DRAFT

346 PORTLAND CEMENT CONCRETE.
(REV 7-20-05) (FA 8-17-05) (1-06)

SECTION 346 (Pages 283-301) is deleted and the following substituted:

SECTION 346
PORTLAND CEMENT CONCRETE

346-1 Description.

Use concrete composed of a mixture of portland cement, aggregate, water, and, where specified, admixtures, pozzolan and ground granulated blast furnace slag. Deliver the portland cement concrete to the site of placement in a freshly mixed, unhardened state.

Obtain concrete from an approved concrete production facility meeting the production and Quality Control (QC) of concrete provisions of this Section and Chapter 9.2 of the Materials Manual Concrete Production Facilities Guidelines, which may be viewed at the following URL: www.dot.state.fl.us/specificationsoffice/materialsmanual/section92.pdf . If the concrete production facility's approval is suspended, the Contractor is solely responsible to obtain the services of another approved concrete production facility or await the re-approval of the affected concrete production facility prior to the placement of any further concrete on the project. There will be no changes in the contract time or completion dates. Bear all delay costs and other costs associated with the concrete production facility approval or re-approval.

346-2 Materials.

346-2.1 General: Meet the following requirements:

Coarse Aggregate.....Section 901
Fine Aggregate*.....Section 902
Portland Cement.....Section 921
Water.....Section 923
Admixtures.....Section 924
Pozzolans and Slag .....Section 929
*Use only silica sand except as provided in 902-5.2.3.

Do not use materials containing hard lumps, crusts or frozen matter, or that is contaminated with dissimilar material.

346-2.2 Types of Cement: Unless a specific type of cement is designated elsewhere, use Type I, Type IP, Type IS, Type IP (MS), Type II, or Type III cement in all classes of concrete.

Use only the types of cements designated for each environmental condition in structural concrete. A mix design for a more aggressive environment may be substituted for a lower aggressive environmental condition.

TABLE 1			
BRIDGE SUPERSTRUCTURES			
Component	Slightly Aggressive Environment	Moderately Aggressive Environment	Extremely Aggressive Environment
Precast Superstructure	Type I or Type III	Type I or Type III with	Type II with Fly Ash or

TABLE 1			
BRIDGE SUPERSTRUCTURES			
Component	Slightly Aggressive Environment	Moderately Aggressive Environment	Extremely Aggressive Environment
and Prestressed Elements		Fly Ash and/or Slag, Type II, Type IP, Type IS, or Type IP (MS)	Slag
Cast In Place	Type I	Type I with Fly Ash and/or Slag, Type II, Type IP, Type IS, or Type IP (MS)	Type II with Fly Ash or Slag
BRIDGE SUBSTRUCTURE, DRAINAGE STRUCTURES AND OTHER STRUCTURES			
Component	Slightly Aggressive Environment	Moderately Aggressive Environment	Extremely Aggressive Environment
All Elements	Type I or Type III	Type I with Fly Ash and/or Slag, Type II, Type IP, Type IP (MS), or Type IS	Type II with Fly Ash or Slag

346-2.3 Pozzolans and Slag: Use as desired, on an equal weight replacement basis, fly ash, silica fume, metakaolin, other pozzolans, and slag materials as a cement replacement in all classes of concrete, with the following limitations:

(1) Mass Concrete:

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 18% to 50% by weight, except where the expected core temperature is to rise above 165° F. When the core temperature is expected to rise above 165° F, the percentage of fly ash is required to be 35% to 50% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 50% to 70% by weight. Ensure that slag is 50% to 55% of total cementitious content by weight of total cementitious materials when used in combination with silica fume and/or metakaolin.

c. For Slightly and Moderately Aggressive environments ensure that there is at least 20% fly ash by weight and 40% Portland cement by weight for mixes containing Portland cement, fly ash and slag.

(2) Drilled Shaft:

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 33% to 37% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 58% to 62% by weight.

(3) For all other concrete uses not covered in (1) and (2) above,

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 18% to 22% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 25% to 70% for Slightly and Moderately Aggressive environments, and 50% to 70% by weight when used in Extremely Aggressive environments. Ensure that slag is 50% to 55% of total cementitious content by weight of total cementitious materials when use in combination with silica fume and/or metakaolin.

c. As an option for Slightly and Moderately Aggressive environments ensure that there is at least 20% fly ash by weight and 40% Portland cement by weight for mixes containing Portland cement, fly ash and slag.

(4) Type IP (MS): Ensure that the quantity of pozzolan in Type IP (MS) is in the range of 15% to 40% by weight.

(5) Silica Fume and Metakaolin:

a. Cure in accordance with the manufacturer's recommendation and approved by the Engineer.

b. Silica Fume-ensure that the quantity of cementitious material replaced with silica fume is 7% to 9% by weight.

c. Metakaolin-ensure that the quantity of cementitious material replaced with metakaolin is 8% to 12% by weight.

346-2.4 Coarse Aggregate Gradation: Produce all concrete using Size No. 57 or Size No. 67 coarse aggregate. With the Engineer's approval, Size No. 8 or Size No. 89 may be used either alone or blended with Size No. 57 or Size No. 67. The Engineer will consider requests for approval of other gradations individually. Submit sufficient statistical data to establish production quality and uniformity of the subject aggregates, and establish the quality and uniformity of the resultant concrete. Furnish aggregate gradations sized larger than nominal maximum size of 1.5 inch [37.5 mm] as two components. Ensure the maximum coarse aggregate size does not violate the reinforcement spacing provisions given for reinforced concrete in the AASHTO Standard Specifications for Highway Bridges.

346-2.5 Admixture Requirements: Admixtures will meet the requirements of this subarticle. Chemical admixtures not covered in this subarticle may be approved by the Engineer. Submit statistical evidence supporting successful laboratory and field trial mixes which demonstrate improved concrete quality or handling characteristics.

Do not use admixtures or additives containing calcium chloride (either in the raw materials or introduced during the manufacturing process) in reinforced concrete.

346-2.5.1 Water Reducer/Water Reducer Retardant Admixtures: Use water-reducing admixture, Type A, or water-reducing and retarding admixture, Type D. Use in accordance with the manufacturer's recommended dosage rate.

346-2.5.2 Air Entrainment Admixtures: Use an air entraining admixture in all concrete mixes except counterweight concrete.

346-2.5.3 High Range Water Reducing and Viscosity Modifying Admixtures:

346-2.5.3.1 General: The Contractor may propose the use of a Type F or G admixture, meeting the requirements of Section 924, in all classes of concrete, except for concrete used in drilled shafts. The use of High Range Water Reducing (HRWR) admixtures in concrete mixes incorporating silica fume or metakaolin is mandatory.

346-2.5.3.2 Flowing Concrete Admixtures for Precast/Prestressed Concrete: The Contractor may propose the use of a Type I or Type II admixture, meeting the requirements of Section 924. Produce flowing concrete mix with target slump of 9 inches [230 mm]. The use of flowing concrete admixtures is limited to the construction of precast/prestressed concrete products. Add the flowing concrete admixtures at the ready mixed concrete production batch plant.

Submit the proposed flowing concrete mix design, containing Type I or II admixture, and test data as specified herein and in 346-6.2.

Subsequent to the laboratory trial batch, perform a field demonstration of the proposed mix design by production and placement of at least three batches, 3 yd^3 [2.3 m^3] minimum size each, of concrete containing flowing concrete HRWR admixture. Take representative samples from each batch and perform slump, air content, density (unit weight), and temperature tests on these samples. Cast specimens from each sample for compressive strength tests. Record the ambient air temperature during the test. Ensure that the concrete properties are within the required specification limits. The plants that are producing concrete with batch sizes of less than 3 yd^3 [2.3 m^3] are required to produce and place at least a total amount of 9 yd^3 [6.9 m^3] and perform the aforementioned tests on at least three randomly selected batches.

Determine the workability of the demonstration concrete batches by performing the slump tests on the samples taken at 15 minute intervals from each batch. Continue sampling and testing until the slump measures 6 inches [150 mm] or less. From the plot of slump versus time, determine the time for each batch when the slump is at 7.5 inches [190 mm]. The shortest time period determined from three consecutive batches, at 7.5 inches [190 mm] slump, is considered the cutoff time of the proposed concrete mix. For production concrete, ensure that the time between the batching and depositing of each load of concrete is less than the cutoff time of the mix and also does not exceed the allowable time limit specified in 346-7.6.

Ensure that the demonstration concrete is mixed, delivered, placed, consolidated and cured in accordance with the proposed method and sequence. Produce the flowing concrete batches at slumps between 7.5 inches to 10.5 inches [190 mm to 265 mm].

Perform inspection of the demonstration concrete during batching, delivery, placement and post placement. During placement, ensure that the concrete batches meet all plastic property requirements of the specifications and maintain their cohesive nature without excessive bleeding, segregation, or abnormal retardation.

Dispose of concrete produced for demonstration purposes at no expense to the Department. Subject to the Engineer’s approval, the Contractor may incorporate this concrete into non-reinforced concrete items and may be included for payment, provided it meets Contract requirements for slump, entrained air, and strength.

After removal of the forms, perform the post-placement inspection of the in-place concrete. Observe for any signs of honeycombs, cracks, aggregate segregation or any other surface defects and ensure that the hardened concrete is free from these deficiencies. The Engineer may require saw cutting of the mock-up products to verify the uniform distribution of the aggregates within the saw cut surfaces and around the reinforcing steel and prestressing strands. The Engineer will require saw cutting of the demonstration mock-up products for plants that are demonstrating the use of the flowing concrete for the first time. Obtain core samples from different locations of mock-up products to inspect the aggregate distribution in each sample and compare it with the aggregate distribution of other core samples. Perform rapid chloride permeability or surface resistivity tests on the core samples or test cylinders.

Submit the results of the laboratory trial batch tests and field demonstration of verified test data and inspection reports to the Engineer, along with certification stating that the results of the laboratory trial batch tests and field demonstration tests indicate that the proposed concrete mix design meets the requirements of the specifications. For the proposed mix design, state the anticipated maximum time limit between the batching and when the concrete of each batch is deposited during the production.

Upon the review and verification of the laboratory trial batch, field demonstration test data, inspection reports and contractor's certification statement, the Department will approve the proposed mix design.

The Department may approve proposed flowing concrete mixes, centrally mixed at the placement site, without the production of demonstration batches, provided that the proposed mix meets the following two criteria:

(1) A previously approved flowing concrete mix of the same class has demonstrated satisfactory performance under the proposed job placing conditions with a minimum of fifteen consecutive Department acceptance tests, which met all plastic and hardened concrete test requirements.

(2) The cementitious materials and chemical admixtures, including the flowing concrete HRWR admixture, used in the proposed mix are the same materials from the same source used in the previously approved mix, (1) above, and the other materials and mix proportions are approved as similar by the Department.

Do not produce or place concrete until the design mixes have been approved.

346-2.5.4 Corrosion Inhibitor Admixture: Use only with concrete containing Type II cement, Class F fly ash or slag, and a water reducing retardant admixture, Type D, or High Range Water Reducer admixture, Type G, to normalize the setting time of concrete. Ensure that all admixtures are compatible with the corrosion inhibitor admixture.

346-3 Classification, Strength, Slump and Air Content.

346-3.1 General: The separate classifications of concrete covered by this Section are designated as Class I, Class II, Class III, Class IV, Class V and Class VI. Strength, slump, and air content of each class are specified in Table 2:

TABLE 2

Class of Concrete	Specified Minimum Strength (28-day) (psi) [(MPa)]	Target Slump (inches) [(mm)](c) (e)	Air Content Range (%)
STRUCTURAL CONCRETE			
I (Pavement)	3,000 [21]	2 [50]	1 to 6
I (Special) (a)	3,000 [21]	3 [75] (b)	1 to 6
II (a)	3,400 [23]	3 [75] (b)	1 to 6
II (Bridge Deck)	4,500 [31]	3 [75] (b)	1 to 6
III	5,000 [35]	3 [75] (b)	1 to 6
III (Seal)	3,000 [21]	8 [200]	1 to 6
IV	5,500 [38]	3 [75] (b)	1 to 6
IV (Drilled Shaft)	4,000 [28]	8 [200]	0 to 6
V (Special)	6,000 [41]	3 [75] (b) (d)	1 to 5
V	6,500 [45]	3 [75] (b) (d)	1 to 5
VI	8,500 [59]	3 [75] (b) (d)	1 to 5

(a) For precast drainage systems that are manufactured at the precast plant the Contractor is permitted to use concrete meeting the requirements of ASTM C 478

[ASTM C 478M] 4,000 psi [30 MPa] in lieu of Class I or Class II concrete. Apply the chloride content limits specified in 346-4.2 to all box culverts.

(b) The Engineer may allow higher target slump, not to exceed 7 inches [180 mm], when a Type F or Type G admixtures is used.

(c) The Engineer may approve a reduction in the target slump for slip-form operations.

(d) When the use of silica fume or metakaolin is required as a pozzolan in Class V, Class V (Special) or Class VI concrete, ensure that the concrete does not exceed a permeability of 1,000 coulombs at 28 days, when tested per AASHTO T 277. Submit 2, 4 x 8 inches [102 x 203 mm] cylindrical test specimens to the Engineer for permeability testing before mix design approval. Take the permeability test specimens from the concrete of the laboratory trial batch or from the field trial batch of at least 3 yd^3 [2.3 m^3]. Verify the mix proportioning of the designed mix and take representative samples of trial batch concrete for the required plastic and hardened property tests. Cure the field trial batch specimens similar to the standard laboratory curing methods. Submit the permeability test specimens at least 7 days prior to the scheduled 28 day test. The average permeability of the two tests, one test per cylinder, is considered the rapid chloride permeability of the concrete mix.

In lieu of rapid chloride permeability test and prior to mix design approval, submit three test cylinders to the Engineer for performing of surface resistivity test in accordance with FM 5-578. Ensure that the result of the average 28 day surface resistivity value of the concrete samples remains greater than or equal to 37 KOhm-cm.

(e) The Engineer may allow a target slump of 9.0 inches [230 mm] when Type I or II admixture is used to produce flowing concrete in the construction of precast concrete products.

346-3.2 Drilled Shaft Concrete: When drilled shaft concrete is placed in any wet shaft, provide concrete in accordance with the following specified slump loss requirements. When concrete is placed in a dry excavation, do not test for slump loss, except where a temporary removable casing is to be used.

Ensure that drilled shaft concrete has a slump between 7 inches and 9 inches [175 mm and 225 mm] when placed and maintains a slump of 4 inches [100 mm] or more throughout the drilled shaft concrete elapsed time. Ensure that the slump loss is gradual as evidenced by slump loss tests described below. The concrete elapsed time is the sum of the mixing and transit time, the placement time and the time required for removal of any temporary casing that causes or could cause the concrete to flow into the space previously occupied by the temporary casing.

Provide slump loss tests before drilled shaft concrete operations begin, demonstrating that the drilled shaft concrete maintains a slump of at least 4 inches [100 mm] throughout the concrete elapsed time. Inform the Engineer at least 48 hours before performing such tests. Perform slump loss testing of the drilled shaft mix using a laboratory acceptable to the Engineer meeting the requirements of 6-9.

Perform the following procedures for slump loss tests:

(1) Prepare the mix for the slump loss test at a temperature consistent with the highest ambient and concrete temperatures expected during actual concrete placement. Obtain the Engineer’s approval of the test temperature.

(2) Ensure that the mix is at least 3 yd^3 [2.3 m^3] and is mixed in a mixer truck.

(3) After initial mixing, determine the slump, concrete temperature, ambient temperature and air content. Ensure that the concrete properties are within the required specification target limits.

(4) Mix the concrete intermittently for 30 seconds every five minutes at the mixing speed of the mixer.

(5) Determine slump, concrete temperature, ambient temperature and air content at 30 minute intervals until the slump is 4 inches [100 mm] or less. Remix the mix for one minute at the mixing speed of the mixer before these tests are run.

(6) Begin all elapsed times when water is initially introduced into the mix.

(7) Ensure that the concrete maintains a slump of at least 4 inches [100 mm] for the anticipated elapsed time.

(8) Obtain the Engineer's approval of slump loss test results in terms of elapsed time before concrete placements.

346-3.3 Mass Concrete: When mass concrete is designated in the Contract Documents, provide an analysis of the anticipated thermal developments in the mass concrete elements for all expected project temperature ranges using the selected mix design, casting procedures, and materials.

Use a Specialty Engineer competent in the design and temperature control of concrete in mass elements. The specialty Engineer will follow the procedure outlined in Section 207 of the ACI Manual of Concrete Practice to formulate, implement, administer and monitor a temperature control plan, making adjustments as necessary to ensure compliance with the Contract Documents. The Specialty Engineer will select the concrete design mix proportions that will generate the lowest maximum temperatures possible to ensure the 35°F temperature differential is not exceeded.

Describe the measures and procedures intended for use to maintain a temperature differential of 35°F [20°C] or less between the interior core center and exterior surface(s) of the designated mass concrete elements during curing. Submit both the mass concrete mix design and the proposed mass concrete plan to monitor and control the temperature differential to the Engineer for acceptance. Provide temperature monitoring devices to record temperature development between the interior core center and exterior surface(s) of the elements in accordance with the accepted mass concrete plan.

The Specialty Engineer, or a qualified technician employed by the Specialty Engineer, must personally inspect and approve the installation of monitoring devices and verify that the process for recording temperature readings is effective for the first placement of each size and type mass component. Submit to the Engineer for approval the qualification of all technicians employed to inspect or monitor mass concrete placements. For placements other than the first, designate an employee(s) approved by the Specialty Engineer, as qualified to inspect monitoring device installation, to record temperature readings, to be in contact at all times with the Specialty Engineer if adjustments must be made as a result of the temperature differential being exceeded, and to immediately implement adjustments to temperature control measures as directed by the Specialty Engineer. Read the monitoring devices and record the readings at intervals no greater than 6 hours. The readings will begin when the mass concrete placement is complete and continue until the maximum temperature differential (not maximum temperature) is reached and a decreasing temperature differential is confirmed as defined in the temperature control plan. Furnish a copy of all temperature readings to the Engineer as they are determined, and a final report within 3-days of completion of monitoring of each element.

If the 35°F [20°C] differential has been exceeded, take immediate action, as directed by the Specialty Engineer who must be available for immediate consultation at any time, to retard further growth of the temperature differential. Use a Specialty Engineer to revise the previously accepted plan to ensure compliance on future placements. Do not place any mass concrete until the Engineer has accepted the mass concrete plan(s). When mass concrete temperature differentials are exceeded provide all analyses and test results deemed necessary by the Engineer for determining the structural integrity and durability of the mass concrete element, to the satisfaction of the Engineer. The Department will make no compensation, either monetary or time, for the analyses or tests or any impacts upon the project.

346-4 Composition of Concrete.

346-4.1 Master Proportion Table: Proportion the materials used to produce the various classes of concrete in accordance with Table 3:

TABLE 3

Class of Concrete	Minimum Total Cementitious Materials Content lb/yd^3 [kg/m^3]	*Maximum Water Cementitious Materials Ratio lb/lb [kg/kg]
I (Pavement)	508 [300]	0.50
I (Special)	508 [300]	0.50
II	564 [335]	0.49
II (Bridge Deck)	611 [365]	0.44
III	611 [365]	0.44
III (Seal)	611 [365]	0.52
IV	658 [390]	0.41
IV (Drilled Shaft)	658 [390]	0.41
V (Special)	752 [445]	0.37**
V	752 [445]	0.37**
VI	752 [445]	0.37**

*The calculation of the water to cementitious materials ratio (w/cm) is based on the total cementitious material including silica fume, slag, fly ash or metakaolin.
**When the use of silica fume or metakaolin is required as a pozzolan, the maximum water cementitious material ratio will be 0.35.

346-4.2 Chloride Content Limits for Concrete Construction:

346-4.2.1 General: Use the following maximum chloride content limits for the concrete application shown:

TABLE 4		
Application	Maximum Allowable Chloride Content lb/yd^3 [kg/m^3]	
	Production	Mix Design
Non Reinforced Concrete	N/A	N/A
Reinforced Concrete that does not require Type II cement plus slag or pozzolan(s)	0.70 [0.42]	0.64 [0.38]
All applications that require Type II cement plus pozzolan(s)	0.40 [0.24]	0.34 [0.20]
Prestressed Concrete	0.40 [0.24]	0.34 [0.20]

Determine the chloride content as the average of three tests on samples taken from the concrete. Ensure that the range of results of the three tests does not exceed a chloride content of 0.08 lb/yd^3 [0.05 kg/m^3] of concrete. When test results are outside of the allowable range, run an additional three tests until the test results are within the allowable range. The Contractor may obtain samples from representative concrete cylinders or cores tested for compressive strength. If the cylinders or cores have been exposed to salt or aggressive environment, discard the outer 1 inch [25 mm] surface of the sample.

346-4.2.2 Sampling and Testing: Determine the chloride content in accordance with FM 5-516 within two weeks of sampling.

(1) For all concrete requiring Type II cement with pozzolan(s) or slag and prestressed concrete, determine the chloride content on a frequency that is in accordance with these Specifications and the following procedures:

(a) When the chloride content is 0.25 lb/yd^3 [0.15 kg/m^3] or less, determine chloride content at a frequency of not less than one for every four weeks of production as long as the test results remain at or below 0.25 lb/yd^3 [0.15 kg/m^3]. As an exception to the aforementioned testing frequency, when eight consecutive tests show chloride content below 0.25 lb/yd^3 [0.15 kg/m^3], the Engineer may reduce the frequency to not less than one for every eight weeks of production.

(b) When the chloride content is greater than 0.25 [0.15] and less than or equal to 0.33 lb/yd^3 [0.20 kg/m^3], determine chloride content at a frequency of not less than one for every two weeks of production, as long as the values remain at or below 0.33 lb/yd^3 [0.20 kg/m^3].

(c) When the chloride content is greater than 0.33 lb/yd^3 [0.20 kg/m^3], make subsequent chloride content tests for each day's production.

(2) For all reinforced concrete, other than the concrete covered in (1) above, determine the chloride content on a frequency of not less than one test every four weeks. As an exception to the aforementioned testing frequency, when eight consecutive chloride content determinations are below 0.40 lb/yd^3 [0.24 kg/m^3] of concrete, the Engineer may reduce the frequency to not less than one for every eight weeks of production.

For any case listed above, when the source of any concrete component material, including admixtures, is changed, determine the chloride content immediately.

Test results obtained at the frequency provided above represent the chloride content of all concrete placed subsequent to the preceding test for the determination of chloride content.

346-4.2.3 Certification: Determine the chloride content, and certify the test results of chloride determinations to the Department. Include in the certification all pertinent data

required by the Department. The Department will require properly executed certifications showing the chloride content within the required limits for acceptance of all concrete produced in accordance with these Specifications.

346-4.2.4 Control Level for Corrective Action: If the test results indicate that the chloride level is greater than the following limits, suspend concrete production until implementing corrective measures acceptable to the Engineer.

(1) Chloride content of 0.65 lb/yd^3 [0.39 kg/m^3] or greater for reinforced concrete that does not require Type II cement plus slag or pozzolan(s).

(2) Chloride content of 0.35 lb/yd^3 [0.21 kg/m^3] or greater for prestressed concrete and all applications that require Type II cement with slag or pozzolan(s).

The Engineer will reject the concrete exceeding the maximum allowable chloride content limits shown in 346-4.2.1.

346-5 Sampling and Testing Methods.

Perform concrete sampling and testing in accordance with the following methods:

TABLE 5

Description	Method
Slump of Hydraulic Cement Concrete	ASTM C 143 [ASTM C 143M]
Air Content of Freshly Mixed Concrete by the Pressure Method*	ASTM C 231
Air Content of Freshly Mixed Concrete by the Volumetric Method*	ASTM C 173 [ASTM C 173M]
Making and Curing Test Specimens in the Field	ASTM C 31 [ASTM C 31M]
Compressive Strength of Cylindrical Concrete Specimens**	ASTM C 39 [ASTM C 39M]
Obtaining and Testing Drilled Core and Sawed Beams of Concrete	ASTM C 42 [ASTM C 42M]
Early Sampling of Fresh Concrete During the Initial Placement	FM 5-501
Low Levels of Chloride in Concrete and Raw Materials	FM 5-516
Density (Unit Weight), Yield and Air Content (Gravimetric) of Concrete	ASTM C 138 [ASTM C 138M]
Temperature of Freshly Mixed Portland Cement Concrete	ASTM C 1064 [ASTM C 1064M]
Sampling Freshly Mixed Concrete	ASTM C 172

*Use the same type of meter for QC tests as the Department uses for Verification testing. When using pressure type meters, use an aggregate correction factor determined by the concrete producer for each mix design to be tested. Record and certify test results for correction factors for each type of aggregate at the concrete production facility.

**For LOTs selected for verification testing use the same size cylinder molds as the Department uses for Verification tests. For the compressive strength testing of precast concrete the use of 4 inch x 8 inch [102 x 203 mm] test cylinders are allowed, provided they meet the requirements of 450-4.1.

346-6 Control of Quality.

346-6.1 General: Develop a Quality Control Plan (QCP) as specified in 6-8. Assume responsibility for meeting the requirements of the approved QCP and Contract Documents. Ensure the QCP includes the necessary requirements to control the quality of the concrete.

QC activities are performed by the Contractor to ensure materials, methods, techniques, personnel, procedures and processes utilized during production meet the specified requirements.

Accept the responsibility for performing QC inspections on all phases of work. Ensure all materials and workmanship incorporated into the project meet the requirements of the Contract Documents.

When concrete plastic properties (slump, air content and temperature) could be significantly affected by handling between the point of delivery and the point of final placement, including the use of pumps, conveyor belts, troughs, chutes, barge transport or other means, provide in the QCP provisions to sample the plastic concrete for all testing at the point of final placement, as a minimum.

Ensure the QCP includes any anticipated requirements for adjusting the concrete at the placement site. Include the testing procedures that will be implemented to control the quality of the concrete and ensure that concrete placed is within the target range. Also, include provisions for the addition of water to concrete delivered to the placement site at designated level areas, to ensure the allowable amount of water stated on the concrete delivery ticket or the maximum water/cementitious materials ratio on the approved design mix are not exceeded. Ensure the anticipated ranges of jobsite water additions are described and the proposed methods of measuring water for concrete adjustments are included.

Failure to meet the requirements of this Specification or the QCP will automatically void that portion of the QCP. To obtain QCP re-approval, implement corrective actions as approved by the Engineer. The Engineer may allow the Contractor to continue any ongoing concrete placement but the Engineer will not accept concrete for any new placement until the QCP reapproval is given by the Engineer.

346-6.2 Concrete Design Mix: Provide concrete that has been produced in accordance with a Department approved design mix, in a uniform mass free from balls and lumps. Discharge the concrete in a manner satisfactory to the Engineer. Perform demonstration batches to ensure complete and thorough placements in complex elements, when requested by the Engineer.

Do not place concretes of different compositions such that the plastic concretes may combine, except where the plans require concrete both with and without silica fume, metakaolin or calcium nitrite in a continuous placement. Produce these concretes using two separate design mixes. For example, designate the mix with calcium nitrite as the original mix and the mix without calcium nitrite as the redesigned mix. Ensure that both mixes contain the same cement, fly ash or slag, coarse and fine aggregates and compatible admixtures. Submit both mixes for approval as separate mix designs, both meeting all requirements of this Section. Ensure that the redesigned mix exhibits plastic and hardened qualities which are additionally approved by the Engineer as suitable for placement with the original mix. The Engineer will approve the redesigned mix for commingling with the original mix and for a specific project application only. Alternately, place a construction joint at the location of the change in concretes.

346-6.2.1 Material Substitutions: Aggregate sources may be substituted within an approved base mix design provided that the aggregate are the same type, the same geological formation and are from an approved source. Obtain the Department’s approval for any material

substitutions before beginning concrete placement. Provide a new base mix design for any cementitious material or admixture substitution. The Department may take up to five working days to review any material substitution request.

For every material substitution made, perform testing for chlorides and assure compliance with 346-4.2.

Ensure the substituted mix meets the theoretical yield requirements, does not exceed the maximum water to cementitious materials ratio, and the cement content equals or exceeds, the approved base mix design.

The Department may require a single 3.0 yd^3 [2.3 m^3] minimum test batch at the approved concrete production facility to demonstrate that the plastic properties of the adjusted mix design is within the slump and air tolerances provided in Table 2. The theoretical unit weight of the proposed mix design will be within 2.0 lbs/ft^3 [35 kg/m^3] of the originally approved theoretical mix design unit weight. Approved adjusted mixes may be transferred.

At any time if the Engineer determines that unsatisfactory results are obtained during production, return to the originally approved base mix design or obtain approval of a new mix design

346-6.3 Delivery Certification: Ensure that an electronic delivery ticket is furnished with each batch of concrete before unloading at the placement site. Ensure that the materials and quantities incorporated into the batch of concrete is recorded on the delivery ticket. Include the following information on the Delivery Ticket:

(1.) Arrival time at job site,
(2.) Time that concrete mix has been completely discharged,
(3.) Number of revolutions upon arrival at the job site,
(4.) Total gallons [liters] of water added at the job site,
(5.) Additional mixing revolutions when water is added,
(6.) Total number of revolutions at mixing and agitating speed.

Items 3 through 6 do not apply to non-agitating concrete transporting vehicles.

Ensure the batcher responsible for production of the batch of concrete signs the delivery ticket, certifying the batch of concrete was produced in accordance with the Contract Documents.

Sign the delivery ticket certifying that the maximum specified water to cementitious materials ratio was not exceeded due to any jobsite adjustments to the batch of concrete, and that the batch of concrete was delivered and placed in accordance with the Contract Documents.

346-6.4 Tolerances: Meet the following tolerances from target values for plastic concrete properties specified in 346-3.1:

TABLE 6

Property	Target Range	Tolerance
Slump (Non-Drilled Shaft Concrete without HRWR)	± 0.75 inch [±20 mm]	± 1.5 inch [±40 mm]
Slump (Non-Drilled Shaft Concrete with HRWR)	± 1.0 inch [±25 mm]	± 1.5 inch [±40 mm]
Slump (Drilled Shaft Concrete)	± 1.0 inch [±25 mm]	± 1.0 inch [±25 mm]
Air Content	As shown in the range in Table 2	

Reject concrete with slump or air content exceeding the above tolerances. Do not allow concrete to remain in a transporting vehicle to reduce slump. Water may be added only upon arrival of the concrete to the job site and not thereafter.

If the slump of non-drilled shaft concrete varies from the target value in excess of 0.75 inch [20 mm] (1 inch [25 mm] for concrete containing HRWR), immediately adjust the concrete mixture to correct the slump of succeeding batches. The Engineer will allow a reasonable time for adjustment, taking into consideration trucks already in route from the concrete production facility. If the Contractor does not implement adjustments at the earliest possible time, the Engineer will reject the concrete and terminate further production until the Contractor makes corrections.

346-7 Mixing and Delivering Concrete.

346-7.1 General Requirements: Operate all concrete mixers at speeds and volumes per the manufacturer's design or recommendation as stipulated on the mixer rating plate.

346-7.2 Transit Mixing: When water is added at the job site, mix the concrete 30 additional mixing revolutions. When mixing for the purpose of adjusting consistency, do not allow the total number of revolutions at mixing speed to exceed 160. Discharge all concrete from truck mixers before total drum revolutions exceed 300.

346-7.3 Mixing at the Site: Use a mixer of sufficient capacity to prevent delays that may be detrimental to the quality of the work. Ensure that the accuracy of batching equipment is in accordance with requirements of this Section.

346-7.4 Concreting in Cold Weather: Do not mix concrete when the air temperature is below 45ºF [7ºC] and falling. The Contractor may mix and place concrete when the air temperature in the shade, and away from artificial heat, is 40ºF [4ºC] and rising. Protect the fresh concrete from freezing until the concrete reaches a minimum compressive strength of 1,500 psi [10 MPa] unless the concrete is to be heat cured.

346-7.5 Concreting in Hot Weather: Hot weather concreting is defined as the production, placing and curing of concrete when the concrete temperature at placing exceeds 85ºF [30ºC] but is less than 100ºF [40ºC].

Unless the specified hot weather concreting measures are in effect reject concrete exceeding 85ºF [30ºC] at the time of placement. Regardless of special measures taken, reject concrete exceeding 100ºF [40ºC]. Predict the concrete temperatures at placement time and implement hot weather measures to avoid production shutdown.

346-7.6 Transit Time: Ensure compliance with the following maximum allowable time between the initial introduction of water into the mix and depositing the concrete in place:

TABLE 7	
Non-Agitator Trucks	Agitator Trucks
45 minutes	60 minutes
75 minutes*	90 minutes*
*When a water reducing and retarding admixture (Type D or Type G) is used.	

346-7.7 Adding Water To Concrete at the Placement Site: Perform an initial slump before the addition of water at the job site. After adjusting the slump, perform a test to confirm that the slump of the concrete is within the target range as defined in Table 6. If the slump exceeds the target range but is within the tolerance range, that load may be accepted, but water

added at the site will be reduced to maintain a slump within the target range on successive loads. If the slump is delivered within the target range, no water will be added to the load. Confirm with another test that the next load is within the target range after the addition of water at the placement site. Repeated incidents of concrete being placed outside the target range will result in revocation of that portion of the QCP. No concrete represented by plastic test results outside of the tolerance range will be accepted for placement.

346-7.8 Sample Location: Obtain samples from the point of final placement.

Where concrete buckets are used to discharge concrete directly to the point of final placement or into the hopper of a tremie pipe, samples will be obtained from the discharge of the bucket. When the concrete is discharged directly from the mixer into the bucket, with a minimal lapse of time before discharge of the bucket, samples may be obtained from the discharge of the mixer.

Where conveyor belts, troughs, pumps, or chutes are used to transport concrete directly to the point of final placement or into the hopper of a tremie pipe, samples will be obtained from the discharge end of the entire conveyor belt, trough, pump, or chute system.

Where concrete is placed in a drilled shaft or other element using a tremie pipe and a concrete pump, samples will be obtained from the discharge of the pump line at the location of the tremie hopper.

Where a concrete pump is used to deposit concrete directly into a drilled shaft which is a wet excavation without the use of a tremie, ensure the discharge end of the pump line remains immersed in the concrete at all times after starting concrete placement, and the following procedure is followed:

a. Obtain initial samples from the discharge of the pump line using the full length of pump line which will be required to start the placement. Ensure the plastic properties of the concrete sampled from the discharge of the pump line are within the target range. Obtain comparative initial samples from the discharge of the mixer delivering concrete to the pump in order to control the plastic properties of the mix.

b. Obtain all other samples from the discharge of the mixer delivering concrete to the pump. Ensure the plastic properties of the concrete being delivered to the pump are within the allowable tolerance, except when necessary and approved by the engineer and based on comparative testing, to provide concrete meeting the Specification requirements at the end of the pump line.

Describe concrete placement and sampling methods in the QCP.

346-8 Plastic Concrete Sampling and Testing.

QC tests will include air content, temperature, slump, compressive strength cylinders, and may include plastic unit weight. In addition, calculate the water to cementitious materials ratio for compliance to the approved mix design.

Ensure that each truck has a valid inspection card issued by the Department, the revolution counter on the mixer is working properly, and calibration of the water dispenser has been performed within the last twelve months and verify batch weights within required limits of the mix design.

Perform plastic concrete tests on the initial delivery of each concrete design mix each day. Ensure QC technicians meeting the requirements of Section 105 are present and performing tests throughout the placement operation. Ensure one technician is present and performing tests throughout the placement operation at each placement site. If a placement site has multiple concrete trucks, identify the number of technicians in the Quality Control Plan. If a placement

site has multiple trucks placing concrete, then have at least two technicians present at that site. Ensure all equipment utilized meets this Specification. Do not proceed with the placement operation until the delivered concrete complies with plastic properties specified. After placement begins, perform QC tests to ensure compliance with Specification requirements on each LOT of concrete. Reject non-complying loads which cannot be adjusted at the jobsite. Ensure that corrections are made on subsequent loads.

Furnish sufficient concrete of each design mix as required by the Engineer for verification testing. When the Engineer's verification tests results do not compare with the QC plastic properties test results, within the limits defined by the Independent Assurance (IA) checklist comparison criteria, disposition of the concrete will be at the option of the Contractor.

If a QC test fails, reject the remainder of that load, terminate the LOT, and notify the Engineer. Make cylinders representing that LOT from the same sample of concrete.

Following termination of a LOT, re-initiate initial plastic properties tests until such time as the water to cementitious materials ratio, air content, temperature and slump comply with the Specification requirements. Initiate a new LOT once the testing indicates compliance with Specification requirements.

When three consecutive LOTs, or when five LOTs in two days of production of the same design mix are outside the specified tolerances, suspend production. Make the necessary revisions to concrete operations and increase the frequency of QC testing in the QCP to bring the concrete within allowable tolerances. Obtain the Engineer's approval of the revisions before resuming production. After production resumes, obtain the Engineer's approval before returning to the normal frequency of QC testing.

If concrete placement stops for more than 90 minutes, perform initial plastic properties testing on the next batch and continue the LOT. Cylinders cast for that LOT will represent the entire LOT.

The Department may perform Independent Verification testing at any time to evaluate the QC of the concrete. The comparison between the Independent Verification testing and the QC testing is identified in the IA Checklist Criteria. When a test does not compare, the Contractor will revise the QCP as deemed necessary by the Engineer. The Department reserves the right to notify the IA to review the testing procedures and equipment.

346-9 Acceptance Sampling and Testing.

346-9.1 General: Perform plastic properties test as per 346-8 and cast a set of three QC cylinders for each LOT of structural concrete incorporated into the project. Take these acceptance samples randomly for each LOT as determined by a random number generator (acceptable to the Department). The Department will independently perform plastic properties test and cast a set of verification cylinders from a separate sample from the same load of concrete as the Contractor's QC sample. For each LOT verified by the Department, cast one additional cylinder from the same sample, and identify it as the QC "hold" cylinder. The Department will also cast one additional "hold" cylinder from each verification sample. Provide curing facilities for initial curing that have the capacity to hold all QC, Verification, and Independent Verification cylinders simultaneously. All cylinders will be clearly identified. Deliver the QC samples to the final curing facility in accordance with ASTM C 31 [ASTM C 31M]. At this same time, the Department will deliver the verification samples to their final curing facility.

Test the QC samples for compressive strength at the age of 28 days in a laboratory meeting and maintaining at all times the qualification requirements listed in 6-9.

The QC testing laboratory will input the compressive strength test results into the Department's sample tracking database within 24 hours. When the QC testing laboratory cannot input the compressive strength test results into the Department's sample tracking database within 24 hours, the QC testing laboratory will notify the Verification testing laboratory within 24 hours of breaking the cylinder and provide the Verification testing laboratory the compressive strength test results. Ensure the compressive strength results are input into the Department's sample tracking database within 72 hours of determining the compressive strength of the cylinders.

The Department will average the QC and Verification compressive strength test data and based on this average at 28 days determine the Comparison Criteria as shown in Table 8. When the difference between QC and Verification are less than or equal to the Comparison Criteria, the QC data is verified. When the difference between QC and verification data exceeds the Comparison Criteria the Engineer will initiate the resolution procedure in accordance with 346-9.5. The QC and Verification laboratories will transport their own hold cylinder to the resolution testing laboratory within 72 hours after the Engineer notifies the Contractor that a resolution is required.

Table 8	
Range of Average Compressive Strength	Comparison Criteria
Less than 3500 psi [23 MPa]	420 psi [2.9 MPa]
3,501 – 4,500 psi [23 - 31 MPa]	590 psi [4.0 MPa]
4,501 – 6,500 psi [31 - 45 MPa]	910 psi [6.3 MPa]
6,501 – 8,500 psi [45 - 59 MPa]	1,275 psi [8.8 MPa]
Greater than 8,500 psi [59 MPa]	1,360 psi [9.4 MPa]

346-9.2 Sampling Frequency for Quality Control Tests:

As a minimum, sample and test concrete of each design mix for water to cementitious materials ratio, air content, temperature, slump and compressive strength in accordance with Table 9. The Engineer will randomly verify one of every four consecutive LOTS of each design mix based on a random number generator, and may perform additional Independent Verification tests. All QC activities, calculations, and inspections will be randomly confirmed by the Department. If there is no verification data for a LOT, then the LOT goes to Resolution Investigation to determine conformance with 346-9.

TABLE 9	
Class Concrete	Maximum LOT Size
I (Pavement)	one lane mile [1.5 lane km] or one day's production, whichever is less
I (Special)	150 yd^3 [125 m^3] or one day's production, whichever is less
II, II (Bridge Deck), III, IV, IV (Drilled Shaft), V (Special), V, VI	50 yd^3 [40 m^3], or one day's production, whichever is less
III (Seal)	Each Seal placement

346-9.2.1 Reduced Frequency for Acceptance Tests: For all structural concrete except Class I and III (Seal), if the previous 15 consecutive strength test results of the same

design mix produced at the same concrete production facility, on a given Contract have all been verified and have attained an average strength greater than two standard deviations above the specified minimum, then the maximum LOT size will be increased to 100 yd^3 [80 m^3].

The average of 15 consecutive breaks can be established based on historical data from the previous project. The data must also represent the same prime/sub contractor. The last test from the previous job must be within the last 60 calendar days. Test data must be from a laboratory meeting the requirements of 6-9.

The average of 15 consecutive compressive strength test results can also be established by a succession of samples on the current project. Only one sample can be taken from each LOT.

If at any time a strength test is not verified and/or the average strength of the previous 15 consecutive samples is less than the specified minimum plus two standard deviations, the maximum LOT size will return to 50 yd^3 [40 m^3]. The maximum LOT size will remain 50 yd^3 [40 m^3] until the thresholds listed above are achieved.

346-9.3 Strength Test Definition: The strength test of a LOT is defined as the average of the compressive strengths tests of three cylinders cast from the same sample of concrete from the LOT.

346-9.4 Acceptance of Hardened Concrete: Hardened concrete will be accepted or rejected on the basis of strength test results as defined in 346-9.3. Do not discard a cylinder strength test result based on low strength (strength below the specified minimum strength as per the provisions of 346-3 and 346-9). When QC strength test results are verified, the Engineer will accept the concrete based on QC test results. The Engineer will accept at full pay only LOTs of concrete represented by strength test results which equal or exceed the respective specified minimum strength.

When one of the three QC cylinders from a LOT is lost, damaged or destroyed, determination of compressive strength will be made by averaging the remaining two cylinders. If more than one QC cylinder from a LOT is lost, damaged or destroyed, the Contractor will core the structure at no additional expense to the Department to determine the compressive strength. Acceptance of the LOT may be based on verification data at the discretion of the Engineer. Obtain the approval of the Engineer to core, and of the core location prior to drilling.

For each QC cylinder that is lost, damaged or destroyed, payment for that LOT will be reduced by $750.00 per 1,000 psi [6.9 MPa] of the specified design strength [Example: loss of two Class IV (Drill Shaft) QC cylinders that has no verification data on that LOT will require the element to be cored and a penalty will be assessed
(4,000 psi / 1,000 psi)([27.6 Mpa / 6.9 MPa]) x $750 x 2 = $6,000]. This reduction will be in addition to any pay adjustment for low strength.

When QC compressive strength test results are not verified, the resolution procedure will be used to accept or reject the concrete. Maintain the “hold” cylinders until the verification of the compressive strength test results.

346-9.5 Resolution Procedure: The Department may initiate an IA review of sampling and testing methods. The resolution procedure may consist of, but need not be limited to, a review of sampling and testing of fresh concrete, calculation of water cementitious materials ratio, handling of cylinders, curing procedures and compressive strength testing. Cores of the hardened concrete may be required.

The Engineer will determine through the resolution procedure whether the QC strength test results or the verification strength test results can be relied upon. When the Engineer

cannot determine that either the QC or verification strength test results are in error, the concrete represented by the four consecutive LOTs will be evaluated based on the QC data. The Engineer will ensure that the QC and verification "hold" cylinders are tested within seven days of the 28-day strength tests.

When the QC strength test results are deemed to be the most accurate, the QC strength test results will represent the four consecutive LOTs and the Department will pay for the resolution testing. When the verification strength test results are deemed to be the most accurate, the Contractor will pay for the resolution testing and the resolution investigation will determine the strength test results for each of the four LOTs.

The results of the resolution procedure will be forwarded to the Contractor within five days. If the Department finds deficiencies based on the Contractor's QCP, the Engineer may suspend that part of the QCP. When the QC plan is suspended, submit corrective actions for approval of the Engineer. The Engineer may take up to five working days to review corrective actions to the QCP. The Engineer will not allow changes to Contract Time or completion dates. Incur all delay costs and other costs associated with QC plan suspension and re-approval.

346-9.6 Small Quantities of Concrete: When a project has a total plan quantity of less than 50 cubic yards, that concrete will be accepted based on the satisfactory compressive strength of the QC cylinders. Provide certification to the Engineer that the concrete was batched and placed in accordance with the Contract Documents. Submit a quality control plan for the concrete placement operation in accordance with Section 105. In addition, the Engineer may conduct Independent Verification (IV) testing as identified in Section 346-9. Evaluate the concrete in accordance with 346-10 at the discretion of the Engineer.

346-10 Investigation of Low Strength Concrete for Structural Adequacy.

346-10.1 General: When a concrete acceptance strength test result falls more than 10% or 500 psi [3.5 MPa] below the specified minimum strength, whichever is the greater deviation from the specified minimum strength, and the Department determines that an investigation is necessary, make an investigation into the structural adequacy of the LOT of concrete represented by that acceptance strength test result at no additional expense to the Department. The Engineer may also require the Contractor to perform additional strength testing as necessary to determine structural adequacy of the concrete.

Furnish either a structural analysis performed by a Specialty Engineer to establish strength adequacy or drilled core samples as specified in 346-10.3 to determine the in-place strength of the LOT of concrete in question at no additional expense to the Department. Obtain the Engineers approval before taking any core samples. When the concrete is deemed to have low strength, obtain and test the cores and report the data to the Engineer within 14 days of the 28 day compressive strength tests. Core strength test results obtained from the structure will be accepted by both the Contractor and the Department as the in-place strength of the LOT of concrete in question. The core strength test results will be final and used in lieu of the cylinder strength test results for determination of structural adequacy and any pay adjustment. The Department will calculate the strength value to be the average of the compressive strengths of the three individual cores. This will be accepted as the actual measured value.

346-10.2 Determination of Structural Adequacy: If core strength test results are less than 500 psi [3.5 MPa] or 10%, whichever is greater, below the specified minimum strength, consider the concrete represented by the cores structurally adequate. If the core strength test results are more than 10% or 500 psi [3.5 MPa], whichever is greater, below the specified minimum strength, the Department will consider the concrete represented by the cores

structurally questionable. Submit a structural analysis performed by a Specialty Engineer. If the results of the structural analysis, approved by the Department, indicates adequate strength to serve its intended purpose with adequate durability, the Contractor may leave the concrete in place subject to the requirements of 346-11, otherwise, remove and replace the LOT of concrete in question at no additional expense to the Department.

346-10.3 Coring for Determination of Structural Adequacy: Furnish three undamaged core samples taken from the same approximate location as where the structural questionable concrete represented by the low strength concrete test cylinders was placed. Select the location of the drilled cores so that the structure is not impaired and does not sustain permanent damage after repairing the core holes. Obtain the approval of the Engineer to core, and of the core location prior to drilling.

346-10.4 Core Conditioning and Testing: The Department will test the cores in accordance with ASTM C 42 [ASTM C 42M]. The Engineer will make the determination whether to test the cores in a dry or wet condition. If the Engineer decides to test the cores in a wet condition, immerse the cores in water for at least 40 hours, and test the cores wet. The cores will be tested within 3-days after obtaining the samples.

346-11 Pay Adjustments for Low Strength Concrete.

346-11.1 General: Any LOT of concrete failing to meet the specified minimum strength as defined in 346-3, 346-9, 346-10 and satisfactorily meeting all other requirements of the Contract Documents, including structural adequacy, the Engineer will individually reduce the price of each low strength LOT in accordance with this Section.

346-11.2 Basis for Pay Adjustments: When an acceptance strength test result falls more than 10% or 500 psi [3.5 MPa], whichever is greater, below the specified minimum strength, core samples may be obtained from the respective LOT of concrete represented by the low acceptance strength test result for determining pay adjustments. Price adjustment will be applied to the certified invoice price the Contractor paid for the concrete.

Do not core hardened concrete for determining pay adjustments when the 28-day acceptance cylinder strength test results are less than 500 psi [3.5 MPa] or 10%, whichever is greater, below the specified minimum strength.

When the Contractor submits acceptable core samples to the Engineer for testing, the Engineer will determine payment reductions based upon the results of the strength tests. Both the Contractor and the Department shall accept the results of strength tests of the drilled cores, subject to 346-11.5 and 346-11.6, as final and in lieu of the cylinder strength test results for determining pay adjustments.

346-11.3 Coring for Determination of Pay Adjustments: Obtain the cores in accordance with 346-10.3.

346-11.4 Core Conditioning and Testing: The Department will test the cores in accordance with 346-10.4.

346-11.5 Core Strength Representing Equivalent 28-Day Strength: For cores tested no later than 42 days after the concrete was cast, the Engineer will accept the core strengths obtained as representing the equivalent 28-day strength of the LOT of concrete in question. The Engineer will calculate the strength value to be the average of the compressive strengths of the three individual cores. The Engineer will accept this strength at its actual measured value.

346-11.6 Core Strength Adjustments: For cores tested later than 42 days after the concrete was cast, the Department will establish the equivalency between 28-day strength and strength at ages after 42 days based on test data developed by a Department approved testing

laboratory to relate strength at the actual test age to 28-day strength for the particular class of concrete and design mix represented by the cores. Obtain such data at no additional expense to the Department. When such data is not available and cannot be produced, as determined by the Department, the Department will determine the equivalent 28-day strength by adjusting the tested core strengths according to the following relationship:

346-11.6.1 Portland Cement Concrete without Pozzolan or Slag:

Equivalent 28-Day Strength, f'c (28) = 1/F (Average Core Strength) x 100,

where:

$F = 4.4 + 39.1 (\ln x) - 3.1 (\ln x)^2$ (Type I Cement)

$F = -17.8 + 46.3 (\ln x) - 3.3 (\ln x)^2$ (Type II Cement)

$F = 48.5 + 19.4 (\ln x) - 1.4 (\ln x)^2$ (Type III Cement)

x = number of days since the concrete was placed

ln = natural log

346-11.6.2 Pozzolanic-Cement Concrete:

Equivalent 28-day compressive strength = $f'_C(28)$, where:

$$f'_C(28) = 0.490 \times f'_C(t) \times e^{\left(\frac{8.31}{t}\right)^{0.276}}$$ (Type I Cement)

$$f'_C(28) = 0.730 \times f'_C(t) \times e^{\left(\frac{2.89}{t}\right)^{0.514}}$$ (Type II Cement)

$$f'_C(28) = 0.483 \times f'_C(t) \times e^{\left(\frac{5.38}{t}\right)^{0.191}}$$ (Type III Cement)

$f'_C(t)$ = Average Core Strength at time t (psi)

t = time compressive strength was measured (days)

346-11.6.3 Slag-Cement Concrete:

Equivalent 28-day compressive strength = $f'_C(28)$, where:

$$f'_C(28) = 0.794 \times f'_C(t) \times e^{\left(\frac{7.06}{t}\right)^{1.06}}$$ (Type I Cement)

$$f'_C(28) = 0.730 \times f'_C(t) \times e^{\left(\frac{6.02}{t}\right)^{0.747}}$$ (Type II Cement)

$$f'_C(28) = 0.826 \times f'_C(t) \times e^{\left(\frac{2.36}{t}\right)^{0.672}}$$ (Type III Cement)

$f'_C(t)$ = Average Core Strength at time t (psi)

t = time compressive strength was measured (days)

346-11.7 Calculating Pay Adjustments: The Engineer will determine payment reductions for low strength concrete, accepted by the Department and represented by either

cylinder or core strength test results below the specified minimum strength, in accordance with the following:

Reduction in Pay is equal to the reduction in percentage of concrete cylinder strength (specified minimum strength minus actual strength divided by specified minimum strength).

For the elements that payments are based on the per foot [meter] basis, the Engineer will adjust the price reduction from cubic yards [cubic meters] basis to per foot [meter] basis, determine the total linear feet [meter] of the elements that are effected by low strength concrete samples and apply the adjusted price reduction accordingly.