October 4, 2019

REVISION OF SECTION 601

STRUCTURAL CONCRETE

1. **NOTICE**

This is a standard special provision that revises or modifies CDOT’s *Standard Specifications for Road and Bridge Construction*. It has gone through a formal review and approval process and has been issued by CDOT’s Project Development Branch with formal instructions regarding its use on CDOT construction projects. It is to be used as written without change. Do not use modified versions of this special provision on CDOT construction projects, and do not use this special provision on CDOT projects in a manner other than that specified in the instructions unless such use is first approved by the Standards and Specifications Unit of the Project Development Branch. The instructions for use on CDOT construction projects appear below.

Other agencies that use the *Standard Specifications for Road and Bridge Construction* to administer construction projects may use this special provision as appropriate and at their own risk.

**Instructions for use on CDOT construction projects:**

Use this standard special provision on projects with structural concrete.

Section 601 of the Standard Specifications is hereby revised for this project as follows:

Delete subsections 601.01 thru 601.07 and replace with the following:

**601.01** This work consists of furnishing and placing hydraulic cement concrete in accordance with these specifications and in conformity with the lines, grades and dimensions as shown on the plans or established.

This work includes preparing concrete surfaces designated in the Contract and applying an approved colored Structural Concrete Coating to them.

**601.02 Classification.** The classes of concrete shown in Table 601-1 shall be used when specified in the Contract.

**Table 601-1**

**CONCRETE FIELD REQUIRMENTS**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Concrete Class** | **Required Field Compressive Strength (psi)** | **Air Content: % Range (Total)** | **Slump2** | **Maximum Water/Cementitious** **Material Ratio:** |
| **B** | 4500 at 28 days | 5 - 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **BZ** | 4000 at 28 days | N/A1 | 6” – 9” | w/cm on Form 1373 |
| **D** | 4500 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **DT** | 4500 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **G** | 4500 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **PS (Girders)** | 8500 at 28 days | N/A1 | 9” maximum | 0.45 |
| **PS (Deck Panels)** | 6000 at 28 days | N/A1 | 9” maximum | 0.45 |
| **P** | 4500 at 28 days | 4 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **S35** | 5000 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **S40** | 5800 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **S50** | 7250 at 28 days | 5 – 8 | +/- 2” of Form 1373 Slump | w/cm on Form 1373 |
| **Shotcrete** | 4500 at 28 days | 7-103 | N/A | 0.45 |

1 5 - 8% when specified

2 Slump shall be a maximum of 9.0 inches for all classes of concrete. Concrete may have a slump above 9.0 inches when designed as Self Consolidating Concrete (SCC). The requirements for slump flow, blocking assessment, and segregation shall apply.

3 Prior to pumping for wet process.

**Class B** concrete is an air entrained concrete for general use. Class D, G or P concrete may be substituted for Class B concrete. Additional requirements are:

1. The coarse aggregate shall have a nominal maximum size of 1½ inches or smaller.
2. Class B Concrete for Slope and Ditch Paving shall be macro-fiber reinforced.

**Class BZ** concrete is concrete for drilled shafts. Additional requirements are:

1. Entrained air is not required unless specified in the Contract. When entrained air is specified in the Contract, the air content shall be 5 to 8 percent.
2. Slump shall be a minimum of 6 inches and a maximum of 9 inches. A minimum slump of 6 inches shall be maintained during the anticipated pour period. The use of retarders and hydration stabilizers are allowed to extend the slump life of the concrete. When the Contractor elects to use SCC, the slump requirement for Class BZ Concrete does not apply.
3. The coarse aggregate size shall be AASHTO M43 size #8 unless otherwise approved by the Engineer.
4. The mix shall either have a permeability not exceeding 2,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 12 kΩ-cm at 28 days using AASHTO T358.
5. The unrestrained shrinkage shall not exceed 0.050 percent at 28 days when tested by CP-L 4103.

**Class D** concrete is a denser general use concrete. Class G may be substituted for Class D concrete. Additional requirements are:

1. The mix shall either have a permeability not exceeding 2,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 12 kΩ-cm at 28 days using AASHTO T358.
2. The unrestrained shrinkage shall not exceed 0.050 percent at 28 days when tested by CP-L 4103.
3. The mix may use an optimized gradation (OG) with a nominal maximum aggregate size of at least ¾ inch.
4. The mix shall have a nominal maximum aggregate size of at least ¾ inch if an OG is not used.
5. When used in slip forming, an edge slump less than 6 mm (0.25 in.) and less than 30 percent surface voids (ranking of 2 or less) is required. The box test is described in CP 63.
6. Class D Concrete for sidewalks on bridge decks and bridge rail shall be macro-fiber reinforced.

**Class DT** concrete is used for bridge deck resurfacing. Additional requirements are:

1. The concrete mix shall consist of a minimum 50 percent AASHTO M 43 size No. 7 or No. 8 coarse aggregate by weight of total aggregate.
2. The mix shall either have a permeability not exceeding 2,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 12 kΩ-cm at 28 days using AASHTO T358.
3. The unrestrained shrinkage shall not exceed 0.050 percent at 28 days when tested by CP-L 4103.

**Class G** concrete is a low shrinkage macro fiber-reinforced concrete. Additional requirements are:

1. The concrete mix shall include approved macro or hybrid polyolefin fibers at a minimum dosage of 4 lbs/cy or the minimum dosage specified on the Department’s Approved Product List (APL), whichever is greater.
2. Shrinkage reducing admixtures may be incorporated into the mix.
3. The unrestrained shrinkage shall not exceed 0.030 percent at 28 days when tested by CP-L 4103.
4. The mix shall either have a permeability not exceeding 2,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 12 kΩ-cm at 28 days using AASHTO T358.
5. The mix may use an OG with a nominal maximum aggregate size of at least ¾ inch. The mix shall have a nominal maximum aggregate size of ¾ inch if an OG is not used.
6. An expansive cement additive may be added to an ASTM C150 Type I/II cement and fly ash to produce an ASTM C845 Type K cement. The proportion of the expansive cement additive will be determined by testing the cementitious material blend in accordance with ASTM C806. The blended material shall have an expansion of 0.04 to 0.10 percent at 7 days when tested in accordance with ASTM C806. When an expansive cement is used, the w/cm ratio shall be 0.45 to 0.55 and the expansion of the laboratory trial mix shall be 0.05 to 0.09 percent at 7 days when tested in accordance with ASTM C878.

**Class P** concrete is used in pavements. Additional requirements are:

1. The Required Field Flexural Strength shall be 650 psi.
2. The concrete mix shall consist of a minimum 55 percent AASHTO M 43 sizes No. 57, No. 6, No. 67, No. 357, or No. 467 coarse aggregate by weight of total aggregate.
3. The mix may use an OG with a nominal maximum aggregate size of at least ¾ inch.
4. ASTM C150 Type III and ASTM C1157 Type HE cements may be used for early opening.
5. The mix shall either have a permeability not exceeding 2,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 12 kΩ-cm at 28 days using AASHTO T358.
6. The unrestrained shrinkage shall not exceed 0.050 percent at 28 days when tested by CP-L 4103.
7. When concrete is to be placed using a paver, an edge slump less than 6 mm (0.25 in.) and less than 30 percent surface voids (ranking of 2 or less) is required. The box test is described in CP 63.
8. A minimum of 20 percent Class F fly ash or 30 percent Slag cement by weight shall be used to replace any ASTM C150 cement, any ASTM C1157 cement, or ASTM C595 Type IL cement. ASTM C595 Type IT(MS), IT(HS), IP(MS) or IP(HS) cements may be used without cement substitutions. Class C fly ash may be used if the calcium oxychloride is determined to be less than 15 g CaOXY/100 g cementitious paste as determined in accordance with AASHTO T 365 for Class 0 Sulfate Exposure.

**Class PS** Class PS concrete is used for prestressed concrete members. Requirements for Class PS concrete are specified in subsection 618.11. ASTM C150 Type III and ASTM C1157 Type HE cements may be used.

**Class S35, S40, and S50** concretes are dense high strength concretes. Additional requirements are:

1. The concrete mix shall be made with AASHTO M 43 sizes No. 57, No. 6, No. 67, No. 7 or No. 8 coarse aggregate.
2. When placed in a bridge deck, the mix shall have a nominal maximum aggregate size of at least ¾ inch.
3. The mixes may use an OG with a nominal maximum aggregate size of at least ¾ inch.
4. For S35 and S40 concretes, the unrestrained shrinkage shall not exceed 0.050 percent at 28 days when tested by CP-L 4103.
5. For S50 concretes, the unrestrained shrinkage shall not exceed 0.040 percent at 28 days when tested by CP-L 4103.
6. For S35 and S40 concretes, the mix shall either have a permeability not exceeding 2,000 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 14 kΩ-cm at 28 days using AASHTO T358.
7. For S50 concrete, the mix shall either have a permeability not exceeding 1,500 coulombs at an age of not more than 56 days when tested in accordance with ASTM C1202, or have a surface resistivity of at least 18 kΩ-cm at 28 days using AASHTO T358.

**Class Shotcrete** concrete is used for shotcrete applications. Additional requirements are:

1. The required air content prior to the pump for wet process applications shall be 7–10 percent.
2. Additional requirements are listed in subsection 641.02.

The Contractor may design Class B, Class BZ, Class D, Class G, Class PS, Class S35, Class S40, and Class S50 concrete to be Self Consolidating Concrete (SCC) with the following requirements:

1. SCC shall have a slump flow of 20 to 26 inches when tested in accordance with ASTM C1611 using an inverted slump cone.
2. SCC shall have a maximum blocking assessment of 2.0 inches when tested in accordance with ASTM C1621.

(3) SCC shall have a maximum static segregation of 10 percent when tested in accordance with ASTM C1610.

**MATERIALS**

**601.03** Materials shall meet the requirements specified in the following subsections:

|  |  |  |
| --- | --- | --- |
| Fine Aggregate |  | 703.01 |
| Coarse Aggregate |  | 703.02 |
| Portland Cement |  | 701.01 |
| Fly Ash |  | 701.02 |
| Silica Fume |  | 701.03 |
| Water |  | 712.01 |
| Air Entraining Admixtures |  | 711.02 |
| Pigments and Admixtures |  | 711.03 |
| Curing Materials |  | 711.01 |
| Preformed Joint Material |  | 705.01 |
| Reinforcing Steel |  | 709.01 |
| Bearing Materials |  | 705.06 |
| Epoxy |  | 712.10 |
| Structural Concrete Coating |  | 708.08 |
| High-reactivity Pozzolans |  | 701.04 |
| Slag Cement |  | 701.05 |

Pozzolans shall consist of fly ash, silica fume, and high-reactivity pozzolan.

Prestressing steel shall meet the requirements of subsection 714.01 except as noted on the plans.

Calcium Chloride shall not be used in reinforced concrete. Calcium Chloride shall be used in non-reinforced concrete only when specified.

Where Fiber-Reinforced Concrete is specified or designated on the plans, the concrete mix shall include approved polyolefin fibers. Unless otherwise specified, a minimum of 1.5 pounds or the manufacturer’s recommended dose per cubic yard of polyolefin fiber reinforcement shall be evenly distributed into the mix. Mixing shall be as recommended by the manufacturer such that the fibers do not ball up. Polyolefin fibers shall meet the requirements of ASTM C1116 and ASTM D7508.

Where Macro Fiber-Reinforced Concrete is specified or designated on the plans, the concrete mix shall include approved macro or hybrid polyolefin fibers at a minimum dosage of 4 lb/cy or the minimum dosage specified on the APL, whichever is greater. The dosage of the fiber may be reduced if trial mix data shows a minimum residual strength of 150 psi as determined in accordance with ASTM C1609 using a load support apparatus compliant with the requirements of ASTM C1812, “Standard Practice for Design of Journal Bearing Supports to be Used in Fiber Reinforced Concrete Beam Tests.” Mixing shall be as recommended by the manufacturer such that the fibers are evenly distributed in the mix and do not ball up. Macro or hybrid polyolefin fibers shall meet the requirements of ASTM C1116 and ASTM D7508.

**601.04 Sulfate Resistance.** The Contractor shall provide protection against sulfate attack on concrete structures and pavements by providing concrete manufactured according to the requirements of the specified Sulfate Exposure Class. The sulfate exposure class for all concrete except Class PS shall be Class 2 unless otherwise specified on the plans. The sulfate exposure class for Class PS shall be Class 0. The requirements for a higher sulfate exposure class may be used for lower sulfate exposure classes.

The Contractor may request to test the soil and water at a structure location to change the sulfate exposure class. Testing and sampling of the location shall be at a frequency approved by the Engineer, in consultation with the Region Materials Engineer. If the Contractor provided test reports that show another class of exposure exists at a structure location, the Engineer may accept a concrete mix for that location at the changed sulfate exposure class.

Cementitious material requirements for each Sulfate Exposure Class are as follows:

Class 0 requires that the concrete have a maximum Water/Cementitious Material Ratio of 0.45 and one of the following:

1. ASTM C150 Type I, II, III or V
2. ASTM C595 Type IL, IP, IP(MS), IP(HS) or IT
3. ASTM C1157 Type GU, HE, MS or HS

Class 1 requires that the concrete have a maximum Water/Cementitious Material Ratio of 0.45 and one of the following:

1. ASTM C150 Type II or V
2. ASTM C595 Type IP(MS) or IP(HS)
3. ASTM C1157 Type MS or HS
4. ASTM C150 Type III. Type III shall have no more than 8 percent C3A.
5. ASTM C595 Type IL(MS), IL(HS), IT(MS) or (HS)

Class 2 requires that the concrete have a maximum Water/Cementitious Material Ratio of 0.45 and one of the following:

1. ASTM C150 Type V with a minimum of a 20 percent substitution of Class F fly ash or slag cement by weight
2. ASTM C150 Type II or III with a minimum of a 20 percent substitution of Class F fly ash or slag cement by weight. The Type II or III cement shall have no more than 0.040 percent expansion at 14 days when tested according ASTM C452.
3. ASTM C1157 Type HS
4. ASTM C150 Type II, III, or V plus High-Reactivity Pozzolan where the blend has less than 0.05 percent expansion at 6 months or 0.10 percent expansion at 12 months when tested according to ASTM C1012
5. ASTM C1157 Type HE or MS plus Class F fly ash, slag cement, or High-Reactivity Pozzolan where the blend has less than 0.05 percent expansion at 6 months or 0.10 percent expansion at 12 months when tested according to ASTM C1012
6. A blend of portland cement meeting ASTM C150 Type II or III with a minimum of 20 percent Class F fly ash or slag cement by weight, where the blend has less than 0.05 percent expansion at 6 months or 0.10 percent expansion at 12 months when tested according to ASTM C1012
7. ASTM C595 Type IP(HS), IL(HS) or IT(HS). Class F fly ash, slag cement, or High-Reactivity Pozzolan may be substituted for Type IL cement.
8. ASTM C595 Type IL(MS) or IT(MS) plus Class F fly ash, slag cement, or High-Reactivity Pozzolan where the blend has less than 0.05 percent expansion at 6 months or 0.10 percent expansion at 12 months when tested according to ASTM C1012

Class 3 requires that the concrete have a maximum Water/Cementitious Material Ratio of 0.40 and one of the following:

1. A blend of portland cement meeting ASTM C150 Type II, III, or V with a minimum of a 20 percent substitution of Class F fly ash or slag cement by weight, where the blend has less than 0.10 percent expansion at 18 months when tested according to ASTM C1012
2. ASTM C 1157 Type HS having less than 0.10 percent expansion at 18 months when tested according to ASTM C1012. Class F fly ash, slag cement, or High-Reactivity Pozzolan may be substituted for cement.
3. ASTM C1157 Type HE, MS or HS plus Class F fly ash, slag cement, or High-Reactivity Pozzolan where the blend has less than 0.10 percent expansion at 18 months when tested according to ASTM C1012
4. ASTM C150 Type II, III, or V plus High-Reactivity Pozzolan where the blend has less than 0.10 percent expansion at 18 months when tested according to ASTM C1012
5. ASTM C595 Type IL(MS) or IT(MS) plus High-Reactivity Pozzolan where the blend has less than 0.10 percent expansion at 18 months when tested according to ASTM C1012
6. ASTM C595 Type IP(HS), IL(HS), or IT(HS) having less than 0.10 percent expansion at 18 months when tested according to ASTM C1012. Class F fly ash, slag cement, or High-Reactivity Pozzolan may be substituted for Type IL cement.
7. ASTM C595 Type IL with a minimum of a 20 percent substitution of Class F fly ash or slag cement by weight, where the blend has less than 0.10 percent expansion at 18 months when tested according to ASTM C1012
8. ASTM C150 Type I, II, III, or V plus a minimum of 20 percent Class F fly ash when the R factor of the fly ash is less than 0.75. R factor is determined using the following from the chemical composition of the fly ash:



ASTM C150 Type III and ASTM C1157 Type HE cements may only be used in Class P or PS Concrete when approved by the Engineer.

Class C fly ash shall not be substituted for cement when Class 1, 2, or 3 sulfate resistance/exposure class is specified.

The maximum Water/Cementitious Material Ratio may be exceeded when an expansive cement additive is used.

When fly ash or high-reactivity pozzolan is used to enhance sulfate resistance, it shall be used in a proportion greater than or equal to the proportion tested in accordance to ASTM C1012, shall be the same source, and shall have a calcium oxide content no more than 2.0 percent greater than the fly ash or high-reactivity pozzolan tested according to ASTM C1012. ASTM C1012 test results are acceptable for up to two years from the completion date of the test.

**Table 601-2**

|  |  |  |
| --- | --- | --- |
| **Water-Soluble Sulfate (SO4) in Dry Soil, (%)** | **Sulfate (SO4) in Water, ppm** | **Sulfate Exposure Class** |
| 0.00 to 0.10 | 0 to 150 | Class 0 |
| 0.11 to 0.20 | 151 to 1,500 | Class 1 |
| 0.21 to 2.00 | 1,501 to 10,000 | Class 2 |
| 2.01 or greater | 10,001 or greater | Class 3 |

**CONSTRUCTION REQUIREMENTS**

**601.05 Mix Design Submittal Requirements.** The Contractor shall submit a Concrete mix design for each class of concrete being placed on the project. Concrete shall not be placed on the project before the Concrete mix design has been approved by the Engineer. The Concrete mix design will be reviewed following the procedures of CP 62. The Concrete mix design will not be approved when the laboratory trial mix data or aggregate data are the results from tests performed more than two years in the past. The concrete mix design shall show the weights and sources of all ingredients including cements, pozzolans, aggregates, fibers, pigments, water, additives and the water to cementitious material ratio (w/cm). When determining the w/cm, the weight of cementitious material (cm) shall be the sum of the weights of the cement, slag cement, fly ash, silica fume, and high-reactivity pozzolan. Water from dosages of admixtures greater than 10 ounces per 100 pounds of cementitious materials shall be included in the calculation of w/cm.

The laboratory trial mix data shall include results of the following:

1. AASHTO T 119 (ASTM C143) Slump of Hydraulic Cement Concrete, except when the concrete is SCC
2. AASHTO T 121 (ASTM C138) Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
3. AASHTO T 152 (ASTM C231) Air Content of Freshly Mixed Concrete by the Pressure Method
4. ASTM C39 Compressive Strength of Cylindrical Concrete Specimens shall be performed with at least two specimens at 7 days and three specimens at 28 days.
5. Class P concrete shall include AASHTO T97 (ASTM C78) Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). At least two specimens will be tested at 7 days and four specimens at 28 days. The lab trial mix shall produce a flexural strength at 28 days of at least 650 psi.
6. Concrete with an OG shall indicate the gradation of the blended aggregates. Optimized gradations shall be developed by an approved mix design technique such as Tarantula Curve, Shilstone, or KU mix.
7. SCC concrete shall include ASTM C1611 Standard Test Method for Slump Flow of Self-Consolidating Concrete. Slump flow shall be measured using an inverted slump cone.
8. SCC concrete shall include ASTM C1621 Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring.
9. SCC concrete shall include ASTM C1610 Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique.
10. When concrete is to be placed using a paver, the edge slump and surface voids shall be reported in accordance with CP 63.

Prior to placement of accelerated Class P Concrete, the Contractor shall provide the Engineer a report of maturity relationships in accordance with CP 69.

Except for Class PS concrete, the laboratory trial mix must produce an average compressive strength of at least the required field compressive strength specified in Table 601-1. For Class PS concrete, the laboratory trial mix must produce an average compressive strength at least 115 percent of the required field compressive strength specified in Table 601-1.

When entrained air is specified in the Contract for Class BZ concrete, the trial mix shall be run with the required air content.

The laboratory trial mix shall have a relative yield of 0.99 to 1.02.

Aggregate data shall include the results of the following:

1. AASHTO T 11 (ASTM C117) Materials Finer Than 75 um (No. 200) Sieve in Mineral Aggregates by Washing
2. AASHTO T 19 (ASTM C29) Unit Weight and Voids in Aggregate
3. AASHTO T 21 (ASTM C40) Organic Impurities in Fine Aggregate for Concrete
4. AASHTO T 27 (ASTM C136) Sieve Analysis of Fine and Coarse Aggregates
5. AASHTO T 84 (ASTM C128) Specific Gravity and Absorption of Fine Aggregate
6. AASHTO T 85 (ASTM C127) Specific Gravity and Absorption of Coarse Aggregate
7. AASHTO T 96 (ASTM C131) Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
8. AASHTO T 104 (ASTM C88) Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
9. CP 37 Plastic Fines in Graded Aggregates and Soils by use of the Sand Equivalent Test
10. ASTM C535 Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
11. ASTM C1260 Determining the Potential Alkali Reactivity of Aggregates (Accelerated Mortar-Bar Method). When an aggregate source is known to be reactive, ASTM C1567 results may be submitted in lieu of ASTM C1260 results.

Aggregate tested by ASTM C1260 with an expansion of 0.10 percent or more, or that is known to be reactive, shall not be used unless mitigative measures are included in the mix design.

Mitigative measures shall be tested using ASTM C1567 and exhibit an expansion less than 0.10 percent by one of the following methods:

1. Combined Aggregates. The mix design sources of aggregates, cement and mitigative measures shall be tested. The proportions of aggregates, cement and mitigative measures shall be those used in the mix design.
2. Individual Aggregates. Each source and size of individual aggregates shall be tested. The source of cement and mitigative measures shall be those used in the mix design. The highest level of mitigative measures for any individual aggregate shall be the minimum used in the mix design.

For all concrete mix designs with ASTM C150 and ASTM C595 Type IL cements, the total substitution of cement shall not exceed 50 percent by weight of total cementitious material.

For all concrete mix designs with ASTM C595 Type IP, IP(MS), IP(HS), or IT cements: fly ash or high-reactivity pozzolan shall not be substituted for cement.

For all concrete mix designs with ASTM C595 IT cements, slag cement shall not be substituted for cement.

For all concrete mix designs with ASTM C595 Type IP, IP(MS), IP(HS) cements, when slag cement is substituted for cement, the total substitution of cement shall not exceed 50 percent by weight of total cementitious material.

For all concrete mix designs with ASTM C1157 cements, the total pozzolan content including pozzolan in cement shall not exceed 30 percent by weight of the cementitious material content. Up to a maximum of 30 percent slag cement by weight of total cementitious material may be substituted for cement.

The Contractor shall submit a new Concrete Mix Design Report meeting the above requirements when a change occurs in the source, type, or proportions of cement, slag cement, fly ash, high-reactivity pozzolan, silica fume, or aggregate. Adjustments to aggregate weights may be made to adjust yield if the combined gradation remains constant (+/-1 percent) or within the optimized band.

When a change occurs in the source or type of approved admixtures or the addition of approved accelerating, retarding or hydration stabilizing admixtures to existing mix designs, the Contractor shall submit a letter stamped by the Concrete Mix Design Engineer approving the changes to the existing mix design. The change shall be approved by the Engineer prior to use.

Unless otherwise permitted by the Engineer, the product of only one type of hydraulic cement from one source of any one brand shall be used in a concrete mix design.

Approval of the concrete mix design by the Engineer does not constitute acceptance of the concrete. Acceptance will be based solely on the test results of concrete placed on the project.

Once approved for a project, the mix design may be used for the duration of the project.

**601.06 Batching** Measuring and batching of materials shall be done in accordance with AASHTO M 157 (ASTM C94).

The Contractor shall furnish a batch ticket (delivery ticket) with each load for all classes of concrete. Concrete delivered without a batch ticket containing complete information as specified shall be rejected. The Contractor shall collect and complete the batch ticket at the placement site and deliver all batch tickets to the Engineer on a daily basis. The Engineer shall have access to the batch tickets at any time during the placement. The following information shall be provided on each batch ticket:

1. Supplier’s name and date
2. Truck number
3. CDOT Project number and location
4. Concrete class designation and item number
5. Cubic yards batched
6. Time batched
7. CDOT mix design number
8. Type, brand, and amount of each admixture and pigment
9. Type, brand, and amount of cement, slag cement, fly ash, and high-reactivity pozzolan
10. Weights of fine and coarse aggregates or combined weight when an OG is pre-blended
11. Moisture of fine and coarse aggregates or combined moisture when an OG is pre-blended
12. Gallons (Pounds) of batch water (including ice)
13. Weight of polyolefin fiber reinforcement

The Contractor shall add the following information to the batch ticket at the placement site:

1. Gallons of water added by truck operator, the time the water was added, and the quantity of concrete in the truck each time water is added
2. Number of revolutions of drum at mixing speed (for truck mixed concrete)
3. Discharge time
4. Location of batch in placement
5. Water to cementitious material ratio

Electronic tickets are allowed as long as CDOT has access to the batch ticket and the batch ticket can be downloaded and saved by the Engineer in PDF format before placement, at any time during placement, and until the project is accepted.

(a) *Hydraulic Cement, Fly Ash, High-Reactivity Pozzolan, Slag Cement and Silica Fume.* All cementitious material shall be measured by mass. Supplementary cementitious materials may be weighed cumulatively with cement. Cement and other cementitious material shall be weighed on a scale and in a weigh hopper, which is separate and distinct from those used for other materials. When the quantity of cementitious material exceeds 30 percent of the full capacity of the scale, the quantity of cement and the cumulative quantity of cement plus supplementary cementitious material shall be within ±1 percent of the required mass. For small batches to a minimum of 1 cubic yard, the quantity of cement and the quantity of cement plus supplementary cementitious material used shall not be less than the required amount or more than 4 percent in excess. A fraction of a bag of cement shall not be used unless weighed.

(b) *Water.* Mixing water shall consist of water added to the batch, ice added to the batch, water occurring as surface moisture on the aggregates, and water introduced in the form of admixtures. The added water shall be measured by mass or volume to an accuracy of 1 percent of the required total mixing water. Added ice shall be measured by weight. In the case of truck mixers, wash water retained in the drum for use in the next batch of concrete shall be accurately measured or shall be discharged prior to loading the next batch of concrete. Total water (including any wash water) shall be measured or weighed to an accuracy of ±3 percent.

(c) *Aggregates.* Aggregates from different sources and of different gradings shall not be stockpiled together.

Aggregate shall be handled from stockpiles or other sources to the batching plant in such manner as to secure a uniform grading of the material. Aggregates that have become segregated, or mixed with earth or foreign material, shall not be used. All aggregates produced or handled by hydraulic methods, and washed aggregates, shall be stockpiled or binned for draining at least 12 hours before being batched. Rail shipment requiring more than 12 hours will be accepted as adequate binning only if the car bodies permit free drainage. In case the aggregates contain high or non-uniform moisture content, storage or stockpile period in excess of 12 hours may be required.

Aggregate shall be measured by mass. The quantity of aggregate used in any batch of concrete as indicated by the scale shall be within ±2 percent of the required mass when weighed in individual weigh batchers. In a cumulative aggregate weigh batcher, the cumulative mass after each successive weighing shall be within ±1 percent of the required cumulative amount when the scale is used in excess of 30 percent of its capacity. For cumulative mass for less than 30 percent of scale capacity, the tolerance shall be ±0.3 percent of scale capacity or ±3 percent of the required cumulative mass, whichever is less.

(d) *Bins and Scales.* The batching plant may include bins, weighing hoppers, and scales for the fine aggregate and for each size of coarse aggregate. A bin, hopper, and scale for cementitious material shall be included. A single weighing hopper with an accumulative scale will be permitted, provided a separate scale is used for weighing cementitious material.

Scales shall meet the requirements of subsection 109.01.

**601.07 Mixing.** Mixing of materials shall be done in accordance with AASHTO M 157 (ASTM C94). Concrete shall be mixed in stationary mixers, in a central-mix plant, in truck mixers, or in self-contained mobile mixers. Mixing time shall be measured from the time all materials, except water, are in the drum.

Admixtures listed in the mix design, or admixtures approved in accordance with subsection 601.04, and water may be added at the project.

(a) *Mixing General.* Concrete shall be deposited in place within 90 minutes after batching when concrete is delivered in truck mixers or agitating trucks, and within 60 minutes when delivered in non-agitating trucks.

The 90 minute time limit for mixer or agitating trucks may be extended to 120 minutes if:

1. No water is added after 90 minutes.
2. The concrete temperature prior to placement is less than 90 °F.

The 90 minute time limit for mixer or agitating trucks may be extended to 180 minutes if:

1. No water is added after 90 minutes.
2. The concrete temperature prior to placement is less than 90 °F.
3. The approved concrete mix contains an approved retarding admixture.

The 90 minute time limit for mixer or agitating trucks may be extended longer than 180 minutes if:

1. An Extended Set Control Admixture (ESCA) is added at the time of batching. Procedures and doses shall be in accordance with manufacturer’s recommendations. The ESCA shall be on the approved products list.
2. The concrete temperature prior to placement is less than 90 °F.
3. Each load of concrete shall be sampled and tested by the Contractor for air content according to CP 61.
4. The Department will cast three additional acceptance cylinders. If the acceptance cylinders tested at 28 days do not meet design strength, the additional cylinders will be tested at 56 days for acceptance.

(b) *Central-Mixed Concrete.* Concrete that is mixed completely in a stationary mixer and transported to the point of delivery either in a truck agitator or a truck mixer operating at agitating speed, or in non-agitating equipment approved by the Engineer, shall conform to the following:

1. The mixing time shall be counted from the time all the solid materials are in the drum.
2. The batch shall be so charged into the mixer so that some water will enter in advance of the cement and aggregate.
3. All water shall be in the drum by the end of the first one fourth of the specified mixing time.
4. The volume of concrete mixed per batch may exceed the mixer's nominal capacity, as shown on the manufacturer’s standard rating plate on the mixer, by up to 10 percent provided concrete test data for strength, segregation, and uniform consistency are satisfactory, and provided spillage of concrete does not occur.
5. Where no mixer uniformity tests are made, the acceptable mixing time for mixers having capacities of 1 cubic yard or less shall be not less than 1 minute. For mixers of greater capacity, this minimum shall be increased 15 seconds for each cubic yard or fraction thereof of additional capacity. Uniformity testing shall be in accordance with AASHTO M157 (ASTM C94).

(c) *Truck Mixing*. Truck mixed concrete shall conform with one of the following:

1. Concrete that is completely mixed in a truck mixer shall be mixed 70 to 100 revolutions at the mixing speed to produce uniform concrete. Concrete uniformity tests shall be made in accordance with AASHTO M157 (ASTM C94). Additional revolutions of the mixer beyond the number found to produce the required uniformity of concrete shall be at a designated agitating speed.
2. For concrete that is partially mixed in a stationary mixer, and then mixed completely in a truck mixer (shrink mixed concrete), the time of partial mixing shall be the minimum required to intermingle the ingredients. After transfer to a truck mixer, it shall be mixed at a speed to produce uniform concrete. Concrete uniformity tests shall be made in accordance with AASHTO M157 (ASTM C94). Additional revolutions of the mixer beyond the number found to produce the required uniformity of concrete shall be at a designated agitating speed.
3. Concrete mixed entirely in a stationary mixer and delivered to the job in a truck mixer shall be remixed for a minimum of 20 revolutions of the mixing drum at mixing speed at the job site prior to discharge.

When water is added at the delivery site to control the consistency of the concrete, the concrete shall be mixed for at least 30 revolutions of the mixer drum at mixing speed for each addition of water before discharge. These revolutions are in addition to the minimum revolutions required for mixing at the delivery site. The added water shall not cause the w/cm ratio to exceed the approved mix design w/cm ratio. Water from all sources shall be documented by the Contractor on the delivery slip for each load of concrete.

The Contractor shall provide a Concrete Truck Mixer Certification. This certification shall show the various pick-up and throw-over configurations and wear marks so that the wear on the blades can be checked. Blades shall be replaced when any part or section is worn 1 inch or more below the original height of the manufacturer's design. A copy of the manufacturer's design, showing the dimensions and arrangement of blades, shall be available to the Engineer at all times.

The Contractor shall furnish a water-measuring device in good working condition, mounted on each transit mix truck, for measuring the water added to the mix after the truck has left the charging plant. Each measuring device shall be equipped with an easy-to-read gauge. Water shall be measured to an accuracy of ±3 percent.

(d) *Self Contained Mobile Mixer.* Proportioning and mixing equipment shall be of the self-contained, mobile, continuous mixing type in accordance with ASTM C685 and subject to the following:

1. The mixer shall be self-propelled and capable of carrying sufficient unmixed dry, bulk cementitious materials, fine aggregate, coarse aggregate, admixtures, and water to produce on the site at least 6 cubic yards of concrete. The mixer shall have one bin for each size aggregate.
2. The mixer shall be capable of positive measurement of cementitious materials being introduced into the mix. A recording meter visible at all times and equipped with a ticket printout shall indicate the quantity of total concrete mix.
3. The mixer shall provide positive control of the flow of water into the mixing chamber. Water flow shall be indicated by flow meter and be readily adjustable to provide for minor variations in the aggregate moisture.
4. The mixer shall be capable of calibration to automatically proportion and blend all components of indicated composition on a continuous or intermittent basis as required by the finishing operation, and shall discharge mixed material through a conventional chute directly in front of the finishing machine.
5. The Contractor shall perform calibration tests according to the equipment manufacturer's recommendations at the beginning of each project, and when there is a change in the mix design proportions or source of materials. The Engineer may require a calibration test or yield check when a change in the characteristics of the mixture is observed. The tolerances in proportioning the various ingredients shall be according to ASTM C685.

Subsection 601.09(h) shall include the following:

When ESCAs are used, the removal of forms, supports and housing, and the discontinuance of heating and curing may begin when the concrete is found to have the required compressive strength.

In subsection 601.12(g) delete the fifth paragraph and replace with the following:

When concrete is placed by pumping, the pumping equipment shall be thoroughly cleaned prior to concrete placement. Excess form release agent shall be removed from the hopper. The pump shall be primed at the Contractor’s expense by pumping and discarding enough concrete to produce a uniform mix exiting the pump. At least 0.25 cubic yards of concrete shall be pumped and discarded to prime the pump. Water or admixtures shall not be added directly into the concrete pump hopper after placement has commenced. If water or admixtures are added to the concrete pump hopper, all concrete in the concrete pump hopper and the line shall be discarded and the pump shall be re-primed at the Contractor’s expense.

In subsection 601.15 delete the second paragraph and replace with the following:

A Pre-placement Conference shall be held at a time mutually agreed upon before the initial placement of bridge deck concrete. Representatives of the ready mix producer and the Contractor shall meet with the Engineer to discuss the following topics:

Delete subsection 601.15(a) and replace with the following:

(a) *Surface Preparation*. Tops of girders, precast deck panels, pier caps, and abutments that will come into contact with bridge deck concrete shall be heated to raise the temperature above 35 °F prior to concrete placement. The proposed preheating method is subject to approval by the Engineer.

Delete subsection 601.15(b).

In subsection 601.15(c) delete paragraphs 3 through 8.

In subsection 601.16 delete paragraphs 1 to 3 and replace with the following:

The minimum curing period shall be 120 hours.

The concrete surface shall be kept moist at all times by fogging with an approved atomizing nozzle or applying a monomolecular film coating to retard evaporation until the curing material is in place.

Concrete bridge decks, including bridge curbs and bridge sidewalks, shall be cured as follows:

Delete subsection 601.16(e).

Delete subsection 601.17 and replace with the following:

**601.17 Acceptance and Pay Factors.** These provisions apply to all concrete. The Contractor shall sample concrete for both Process Control (PC) and Owner Acceptance (OA) in accordance with CP 61. The Engineer will witness the sampling and take possession of the OA samples at a mutually agreed upon location. The Contractor shall be responsible for Process Control (PC) testing for concrete. PC testing shall be performed at least once per day and then once per 50 cubic yards for concrete slump, unit weight, and concrete temperature.

If the produced concrete does not have a relative yield of 0.99 to 1.02 for two consecutive yield determinations, concrete production shall cease and the Contractor shall present a plan to correct the relative yield to the Engineer.

When SCC is used, the Contractor shall test the first load of SCC prior to placement for Slump Flow (ASTM C1611) and Blocking Assessment (ASTM C1621). The Contractor shall take a sample from the first portion of the load and complete the slump flow and blocking assessment prior to depositing any portion of the load. The tests shall not be performed more than 15 minutes prior to placement. The slump flow shall be 20 to 26 inches. The blocking assessment shall be less than or equal to 2.0 inches. The Contractor will be allowed to make adjustments to the load with admixtures. After adjustments have been made, the slump flow and blocking assessment shall be retested. Each subsequent load of SCC shall be tested for Slump Flow. If the slump flow differs from the first load by more than 2.0 inches, the load shall be adjusted to have a slump flow within 2.0 inches of the first load, or the load may be tested for Blocking Assessment (ASTM C1621). If the load is tested for and meets the requirements for Blocking Assessment (ASTM C1621), the load’s slump flow will be used for the acceptance of the following loads. When concrete placement is halted for more than 15 minutes, the slump flow and blocking assessment shall be retested prior to resuming placement. When the slump flow exceeds 26 inches, the concrete may be placed if the depth of penetration is less than 11 millimeters when tested using ASTM C1712 Test Method for Static Segregation Resistance of Self-Consolidating Concrete. If a load of concrete has a slump flow greater than 26 inches and a depth of penetration less than 11 millimeters, the next load shall be tested for slump flow and blocking assessment to establish a new slump flow target.

When SCC is used, subsection 601.17(b) does not apply.

When SCC is used, the test methods for fabricating specimens in accordance with subsections 601.17(a) and 601.17(c) acceptance shall be modified to use ASTM C1758, Practice for Fabricating Test Specimens with SCC, for filling the test specimens with concrete.

1. *Air Content.* The first three batches at the beginning of each day’s production shall be tested by the Contractor’s PC and CDOT’s OA for air content. When the PC and OA air content measurements differ by more than 0.5 percent, both the PC and OA air meters shall be checked in accordance with ASTM C231. When air content is below the specified limit, it may be adjusted in accordance with subsection 601.08. Successive batches shall be tested by the Contractor’s PC and witnessed by the Engineer until three consecutive batches are within specified limits. After the first three batches, CDOT will follow the random minimum testing schedule. After the first three batches, the Contractor shall perform PC testing at a frequency of one random sample per 50 cubic yards. Air content shall not be adjusted after a CDOT OA test.

At any time during the placement of the concrete, when an OA test on a batch deviates from the minimum or maximum percent of total air content specified, the batch that deviates from the specified air content by 1 percent or less may be accepted at a reduced price using Table 601-3.

Portions of loads incorporated into structures prior to determining test results which indicate rejection as the correct course of action shall be subject to acceptance at reduced price, no payment, or removal as determined by the Engineer.

1. *Slump*. Except for Class BZ concrete, the slump of the delivered concrete shall be the slump of the approved concrete mix design plus or minus 2.0 inches. The maximum slump shall be 9.0 inches. Slump acceptance, but not rejection, may be visually determined by the Engineer. Any batch that exceeds the slump of the approved concrete mix design by more than 2.0 inches will be retested. If the mix design slump is exceeded by more than 2.0 inches a second time, that load will be rejected. If the slump is greater than 2 inches lower than the approved concrete mix design, the load may be adjusted by adding a water reducer or by adding water (if the w/cm allows) and retested.

Portions of loads incorporated into structures prior to determining test results which indicate rejection as the correct course of action shall be subject to reduced payment or removal as determined by the Engineer.

1. *Strength (When Specified).* The concrete will be considered acceptable when the running average of three consecutive strength tests per mix design for an individual structure is equal to or greater than the specified strength and no single test falls below the specified strength by more than 500 psi. A test is defined as the average strength of three test cylinders cast in plastic molds from a single sample of concrete and cured under standard laboratory conditions prior to testing. If the compressive strength of any one test cylinder differs from the average by more than 10 percent that compressive strength will be deleted and the average strength will be determined using the compressive strength of the remaining two test cylinders.

When the average of three consecutive strength tests is below the specified strength, the individual low tests will be used to determine the pay factor in accordance with Table 601-3. If less than three strength tests are available the individual low tests, if any, will be used to determine the pay factor in accordance with Table 601-3. The pay factor will be applied to the quantity of concrete represented by the individual low test. For concrete having a specified strength of less than 4500 psi, when the compressive strength test is below the specified strength by more than 500 psi, the concrete represented will be rejected. For concrete having specified strength of 4500 psi or greater, when the compressive strength test is below the specified strength by more than 500 psi but not more than 1000 psi, the concrete represented will be evaluated by the Department for removal, corrective action, or acceptance at a reduced price. All costs of the evaluation shall be at the Contractor's expense. When the compressive strength test is below the specified strength by more than 1000 psi, the concrete represented will be rejected.

The Contractor may take cores at its own expense and in accordance with Colorado Procedure 65 within 10 working days of being notified of a price reduction or up to 45 days after placement, whichever is later, to provide an alternative determination of strength. Price reduction for strength will be based on the 28 day compressive strength of acceptance cylinders or corresponding cores strength, whichever is greater. If the core compressive strength is at least 90 percent of the specified field compressive strength, the concrete represented by the cores will be accepted with no price reduction.

The Engineer may use cores to determine acceptance or rejection of a part of the structure instead of acceptance cylinders. The Engineer will notify the Contractor in writing that CDOT will core the structure. The location of the coring will be directed by the Engineer. Coring and testing will be performed at the expense of the Department regardless of the result. Cores will be taken and tested in accordance with AASHTO T24 between 28 days and 45 days after concrete placement. Cores will be a minimum of 4 inches in diameter, unless otherwise approved by the Engineer. A minimum of three cores in a two square foot area will be obtained for locations of the structure that are suspect. If the compressive strength of any one core differs from the average by more than 10 percent that compressive strength will be deleted and the average strength will be determined using the compressive strength of the remaining two cores. If the compressive strength of more than one core differs from the average by more than 10 percent, the average strength will be determined using all three compressive strengths of the cores. If the average core compressive strength is greater than or equal to 85 percent of the specified 28 day compressive strength, the concrete represented by the cores will be accepted. If the average core compressive strength is less than 85 percent of the specified 28 day compressive strength, the structure will be evaluated by the Department according to subsection 105.03 for removal and replacement. Pay factors will not be based on cores taken by the Engineer. If the concrete represented by the cores is accepted, all costs associated with the repair of the core holes, including preparation and submittal of the repair method, will be measured and paid for separately.

After the Department performs additional core testing as described above, the Contractor may make one request that the structure be cored by the Contractor, tested and re-evaluated by the Department within 45 days after concrete placement. Coring and testing costs will be at the expense of the Contractor regardless of the result. Cores shall be taken at the same area of the structure as those obtained by the Engineer. The Engineer will approve the location of the cores prior to the Contractor coring the structure. All costs associated with the repair of these core holes, including preparation and submittal of the repair method, will not be measured and paid for separately, but shall be included in the work.

If the concrete in the structure is found to be sufficient resulting time delays will be considered excusable. If the concrete in the structure is still found to be deficient, resulting time delays will be considered non-excusable for this evaluation. Compensation for time delays will be evaluated by the Engineer in accordance with subsection 108.08.

The Contractor shall submit a proposed repair method for the core holes for approval prior to coring. The method shall use an approved non-shrink concrete patching material with a minimum compressive strength of 4500 psi. The Contractor shall submit the manufacturer’s recommendations along with the repair method. The Engineer will review and approve the proposed methodology prior to patching.

The Engineer will distribute electronically to the concrete supplier all compressive strength Owner Acceptance (OA) data for the concrete supplied to the project. The Engineer will distribute the OA compressive strength data within two business days of the 7 day and 28 day compressive strength testing. The data will include the compressive strength and batch ticket number at a minimum. The Contractor shall not have a valid dispute or claim as a result of any action or inaction by the Department related to the distribution of test results.

1. *Pay Factors.* The pay factor for concrete which is allowed to remain in place at a reduced price shall be determined according to Table 601-3 and shall be applied to the unit price bid for the Item.

If deviations occur in air content and strength within the same batch, the pay factor for the batch shall be the product of the individual pay factors.

**Table 601-3**

**PAY FACTORS**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Percent Total Air** | | **Strength** | | |
| **Deviations From Specified Air (Percent)** | **Pay Factor (Percent)** | **Below Specified Strength (psi)**  **[ < 4500 psi Concrete]** | **Pay Factor (Percent)** | **Below Specified Strength (psi)**  **[ ≥ 4500 psi Concrete]** |
| 0.0 – 0.2 | 98 | 1 – 100 | 98 | 1 – 100 |
| 0.3 – 0.4 | 96 | 101 – 200 | 96 | 101 – 200 |
| 0.5 – 0.6 | 92 | 201 – 300 | 92 | 201 – 300 |
| 0.7 – 0.8 | 84 | 301 – 400 | 84 | 301 – 400 |
| 0.9 – 1.0 | 75 | 401 – 500 | 75 | 401 – 500 |
| Over 1.0 | Reject | Over 500 | Reject |  |
| Concrete represented by out-of-spec tests will only be priced reduced with the lowest pay factor, not for each pay factor. | | | 65 | 501 – 600 |
| 54 | 601 – 700 |
| 42 | 701 – 800 |
| 29 | 801 – 900 |
| 15 | 901 – 1000 |
| Reject | Over 1000 |

1. *Bonding of Bridge Deck Overlay.* After the curing period for Class DT concrete has elapsed, the overlay shall be “sounded” by the Contractor in accordance with ASTM D4580 Standard Practice for Measuring Delamination in Concrete Bridge Decks by Sounding to determine if the Class DT concrete has bonded to the bridge deck. In areas where the Class DT concrete has not bonded to the bridge deck, it shall be removed and replaced at the Contractor’s expense.
2. *Maturity Meter Strength.* When maturity meters are specified for determining strength for removing forms, removing false work, backfilling against structures, or loading the structure, the Contractor shall provide the Engineer a report of maturity relationships in accordance with CP 69 prior to placement of concrete.

If a maturity meter fails, is tampered with, destroyed, or was not placed, the following shall apply:

The minimum curing time or waiting time for removing forms, removing false work, backfilling against structures, or loading the structure shall be 28 days.

The Contractor may choose at his own expense to core the structure represented by the maturity meter. Cores shall be obtained and tested according to CP 65. Cores shall be a minimum of 4 inches in diameter. A minimum of three cores in a two square foot area shall be obtained. If the compressive strength of any one core differs from the average by more than 10 percent that compressive strength will be deleted and the average strength will be determined using the compressive strength of the remaining two cores. If the compressive strength of more than one core differs from the average by more than 10 percent, the average strength will be determined using all three compressive strengths of the cores. The average compressive strength of the cores shall achieve the specified compressive strength of the structure. A structure may be cored only once.

1. *Water to Cementitious Material Content (w/cm) Ratio.* The maximum w/cm ratio is the ratio that was used in the laboratory trial mix for the Concrete mix design. The w/cm ratio shall be determined for each batch of concrete by the Contractor and provided to the Engineer for approval prior to placement. If an adjustment to the mix is made after the Engineer’s approval, the w/cm ratio shall be determined and submitted to the Engineer prior to the continuation of placement. Concrete that is placed without the Engineer’s approval shall be removed and replaced at the Contractor’s expense.