ITEM 421

HYDRAULIC CEMENT CONCRETE

421.1. Description. Furnish hydraulic cement concrete for concrete pavements, concrete structures, and other concrete construction.

421.2. Materials.

A. Cement. Furnish cement conforming to DMS-4600, "Hydraulic Cement."

B. Supplementary Cementing Materials (SCM).

1. **Fly Ash.** Furnish fly ash conforming to DMS-4610, "Fly Ash."
2. **Ultra-Fine Fly Ash (UFFA).** Furnish UFFA conforming to DMS-4610, "Fly Ash."
3. **Ground Granulated Blast-Furnace Slag (GGBFS).** Furnish GGBFS conforming to DMS-4620, "Ground Granulated Blast-Furnace Slag," Grade 100 or 120.
4. **Silica Fume.** Furnish silica fume conforming to DMS-4630, "Silica Fume."
5. **Metakaolin.** Furnish metakaolin conforming to DMS-4635, "Metakaolin."

C. Chemical Admixtures. Furnish admixtures conforming to DMS-4640, "Chemical Admixtures for Concrete." Do not use calcium chloride.

D. Water. Furnish mixing and curing water that is free from oils, acids, organic matter, or other deleterious substances. Water from municipal supplies approved by the Texas Department of Health will not require testing. When using water from other sources, provide test reports showing compliance with Table 1 before use.

Water that is a blend of concrete wash water and other acceptable water sources, certified by the concrete producer as complying with the requirements of both Table 1 and Table 2, may be used as mix water. Test the blended water weekly for 4 weeks for compliance with Table 1 and Table 2 or provide previous test results. Then test every month for compliance. Provide water test results upon request.

Table 1
Chemical Limits for Mix Water

Contaminant	Test Method	Maximum Concentration (ppm)
Chloride (Cl) Prestressed concrete Bridge decks & superstructure All other concrete	ASTM D 512	 500 500 1,000
Sulfate (SO_4)	ASTM D 516	1,000
Alkalies ($Na_2O + 0.658K_2O$)	ASTM D 4191 & ASTM D 4192	600
Total solids	AASHTO T 26	50,000

Table 2
Acceptance Criteria for Questionable Water Supplies

Property	Test Method	Limits
Compressive strength, min % control at 7 days	ASTM C 109[1]	90
Time of set, deviation from control, Min.	ASTM C 191[1]	from 60 early to 90 later

1. Base comparisons on fixed proportions and the same volume of test water compared to the control mix using city water or distilled water.

Do not use mix water that has an adverse effect on the air-entraining agent, on any other chemical admixture, or on strength or time of set of the concrete. When using white hydraulic cement, use mixing and curing water free of iron and other impurities that may cause staining or discoloration.

E. Aggregate. Supply aggregates that meet the definitions in Tex-100-E. Provide coarse and fine aggregates from sources listed in the Department's Concrete Rated Source Quality Catalog (CRSQC). Provide aggregate from non-listed sources only when tested and approved by the Engineer before use. Allow 30 calendar days for the Engineer to sample, test, and report results for non-listed sources. Do not combine approved material with unapproved material.

1. Coarse Aggregate. Provide coarse aggregate consisting of durable particles of gravel, crushed blast furnace slag, recycled crushed hydraulic cement concrete, crushed stone, or combinations thereof that are free from frozen material and from injurious amounts of salt, alkali, vegetable matter, or other objectionable material, either free or as an adherent coating. Provide coarse aggregate of uniform quality throughout.

Provide coarse aggregate that, when tested in accordance with Tex-413-A, has:

- at most 0.25% by weight of clay lumps,
- at most 1.0% by weight of shale, and
- at most 5.0% by weight of laminated and friable particles.

Wear must not be more than 40% when tested in accordance with Tex-410-A.

Unless otherwise shown on the plans, provide coarse aggregate with a 5-cycle magnesium sulfate soundness of not more than 18% when tested in accordance with Tex-411-A. Crushed recycled hydraulic cement concrete is not subject to the 5-cycle soundness test.

The loss by decantation as tested in accordance with Tex-406-A, plus the allowable weight of clay lumps, must not exceed 1.0% or the value shown on the plans, whichever is smaller. In the case of aggregates made primarily from crushing stone, if the material finer than the No. 200 sieve is established to be the dust of fracture and essentially free from clay or shale as established by Tex-406-A, Part III, the limit may be increased to 1.5%. When crushed limestone coarse aggregate is used in concrete pavements, the decant may exceed 1.0% but not more than 3.0% if the material finer than the No. 200 sieve is determined to be at least 67% calcium carbonate in accordance with Tex-406-A, Part III.

Unless otherwise specified, provide aggregate conforming to the gradation requirements shown in Table 3 when tested in accordance with Tex-401-A.

Table 3
Coarse Aggregate Gradation Chart

Aggregate Grade No.[1]	Nominal Size	Percent Passing on Each Sieve								
		2-1/2"	2"	1-1/2"	1"	3/4"	1/2"	3/8"	No. 4	No. 8
1	2"	100	80–100	50–85		20–40			0–5	
2 (467)	1–1/2"		100	95–100		35–70		10–30	0–5	
3	1–1/2"		100	95–100		60–90	25–60		0–5	
4 (57)	1"			100	95–100		25–60		0–10	0–5
5 (67)	3/4"				100	90–100		20–55	0–10	0–5
6 (7)	1/2"					100	90–100	40–70	0–15	0–5
7	3/8"						100	70–95	0–25	
8	3/8"						100	95–100	20–65	0–10

1. Corresponding ASTM C 33 gradation shown in parentheses.

2. Fine Aggregate. Provide fine aggregate consisting of clean, hard, durable particles of natural or manufactured sand or a combination thereof with or without mineral filler. Provide fine aggregate free from frozen material and from injurious amounts of salt, alkali, vegetable matter, or other objectionable material, and containing no more than 0.5% clay lumps by weight in accordance with Tex-413-A.

Provide fine aggregate that does not show a color darker than standard when subjected to the color test for organic impurities in accordance with Tex-408-A.

Unless otherwise shown on the plans, use fine aggregate with an acid insoluble residue of at least 60% by weight when tested in accordance with Tex-612-J in all concrete subject to direct traffic.

Unless otherwise shown on the plans, when necessary, blend the fine aggregate to meet the acid insoluble residue requirement. When blending, use the following equation:

Acid Insoluble (%) = $\{(A1)(P1)+(A2)(P2)\}/100$

where:

A1 = acid insoluble (%) of aggregate 1
A2 = acid insoluble (%) of aggregate 2
P1 = percent by weight of *A1* of the fine aggregate blend
P2 = percent by weight of *A2* of the fine aggregate blend

Provide fine aggregate or combinations of aggregates, including mineral filler, conforming to the gradation requirements shown in Table 4 when tested in accordance with Tex-401-A unless otherwise specified.

Table 4
Fine Aggregate Gradation Chart (Grade 1)

Sieve Size	Percent Passing
3/8 in.	100
No. 4	95–100
No. 8	80–100
No. 16	50–85
No. 30	25–65
No. 50	10–35[1]
No. 100	0–10
No. 200	0–3[2]

1. 6–35 when sand equivalent value is greater than 85.
2. 0–6 for manufactured sand.

Unless otherwise shown on the plans, provide fine aggregate with a sand equivalent of at least 80 in accordance with Tex-203-F.

For all classes of concrete except Class K, provide fine aggregate with a fineness modulus between 2.30 and 3.10 as determined by Tex-402-A. For Class K concrete, provide a fine aggregate with a fineness modulus between 2.60 to 2.80 unless otherwise shown on the plans.

3. **Mineral Filler.** Provide mineral filler consisting of stone dust, clean crushed sand, or other approved inert material with 100% passing the No. 30 sieve and 65 to 100% passing the No. 200 sieve when tested in accordance with Tex-401-A.

F. Mortar and Grout. When required or shown on the plans, provide mortar and grout consisting of 1 part hydraulic cement, 2 parts sand, and sufficient water to provide the desired consistency. Provide mortar with a consistency such that the mortar can be easily handled and spread by trowel. Provide grout of a consistency that will flow into and completely fill all voids.

421.3. Equipment.

A. Concrete Plants and Mixing Equipment. Except for volumetric mixers (auger/mixer), each plant and truck mixer must be currently certified by the National Ready Mixed Concrete Association (NRMCA) or have an inspection report signed and sealed by a licensed professional engineer showing that concrete measuring, mixing, and delivery equipment meets all requirements of ASTM C 94. A new certification or signed and sealed report is required every time a plant is moved. Plants with a licensed engineer's inspection require reinspection every 2 years. Provide a copy of the certification or the signed and sealed inspection report to the Engineer. When equipment or facilities fail to meet specification requirements, remove them from service until corrected.

1. **Scales.** Check all scales prior to beginning of operations, after each move, or whenever their accuracy or adequacy is questioned, and at least once every 6 mo. Immediately correct deficiencies, and recalibrate. Provide a record of calibration showing scales in compliance with

ASTM C 94 requirements. Check batching accuracy of volumetric water batching devices and admixture dispensing devices at least every 90 days. Perform daily checks as necessary to ensure measuring accuracy.

2. **Volumetric Mixers.** Provide volumetric mixers with rating plates defining the capacity and the performance of the mixer in accordance with the Volumetric Mixer Manufacturers Bureau or equivalent. Provide volumetric mixers that comply with ASTM C 685. Provide test data showing mixers meet the uniformity test requirements of Tex-472-A.

3. **Agitators and Truck and Stationary Mixers.** Inspect and furnish inspection reports on truck mixers and agitators annually. If an inspection within 12 mo. is not practical, a 2-mo. grace period (for a maximum of 14 mo. between inspections) is permitted. Include in the report the condition of blades and fins and their percent wear from the original manufacturer's design. Repair mixing equipment exhibiting 10% or more wear before use. Provide truck mixers and agitators equipped with means to readily verify the number of revolutions of the drum, blades, or paddles.

   Provide stationary and truck mixers capable of combining the ingredients of the concrete within the specified time or the number of revolutions specified into a thoroughly mixed and uniform mass and capable of discharging the concrete so that at least 5 of the 6 requirements of Tex-472-A are met.

   As directed, to resolve issues of mix uniformity and mixer performance, perform concrete uniformity tests on mixers or agitators in accordance with Tex-472-A.

   Perform the mixer or agitator uniformity test at the full rated capacity of the equipment and within the maximum mixing time or maximum number of revolutions. Remove from service all equipment that fails the uniformity test.

   Inspect and maintain mixers and agitators. Keep them reasonably free of concrete buildup, and repair or replace worn or damaged blades or fins.

   Ensure all mixers have a plate affixed showing manufacturer's recommended operating speed and rated capacity for mixing and agitating.

B. Hauling Equipment. Provide hauling equipment capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity.

When using non-agitating equipment for transporting concrete, provide equipment with smooth, mortar-tight metal containers equipped with gates that prevent accidental discharge of the concrete.

C. Testing Equipment. Unless otherwise shown on the plans or specified, in accordance with the pertinent test procedure, furnish and maintain:

- test molds,
- curing facilities,
- maturity meters if used, and
- wheelbarrow or other container acceptable for the sampling of the concrete.

Provide strength-testing equipment in accordance with the Contract controlling test unless shown otherwise.

421.4. Construction.

A. Classification and Mix Design. Furnish mix designs using ACI 211, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," or other approved procedures for the classes of concrete required in accordance with Table 5. Do not exceed the maximum water-to-cementitious-material ratio.

A higher-strength class of concrete with equal or lower water-to-cementitious-material ratio may be substituted for the specified class of concrete.

To account for production variability and ensure minimum compressive strength requirements are met, over-design the mix in accordance with Table 6.

1. **Cementitious Materials.** Use cementitious materials from prequalified sources; otherwise, request sampling and testing for approval before use. Unless otherwise specified or approved,

limit cementitious material content to no more than 700 lb. per cubic yard. When supplementary cementing materials are used, "cement" is defined as "cement plus supplementary cementing material."

Use Type III cement only in precast concrete or when specified or permitted.

For monolithic placements, use cement of the same type and from the same source.

When sulfate-resistant concrete is required, use mix design options 1, 2, 3, or 4 given in Section 421.4.A.6, "Mix Design Options," using Type I/II, II, V, IP, or IS cement. Do not use Class C fly ash in sulfate-resistant concrete.

Do not use supplementary cementing materials when white hydraulic cement is specified.

Table 5
Concrete Classes

Class of Concrete	Design Strength, Min. 28-day f'_c (psi)	Maximum W/C Ratio[1]	Coarse Aggregate Grades[2,3]	General Usage[4]
A	3,000	0.60	1–4, 8	Inlets, manholes, curb, gutter, curb & gutter, conc. retards, sidewalks, driveways, backup walls, anchors
B	2,000	0.60	2–7	Riprap, small roadside signs, and anchors
C[5]	3,600	0.45	1–6	Drilled shafts, bridge substructure, bridge railing, culverts except top slab of direct traffic culverts, headwalls, wing walls, approach slabs, concrete traffic barrier (cast-in-place)
D	1,500	0.60	2–7	Riprap
E	3,000	0.50	2–5	Seal concrete
F[5]	Note 6	0.45	2–5	Railroad structures; occasionally for bridge piers, columns, or bents
H[5]	Note 6	0.45	3–6	Prestressed concrete beams, boxes, piling, and concrete traffic barrier (precast)
S[5]	4,000	0.45	2–5	Bridge slabs, top slabs of direct traffic culverts
P	See Item 360	0.45	2–3	Concrete pavement
DC[5]	5,500	0.40	6	Dense conc. overlay
CO[5]	4,600	0.40	6	Conc. overlay
LMC[5]	4,000	0.40	6–8	Latex-modified concrete overlay
SS[5]	Note 7	0.45	4–6	Slurry displacement shafts, underwater drilled shafts
K[5]	Note 6	0.45	Note 6	Note 6
HES	Note 6	0.45	Note 6	Note 6

1. Maximum water-cement or water-cementitious ratio by weight.
2. Unless otherwise permitted, do not use Grade 1 coarse aggregate except in massive foundations with 4-in. minimum clear spacing between reinforcing steel bars. Do not use Grade 1 aggregate in drilled shafts.
3. Unless otherwise approved, use Grade 8 aggregate in extruded curbs.
4. For information only.
5. Structural concrete classes.
6. As shown on the plans or specified.
7. Cementitious material content shall be minimum 658 lb/cy of concrete.

Table 6
Over Design to Meet Compressive Strength Requirements[1]

No. of Tests[2,3]	Standard Deviation, psi				
	300	**400**	**500**	**600**	**700**
15	470	620	850	1,120	1,390
20	430	580	760	1,010	1,260
30 or more	400	530	670	900	1,130

1. When designing the mix, add the tabulated amounts to the minimum design strength in Table 5.
2. Number of tests of a concrete mixture used to estimate the standard deviation of a concrete production facility. Test of another mix within 1,000 psi of the specified strength may be used.
3. If less than 15 prior tests are available, the overdesign should be 1,000 psi for specified strength less than 3,000 psi, 1,200 psi for specified strengths from 3,000 to 5,000 psi and 1,400 psi for specified strengths greater than 5,000 psi.

2. **Aggregates.** Limit the use of recycled crushed hydraulic cement concrete as a coarse or fine aggregate to Class A, B, D, E, and P concrete. Limit recycled crushed concrete fine aggregate to a maximum of 20% of the fine aggregate.

   When white hydraulic cement is specified, use light-colored aggregates.

3. **Chemical Admixtures.** Use only preapproved concrete chemical admixtures from the list of prequalified concrete admixtures maintained by the Construction Division. Submit non-preapproved admixtures for testing to the Engineer for approval. Do not use high-range water-reducing admixtures (Type F or G) or accelerating admixtures (Type C or E) in bridge deck concrete.

4. **Air Entrainment.** Air-entrain all concrete except for Class B in accordance with Table 7 unless otherwise shown on the plans. Use moderate exposure values unless otherwise specified. If the air content is more than 1-1/2 percentage points below or 3 percentage points above the required air, the load of concrete will be rejected. If the air content is more than 1-1/2 but less than 3 percentage points above the required air, the concrete may be accepted based on strength tests.

Table 7
Air Entrainment

Nominal Maximum Aggregate Size, in.	% Air[1]	
	Moderate Exposure	**Severe Exposure**
3/8 (Grades 7 & 8)	6	7-1/2
1/2 (Grade 6)	5-1/2	7
3/4 (Grade 5)	5	6
1 (Grade 4)	4-1/2	6
1-1/2 (Grades 2 & 3)	4-1/2	5-1/2
2 (Grade 1)	4	5

1. For specified concrete strengths above 5,000 psi a reduction of 1 percentage point is permitted.

5. **Slump.** Unless otherwise specified, provide concrete slump in accordance with Table 8 using the lowest slump possible that can be placed and finished efficiently without segregation or honeycombing.

   Concrete that exceeds the maximum acceptable placement slump at time of delivery will be rejected.

   When approved, the slump of a given concrete mix may be increased above the values shown in Table 8 using chemical admixtures, provided that the admixture-treated concrete has the same or lower water–cement or water–cementitious-material ratio and does not exhibit segregation or excessive bleeding. Request approval for the mix design sufficiently in advance for proper evaluation by the Engineer.

Table 8
Slump Requirements

Concrete Designation	Recommended Design and Placement Slump, in.	Maximum Acceptable Placement Slump, in.
Drilled shafts	See Item 416	See Item 416
Thin walled section (9 in. or less)	4	6-1/2
Approach slabs, concrete overlays, caps, columns, piers, wall sections (over 9 in.)	3	5
Bridge slabs	4	5-1/2
Prestressed concrete members[1]	4	6-1/2
Concrete traffic barrier, concrete bridge railing	4	6-1/2
Dense concrete overlay	3/4	2
Latex-modified conc. for bridge deck overlays	3	7-1/2
Concrete placed underwater	6	8-1/2
Concrete pavement (slip-formed)	1-1/2	3
Concrete pavement (formed)	4	6-1/2
Riprap, curb, gutter, slip-formed, and extruded concrete	As approved	As approved

1. If a high-range water reducer (HRWR) is used, maximum acceptable placement slump will be 9 in.

6. **Mix Design Options.** For structural concrete identified in Table 5 and any other class of concrete designed using more than 520 lb. of cementitious material per cubic yard, use one of the mix design Options 1–8 shown below.

   For concrete classes not identified as structural concrete and designed using less than 520 lb. of cementitious material per cubic yard, use one of the mix design Options 1–8 shown in Table 5, except that Class C fly ash may be used instead of Class F fly ash for Options 1, 3, and 4 unless sulfate-resistant concrete is required.

   a. **Option 1.** Replace 20 to 35% of the cement with Class F fly ash.

   b. **Option 2.** Replace 35 to 50% of the cement with GGBFS.

   c. **Option 3.** Replace 35 to 50% of the cement with a combination of Class F fly ash, GGBFS, or silica fume. However, no more than 35% may be fly ash, and no more than 10% may be silica fume.

   d. **Option 4.** Use Type IP or Type IS cement. (Up to 10% of a Type IP or Type IS cement may be replaced with Class F fly ash, GGBFS, or silica fume.)

   e. **Option 5.** Replace 35 to 50% of the cement with a combination of Class C fly ash and at least 6% of silica fume, UFFA, or metakaolin. However, no more than 35% may be Class C fly ash, and no more than 10% may be silica fume.

   f. **Option 6.** Use a lithium nitrate admixture at a minimum dosage of 0.55 gal. of 30% lithium nitrate solution per pound of alkalis present in the hydraulic cement.

   g. **Option 7.** When using hydraulic cement only, ensure that the total alkali contribution from the cement in the concrete does not exceed 4.00 lb. per cubic yard. of concrete when calculated as follows:

$$\text{lb. alkali per cu. yd.} = \frac{(\text{lb. cement per cu. yd.}) \times (\%\ Na_2O \text{ equivalent in cement})}{100}$$

   In the above calculation, use the maximum cement alkali content reported on the cement mill certificate.

   h. **Option 8.** For any deviations from Options 1–7, perform the following:

- Test both coarse and fine aggregate separately in accordance with ASTM C 1260, using 440 g of the proposed cementitious material in the same proportions of hydraulic cement to supplementary cementing material to be used in the mix.
- Before use of the mix, provide the certified test report signed and sealed by a licensed professional engineer demonstrating that the ASTM C 1260 test result for each aggregate does not exceed 0.10% expansion.

B. Trial Batches. Perform all preliminary trial batches and testing necessary to substantiate the proposed mix designs, and provide documentation including mix design, material proportions, and test results substantiating that the mix design conforms to specification requirements.

Make all final trial batches using the proposed ingredients in a mixer that is representative of the mixers to be used on the job. Make the batch size at least 50% of the mixer's rated capacity. Perform fresh concrete tests for air and slump, and make, cure, and test strength specimens for compliance with specification requirements. Test at least 3 sets of design strength specimens with 2 specimens per set in accordance with Tex-418-A or Tex-448-A for each test age. Before placing, provide the Engineer the option of witnessing final trial batches, including the testing of the concrete. If not provided this option, the Engineer may require additional trial batches, including testing, before the concrete is placed.

Establish 7-day compressive strength target values using the following formula for each concrete mix to be used:

$$\text{Target value} = \text{Minimum design strength} \times \frac{\text{7 - day avg. trial batch strength}}{\text{28 - day avg. trial batch strength}}$$

When there are changes in aggregates or in type, brand, or source of cement, SCM, or chemical admixtures, reevaluate the mix as a new mix design. A change in vendor does not necessarily constitute a change in materials or source. When only the brand or source of cement is changed and there is a prior record of satisfactory performance of the cement with the ingredients, new trial batches may be waived by the Engineer.

When the maturity method is specified or permitted, establish the strength–maturity relationship in accordance with Tex-426-A. When using the maturity method any changes in any of the ingredients, including changes in proportions, will require the development of a new strength–maturity relationship for the mix.

C. Storage of Materials.

1. **Cement, Supplementary Cementing Materials, and Mineral Filler.** Store all cement, supplementary cementing materials, and mineral filler in weatherproof enclosures that will protect them from dampness or absorption of moisture.

   When permitted, small quantities of sacked cement may be stored in the open, on a raised platform, and under waterproof covering for up to 48 hours.

2. **Aggregates.** Handle and store concrete aggregates in a manner that prevents contamination with foreign materials. If the aggregates are stored on the ground, clear the sites for the stockpiles of all vegetation, level the sites, and do not use the bottom 6-in. layer of aggregate without cleaning the aggregate before use.

   When conditions require the use of 2 or more grades of coarse aggregates, maintain separate stockpiles and prevent intermixing. Where space is limited, separate the stockpiles using physical barriers. Store aggregates from different sources in different stockpiles unless the Engineer authorizes pre-blending of the aggregates. Minimize segregation in stockpiles. Remix and test stockpiles when segregation is apparent.

   Sprinkle stockpiles to control moisture and temperature as necessary. Maintain reasonably uniform moisture content in aggregate stockpiles.

3. **Admixtures.** Store admixtures in accordance with manufacturer's recommendations and prevent admixtures from freezing.

D. Measurement of Materials. Except for volumetric mixers, measure concrete materials by weight. Measure mixing water, consisting 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, by volume or weight. Measure ice by weight. Measure cement and supplementary cementing materials in a weigh hopper and on a separate scale from those used for other materials. Measure the cement first when measuring the cumulative weight. Measure concrete chemical admixtures in powdered form by weight. Measure concrete chemical admixtures in liquid form by weight or volume. Measure batch materials within the tolerances of Table 9.

Table 9
Measurement Tolerances – Non-Volumetric Mixers

Material	Tolerance (%)
Cement, wt.	±1
Mineral admixture, wt.	±1
Cement + SCM (cumulative weighing), wt.	±1
Water, wt. or volume	±3
Fine aggregate, wt.	±2
Coarse aggregate, wt.	±2
Fine + coarse aggregate (cumulative weighing), wt.	±1
Chemical admixtures, wt. or volume	±3

When measuring cementitious materials at less than 30% of scale capacity, ensure that the quantity measured is accurate to not less than the required amount and not more than 4% in excess. When measuring aggregates in a cumulative weigh batcher at less than 30% of the scale capacity, ensure that the cumulative quantity is measured accurate to ±0.3% of scale capacity or ±3% of the required cumulative weight, whichever is less.

For volumetric mixers, base tolerances on volume–weight relationship established by calibration, and measure the various ingredients within the tolerances of Table 10.

Correct batch weight measurements for moisture.

When approved, under special circumstances, measure cement in bags of standard weight. Weighing of sacked cement is not required. Do not use fractional bags except for small hand-mixed batches of approximately 5 cu. ft. or less and when an approved method of volumetric or weight measurement is used.

Table 10
Measurement Tolerances – Volumetric Mixers

Material	Tolerance
Cement, wt. %	0 to +4
SCM, wt. %	0 to +4
Fine aggregate, wt. %	±2
Coarse aggregate, wt. %	±2
Admixtures, wt. or volume %	±3
Water, wt. or volume %	±1

E. Mixing and Delivering Concrete. Mix and deliver concrete by means of one of the following operations:

- central-mixed,
- shrink-mixed,
- truck-mixed,
- volumetric mixer-mixed, or
- hand-mixed.

Operate mixers and agitators within the limits of the rated capacity and speed of rotation for mixing and agitation as designated by the manufacturer of the equipment.

For shrink-mixed and truck-mixed concrete, when there is a reason to suspect the uniformity of concrete delivered using a truck mixer or truck agitator, conduct slump tests of 2 individual samples taken after discharging approximately 15% and 85% of the load as a quick check of the probable degree of uniformity. Take the 2 samples within an elapsed time of at most 15 min. If the slumps of the 2 samples differ by more than the values shown in Table 11, investigate the causes and take corrective actions including adjusting the batching sequence at the plant and the mixing time and number of revolutions. Delivery vehicles that fail to meet the mixing uniformity requirements must not be used until the condition is corrected.

Table 11
Slump Tolerance[1]

Average Slump	Slump Tolerance[2]
4 in. or less	1.0 in.
4 to 6 in.	1.5 in.

1. Do not apply these tolerances to the required slumps in Table 8.
2. Maximum permissible difference in results of test of samples from 2 locations in the concrete batch.

Re-tempering or adding concrete chemical admixtures is only permitted at the job site when concrete is delivered in a truck mixer. Do not add water after the introduction of mixing water at the batch plant except on arrival at the job site, with approval, to adjust the slump of the concrete. When this water is added, do not exceed the mix design water–cementitious-material ratio. Turn the drum or blades at least 30 additional revolutions at mixing speed to ensure thorough and uniform mixing of the concrete. Do not add water or chemical admixtures to the batch after any concrete has been discharged.

Maintain concrete delivery and placement rates sufficient to prevent cold joints.

Before unloading, furnish the delivery ticket for the batch of concrete containing the information required on Department Form 596, "Concrete Batch Ticket."

When the concrete contains silica fume, adjust mixing times and batching operations as necessary to ensure the material is completely and uniformly dispersed in the mix. The dispersion of the silica fume within the mix will be verified by the Construction Division, Materials and Pavements Section, using cylinders made from trial batches. If uniform dispersion is not achieved, make necessary changes to the batching operations until uniform and complete dispersion of the silica fume is achieved.

1. **Central-Mixed Concrete.** Provide concrete that is mixed completely in a stationary mixer. Mix concrete for a period of 1 min. for 1 cu. yd. and 15 sec. for each additional cu. yd. of rated capacity of the mixer unless mixer performance test data demonstrate that shorter mixing times can be used to obtain a uniform mix in accordance with Tex-472-A. Count the mixing time from the time all the solid materials are in the drum. Charge the mixer so that some water will enter before the cement and aggregate. Ensure that all water is in the drum by the end of the first 1/4 of the specified mixing time. Adjust the mixing time if necessary to achieve a uniform mix. Concrete mixed completely in a stationary mixer must be delivered to the project in a truck mixer, truck agitator, or non-agitating delivery vehicle. When a truck mixer or truck agitator is used for transporting concrete, use the manufacturer's designated agitating speed for any turning during transportation. Non-agitating delivery vehicles must be clean and free of built-up concrete with adequate means to control concrete discharge. Deliver the concrete to the project in a thoroughly mixed and uniform mass, and discharge the concrete with a satisfactory degree of uniformity. Resolve questions regarding the uniformity of the concrete by testing when directed by the Engineer in accordance with Tex-472-A.
2. **Shrink-Mixed Concrete.** Provide concrete that is first partially mixed in a stationary mixer and then mixed completely in a truck mixer. Partially mix for the minimum time required to intermingle the ingredients in the stationary mixer, and then transfer to a truck mixer and mix the concrete at the manufacturer's designated mixing speed for an adequate amount of time to produce thoroughly mixed concrete. Deliver the concrete to the project in a thoroughly mixed and uniform mass, and discharge the concrete with a satisfactory degree of uniformity.
3. **Truck-Mixed Concrete.** Mix the concrete in a truck mixer from 70 to 100 revolutions at the mixing speed designated by the manufacturer to produce a uniform concrete mix. Deliver the

concrete to the project in a thoroughly mixed and uniform mass and discharge the concrete with a satisfactory degree of uniformity. Additional mixing at the job site at the mixing speed designated by the manufacturer is allowed as long as concrete is discharged before the drum has revolved a total of 300 revolutions after the introduction of the mixing water to the cement and the aggregates.

4. **Volumetric Mixer-Mixed Concrete.** Unless otherwise specified or permitted, perform all mixing operations in accordance with manufacturer's recommended procedures. Provide an accurate method of measuring all ingredients by volume, and calibrate equipment to assure correct measurement of materials within the specified tolerances.

5. **Hand-Mixed Concrete.** When permitted, for small placements of less than 2 cu. yd., mix up to a 2-sack batch of concrete by hand methods or in a small motor-driven mixer. For such placements, proportion the mix by volume or weight.

F. Placing, Finishing, and Curing Concrete. Place, finish, and cure concrete in accordance with the pertinent Items.

G. Sampling and Testing of Concrete. Unless otherwise specified, all fresh and hardened concrete is subject to testing as follows:

1. **Sampling Fresh Concrete.** Provide all material to be tested. Fresh concrete will be sampled for testing at the discharge end if using belt conveyors or pumps. When it is impractical to sample at the discharge end, a sample will be taken at the time of discharge from the delivery equipment and correlation testing will be performed and documented to ensure specification requirements are met at the discharge end.

2. **Testing of Fresh Concrete.**

   a. **Air Content.** Tex-414-A or Tex-416-A.

   b. **Slump.** Tex-415-A.

   c. **Temperature.** Tex-422-A.

   d. **Making and Curing Strength Specimens.** Tex-447-A.

3. **Testing of Hardened Concrete.** Only compressive strength testing will be used unless otherwise specified or shown on the plans.

   a. **Compressive Strength.** Tex-418-A.

   b. **Flexural Strength.** Tex-448-A.

   c. **Maturity.** Tex-426-a.

4. **Certification of Testing Personnel.** Contractor personnel performing testing must be either ACI-certified or qualified by a Department-recognized equivalent written and performance testing program for the tests being performed. Personnel performing these tests are subject to Department approval. Use of a commercial laboratory is permitted. All personnel performing testing using the maturity method must be qualified by a training program recognized by the Department before using this method on the job.

5. **Adequacy and Acceptance of Concrete.** The Engineer will sample and test the fresh and hardened concrete for acceptance. The test results will be reported to the Contractor and the concrete supplier. For any concrete that fails to meet the required strengths as outlined below, investigate the quality of the materials, the concrete production operations, and other possible problem areas to determine the cause. Take necessary actions to correct the problem including redesign of the concrete mix. The Engineer may suspend all concrete operations under the pertinent Items if the Contractor is unable to identify, document, and correct the cause of the low strengths in a timely manner. Resume concrete operations only after obtaining approval for any proposed corrective actions.

   a. **Structural Concrete.** For concrete classes identified as structural concrete in Table 5, the Engineer will make and test 7-day and 28-day specimens. Acceptance will be based on the design strength given in Table 5.

The Engineer will evaluate the adequacy of the concrete by comparing 7-day test results to the target value established in accordance with Section 421.4.B, "Trial Batches."

b. All Other Concrete. For concrete classes not identified as structural concrete in Table 5, the Engineer will make and test 7-day specimens. The Engineer will base acceptance on the 7-day target value established in accordance with Section 421.4.B, "Trial Batches."

6. Test Sample Handling. Unless otherwise shown on the plans or directed, remove forms and deliver department test specimens to curing facilities, in accordance with pertinent test procedures. Clean and prepare forms for reuse.

421.5. Measurement and Payment. The work performed, materials furnished, equipment, labor, tools, and incidentals will not be measured or paid for directly but will be subsidiary to pertinent Items.