimus 2004
Producer Carlson Matls.

Date	Lab #	3/8" 9.5 mm	#4 4.75 mm	#8 2.36 mm	#16 1.18 mm	#30 600 µm	#50 300 µm	#100 150 µm	#200 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 insert									
Average		100	96	87	72	44	11.1	1.3	0.6
Standard Deviation		0	0.89	2.23	2.71	1.02	1.26	0.29	0.10
Maximum		100	97	89	74	45	13	1.6	0.8
Minimum		100	95	84	68	42	9.6	0.9	0.5