<table>
<thead>
<tr>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
</tr>
<tr>
<td>Cement</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
</tr>
<tr>
<td>Fine Aggregate</td>
</tr>
<tr>
<td>Water</td>
</tr>
</tbody>
</table>
Concrete Mix Design Technician Course

Tennessee Department of Transportation

Volume 19.0

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Welcome!

Concrete Mix Design Technician Certification

Classroom Rules

- Be Respectful
- Facility Information
- Keep It Clean
- Phone Etiquette
Who Are YOU?

- Name
- Company
- Experience

Technician Certification Program

- Asphalt Roadway Inspector
- Asphalt Plant Inspector
- Asphalt Mix Design
- Concrete Field Testing
- Concrete Plant Quality Control
- **Concrete Mix Design**
- Aggregate
- Nuclear Gauge Safety
Introduction

Purpose of Certification

• To ensure proper performance of tests
• To improve reliability of results
• For quality control
• To comply with federal requirements

Course Highlights

• Course schedule
  • Slide presentations
  • Written exam
  • Results
  • Certification

• Recertification
  • Every 5 years
Introduction

Examination

• Written Exam (No Phones Allowed)
  • Open-book
  • To Pass
    • Must get 75% overall

Results

• Available within one week of completion
• Contact the Headquarters Materials & Tests (HQMT) Training Coordinator, Kim Whitby
  • kimberly.whitby@tn.gov
  • 615-350-4158
Resources

- Course materials
  - Course textbook
  - Presentation slides and videos
- TDOT
  - Standard Specifications, January 1, 2015
  - Special Provisions
- Contacts
  - Region 1: Brad Baskette
  - Region 2: Tony Renfro
  - Region 3: Kevin Isenberg
  - Region 4: Mitch Blankenship

AASHTO / ASTM Resources

- Making and Curing Concrete Test Specimens in the Laboratory: ASTM C192
- Compressive Strength of Cylindrical Concrete Specimens: AASHTO T 22 / ASTM C39
Resources

- Tennessee Department of Transportation
  - https://www.tn.gov/tdot.html
- American Road & Transportation Builders Association
  - https://www.artba.org/
- Tennessee Road Builders Association
  - www.trba.org/
- Tennessee Ready Mixed Concrete Association
  - www.tnconcrete.org/
- American Association of State Highway Transportation Officials
  - https://www.transportation.org
- American Society for Testing and Materials
  - https://www.astm.org/
- American Concrete Institute
  - https://www.concrete.org/
- Construction Materials Engineering Council
  - https://www.cmec.org/
- Portland Cement Association
  - www.cement.org/

ADA Notice of Requirements

- Can be found at the following website:

- To be in compliance with TDOTs requirements listed on the website above, it is our goal to provide reasonable accommodations to those who identify themselves as having a disability and request such accommodations

- Please feel free to bring it to any of the course instructors and accommodations will be administered as discretely as possible
Questions
1

Basic Concrete Ingredients
Basic Ingredients

Concrete is a mixture of paste and aggregates.

- 6% Air
- 11% Portland Cement
- 41% Gravel or Crushed Stone (Coarse Aggregate)
- 26% Sand (Fine Aggregate)
- 16% Water

Concrete is a mixture of paste and aggregates.
Basic Ingredients

Types of Cement

**Type I – Normal Use**
- Used for common applications

**Type II – Moderate Sulfate Resistance and Heat of Hydration**
- Where concrete contacts with soil or water with modest sulfate concentrations.
- Used when you have large volumes of concrete

**Type III – High Early Strength**
- Cement sets faster and produces higher early strength than Type I

**Type IV - Low Heat of Hydration**
- Produces less heat and generally used with massive structures
- Very few sources still exist

**Type V – Sulfate Resistant**
- Only used where high concentrations of sulfate in the soil or groundwater

http://www2.cement.org/basics/images/flashtour.html
Basic Ingredients

**Pozzolans**  
*(Supplementary Cementitious Materials)*

- No cementing value alone, but in concrete react with lime from cement hydration to form additional cementing compounds
- Generally, reduce early strength of concrete
- Contribute to strength at later ages
- Examples: fly ash, silica fume, ground granulated blast furnace slag

**Fly Ash**

- Two types
  - C-ash
  - F-ash
- Reduction in water
- Increased workability
- Reduces bleeding and segregation
- Improved pumpability
- Reduced heat of hydration
Basic Ingredients

**Slag Cement**
(GGBFS)

- Has minimal pozzolanic properties
- Slightly less water
- Setting time delayed
- Early strengths depressed
- Later strengths increased

**Silica Fume**

- Used in addition to relatively high cement contents
  - Produce extremely dense, strong, concrete mixtures
- Has extremely fine particles
  - Increase in water demand
  - Normally used with high range water reducers
- Increase strength
- Reduces permeability
- High risk of shrinkage cracking due to reduction in bleeding
### Effects of SCMs on Fresh Concrete Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Fly ash</th>
<th>GGBF slag</th>
<th>Silica fume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class F</td>
<td>Class C</td>
<td></td>
</tr>
<tr>
<td>Water requirements</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td>↑ ↓</td>
</tr>
<tr>
<td>Workability</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td>↑ ↓</td>
</tr>
<tr>
<td>Bleeding and segregation</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td></td>
</tr>
<tr>
<td>Air content</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td></td>
</tr>
<tr>
<td>Heat of hydration</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td></td>
</tr>
<tr>
<td>Setting time</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
<td></td>
</tr>
<tr>
<td>Finishability</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
<td></td>
</tr>
<tr>
<td>Pumpability</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
<td></td>
</tr>
<tr>
<td>Plastic shrinkage cracking</td>
<td>← →</td>
<td>← →</td>
<td></td>
</tr>
</tbody>
</table>

* Effect depends on properties of fly ash, including carbon content, alkali content, fineness, and other chemical properties

### Effects of SCMs on Hardened Concrete Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Fly ash</th>
<th>GGBF slag</th>
<th>Silica fume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class F</td>
<td>Class C</td>
<td></td>
</tr>
<tr>
<td>Early strength</td>
<td>↓ ↓</td>
<td>← →</td>
<td>↑ ↓</td>
</tr>
<tr>
<td>Long-term strength</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
</tr>
<tr>
<td>Permeability</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
</tr>
<tr>
<td>Chloride ingress</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
</tr>
<tr>
<td>ASR</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
<td>↓ ↓</td>
</tr>
<tr>
<td>Sulfate resistance</td>
<td>↑ ↓</td>
<td>↑ ↓</td>
<td></td>
</tr>
<tr>
<td>Freezing and thawing</td>
<td>← →</td>
<td>← →</td>
<td></td>
</tr>
<tr>
<td>Abrasion resistance</td>
<td>← →</td>
<td>← →</td>
<td></td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>← →</td>
<td>← →</td>
<td></td>
</tr>
</tbody>
</table>
Basic Ingredients

Chemical Admixtures

- **Type A - Water Reducers**
  - Reduce mixing water 5%-30%
  - Increase ultimate strength
  - Improve workability

- **Type B - Retarders**
  - Longer set time
  - Improve hot weather workability

- **Type C - Accelerators**
  - Shorter set time
  - Increase early strength

- **Type D = Type A + Type B**

- **Type E = Type A + Type C**

- **Type F - High Range Water Reducer**
  - Min. 12% reduction in mixing water
  - Increase ultimate strength
  - Improve workability

- **Type G = Type F + Type B**

- **Type S - Specific Performance**
  - Viscosity modifying
  - Shrinkage reducing
  - Corrosion inhibitor
  - Etc.

Air Entrainment

- Improves durability
- Improves workability
- Reduces water demand
- Generally, for every 1% air, concrete loses about 5% strength

Entrapped air

Entrained air
Coarse Aggregate

- Crushed Limestone, Gravel, Granite, Sandstone, and Slag available in Tennessee
- Retained on #4 sieve
- Desire well graded aggregates
  - Less water to produce workable mix
  - Increased compressive strengths with comparable cement
- Must be sound and resistant to abrasion

Coarse Aggregate Sizes

- Concrete Pavement requires a No. 467 aggregate blend
- Must submit a written request to Regional Materials & Tests with justification for use of a stone size other than in Table 903.03-1

<table>
<thead>
<tr>
<th>Application</th>
<th>Coarse Aggregate Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural concrete</td>
<td>No. 57</td>
</tr>
<tr>
<td>Self-Consolidating Concrete</td>
<td>Maximum No. 67</td>
</tr>
<tr>
<td>Prestressed concrete</td>
<td>No. 57 or 67</td>
</tr>
<tr>
<td>Prestress concrete</td>
<td>Any size fraction</td>
</tr>
<tr>
<td>Concrete for Bridge Repair</td>
<td>No. 5, 57, 67, or 78</td>
</tr>
<tr>
<td>Concrete curbing placed by mechanized extraction methods</td>
<td>No. 5, 57, 67, or 78</td>
</tr>
<tr>
<td>Cement treated permeable base</td>
<td>No. 57</td>
</tr>
</tbody>
</table>

(1) Gradation shall conform to 903.22.
(2) Aggregate shall meet the quality requirements specified below.
Basic Ingredients

Fine Aggregate

• Natural sand
  • Dredged river sand
  • Pit sand
  • Processed sandstone
• Manufactured Sand
  • Processed limestone
• Passing #4 sieve
• Must be sound

Surface Aggregates
(TDOT Specification 903.24)

• Resistant to polishing
• Maintains high frictional properties
• Natural sand required for any concrete riding
  • TDOT Specifications 501.02 and 604.03
• Coarse surface aggregate must be used in:
  • Concrete pavement travel lanes including mainline pavements and ramps
  • Bridge decks and approach slabs on interstates and 4 or more lane highways
Questions
Making and Curing Concrete Test Specimens in the Laboratory

ASTM C 192
Making Specimens

TDOT Standard Method of Test for
Making and Curing Concrete Test
Specimens in the Laboratory

References
TDOT Standard Specifications
ASTM C192

Apparatus

- Cylinder molds
- Beam and prism molds
- Tamping rods
- Mallets
- Vibrators
- Scoops
- Testing equipment
- Sampling and mixing pan
- Scales
- Concrete mixer
Preparation of Materials
(Temperature)

All materials in the mix should be at room temperature in the range of 68°F to 86°F

Preparation of Materials
(Cementitious Material)

• Storage
  • A dry place
  • Moisture-proof containers
• Pass through a #20 sieve to remove all lumps, remixed on a tarp or plastic sheet, and returned to containers
• Mix thoroughly for uniformity
Making Specimens

Preparation of Materials
(Aggregates)

• Maintain aggregate in SSD condition
• Obtain the specific gravity and absorption from the aggregate facility
• Determine moisture content of aggregates
• Free Moisture = Moisture Content - Absorption
• Determine moisture corrections for aggregates and batching water
• Moisture corrections are important for maintaining an accurate w/cm

Preparation of Materials
(Chemical Admixtures)

• Consult with admixture manufacturer to determine if powered admixtures should be mixed with cement or sand before incorporating in the mix
**Preparation of Materials**
*(Chemical Admixtures)*

- Water-soluble and liquid admixtures should be added in solution to the mixing water before use
- Incompatible admixtures (i.e. in concentrated form) should not be combined before adding to the mixer
- Time, sequence, and method of adding the admixtures should remain constant from batch to batch

**Machine-Mixing**

- Mix so that there is 10% excess
- Sequence
  1) Coarse aggregate
  2) Small amount of mixing water and solution of admixture
  3) Start mixer
  4) Fine aggregate, cement, and water
  5) 3 minutes mixing
  6) 3 minutes rest (covered, to avoid evaporation)
  7) 2 minutes final mixing
  8) Deposit in clean, damp mixing pan, and remix to uniformity
Making Specimens

Fresh Concrete Testing

• Determine air content, slump, temperature, unit weight, and yield of the batch
  • Air Content
    • Achieving the target air content and air void system is one of the most challenging aspects of controlling concrete mixtures
    • Entrained air adds to the durability of hardened concrete and the workability of fresh mixtures
  • Slump
    • Measures consistency of freshly mixed concrete
    • Not determined for no-slump concrete (< 1/4”)
  • Temperature
    • Check that temps are within tolerances
  • Unit Weight
    • Mass per cubic foot of freshly-mixed concrete
  • Yield
    • Volume of concrete produced from a mixture of known quantities of component materials

• Look for signs of segregation

Cylindrical Specimens

• Concrete pavement cylinders shall be 6”x12”
• Make all other cylinders 4”x8”
• Cylinder diameter must be at least 3 times the nominal maximum size of the aggregate
Prismatic Specimens

- Beams for flexural strength
  - Typically, 6”x6” cross-section with 18” span
- Prisms for freezing and thawing, length change, volume change

Number of Cylinders

TDOT Specifications require test results for compressive strength at 7, 14, and 28 days

- 2 cylinders per test
- For high early mixes, need results for early breaks (e.g. 18 hours)
### Making Specimens

**TABLE 1 Number of Layers Required for Specimens**

<table>
<thead>
<tr>
<th>Specimen Type and Size</th>
<th>Mode of Consolidation</th>
<th>Numbers of Layers of Approximate Equal Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinders:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter, mm [in.]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 to 100 [3 or 4]</td>
<td>rodding</td>
<td>2</td>
</tr>
<tr>
<td>150 [6]</td>
<td>rodding</td>
<td>3</td>
</tr>
<tr>
<td>225 [9]</td>
<td>rodding</td>
<td>4</td>
</tr>
<tr>
<td>up to 225 [9]</td>
<td>vibration</td>
<td>2</td>
</tr>
<tr>
<td>Prisms and horizontal creep Cylinders:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, mm [in.]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>up to 200 [8]</td>
<td>rodding</td>
<td>2</td>
</tr>
<tr>
<td>over 200 [8]</td>
<td>rodding</td>
<td>3 or more</td>
</tr>
<tr>
<td>up to 200 [8]</td>
<td>vibration</td>
<td>1</td>
</tr>
<tr>
<td>over 200 [8]</td>
<td>vibration</td>
<td>2 or more</td>
</tr>
</tbody>
</table>

**Making Specimens (Continued)**

**TABLE 2 Diameter of Rod and Number of Roddings to be Used in Molding Test Specimens**

<table>
<thead>
<tr>
<th>Cylinders: Diameter of Cylinder, mm [in.]</th>
<th>Diameter of Rod mm [in.]</th>
<th>Number of Roddings/Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 [6]</td>
<td>16 ± 2 [± 0.14]</td>
<td>25</td>
</tr>
<tr>
<td>250 [10]</td>
<td>16 ± 2 [± 0.14]</td>
<td>50</td>
</tr>
<tr>
<td>Top Surface Area of Specimen, cm² [in.²]</td>
<td>Diameter of Rod mm [in.]</td>
<td>Number of Roddings/Layer</td>
</tr>
<tr>
<td>160 [6] or less</td>
<td>10 ± 2 [± 0.14]</td>
<td>25</td>
</tr>
<tr>
<td>185 to 310 [25 to 48]</td>
<td>10 ± 2 [± 0.14]</td>
<td>one for each 7 cm² [1 in.²] of surface</td>
</tr>
<tr>
<td>320 [60] or more</td>
<td>16 ± 2 [± 0.14]</td>
<td>one for each 14 cm² [2 in.²] of surface</td>
</tr>
<tr>
<td>Horizontal Creep Cylinders</td>
<td>Diameter of Cylinder mm [in.]</td>
<td>Number of Roddings/Layer</td>
</tr>
<tr>
<td></td>
<td>150 [6]</td>
<td>16 ± 2 [± 0.14]</td>
</tr>
</tbody>
</table>
Methods of Consolidation

- Rod or vibrate: Slump ≥ 1”
- Vibration: Slump < 1”

Making Drycast Cylinders

- When concrete is too stiff to be consolidated via rodding or internal vibration, use the method in ASTM C497
  - Vibrating table
  - 3 layers
  - Vibrate with cylindrical hammer on surface of each lift until cement paste oozes around hammer
Making Specimens

Finishing Specimens

• Strike-off the surface
• No depressions or projections larger than 1/8”
• Cover immediately to prevent evaporation
  • Nonabsorptive, nonreactive cover
  • Plastic sheeting
  • Wet burlap
• Ensure cardboard molds do not get wet
• Mold specimens near storage area
• Store specimens immediately after striking off
• Storage area should be free of vibration

Curing

• Remove from molds within 24 ± 8 hours after casting
• Moist cure at 73.5 ± 3.5°F until tested
• Free water on entire surface at all times
  • Immersion in saturated-lime water
  • Moist room or cabinet
  • No dripping or running water
• Vibration-free area for first 48 hours
• *Flexural strength test specimens* shall be saturated in lime solution at least 20 hours prior to testing
3

Compressive Strength of Cylindrical Concrete Specimens

AASHTO T 22
ASTM C 39
Compressive Strength

**TDOT Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens**

References
- TDOT Standard Specifications
- AASHTO T 22
- ASTM C39

Summary of Method
- A compressive axial load is applied to concrete cylinders or cores at a prescribed rate until failure occurs
- The maximum load divided by the cross-sectional area of the cylinder is considered to be the compressive strength
Significance & Use

- This test method is used to determine the compressive strength of cylinders that have been properly prepared and cured.
- The compressive strength is used as a basis for performance of a mix.
- The results are also used to determine compliance with TDOT Specifications.

Compressive Strength Testing Machine

- Bearing blocks
- Load indicator
Compressive Strength

Testing Machine Requirements

- Sufficient capacity
- Proper rate of loading (35 ± 7 psi/s)
- Calibration
  - Upon installation, repair, or relocation
  - Annually
  - When accuracy is in question

Bearing Block Requirements

Typical Spherical Bearing Block
Load Indication Requirements

- Digital indicators must have numerical increments ≤ 0.1% of full scale load
- Analog indicators must have a graduated scale readable to the nearest 0.1% of full scale load
- Dial must have a zero adjustment
- 1% accuracy of maximum load

Cylinder Diameters

Specimens are not tested if any diameter of the cylinders differs from any other diameter of the same cylinder by more than 2%
Cylinder Requirements

- The ends must not depart from perpendicularity to the axis by more than 0.5°
- 6”x12” cylinder
  - 0.12” for 12”
- 4”x8” cylinder
  - 0.08” for 8”
- Cap, saw, or grind the ends

Cylinder Requirements

The ends of cylinders to be tested for compressive strength must be plane to within 0.002”
Specimens

- Measure length to the nearest 0.05” at three locations around circumference
- Record average length to nearest 0.05”

Time Tolerances

- Test specimens shall be broken within the permissible time tolerance for a given test age
- 2% tolerance for any age not specified

<table>
<thead>
<tr>
<th>Test Age</th>
<th>Permissible Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 hour</td>
<td>± 0.5 hours</td>
</tr>
<tr>
<td>3 days</td>
<td>± 2 hours</td>
</tr>
<tr>
<td>7 days</td>
<td>± 6 hours</td>
</tr>
<tr>
<td>28 days</td>
<td>± 20 hours</td>
</tr>
<tr>
<td>90 days</td>
<td>± 2 days</td>
</tr>
</tbody>
</table>
Procedure

• Compression tests of moist-cured specimens shall be made as soon as possible after removal from moist storage
• Cylinders shall be tested in the moist condition

Procedure

• Wipe clean the faces of the upper and lower plates
• Wipe both ends of the cylinder
• If using compression pads, keep record of use and replace when required
Procedure

- Place the cylinder on the lower plate
- Align the axis of the cylinder with the center of the upper plate

Procedure

Rotate the bearing block to ensure freedom of movement
Compressive Strength

Procedure

- Apply a continuous load without shock
- Apply the load until the cylinder fails

Point of Failure

Rate of Loading

- Hydraulic machines
  - 35 ± 7 psi/s
- Screw-type machines
  - Preliminary testing necessary to establish required rate of movement
  - Less common
Compressive Strength

Measured Strength

If cylinder breaks lower than expected, examine the fracture for:

• Large air voids
• Segregation
• Verify end preparation
• Cracking of aggregate

Cylinder Fractures

![Cylinder Fractures Diagram]

- Cone
- Cone and Split
- Cone and Shear
- Shear
- Columnar
Calculating Compressive Strength

\[ f'_c = \frac{F_{\text{max}}}{A} \times C \]

- \( f'_c \): compressive strength
- \( F_{\text{max}} \): maximum load
- \( A \): cross-sectional area
- \( C \): correction factor

L/D Correction Factor

<table>
<thead>
<tr>
<th>L/D:</th>
<th>&gt;1.75</th>
<th>1.75</th>
<th>1.50</th>
<th>1.25</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor:</td>
<td>1.00</td>
<td>0.98</td>
<td>0.96</td>
<td>0.93</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Compressive Strength

L/D Correction Factor

Example 1

Given:
- A standard 4"x8" cylinder of Class D concrete
- No preparation of the cylinder is required
- The cylinder fails at a maximum force of 53,259 pounds

4" 8"
Example 2

Given:
- A standard 6”x12” cylinder of Class CP
- The ends were prepared so that the length of the cylinder is 9 inches
- The cylinder fails at a maximum force of 92,075 pounds

Report

- Identification number
- Diameter
- Cross-sectional area
- Maximum load
- Compressive strength to nearest 10 psi
- Type of fracture
- Defects in specimen or caps
- Age of specimen
Questions
4

Concrete Mix Design
Absolute Volume Method for Concrete Mix Design

References
TDOT Standard Specifications
TDOT Supplemental Specifications
PCA, *Design and Control of Concrete Mixtures*, 13th Ed.
NRMCA, *Proportioning Concrete Mixtures*

Before Designing a Mix

Need the following:
- Class of concrete/Type of construction
  - Slump
  - Maximum w/c ratio
  - Minimum cement
  - Air content
- Cement
  - Specific gravity
- Other cementitious materials
  - Pozzolans
  - GGBFS
  - Silica fume
- Fine aggregate
  - Specific gravity
  - Gradation
  - Fineness modulus
- Coarse aggregate
  - Specific gravity
  - Gradation
  - Nominal maximum size
Step 1: Class of Concrete

Determine the class of concrete:
- Class CP – Concrete Pavement
- Class A – Structural, General Use
  - Class A Paving
- Class D, DS – Bridge Decks
- Class L – Lightweight
- Class S – Seal
- Class X – Plans Specific
- Class SCC, SH-SCC – Self Consolidating Concrete
- Class P-SCC
- Class P – Prestressed/Precast Bridge Members
- HE – High Early Strength
- Precast Concrete

Class CP

(TDOT Specifications Table 501.03-1)

Concrete Pavement

Table 501.03-1: Class CP – Paving Concrete

<table>
<thead>
<tr>
<th>28 Day Compressive Strength, min (PSI)</th>
<th>Minimum Cementitious Content (pounds per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content (%)</th>
<th>Slump (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>526&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.49</td>
<td>5% design 3 – 8% production</td>
<td>0 - 2&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>545&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>3 ± 1&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> 526 pounds required when the coarse aggregate is crushed stone
<sup>2</sup> 545 pounds required when the coarse aggregate is gravel
<sup>3</sup> Allowable slump for slipform paving
<sup>4</sup> Allowable slump for other than slipform paving
**Class A**
(TDOT Specifications Table 604.03-1)

- General Use Structural Concrete
- Class A Slipform has different slump requirements
- Class A Paving requires surface aggregate

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design + production tolerance)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3,000</td>
<td>564</td>
<td>0.45</td>
<td>6 ± 2</td>
<td>3 ± 1 (1)</td>
</tr>
</tbody>
</table>

(1) For slip forming, the slump shall range from 0 to 3 inches.

**Class D, DS**
(TDOT Specifications Table 604.03-1)

- Bridge Deck Concrete
- Class DS requires surface aggregate

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design + production tolerance)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>4,000</td>
<td>620</td>
<td>0.40</td>
<td>7 (5)</td>
<td>8 max (4)</td>
</tr>
</tbody>
</table>

(2) Use Class D concrete in all bridge decks except box and slab type structures unless otherwise shown on the Plans.

(3) Design Class D and Class L concrete at 7% air content. Acceptance range for pumping and other methods of placement is 4.5-7.5%. Sampling will be at the truck chute.

(4) Water reducing admixtures are acceptable; however, do not exceed the maximum water/cement ratio in order to achieve the required slump.
## Class L
(TDOT Specifications Table 604.03-1)

### Lightweight Concrete

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design ± production tolerance)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>4,000</td>
<td>620</td>
<td>0.40</td>
<td>7 (5)</td>
<td>8 max (4)</td>
</tr>
</tbody>
</table>

(1) Design Class D and Class L concrete at 7% air content. Acceptance range for pumping and other methods of placement is 4.5-7.5%. Sampling will be at the truck chute.

(4) Water reducing admixtures are acceptable; however, do not exceed the maximum water/cement ratio in order to achieve the required slump.

(5) The unit weight of air dried Class L concrete (lightweight concrete) shall not exceed 115 pounds per cubic foot as determined according to ASTM C567.

## Class S
(TDOT Specifications Table 604.03-1)

- Seal Concrete
- Underwater foundation applications
- Used when washout of cement is a concern

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design ± production tolerance)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (Seal)</td>
<td>3,000</td>
<td>682</td>
<td>0.47</td>
<td>6 ± 2</td>
<td>6 ± 2</td>
</tr>
</tbody>
</table>

(6) The use of fly ash as a cement replacement will be allowed in Class S (Seal) concrete.
Class X

- Plans Specific Requirements
  - For local programs, mix design approved by Local Government

Class SCC & SH-SCC

(TDOT Specifications Table 604.03-4)

- Class SCC can be used as a replacement for Class A
- Class SH-SCC is used in drilled shafts

Table 604.03-4: Composition of Self-Consolidating Concrete

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Max 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design ± production tolerance)</th>
<th>Slump Flow (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC (2.5 A)</td>
<td>4,500</td>
<td>620</td>
<td>0.45</td>
<td>6 ± 2</td>
<td>26 ± 5</td>
</tr>
<tr>
<td>SH-SCC (2.5 A)</td>
<td>4,500</td>
<td>620</td>
<td>0.45</td>
<td>6 ± 2</td>
<td>26 ± 5</td>
</tr>
</tbody>
</table>

1. Or as shown on the Plans or approved shop drawings.
2. Acceptance range for the T50 test in accordance with ASTM C1611 shall be between 2-2.5 seconds.
3. Passing ability in accordance with ASTM C1621 shall be less than 2 inches for acceptance.
4. Visual Stability Index (VSI) shall not exceed 1.0 as per ASTM C1611 for acceptance.
5. Static segregation as measured by ASTM C1610 shall not exceed 20%.
6. Air Content may be reduced if placed under water or underground if approved by the Engineer.
Mix Design

Class P-SCC
(TDOT Specifications Table 615.09-1)

For prestressed members

Table 615.09-1: Class P Concrete

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design ± production tolerance)</th>
<th>Slump or Slump Flow (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-SCC</td>
<td>5,000(^{(1)})</td>
<td>658</td>
<td>0.45</td>
<td>0-6(^{(2)})</td>
<td>26 ± 5</td>
</tr>
</tbody>
</table>

(1) Or as shown on the Plans or approved shop drawings.
(2) Air entraining is optional with the Contractor, unless otherwise shown on the Plans or shop drawings.

Class P
(TDOT Specifications Table 615.09-1)

- Prestressed Concrete Bridge Members
- Strengths will be dictated by approved plans or shop drawings

Table 615.09-1: Class P Concrete

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design ± production tolerance)</th>
<th>Slump or Slump Flow (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>5,000(^{(1)})</td>
<td>658</td>
<td>0.45</td>
<td>0-8(^{(2)})</td>
<td>2 ± 1(^{(3)})</td>
</tr>
</tbody>
</table>

(1) Or as shown on the Plans or approved shop drawings.
(2) Air entraining is optional with the Contractor, unless otherwise shown on the Plans or shop drawings.
(3) Not to exceed 3 inches before the addition of high range admixtures, and not to exceed 10 inches after the addition of high range admixtures. If water-cement ratio is equal to or less than 0.35 then the maximum slump is 10 inches. If the water-cement ratio is 0.36 – 0.45, the maximum slump is 8 inches.
### High Early Strength Concrete

*(TDOT Specifications 604.03.C)*

- Concrete strength requirement prior to 28 days
- Concrete repair applications
- Minimum Cement Content:
  - Type I – 714 lbs/yd³
  - Type III – 620 lbs/yd³
- Contractor can elect to use in place of Class A

### Precast Concrete

*(SOP 5-3)*

- Different precast products have different design requirements
- Noise walls panels: Class A
- Retaining wall panels, junction boxes, and spring boxes: Class D
- Mix designs for all other products are in accordance with:
  - Applicable AASHTO/ASTM Standards
  - Approved Shop Drawings
  - Contract Plans
  - TDOT Standard Drawings and Specifications
  - All mix design submittals shall include acceptance tolerances
Fine Aggregate Proportioning

• For most classes of concrete, the fine aggregate shall not exceed 44% of the total aggregate by volume

• Exceptions
  • Class A Slipform: 46% max
  • Class SCC, SH-SCC, P-SCC: 50% max
  • Curb and gutter: 40 - 65%
  • Drycast used for precast products: 60% max

Step 2: Water Content

• Determine the minimum amount of cement required and the maximum w/cm ratio
• Water/Cementitious Materials ratio on design is the maximum
• Determine the maximum allowable water content using the equation below

\[
\frac{w}{cm} = \frac{\text{weight of water}}{\text{weight of cementitious material}}
\]

weight of water = w/cm ratio × weight of cementitious material
**Step 3: Absolute Volumes**

Calculate the absolute volume of any material

\[ V_{ft^3} = \frac{W_{lbs.}}{G \times U} \]

- \( V_{ft^3} \) = absolute volume of material, ft\(^3\)
- \( W_{lbs} \) = weight of material, lbs
- \( G \) = specific gravity of material
- \( U \) = unit weight of water (usually assumed 62.4 lbs/ft\(^3\))

**Step 4: Weight of Material**

Calculate the weight of any material

\[ W_{lbs} = V_{ft^3} \times G \times U \]

- \( W_{lbs} \) = weight of material, lbs
- \( V_{ft^3} \) = absolute volume of material, ft\(^3\)
- \( G \) = specific gravity of material
- \( U \) = unit weight of water (usually assumed 62.4 lbs/ft\(^3\))
Step 5: Unit Weight of Mix

Calculate the unit weight of the mix

\[ U_{\text{lbs/ft}^3} = \frac{W_{\text{total, lbs.}}}{V_{\text{total, ft}^3}} \]

- \( U_{\text{lbs/ft}^3} \) = unit weight of mix, lbs/ft\(^3\)
- \( W_{\text{total, lbs.}} \) = total weight of all the materials, lbs
- \( V_{\text{total, ft}^3} \) = total volume of the mix, ft\(^3\) (should be 27 ft\(^3\))
Concrete Mix Design
Submittal & Approval
**TDOT Process for**

Concrete Mix Design Submittal & Approval

**References**
TDOT Standard Specifications
TDOT Supplemental Specifications
SOP 4-4

**SOP 4-4**

- Submittal and approval process for concrete mixes
  - Ready mix
  - Volumetric mobile mixers
  - Prestressed
  - Precast
Trial Batch
(SOP 4-4)

- Prepare trial batches for design, including admixtures in the proper proportions, no more than 90 days before the design submittal
- Gradations and specific gravity for coarse and fine aggregates used in trial batch shall reflect the characteristics of stockpiles to be used in the mix
- Any trial batch mixed for Class SCC, P-SCC, SH-SCC shall be verified in the presence of Regional Materials & Tests
  - The field trial must simulate expected field conditions including expected transport time
  - Static Segregation Test (ASTM C 1610) shall be performed in addition to acceptance tests for verification of the mix design

Trial Batch Testing
(SOP 4-4)

- Tests shall be conducted to determine:
  - Slump (Slump Flow for SCC)
  - Temperature
  - Air Content
  - Unit Weight and Yield
  - Passing Ability (SCC)
  - Static Segregation (SCC)
  - T-50 (SCC)
- The hardened specimens, after proper curing, shall then be tested for compressive strength
Types of Designs
(SOP 4-4)

• New
  • Submit mix design template including all data from trial batch

• Temporary
  • Submit like a new design
  • 7 or 14 day breaks must exceed 28-day requirement
  • Design expires if 28-day breaks are not submitted

• Same As
  • A “same as” design is associated to multiple projects for a plant instead submitting a new one each time
  • Must be approved design from current year
  • Concrete Design Contract Association Request Form
  • Not permitted for Class X, SCC, P-SCC, and SH-SCC designs

Design Submittals
(SOP 4-4)

• Submit to HQMT at least 14 days prior to mix production via email
• Ready Mix or Prestressed: TDOT.Concrete.Email@tn.gov
• Precast: TDOT.PrecastMTR@tn.gov
  • Subject line
    • New or Same as
    • Contract, Pin, or Bridge Grant Number
  • Include:
    • If required, include “Surface Aggregates Required”
    • Attach design template/same-as form
    • Contact information
  • Must be submitted by:
    • TDOT Concrete Mix Design Technician
    • PE licensed in TN
Expiration of Mix Designs
(SOP 4-4)

- Approved concrete mix designs will expire at the end of each calendar year (i.e. December 31st)
- Mix designs will be subject to expiration if the following are not satisfied:
  - Design strength
  - Field requirements/performance

Mix Design Template

- Use the newest version
- Mix designs are plant specific
- Include the following on each template:
  - Required compressive strength
    - If Class X, also send a copy of the plans sheet
  - All fresh concrete properties from trial batch
  - Compressive strength results from the trial batch at 7, 14, and 28 days
    - High early designs need breaks for specified early strength time
      - e.g. 3000 psi at 18 hours
  - All material sources must be TDOT approved
    - Producer List
    - Qualified Products List (QPL)
    - Batch weights of all materials
Cementitious Materials
(Mix Design Template)

- Cement, Fly Ash, Slag
  - Type, class, grade
  - Specific Gravity ($G_s$) from producer, typically 3.15
- Fly ash outage
  - New trial batch required with the exception of an emergency (project may be delayed)
  - Only submit new designs as necessary for each project

Cement
(TDOT Specification 901.01)

- The maximum allowable equivalent alkalis is 0.6% for all cements and blended cements used in concrete riding surfaces that include surface aggregates
- Equivalent alkalis are found on the Mill Test Report
Cement Replacement

Table 604.03-3: Type I or Type II Cement Modified by Fly Ash or Ground Granulated Blast Furnace Slag (GGBFS)

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Maximum Cement Replacement Rate % (by weight)</th>
<th>Minimum Modifier Cement Substitution Rates (by weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGBFS (grade 100 or 120)</td>
<td>35.0</td>
<td>1:1</td>
</tr>
<tr>
<td>Class “F” Fly Ash</td>
<td>25.0</td>
<td>1:1</td>
</tr>
<tr>
<td>Class “C” Fly Ash</td>
<td>25.0</td>
<td>1:1</td>
</tr>
</tbody>
</table>

The Contractor may use ternary cementitious mixtures (mixtures with Portland cement, ground granulated blast furnace slag, and fly ash) for Class A and Class D concrete provided that the minimum Portland cement content is 50%. The maximum amount of fly ash substitution in a ternary cementitious mixture shall be 20%. The Department will allow Type IS cement with ternary cementitious mixtures. When using a Type IS cement, do not use any additional slag as a partial replacement for the hydraulic cement.

Cement Replacement Examples

- **Example 1:**
  - 620 lbs cement
  - Maximum class C fly ash replacement
  \[
  620 \text{ lbs} \times 25\% = 155 \text{ lbs ”C” Fly Ash}
  \]

- **Example 2:**
  - 564 lbs cement
  - 20% class F fly ash replacement
  \[
  564 \text{ lbs} \times 20\% = 113 \text{ lbs ”F” Fly Ash}
  \]
Coarse & Fine Aggregates
(Mix Design Template)

- Type and size: crush stone, gravel, surface, lightweight
- Specific gravities and absorptions from producer(s)
- Allow 1 change in coarse aggregate:
  - If like material, and SG is within 0.15 of original
- Coarse and fine aggregate gradations
  - Fine aggregate Fineness Modulus (2.3-3.1)

Water
(Mix Design Template)

- Municipal or non-municipal
- For non-municipal also submit most recent water results per TDOT Specification 921.01

<table>
<thead>
<tr>
<th>Maximum Concentration in Mixing Water</th>
<th>Limits</th>
<th>ASTM Test Method (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Ion Content, ppm</td>
<td>500</td>
<td>C114</td>
</tr>
<tr>
<td>Alkalies as (Na2O + 0.658 K2O), ppm</td>
<td>600</td>
<td>C114</td>
</tr>
<tr>
<td>Sulfates as SO4, ppm</td>
<td>3000</td>
<td>C114</td>
</tr>
<tr>
<td>Total Solids by mass, ppm</td>
<td>50000</td>
<td>C1603</td>
</tr>
<tr>
<td>pH</td>
<td>4.5-8.5</td>
<td>(2)</td>
</tr>
</tbody>
</table>

(1) Other methods (EPA or those used by water testing companies) are generally acceptable.
(2) No ASTM method available.
Admixtures
(Mix Design Template)

• Brand and type
• Dosage rates used in trial batch
• Concrete mixtures using multiple admixture manufacturers must prove compatibility
  • 3 months of field data from non TDOT projects
  • Trial and field batch witnessed by HQ Materials & Tests or designee

Precast & Prestressed Mix Designs

• Submit designs for the following year by November 1st
• If resubmitting the previous year mix design, provide trial batch data or project break data from the past 90 days
• Precast mix design requirements are listed in SOP 5-3
• Prestressed mix design requirements are listed in SOP 5-4 and TDOT Specifications 615.09
  • Prestressed producers may use a mix design with a higher strength than that called for by contract plans, shop drawings, etc.
  • Approved prestressed designs will designate the maximum strength requirement it can be used for
Volumetric Mobile Mixers
(TDOT Specification 604.04B)

- Individual performing calibration must have BOTH of the following certifications:
  - VMMB Volumetric Mixer Operator
  - TDOT Concrete Mix Design Technician

- Perform the calibration of gate settings according to the manufacturer’s recommendations for the mix design to be used
  - All calibrations shall be kept with truck

- Inspections and calibrations shall be performed at a minimum of every 6 months, every 2500 cubic yards, or when a new mix design is to be used

Materials & Tests Website


Click on Field Operations
Materials & Tests Website
(continued)

Approved surface aggregate list

Mix design template (ready mix & volumetric)

Mix design template (precast & prestressed)

Questions
Table 604.03-1: Composition of Various Classes of Concrete

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Min 28-Day Compressive Strength (psi)</th>
<th>Min Cement Content (pound per cubic yard)</th>
<th>Maximum Water/Cement Ratio (pound/pound)</th>
<th>Air Content % (Design + production tolerance)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3,000</td>
<td>564</td>
<td>0.45</td>
<td>$6 \pm 2$</td>
<td>$3 \pm 1^{(1)}$</td>
</tr>
<tr>
<td>D, DS$^{(2, 3)}$</td>
<td>4,000</td>
<td>620</td>
<td>0.40</td>
<td>$7^{(3)}$</td>
<td>$8 \text{ max}^{(4)}$</td>
</tr>
<tr>
<td>L$^{(3, 5)}$</td>
<td>4,000</td>
<td>620</td>
<td>0.40</td>
<td>$7^{(3)}$</td>
<td>$8 \text{ max}^{(4)}$</td>
</tr>
<tr>
<td>S (Seal)$^{(6)}$</td>
<td>3,000</td>
<td>682</td>
<td>0.47</td>
<td>$6 \pm 2$</td>
<td>$6 \pm 2$</td>
</tr>
<tr>
<td>X$^{(7)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

$^{(1)}$ For slip forming, the slump shall range from 0 to 3 inches.

$^{(2)}$ Use Class DS concrete in riding surfaces as described in 903.03 and in accordance to Specification 903.24 requirements. Use Class D concrete in all other bridge decks except box and slab type structures unless otherwise shown on the Plans.

$^{(3)}$ Design Class D, Class DS, and Class L concrete at 7% air content. Acceptance range for pumping and other methods of placement is 4.5-7.5%. Sampling will be at the truck chute.

$^{(4)}$ Water reducing admixtures are acceptable; however, do not exceed the maximum water/cement ratio in order to achieve the required slump.

$^{(5)}$ The unit weight of air dried Class L concrete (lightweight concrete) shall not exceed 115 pounds per cubic foot as determined according to ASTM C567.

$^{(6)}$ The use of fly ash as a cement replacement will be allowed in Class S (Seal) concrete.

$^{(7)}$ Plan specific requirements.
### TABULATION OF CONCRETE MIX DESIGN PROPORTIONS

**Class of Concrete:** A

Use the table in Section 604.03 of the Standard Specifications (Classification and Proportioning and Quality Assurance)

### Constituent Materials

<table>
<thead>
<tr>
<th>Constituent Materials</th>
<th>Weight</th>
<th>Specific Gravity</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paste</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>%W cm</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Fly Ash</td>
<td>%W Flyash</td>
<td>= (W cm x %W Flyash)/100</td>
<td></td>
</tr>
<tr>
<td>Slag</td>
<td>%W Slag</td>
<td>= (W cm x %W Slag)/100</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>w/cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td>Design Air</td>
<td></td>
</tr>
<tr>
<td><strong>Aggregate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse (CA)</td>
<td>W CA</td>
<td>2.79</td>
<td>%V CA</td>
</tr>
<tr>
<td>Fine (FA)</td>
<td>W FA</td>
<td>2.63</td>
<td>%V FA</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>W Total</td>
<td></td>
<td>%V Total</td>
</tr>
<tr>
<td><strong>UNIT WEIGHT</strong></td>
<td>U Concrete</td>
<td>= W Total/V Total</td>
<td></td>
</tr>
</tbody>
</table>

### Weight Calculations

- **Concrete:**
  - Total Volume of Aggregate Required:
    \[ V_{agg} = 27\times(V_{cm} + V_{water} + V_{air}) \]
  - Total Weight and Volume of Paste:
    \[ V_{paste} = V_{cm} + V_{water} \]
    \[ W_{paste} = W_{cm} + W_{water} + W_{air} \]
    \[ U_{concrete} = W_{total}/V_{total} \]

### Specific Gravity Calculations

- **Cement:**
  \[ W_{cement} = (W_{cm} \times %W_{cement})/100 \]

- **Fly Ash:**
  \[ W_{flyash} = (W_{cm} \times %W_{flyash})/100 \]

- **Slag:**
  \[ W_{slag} = (W_{cm} \times %W_{slag})/100 \]

### Volume Calculations

- **Cement:**
  \[ V_{cement} = W_{cement}/(G_{s,cement} \times U) \]

- **Fly Ash:**
  \[ V_{flyash} = W_{flyash}/(G_{s,flyash} \times U) \]

- **Slag:**
  \[ V_{slag} = W_{slag}/(G_{s,slag} \times U) \]

### Water

- **Water:**
  \[ W_{water} = W_{cm} \times w/cm \]
  \[ V_{water} = W_{water}/(G_{s,water} \times U) \]

### Aggregate

- **Coarse (CA):**
  \[ W_{ca} = V_{ca} \times G_{s,ca} \times U \]

- **Fine (FA):**
  \[ W_{fa} = V_{fa} \times G_{s,fa} \times U \]

### Total

- **Total Weight and Volume:**
  \[ W_{total} = W_{paste} + W_{ca} + W_{fa} \]
  \[ V_{total} = V_{paste} + V_{ca} + V_{fa} \]
# TABULATION OF CONCRETE MIX DESIGN PROPORTIONS

**Class of Concrete:** D with max ash

Use the table in Section 604.03 of the Standard Specifications (Classification and Proportioning and Quality Assurance)

### Constituent Materials

<table>
<thead>
<tr>
<th>Constituent Materials</th>
<th>Weight</th>
<th>Specific Gravity</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cement</strong></td>
<td>( W_{\text{cm}} \times %W_{\text{Cement}} \div 100 )</td>
<td></td>
<td>( V_{\text{Cement}} = W_{\text{Cement}} \div (G_s,\text{Cement} \times U) )</td>
</tr>
<tr>
<td><strong>Fly Ash</strong></td>
<td>( W_{\text{FlyAsh}} = W_{\text{cm}} \times %W_{\text{FlyAsh}} \div 100 )</td>
<td>2.55</td>
<td>( V_{\text{FlyAsh}} = W_{\text{FlyAsh}} \div (G_s,\text{FlyAsh} \times U) )</td>
</tr>
<tr>
<td><strong>Slag</strong></td>
<td>( W_{\text{Slag}} = W_{\text{cm}} \times %W_{\text{Slag}} \div 100 )</td>
<td></td>
<td>( V_{\text{Slag}} = W_{\text{Slag}} \div (G_s,\text{Slag} \times U) )</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>( W_{\text{Water}} = W_{\text{cm}} \times w/cm )</td>
<td></td>
<td>( V_{\text{Water}} = W_{\text{Water}} \div (G_s,\text{Water} \times U) )</td>
</tr>
</tbody>
</table>

### Total Weight and Volume of Paste

\[ W_{\text{Paste}} = W_{\text{cm}} + W_{\text{Water}} \]

\[ V_{\text{Paste}} = V_{\text{cm}} + V_{\text{Water}} + V_{\text{Air}} \]

### Total Volume of Aggregate Required

\[ V_{\text{Agg}} = 27 \div (V_{\text{cm}} + V_{\text{Water}} + V_{\text{Air}}) \]

### Aggregate

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Weight</th>
<th>Specific Gravity</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coarse (CA)</strong></td>
<td>( W_{\text{CA}} = V_{\text{CA}} \times G_s,\text{CA} \times U )</td>
<td>2.79</td>
<td>( V_{\text{CA}} = (%V_{\text{CA}} \times V_{\text{Agg}}) \div 100 )</td>
</tr>
<tr>
<td><strong>Fine (FA)</strong></td>
<td>( W_{\text{FA}} = V_{\text{FA}} \times G_s,\text{FA} \times U )</td>
<td>2.63</td>
<td>( V_{\text{FA}} = (%V_{\text{FA}} \times V_{\text{Agg}}) \div 100 )</td>
</tr>
</tbody>
</table>

### TOTAL

\[ W_{\text{Total}} = W_{\text{Paste}} + W_{\text{CA}} + W_{\text{FA}} \]

\[ V_{\text{Total}} = V_{\text{Paste}} + V_{\text{CA}} + V_{\text{FA}} \]

### UNIT WEIGHT

\[ U_{\text{Concrete}} = \frac{W_{\text{Total}}}{V_{\text{Total}}} \]
## TABULATION OF CONCRETE MIX DESIGN PROPORTIONS

**A Ternary w/ max ash**

Use the table in Section 604.03 of the Standard Specifications (Classification and Proportioning and Quality Assurance)

### Constituent Materials

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight</th>
<th>Specific Gravity</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>( W_{cm} \times \text{%W}_{Cement} / 100 )</td>
<td>( V_{Cement} = W_{Cement} / (G_{s,Cement} \times U) )</td>
<td></td>
</tr>
<tr>
<td>Fly Ash</td>
<td>( W_{cm} \times \text{%W}_{Flyash} / 100 )</td>
<td>( 2.55 )</td>
<td>( V_{Flyash} = W_{Flyash} / (G_{s,Flyash} \times U) )</td>
</tr>
<tr>
<td>Slag</td>
<td>( W_{cm} \times \text{%W}_{Slag} / 100 )</td>
<td>( 2.63 )</td>
<td>( V_{Slag} = W_{Slag} / (G_{s,Slag} \times U) )</td>
</tr>
<tr>
<td>Water</td>
<td>( W_{cm} \times \text{w/cm} )</td>
<td></td>
<td>( V_{Water} = W_{Water} / (G_{s,Water} \times U) )</td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td>( V_{Air} = (\text{Design Air} \times 27) / 100 )</td>
</tr>
</tbody>
</table>

### Volume of Aggregate Required

\( V_{Agg} = 27 \times (V_{cm} + V_{water} + V_{air}) \)

### Aggregate

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Weight</th>
<th>%</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse (CA)</td>
<td>( V_{CA} = %V_{CA} \times V_{Agg} / 100 )</td>
<td>( 56% )</td>
<td>( V_{CA} = %V_{CA} \times V_{Agg} / 100 )</td>
</tr>
<tr>
<td>Fine (FA)</td>
<td>( V_{FA} = %V_{FA} \times V_{Agg} / 100 )</td>
<td>( 44% )</td>
<td>( V_{FA} = %V_{FA} \times V_{Agg} / 100 )</td>
</tr>
</tbody>
</table>

### TOTAL

\( V_{Total} = V_{Paste} + V_{CA} + V_{FA} \)

### UNIT WEIGHT

\( U_{Concrete} = W_{Total} / V_{Total} \)