

DIVISION 550
Bridge Construction

Section 551—Driven Piles

Description

551.01 Work. Furnish and drive piles. In addition, furnish and place reinforcing steel and concrete in concrete-filled steel shell and concrete-filled pipe piles.

Piles are designated as steel H-piles, steel pipe piles, concrete-filled steel shell piles, concrete-filled pipe piles, precast concrete piles, prestressed concrete piles, or timber piles. Pile load tests are designated as static or dynamic.

Materials

551.02 Requirements. Furnish material that conforms to the specifications in the following sections and subsections:

Concrete Piles	715.03
Paint	708
Pile Shoes	715.08
Reinforcing Steel	554
Sheet Piles	715.07
Splices	715.09
Steel H-Piles	715.06
Steel Pipes	715.05
Steel Shells	715.04
Structural Concrete	552
Treated Timber Piles	715.02
Untreated Timber Piles	715.01

Construction

551.03 Pile-Driving Equipment. Furnish equipment meeting the following requirements:

(a) **Pile Hammers.** Furnish pile hammers as shown below.

(1) **Gravity Hammers.** Use gravity hammers to drive timber piles only, and where the ultimate bearing capacity of the timber pile is less than 800 kN. Furnish a hammer with a ram weighing between 900 and 1,600 kg and limit the drop height to 4 m. Ensure that the ram mass is greater than the combined mass of the drive head and pile. Provide hammer guides to ensure concentric impact on the drive head.

(2) *Open-End Diesel Hammers.* Equip open-end (single-acting) diesel hammers with a device, such as rings on the ram or a scale (jump stick) extending above the ram cylinder, to permit visual determination of hammer stroke. Submit a chart from the hammer manufacturer equating stroke and blows per minute for the hammer to be used. A speed-versus-stroke calibration may be used if approved.

(3) *Closed-End Diesel Hammers.* Submit a chart, calibrated to actual hammer performance within 90 days of use, equating bounce chamber pressure to either equivalent energy or stroke for the hammer to be used. Equip hammers with a dial gage for measuring pressure in the bounce chamber. Make the gage readable at ground level. Calibrate the dial gage to allow for losses in the gage hose. Verify the accuracy of the calibrated dial gage during driving operations by ensuring that cylinder lift occurs when bounce chamber pressure is consistent with the maximum energy given in the hammer specifications. Do not use closed-end diesel hammers that do not attain cylinder lift at the maximum energy-bounce chamber pressure relationship given in the hammer specification.

(4) *Air or Steam Hammers.* Furnish plant and equipment for steam and air hammers with sufficient capacity to maintain the volume and pressure specified by the hammer manufacturer. Equip the hammer with accurate pressure gages that are easily accessible. Use a hammer with the mass of the striking parts equal to or greater than one-third the combined mass of the driving head and pile. Ensure that the combined mass is at least 1,250 kg.

When driving test piles, measure inlet pressures for double-acting and differential-acting air or steam hammers with a needle gage at the head of the hammer. If required, also measure inlet pressures during the driving of the production piles. A pressure-versus-speed calibration may be developed for the specific driving conditions at the project as an alternative to periodic measurements with a needle gage.

(5) *Nonimpact Hammers.* Do not use nonimpact hammers, such as vibratory hammers, unless permitted in writing, SHOWN ON THE DRAWINGS, or provided in the SPECIAL PROJECT SPECIFICATIONS. If permitted, use such equipment for installing production piles only after the pile tip elevation, or embedment length, for safe support of the pile load is established by static or dynamic load testing. Control the installation of production piles when using vibratory hammers by power consumption, rate of penetration, specified tip elevation, or other acceptable methods that will ensure the required pile load capacity is obtained. On 1 out of every 10 piles driven, strike with an impact hammer of suitable energy to verify that the required pile capacity is obtained.

(b) *Approval of Pile-Driving Equipment.* Furnish pile-driving equipment of such size that the production piles can be driven with reasonable effort to the required lengths without damage.

The Government will evaluate the suitability of the equipment and will accept or reject the driving system within 21 days of receipt of the pile and driving equipment information. Approval of pile-driving equipment will be based on a wave equation analysis under the following conditions:

- When dynamic load testing is required.
- When ultimate pile capacities exceed 2,400 kN.
- When precast or prestressed concrete piles are used.
- When double-acting or differential hammers, air, steam, or diesel are used.

When the wave equation analysis is not used, approval of the pile-driving equipment will be based on minimum hammer energy in table 551-1. Approval of a pile hammer relative to driving stress damage does not relieve the Contractor of responsibility for damaged piles.

Table 551-1.—Minimum pile hammer energy.

Ultimate Pile Capacity (kN)	Minimum Rated Hammer Energy (kJ)
≤ 800	14.0
1,330	21.2
1,600	28.1
1,870	36.0
2,140	44.9
2,400	54.4
> 2,400	Wave equation required

If the wave equation analysis shows an inability to drive the pile(s) to the required ultimate pile-bearing capacity with an acceptable blow count, or that pile damage will occur, change the proposed driving equipment until the wave equation analysis indicates that piles can be driven as specified. Submit proposed changes to the CO for review.

Approval of the pile-driving system is specific to the equipment submitted. If the proposed equipment is modified or replaced, resubmit the revised data for approval before using. The revised driving system will be accepted or rejected within 21 days of receipt of the revised pile, equipment, and wave equation analysis information (if required). Use only the approved equipment during pile-driving operations.

(1) *Equipment Submittal.* Submit two copies of the following pile-driving equipment information at least 30 days before driving piles. When dynamic load tests are required, submit a wave equation analysis performed by a pile specialty consultant who meets the requirements specified in Subsection 551.12(a). If dynamic load testing is not required, the Government will perform the wave equation analysis.

(a) *General.* Project and structure identification, pile driving contractor or subcontractor, and auxiliary methods of installation, such as jetting or preboring, and the type and use of the equipment.

(b) *Hammer.* Manufacturer, model, type, serial number, rated energy (_____ at _____ length of stroke), and modifications.

(c) *Capblock (Hammer Cushion).* Material, thickness, area, modulus of elasticity (E), and coefficient of restitution (e).

(d) *Pile Cap.* Helmet mass, bonnet mass, anvil block mass, and drivehead weight.

(e) *Pile Cushion.* Cushion material, thickness, area, modulus of elasticity (E), and coefficient of restitution (e).

(f) *Pile.* Pile type, length (in leads), mass per meter, wall thickness, taper, cross-sectional area, design pile capacity, description of splice, and tip treatment description.

(2) *Wave Equation.* The required number of hammer blows indicated by the wave equation at the ultimate pile capacity shall be between 3 and 15 per 25 mm. In addition, ensure that the pile stresses resulting from the wave equation analysis do not exceed the values at which pile damage is impending. The point of impending damage is defined for steel, concrete, and timber piles as follows:

(a) *Steel Piles.* Limit the compressive driving stress to 90 percent of the yield stress of the pile material.

(b) *Concrete Piles.* Limit the tensile (TS) and compressive (CS) driving stresses to:

$$TS - 3f'_c + EPV$$

$$CS - 0.85f'_c - EPV$$

where

$$f'_c = 28\text{-day design compressive strength of concrete}$$

$$EPV = \text{effective prestress value (prestressed piles only)}$$

(c) *Timber Piles.* Limit the compressive driving stress to 3 times the allowable static design stress.

(3) *Minimum Hammer Energy.* Ensure that the energy of the driving equipment submitted for approval, as rated by the manufacturer, is at least the energy specified in table 551-1 that corresponds to the required ultimate pile capacity.

(c) *Driving Appurtenances.* Furnish the driving appurtenances shown below.

(1) *Hammer Cushion.* Equip all impact pile-driving equipment, except gravity hammers, with a suitable thickness of hammer cushion material to prevent damage to the hammer or pile and to ensure uniform driving behavior. Fabricate hammer cushions from durable, manufactured material in accordance with the hammer manufacturer's recommendations. Do not use wood, wire rope, or asbestos hammer cushions. Place a striker plate, as recommended by the hammer manufacturer, on the hammer cushion to ensure uniform compression of the cushion material. Inspect the hammer cushion in the presence of the CO when beginning pile-driving at each bent or substructure unit or after each 100 hours of pile-driving, whichever is less. Replace the cushion when its thickness is reduced by more than 50 percent of its original thickness or when it begins to burn.

(2) *Pile Drive Head.* Provide adequate drive heads for impact hammers, and provide appropriate drive heads, mandrels, or other devices for special piles, in accordance with the manufacturer's recommendations. Align the drive head axially with the hammer and pile. Fit the drive head around the pile head so that it will prevent transfer of torsional forces during driving while maintaining proper alignment of hammer and pile.

(3) *Leads.* Support piles in line and position with leads while driving. Construct pile driver leads to allow freedom of movement of the hammer while maintaining axial alignment of the hammer and the pile. Do not use swinging leads unless permitted in writing, SHOWN ON THE DRAWINGS, or provided in the SPECIAL PROJECT SPECIFICATIONS. When swinging leads are permitted, fit swinging leads with a pile gate at the bottom of the leads and, in the case of battered piles, with a horizontal brace between the crane and the leads. Adequately embed the leads in the ground or constrain the pile in a structural frame (template) to maintain proper alignment. Provide leads of sufficient length that do not require a follower and will permit proper alignment of battered piles.

(4) *Followers.* Followers are not permitted unless approved in writing. When followers are permitted, drive the first pile in each bent or substructure unit and every tenth pile driven thereafter, full length without a follower, to verify that adequate pile embedment is being attained to develop the required ultimate pile capacity. Provide a follower of such material and dimensions that will permit the piles to be driven to the required penetration. Hold and maintain the follower and pile in proper alignment during driving.

(5) *Jetting.* Do not use jetting unless approved in writing. Provide jetting equipment with sufficient capacity to deliver a consistent pressure equivalent to at least 700 kPa at two 20-mm jet nozzles. Jet so as not to affect the lateral stability of the final in-place pile. Remove jet pipes when the pile tip is at least 1.5 m above the prescribed tip elevation, and drive the pile to the required ultimate pile capacity with an impact hammer. Control, treat, if necessary, and dispose of all jet water in an approved manner.

551.04 Pile Lengths. Unless otherwise specified, furnish piles with sufficient length to obtain the required penetration and bearing capacity and extend into the pile cap or footing as SHOWN ON THE DRAWINGS. In addition, increase the length to provide fresh heading and to provide for the Contractor's method of operation. When test piles are required, furnish piles in the lengths determined by the test piles, increased to provide for the Contractor's method of operation.

551.05 Test Piles. Construct test piles at locations SHOWN ON THE DRAWINGS. Excavate the ground at the site of each test pile or production pile to the elevation of the bottom of the footing or pile cap before the pile is driven. Furnish test piles that are longer than the estimated length of production piles. Drive test piles with the same equipment as the production piles.

Drive test piles to the required ultimate capacity at the estimated tip elevation. Allow test piles that do not attain the required ultimate capacity at the estimated tip elevation to "set up" for 24 hours before redriving. Warm the hammer before redriving begins by applying at least 20 blows to another pile. If the required ultimate capacity is not attained on redriving, drive a portion or all of the remaining test pile length and repeat the "set up" and redrive procedure as directed. Splice and continue driving until the required ultimate pile capacity is obtained.

Ensure that test piles that are used in the completed structure conform to the requirements for production piles. Remove test piles that are not incorporated into the completed structure to at least 0.5 m below finished grade.

Do not order piling to be used in the completed structure until test pile data have been reviewed and the production pile order lengths are determined. The CO will provide an estimated length list or pile order list within 10 days after completion of all test pile driving.

551.06 Driven-Pile Capacity. Drive piles with approved pile-driving equipment to the specified penetration and to the depth necessary to obtain the required ultimate pile capacity. Splice piles that do not obtain the required ultimate capacity at the ordered length and drive with an impact hammer until the required ultimate pile capacity is achieved.

Use the dynamic formula to determine ultimate pile capacity of the in-place pile, unless the wave equation is required in accordance with Subsection 551.03(b).

(a) **Wave Equation.** Adequate penetration will be considered to be obtained when the specified wave equation resistance criteria are achieved within 1.5 m of the designated tip elevation as SHOWN ON DRAWINGS. Drive any piles that do not achieve the specified resistance within these limits to a penetration determined by the CO.

(b) **Dynamic Formula.** Drive the piles to the penetration necessary to obtain the ultimate pile capacity in accordance with the following formula:

$$Ru = (7\sqrt{E \log(10N)}) - 550$$

where

Ru = ultimate pile capacity in kilonewtons

E = manufacturer's rated hammer energy in joules at the ram stroke observed or measured in the field

$E = W \times H \times 9.81$

W = mass kilograms of striking parts of hammer

H = meter height of fall of the ram measured during pile driving in the field

$\log(10N)$ = logarithm to the base 10 of the quantity 10 multiplied by N

N = number of hammer blows per 25 mm at final penetration

Solving for N :

$$N = 10^x$$

$$x = \left(\frac{Ru + 550}{7\sqrt{E}} \right) - 1$$

Factor of Safety (FS) = 3.0

(1) **Jetted Piles.** Determine the in-place ultimate capacity of jetted piles based on impact hammer blow counts (dynamic formula) after the jet pipes have been removed. After the pile penetration length necessary to produce the required ultimate pile capacity has been determined by impact hammer blow count, install the remaining piles in each group or in each substructure unit to similar depths with similar methods. Confirm that the required ultimate pile capacity has been achieved by using the dynamic formula.

(2) **Vibratory Hammers.** The ultimate bearing capacity of piles driven with vibratory hammers will be based on impact driving blow count after the vibratory equipment has been removed. When vibratory installation of the piles is approved

by the CO and the vibrated piles do not attain the required ultimate pile-bearing capacity at the specified length, splice them as required without compensation, and drive with a specified impact pile hammer until the required ultimate pile-bearing capacity is achieved.

(3) *Conditions for Dynamic Formula.* The dynamic formula is applicable only if all of the following criteria apply:

- (a) The hammer is in good condition and operating in a satisfactory manner.
- (b) The hammer ram falls freely.
- (c) A follower is not used.
- (d) The head of the pile is not broomed or crushed.

(c) **“Set Period” & Redriving.** If piles do not attain the required bearing capacity when driven to the specified length, allow the piles to stand for a “set period” without driving. The “set period” shall be a minimum of 24 hours unless otherwise approved by the CO. After the “set period,” perform check driving on either 2 piles in each bent or on 1 pile in 10 piles, whichever is more. The CO will designate the piles on which check driving is to be performed. Do not use a cold hammer for redriving. Warm up the hammer before redriving begins by applying at least 20 blows to another pile. Perform redriving by driving the pile to the required bearing with a maximum of 15 blows. If the specified hammer blow count is not attained on redriving, the CO may require driving all of the remaining pile length and repeating the “set period” and redriving procedure. Splice any piles driven to plan grade that do not attain the hammer blow count required, and drive until the required bearing is obtained. If the required bearing capacity is attained for each pile that is redriven, then the remaining piles in that bent will be considered satisfactory when driven to at least the same penetration and resistance as the redriven piles.

551.07 Preboring. Unless otherwise provided in the SPECIAL PROJECT SPECIFICATIONS, prebore holes to natural ground when piles are driven through compacted embankments more than 1.5 m in depth. Use augering, wet rotary drilling, or other approved methods of preboring. Except for piles end bearing on rock or hardpan, stop preboring at least 1.5 m above the pile tip elevation and drive the pile with an impact hammer to a penetration that achieves the required ultimate pile capacity. Preboring may extend to the surface of the rock or hardpan where piles are to be end bearing on rock or hardpan. Seat installed piles into the end bearing strata.

Prebore holes smaller than the diameter or diagonal of the pile cross section while allowing penetration of the pile to the specified depth. If subsurface obstructions such as boulders or rock layers are encountered, the hole diameter may be increased to the least dimension adequate for pile installation. After driving is completed,

fill any void space remaining around the pile with sand or other approved material. Do not use a punch or a spud in lieu of preboring.

Do not impair the carrying capacity of existing piles or the safety of adjacent structures. If preboring disturbs the load carrying capacities of previously installed piles or structures, restore the required ultimate capacity of piles and structures by approved methods.

551.08 Jetting. Jetting will be permitted only when SHOWN ON THE DRAWINGS or approved in writing by the CO. When jetting is not required, but approved at the Contractor's request, determine the number of jets and the volume and pressure of water at the jet nozzles necessary to freely erode the material adjacent to the pile without affecting the lateral stability of the final in-place pile. Control, treat if necessary, and dispose of all jet water in a satisfactory manner. Drive all jetted piles with an approved impact hammer.

551.09 Preparation & Driving. Perform the work specified in Section 206 prior to driving piles. Make the heads of all piles plane and perpendicular to the longitudinal axis of the pile. Coordinate pile driving so as not to damage other parts of the completed work.

Drive piles to within 50 mm of plan location at cutoff elevation for bent caps, and within 150 mm of plan location for piles capped below finished ground. Ensure that the pile is no closer than 100 mm to any cap face and no closer than 225 mm to the face of any footing. Drive piles so that the axial alignment is within 20 mm/m of the required alignment. The CO may stop driving to check the pile alignment. Check the alignment of piles that cannot be internally inspected after installation before the last 1.5 m are driven. Do not pull laterally on piles or splice to correct misalignment. Do not splice a properly aligned section on a misaligned pile.

Unless otherwise SHOWN ON THE DRAWINGS, drive piles at least 5 m below the footing or cap. If the required minimum penetration cannot be obtained, provide a larger hammer, prebore or jet holes, or use other methods approved by the CO and in accordance with Subsection 551.03.

If the specified location and/or alignment tolerances are exceeded, the effect of the pile misalignment on the substructure design will be investigated. If the CO determines that corrective measures are necessary, implement suitable measures to correct the problem without compensation.

Place individual piles in pile groups, either starting from the center of the group and proceeding outward in both directions, or starting at the outside row and proceeding progressively across the group.

In an approved manner, correct all piles that are driven improperly, driven out of proper location, misaligned, or driven below the designated cutoff elevation. Replace piles damaged during handling or driving. Obtain approval for the proposed method(s) of correcting or repairing deficiencies.

Ensure that the method used in driving piles does not produce crushing and spalling of the concrete; injurious splitting, splintering, and brooming of the wood; or deformation of the steel.

(a) Timber Piles. Use piling that meets the minimum diameter requirements SHOWN ON THE DRAWINGS. Do not use piles with checks wider than 15 mm. Drive treated timber piles within 6 months after treatment. Handle and care for pressure-treated piles in accordance with American Wood Preservers Association (AWPA) standard M 4 and applicable portions of Subsection 557.04.

Install pile shoes as SHOWN ON THE DRAWINGS. Carefully shape the pile tip to secure an even, uniform bearing for the pile shoe. Fasten the shoe securely to the pile. Treat all holes, cuts, or daps in treated piles with two brush applications of creosote-coal tar solution or other preservative, as provided in the SPECIAL PROJECT SPECIFICATIONS.

Regulate the drop of the hammer to avoid damage to the pile if driving with a gravity hammer is permitted.

Select piles for any one bent to avoid undue bending or distortion of the sway bracing. Exercise care in the distribution of piles of various sizes to obtain uniform strength and rigidity in the bents of any given structure.

(b) Steel Piles. Furnish full length unspliced piles for lengths up to 18 m. If splices are required in the first pile driven and it is anticipated that subsequent piles will also require splices, place the splices in the lower one-third of the pile. Splice lengths less than 3 m are not permitted, and only two splices per pile are allowed, unless otherwise approved by the CO.

Load, transport, unload, store, and handle steel piles so that the metal is kept clean and free from damage. Do not use piles that exceed the camber and sweep permitted by allowable mill tolerance. Steel piles damaged during installation are considered unsatisfactory unless load tests prove that the bearing capacity is 100 percent of the required ultimate capacity. Load tests performed will be at no cost to the Government.

(c) Precast & Prestressed Concrete Piles. Support concrete piles during lifting or moving at the points SHOWN ON THE DRAWINGS or approved shop drawings. If points are not shown, provide support at the quarter points. Provide slings or other

equipment when raising or transporting concrete piles to avoid bending the pile or breaking edges.

Protect the heads of concrete piles with a pile cushion at least 100 mm thick. Cut the pile cushion to match the cross section of the pile top. Replace the pile cushion if it is either compressed more than one-half its original thickness or begins to burn. Provide a new pile cushion for each pile.

A concrete pile is defective if any defect is observed that will affect the strength or long-term performance of the pile.

(d) Concrete-Filled Pipe or Steel Shell Piles. Furnish and handle the steel shells or pipes in accordance with Subsection 551.09(b). Cutting shoes for shells or pipes may be inside or outside the shell. Use high-carbon structural steel with a machined ledge for shell bearing or cast steel with a ledge designed for attachment with a simple weld.

When practicable, drive all pile shells or pipes for a substructure unit prior to placing concrete in any of the shells or pipes. Do not drive pile shells or pipes within 5 m of any concrete-filled pile shell or pipe until the concrete has cured for at least 7 days, or 3 days if using high-early-strength concrete. Do not drive any pile shell or pipe after it is filled with concrete.

Remove and replace shells that are determined to be unacceptable for use due to breaks, bends, or kinks.

551.10 Splices. Submit details for pile field splices for approval. Align and connect pile sections so the axis of the spliced pile is straight.

(a) Steel Piles. Submit a welder certification for each welder. Use welders certified for structural welding.

Make surfaces to be welded smooth, uniform, and free from loose scale, slag, grease, or other material that prevents proper welding. Steel may be oxygen cut. Carbon-arc gouging, chipping, or grinding may be used for joint preparation.

Weld in accordance with AASHTO/American Welding Society (AWS) D 1.5, Bridge Welding Code. Weld the entire pile cross section using prequalified AWS groove weld butt joints. Weld so there is no visual evidence of cracks, lack of fusion, undercutting, excessive piping, porosity, or inadequate size. Manufactured splices may be used in place of full penetration groove butt welds.

(b) Concrete Pile Splices. Submit drawings of proposed splices for approval. Use dowels or other acceptable mechanical means to splice precast concrete or precast

prestressed concrete piles. Ensure that the splice develops strengths in compression, tension, and bending equal to or exceeding the strength of the pile being spliced.

(c) **Concrete Pile Extensions.** Construct precast concrete piles and prestressed piles as shown below.

(1) **Precast Concrete Piles.** Extend precast concrete piles by removing the concrete at the end of the pile and leaving 40 diameters of reinforcement steel exposed. Remove the concrete to produce a face perpendicular to the axis of the pile. Securely fasten reinforcement of the same size as that used in the pile to the projecting reinforcing steel. Form the extension to prevent leakage along the pile.

Immediately before placing concrete, wet the top of the pile thoroughly and cover with a thin coating of neat cement, retempered mortar, or other approved bonding material. Place concrete of the same mix design and quality as that used in the pile. Keep forms in place for not less than 7 days after the concrete has been placed. Cure and finish in accordance with Section 552.

(2) **Prestressed Piles.** Extend prestressed precast piles in accordance with Subsection 551.10(c)(1). Include reinforcement bars in the pile head for splicing to the extension bars. Do not drive extended prestressed precast piles.

(d) **Timber Piles.** Do not splice timber piles.

551.11 Heaved Piles. Check for pile heave during the driving operation. Take level readings immediately after each pile is driven and again after piles within a radius of 5 m are driven. Redrive all piles that heave more than 5 mm. Redrive to the specified resistance or penetration. Continue readings until the CO determines that such checking is no longer required.

551.12 Pile Load Tests. Pile load tests are not required unless SHOWN ON THE DRAWINGS.

(a) **Dynamic Load Test.** Use a qualified pile specialty consultant with at least 3 years experience in dynamic load testing and analysis, to perform the dynamic load test, the Case Pile Wave Analysis Program (CAPWAP), and the wave equation analysis including the initial wave analysis specified in Subsection 551.03(b)(1). Submit a resume of the specialty consultant for approval by the CO.

Furnish a shelter to protect the dynamic test equipment from the elements. Locate the shelter within 15 m of the test location. Provide a shelter with a minimum floor size of 6 m² and minimum ceiling height of 2 m. Maintain the inside temperature between 10 °C and 35 °C.

Furnish equipment and perform dynamic load tests in accordance with ASTM D 4945 under the supervision of the CO.

Place the piles designated as dynamic load test piles in a horizontal position and not in contact with other piles. Drill holes for mounting instruments near the head of the pile. Mount the instruments and take wave speed measurements. Place the designated pile in the leads. Provide at least a 1.2 x 1.2-m rigid platform, with a 1.1-m safety rail, that can be raised to the top of the pile.

Provide a suitable electrical power supply for the test equipment. If field generators are used as the power source, provide functioning meters for monitoring power voltage and frequency.

Drive the pile to the depth at which the dynamic test equipment indicates that the required ultimate pile capacity is achieved. If necessary to maintain stresses in the pile below the values shown in Subsection 551.03(b)(2), reduce the driving energy transmitted to the pile by using additional cushions or reducing the energy output of the hammer. If nonaxial driving is indicated, immediately realign the driving system.

At least 24 hours after the initial driving, redrive each dynamic load test pile with instrumentation attached. Warm the hammer before redriving by applying at least 20 blows to another pile. Redrive the dynamic load test pile for a maximum penetration of 150 mm or a maximum of 50 blows, whichever occurs first. Practical driving refusal is defined as 15 blows per 25 mm for steel piles, 8 blows per 25 mm for concrete piles, and 5 blows per 25 mm for timber piles.

Verify the assumptions used in the initial wave equation analysis submitted in accordance with Subsection 551.03(b) using CAPWAP. Analyze one blow from the original driving and one blow from the redriving for each pile tested.

Perform additional wave equation analyses with adjustments based on the CAPWAP results. Provide a graph showing blow count versus ultimate capacity. For open-end diesel hammers, provide a blow count versus stroke graph for the ultimate capacity. Provide the driving stresses, transferred energy, and pile capacity as a function of depth for each dynamic load test.

Based on the results of the dynamic load testing, CAPWAP analyses, and wave equation analyses, the production driving criteria may be approved by the CO, who will provide the order list and the required cutoff elevations, or additional pile penetration and testing may be specified. This information will be provided within 10 days after receipt of all required test data for the test piles driven.

(b) Static Load Tests. Perform static load tests in accordance with ASTM D 1143 using the quick load test method, except as modified herein. Submit drawings of

the proposed loading apparatus for approval by the CO, in accordance with the following:

- (1) Have a licensed professional engineer prepare the drawings.
- (2) Furnish a loading system capable of applying 150 percent of the ultimate pile capacity or 9,000 kN, whichever is less.
- (3) Construct the apparatus to allow increments of load to be placed gradually without causing vibration to the test pile.

When tension (anchor) piles are required, drive tension piles at the location of permanent piles when feasible. Do not use timber or tapered piles installed in permanent locations as tension piles. Take the test to plunging failure or the capacity of the loading system.

The safe axial pile load is defined as 50 percent of the failure load. The failure pile load is defined as follows:

- For piles 600 mm or less in diameter or diagonal width:

$$S_f = S + (3.8 + 0.008 D)$$

- For piles greater than 600 mm in diameter or diagonal width:

$$S_f = S + \frac{D}{30}$$

where

S_f = settlement at failure in millimeters

D = pile diameter or diagonal width in millimeters

S = elastic deformation of pile in millimeters

Determine top elevation of the test pile immediately after driving and again just before load testing to check for heave. Wait a minimum of 3 days between the driving of any anchor or the load test piles and the commencement of the load test. Prior to testing, redrive or jack to the original elevation any pile that heaves more than 6 mm.

After completion of static testing, remove or cut off any test or anchor piling not a part of the finished structure at least 500 mm below either the bottom of the footing or the finished ground elevation.

Based on the results of the static load testing, the production driving equipment may be approved by the CO, who will provide the order list and the required cutoff elevations, or additional tests may be specified. This information will be provided within 10 days after receipt of all required test data for the test piles driven.

551.13 Pile Cutoffs. Cut off the tops of all production piles and pile casings at the required elevation. Cut off the piles clean and straight parallel to the bottom face of the structural member in which they are embedded.

Ensure full bearing between timber caps and piles by making accurate, square cuts.

Remove all unused pile cutoff lengths and dispose of them in accordance with applicable State and local laws and regulations. Dispose of treated timber pile cutoffs in accordance with the requirements of Subsection 202.04(a) for disposal of treated material.

(a) Steel Piles. Do not paint steel to be embedded in concrete. Before painting the exposed steel pile, thoroughly clean the metal surface of any substance that will inhibit paint adhesion. Paint in accordance with Section 563. Paint portions of completed trestle or other exposed piling to a point not less than 1 m below finished groundline or to the waterline, as SHOWN ON THE DRAWINGS or as provided in the SPECIAL PROJECT SPECIFICATIONS.

(b) Wood Piles. When possible, cut the top of the pile on a bevel. Treat the heads of all treated timber piles that are not embedded in concrete using one of the following methods:

- (1) Where possible, reduce the moisture content of the wood to no more than 25 percent and allow no free moisture on the surface. Brush on one application of creosote-coal tar solution as required in AWPAs standards, or preservatives as provided in the SPECIAL PROJECT SPECIFICATIONS.
- (2) Build up a protective cap by applying alternate layers of loosely woven fabric and hot asphalt or tar similar to membrane waterproofing, using three layers of asphalt or tar and two layers of fabric. Use fabric at least 150 mm wider in each direction than the diameter of the pile. Turn the fabric down over the pile and secure the edges by binding with two turns of 3-mm-diameter galvanized wire. Apply a final layer of asphalt or tar to cover the wire. Neatly trim the fabric below the wires.
- (3) Cover the sawed surface with three applications of a hot mixture of 60 percent creosote and 40 percent roofing pitch, or thoroughly brush coat with three applications of hot creosote and cover with hot roofing pitch.

551.14 Unsatisfactory Piles. Correct unsatisfactory piles using an approved method. Methods of correcting unsatisfactory piles may include one or more of the following:

- (a) Using the pile at a reduced capacity.
- (b) Installing additional piles.
- (c) Repairing damaged piles.
- (d) Replacing damaged piles.
- (e) Splicing on additional length(s) and driving, when necessary.
- (f) Building up pile(s).

551.15 Placing Concrete in Steel Shell or Pipe Piles. After driving, clean the inside of shells and pipes by removing all loose material. Keep the shell or pipe substantially watertight. Provide suitable equipment for inspecting the entire inside surface of the driven shell or pipe just before placing concrete.

(a) **Reinforcing Steel.** When reinforcing steel is required, make the spacing between adjacent cage elements at least 5 times the maximum size of aggregate in the concrete.

Securely tie concrete spacers or other approved spacers at fifth points around the perimeter of the reinforcing steel cage. Install spacers at intervals not to exceed 3 m measured along the length of the cage.

Place the reinforcement cage into the driven shell or pipe when the concrete reaches the lower limits of the reinforcement. Support the reinforcement so it remains within 50 mm of the required vertical location. Support the cage from the top until the concrete reaches the top of the pile.

(b) **Concrete.** Construct concrete in accordance with Section 552. Place concrete in one continuous operation from the bottom to the top of the pile. Before the initial concrete set, consolidate the top 3 m of the concrete pile using approved vibratory equipment.

Measurement

551.16 Method. Use the method of measurement that is DESIGNATED IN THE SCHEDULE OF ITEMS.

Measure piles by the meter or by the each. When measurement is by the meter, measure the length of pile from the cutoff elevation rounded to the tip.

Measure pile load tests by the each or by the lump sum.

Measure preboring by the meter.

Measure splices by the each for those made as required to drive piling in excess of the estimated plan tip elevation.

Measure test piles and pile shoes by the each.

Payment

551.17 Basis. The accepted quantities will be paid for at the contract unit price for each PAY ITEM DESIGNATED IN THE SCHEDULE OF ITEMS.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
551(01) _____ piles, furnished	Meter
551(02) _____ piles, driven	Meter
551(03) _____ piles, furnished	Each
551(04) _____ piles, driven	Each
551(05) _____ pile load test	Each
551(06) _____ pile load test	Lump Sum
551(07) Preboring	Meter
551(08) Splices	Each
551(09) Test piles	Each
551(10) Pile shoes	Each

Section 552—Structural Concrete

Description

552.01 Work. Furnish, place, finish, and cure concrete in bridges, culverts, and other structures.

Structural concrete class is designated as shown in table 552-1.

Table 552-1.—Composition of concrete.

Class of Concrete	Minimum Cement Content (kg x m ³)	Maximum W/C Ratio	Slump ^a (mm)	Minimum Air Content ^b (%)	Coarse Aggregate AASHTO M 43
A	360	0.49	50–100	–	No. 57
A(AE)	360	0.44	25–100	5.0	No. 57
C	390	0.49	50–100	–	No. 7
C(AE)	390	0.44	25–75	6.0	No. 7
P	390	0.44	0–100	–	No. 67
Seal	390	0.54	100–200	–	No. 57

a. Maximum slump is 200 mm if approved mix design includes a high-range water reducer.

b. See Subsection 552.03 for maximum air content.

Materials

552.02 Requirements. Furnish material that conforms to specifications in the following subsections:

Air-Entraining Admixtures	711.02
Boiled Linseed Oil	725.14
Chemical Admixtures	711.03
Coarse Aggregate	703.02
Color Coating	725.23
Curing Material	711.01
Elastomeric Bearing Pads	717.10
Elastomeric Compression Joint Seals	717.16
Epoxy Resin Adhesives	725.21
Fine Aggregate	703.01
Fly Ash	725.04
High-Strength Nonshrink Grout	701.02
Latex Modifier	711.04
Low-Strength Grout	701.03
Mortar	701.04
Portland Cement	701.01

Sealants, Fillers, Seals, & Sleeves 712.01
Water 725.01

Construction

552.03 Composition (Concrete Mix Design). Design and produce concrete mixtures that conform to table 552-1 for the class of concrete specified and the minimum strength requirements as SHOWN ON THE DRAWINGS or in Subsection 552.04. Determine design strength values in accordance with ACI 214. Ensure that structural concrete also conforms to the following ACI specifications:

- ACI 211.1 for normal and heavyweight concrete.
- ACI 211.2 for lightweight concrete.
- ACI 211.3 for no-slump concrete.

Submit written concrete mix designs for approval at least 30 days before production. Include the following in each mix design submittal:

- (a) Project identification.
- (b) Name and address of Contractor and concrete producer.
- (c) Mix design designation.
- (d) Class of concrete and intended use.
- (e) Material proportions.
- (f) Name and location of material sources for aggregate, cement, admixtures, and water.
- (g) Type of cement and type of cement replacement, if used. Fly ash, ground iron blast-furniture slag, or silica fume may partially replace cement as follows in any mix design except for prestressed concrete:
 - (1) Fly ash.
 - (a) Class F. Not more than 20 percent of the minimum weight of Portland cement in table 552-1 may be replaced with class F fly ash at the rate of 1.5 parts fly ash per 1 part cement.
 - (b) Class C. Not more than 25 percent of the minimum mass of Portland cement in table 552-1 may be replaced with class C fly ash at the rate of 1 part fly ash per 1 part cement.

- (2) Ground iron blast-furnace slag. Not more than 50 percent of the minimum mass of Portland cement in table 552-1 may be replaced with ground iron blast-furnace slag at the rate of 1 part slag per 1 part cement.
- (3) Silica fume (microsilica). Not more than 10 percent of the minimum mass of Portland cement in table 552-1 may be replaced with silica fume at the rate of 1 part silica fume per 1 part cement.

The water/cement ratio for modified concrete is the ratio of the mass of water to the combined masses of Portland cement and cement substitute.

- (h) Cement content in kilograms per cubic meter of concrete.
- (i) The saturated surface dry batch weight of the coarse and fine aggregate in kilograms per cubic meter of concrete.
- (j) Water content (including free moisture in the aggregate plus water in the drum, exclusive of absorbed moisture in the aggregate) in kilograms per cubic meter of concrete.
- (k) Target water/cement ratio.
- (l) Dosage of admixtures. Entrained air may be obtained either by the use of an air-entraining Portland cement, or by the use of an air-entraining admixture. Do not use set-accelerating admixtures with class P (prestressed) concrete. Do not mix chemical admixtures from different manufacturers.
- (m) Sieve analysis of fine and coarse aggregate.
- (n) Absorption of fine and coarse aggregate.
- (o) Bulk specific gravity (dry and saturated surface dry) of fine and coarse aggregate.
- (p) Dry rodded unit mass of coarse aggregate in kilograms per cubic meter.
- (q) Fineness modulus (FM) of fine aggregate.
- (r) Deleterious substances (coarse and fine aggregate); clay lumps and friable particles; material finer than the 75- μm sieve; coal and lignite (AASHTO M 80 7.1.6); chert (coarse aggregate only); and organic impurities (fine aggregate only).
- (s) Evaluation of potential aggregate reactivity.
- (t) Percentage of wear (L.A.R.) for coarse aggregate only.
- (u) Sand equivalent (fine aggregate only).

- (v) Material certifications for cement, admixtures, and aggregate.
- (w) TV's for concrete slump with and without high-range water reducers.
- (x) TV's for concrete air content. Include the proposed range of air content for concrete to be incorporated into the work. Describe the methods by which air content will be monitored and controlled. Provide acceptable documentation that the slump and compressive strength of the concrete are within specified limits throughout the full range of proposed air content. In the absence of such acceptable documentation, ensure that the maximum air content is 10 percent.
- (y) Concrete unit mass.
- (z) Compressive strengths of 7- and 28-day concrete. Pending 28-day strength results, a mix design may be approved on the basis that the 7-day compressive strength results equal or exceed 85 percent of the minimum strength requirements, when no accelerators or early strength cements are used.
- (aa) Material samples, if requested.

Use a testing laboratory that is fully equipped and capable of performing the required tests and services. Base the mix design on representative samples of aggregates, cement, water, and admixtures to be used on the project. Take aggregate samples in accordance with AASHTO T 2 and reduce to testing size in accordance with AASHTO T 248. Submit a separate proposed mix design for each class of concrete to the CO for review.

Current mix designs for other projects may be acceptable, provided that all items required herein are covered by certified submittals. Ensure that mix design and aggregate quality tests from other projects have been run within 12 months of the date of submittal, and that the aggregate source is the same.

Begin production only after the mix design is approved.

Furnish a new mix design for approval if there is a change in a source of material, or when the FM of the fine aggregate changes by more than 0.20.

Use type II cement for all classes of concrete, but use type III cement when concrete work is permitted by the CO in air temperatures below 2 °C. Type III cement may be used in class A and seal concrete with the approval of the CO. Type III cement may be used in class P concrete when documented in the approved mix design.

552.04 Concrete Compressive Strength. Use the minimum 28-day compressive strength for the given classes of concrete shown in table 552-2, unless otherwise SHOWN ON THE DRAWINGS.

Table 552-2.—Specified minimum concrete strength (MPa).

Concrete Class	At Time of Transfer of Prestress Force		
	7-Day	28-Day	
A & A(AE)	—	15.9	24.2
C & C(AE)	—	18.2	27.7
P	31.5	—	40
P (AE)	31.5	—	34.5
Seal	—	13.8	20.7

Make two standard test specimens for a strength test. Take enough specimens to make at least one 7-day strength test and one 28-day strength test (a minimum total of four specimens) for each structural element. Use the average of the strengths of the two specimens for test result, but discard any specimen that shows definite evidence, other than low strength, of improper sampling, molding, handling, curing, or testing, and consider the strength of the remaining cylinder to be the test result.

Extend the standard 28-day curing period for compressive strength tests for fly-ash-modified concrete by 1 day (rounded to the nearest whole day) for each 1.5 percent of Portland cement replaced with fly ash at the selected rate. (Example: If the maximum of 20 percent cement is replaced, the curing period for cylinders is 41 days.)

552.05 Storage & Handling of Material. Store and handle all material in a manner that prevents segregation, contamination, or other harmful effects. Do not use cement and fly ash containing evidence of moisture contamination. Store and handle aggregate in a manner that ensures a uniform moisture content at the time of batching.

Obtain the CO's approval before using cement that has been stored on the site for more than 60 days. Provide separate storage of cement that is of different blends, types, or from different mills.

552.06 Measuring Material. Batch the concrete in accordance with the approved mix design and the following tolerances:

Cement	± 1%
Water	± 1%
Aggregate	± 2%
Additive	± 3%

Submit to the CO, for approval, a written procedure for adding the specified amount of admixture. Provide separate scales for the admixtures that are to be proportioned by mass and accurate measures for those to be proportioned by volume.

A calibrated volumetric system may be used if the specified tolerances are maintained.

552.07 Batching Plant, Mixers, & Agitators. Use a batching plant, mixer, and agitator conforming to AASHTO M 157. Use continuous volumetric mixing equipment that conforms to AASHTO M 241.

552.08 Mixing. Mix the concrete in a central-mix plant or in truck mixers. Operate all equipment within manufacturer's recommended capacity. Produce concrete of uniform consistency.

(a) Central-Mix Plant. Dispense liquid admixtures through a controlled flowmeter. Use dispensers with sufficient capacity to measure, at one time, the full quantity of admixture required for each batch. If more than one admixture is used, dispense each with separate equipment.

Charge the coarse aggregate, one-third of the water, and all air-entraining admixture into the mixer first, then add remainder of the material.

Mix for at least 50 seconds. Begin mixing time after all cement and aggregate are in the drum. Add the remaining water during the first quarter of the mixing time. Add 4 seconds to the mixing time if timing starts the instant the skip reaches its maximum raised position. Transfer time in multiple-drum mixers is included in mixing time. Mixing time ends when the discharge chute opens.

Remove the contents of an individual mixer before a succeeding batch is charged into the drum.

(b) Truck Mixer. Do not use mixers with any section of the blades worn 25 mm or more below the original manufactured height. Do not use mixers and agitators with accumulated hard concrete or mortar in the mixing drum.

Add admixtures to the mix water before or during mixing.

Charge the batch into the drum so a portion of the mixing water enters in advance of the cement.

Mix each batch of concrete not less than 70 or more than 100 revolutions of the drum or blades at mixing speed. Begin the count of mixing revolutions as soon as all material, including water, is in the mixer drum.

Do not allow the sum of all drum revolutions at both mixing and agitating speeds to exceed 300 before all concrete has been discharged from the drum; but ensure that the sum of all drum revolutions does not exceed 200 if the outside air temperature is over 30 °C. If mixing is done before arrival of the truck at the point of delivery, rotate the drum at mixing speed for 10 to 15 revolutions to reblend possible stagnant spots.

If set-retarding admixture is used, do not allow the sum of all drum revolutions at both mixing and agitating speeds to exceed 550 before all concrete has been discharged from the drum; but ensure that the sum of all drum revolutions does not exceed 450 if the outside air temperature is over 30 °C.

Do not handmix except in case of emergency and with the written approval of the CO. When permitted, perform only on watertight platforms. Do not exceed 0.1 m³ volume for handmixed batches. Do not permit handmixing for concrete that is to be placed under water.

552.09 Delivery. Submit a written schedule of concreting operations, including scheduling, personnel, and equipment, when requested by the CO. Provide the CO 24-hour notice prior to placing any concrete.

Produce and deliver concrete to permit a continuous placement. Do not permit concrete to achieve initial set before the remaining concrete is placed adjacent to it. Never allow the time interval between placement to exceed 30 minutes. Use methods of delivering, handling, and placing that will minimize rehandling of the concrete and prevent any damage to the structure.

Do not place concrete that has developed an initial set. Never retemper concrete by adding water.

(a) **Truck Mixer/Agitator.** Use the agitating speed for all rotation after mixing. When a truck mixer or truck agitator is used to transport concrete that is completely mixed in a stationary central construction mixer, mix during transportation at manufacturer's recommended agitating speed.

Water and admixtures (if in the approved mix design) may be added at the project to obtain the required slump or air content, provided that the total of all water in the mix does not exceed the maximum water/cement ratio. If additional water is necessary, add only once and remix with 30 revolutions at mixing speed. Complete the remixing within 45 minutes (75 minutes for type I, IA, II, or IIA cements with water-reducing or -retarding admixture) after the initial introduction of the mixing water to the cement or the cement to the aggregates.

After the beginning of the addition of the cement, complete the discharge of the concrete within the time specified in table 552-3, unless otherwise approved by the CO or as allowed by the SPECIAL PROJECT SPECIFICATIONS.

Table 552-3.—Concrete discharge time limits.

Cement Type With and Without Admixtures	Time Limit (h)	
	≤ 30 °C	> 30 °C
Type I, IA, II, or IIA	1.50	1.00
Type I, IA, II, or IIA with water-reducing or -retarding admixture	2.00	1.50
Type III	1.25	0.75
Type III with water-reducing or -retarding admixture	1.75	1.25

Note: Temperatures are ambient air measured on formwork.

(b) Nonagitating Equipment. Nonagitating equipment may be used to deliver concrete if the concrete discharge is completed within 20 minutes from the beginning of the addition of the cement to the mixing drum. Use equipment with smooth, mortar-tight, metal containers capable of discharging the concrete at a controlled rate without segregation. Provide covers when needed for protection.

552.10 Quality Control of Mix. Submit and follow a quality control plan for the following:

(a) Mixing. Designate a competent and experienced concrete technician to be at the mixing plant in charge of the mixing operations and to be responsible for the overall quality control, including:

- (1) The proper storage and handling of all components of the mix.
- (2) The proper maintenance and cleanliness of plant, trucks, and other equipment.
- (3) The gradation testing of fine and coarse aggregates.
- (4) The determination of the FM of fine aggregate.
- (5) The measurement of moisture content of the aggregates and adjustment of the mix proportions, as required before each day's production, or more often if necessary, to maintain the required water/cement ratio.
- (6) The computation of the batch weights for each day's production and the checking of the plant's calibration as necessary.
- (7) The completion of batch tickets. Include the following information:
 - (a) Concrete supplier.
 - (b) Ticket serial number.
 - (c) Date and truck number.
 - (d) Contractor.
 - (e) Structure or location of placement.
 - (f) Mix design and concrete class.
 - (g) Component quantities and concrete total volume.
 - (h) Moisture corrections for aggregate moisture.
 - (i) Total water in mix at plant.
 - (j) Time of batching and time at which discharge must be completed.

(k) Maximum water that may be added to the mix at the jobsite.

Provide equipment necessary for the above tests and controls. Furnish copies of work sheets for items (3), (4), (5), and (6) as they are completed.

(b) Delivery & Sampling. Designate at least one competent and experienced concrete technician to be at the project and be responsible for concrete delivery, discharge operations, and sampling, including:

- (1) The verification that adjustments to the mix before discharge comply with the specifications.
- (2) The completion of the batch ticket, the recording of the apparent water/cement ratio, and the time discharge is completed. Furnish a copy of each batch ticket at the time of placement.
- (3) The furnishing of all equipment and the performance of temperature, unit weight, air content, slump, and other tests to verify specification compliance before and during each placement operation.

Sample every batch after at least 0.2 m³ are discharged and before placing any of the batch in the forms. When continuous mixing is used, sample approximately every 10 m³. Test the air content in accordance with AASHTO T 152 or T 196, and evaluate the result based on a single test or the average of two tests.

Test slump and temperature of each batch in accordance with AASHTO T 119 and AASHTO T 152 or T 196.

If three successive samples are tested and compliance with the specifications is indicated, screening tests may be reduced to a frequency approved by the CO. Resume initial testing frequency if a test shows a failing temperature, air content, or slump, or when directed.

If there is no prior experience with the approved mix design or if special handling procedures, such as pumping, change one or more of the characteristics between discharge of the load and placement in the forms, correlate the discharge tests with the placement tests to define these changes. Provide documentation. Repeat the correlations as often as necessary or as directed.

- (4) The taking of samples for strength tests in accordance with AASHTO T 141 and T 23 from batches specified by the CO. Composite samples are not required. The point of sampling is from the discharge stream at the point of placement. Provide cylinder molds. Make compressive strength test

cylinders as directed by the CO, provide the appropriate initial curing, and carefully transport the cylinders to the jobsite curing facility. Cylinders will be used for 28-day breaks, verification, projected strengths, or other purposes specified. Assist in the performing of other tests as requested.

(c) **Testing.** Determine compressive strength of concrete test cylinders in accordance with AASHTO T 22, and of drilled concrete cores in accordance with AASHTO T 24.

Ensure that the average of all the strength tests representing the concrete in each structural element meets the following requirements:

- (1) For concrete in structures designed by the service load method, when seven or more strength tests are available, not more than 20 percent of the strength tests shall have values less than the specified strength, and the average of any six consecutive strength tests shall be equal to or greater than the specified strength. This paragraph does not apply to designs by the strength method where the service load method was used to check fatigue and crack control.
- (2) For concrete in structures designed by the strength method and in all prestressed members, when seven or more strength tests are available, not more than 10 percent of the strength tests shall have values less than the specified strength, and the average of any three consecutive strength tests shall be equal to or greater than the specified strength. In applying this requirement to prestressed members, the strength tests performed on all similar members, such as all beams, shall be grouped together for purposes of counting the number of tests available. This paragraph also applies to designs by the strength method where the service load method was used to check fatigue and crack control.

If six or fewer strength tests are available, the average of all the tests shall be equal to or greater than the strengths shown in the following:

Number of Strength Tests	Required Average Strength (% of specified strength)	
	Class A, C, and Seal	Class P
1	79	86
2	90	97
3	94	102
4	97	105
5	99	107
6	100	108

If the concrete strength tests fail to meet the requirements of this specification, the CO may order the Contractor to have a testing laboratory that is acceptable to the Forest Service take and test core samples of questionable concrete. The CO may

order all low-strength concrete removed and replaced if core strengths are below specified strengths. All costs connected with concrete coring and removal and replacement of concrete that fails to meet these requirements shall be borne by the Contractor.

552.11 Field Adjustment of Concrete Mix. Field adjustment of the concrete mix designs will be necessary to compensate for the free-water content in the aggregates.

After initial mixing, if the consistency (slump) is outside the specification limits (table 552-1) by less than 25 mm, the CO may approve the addition of water or cement, provided all that the following conditions are met:

(a) **Addition of Water.** Water may be added, provided that:

- (1) The maximum allowable water content in kilograms per cubic meter of concrete (table 552-1) is not exceeded.
- (2) The maximum allowable mixing time (or number of drum revolutions) is not exceeded.
- (3) Concrete is remixed for at least half of the minimum mixing time (or number of drum revolutions).

(b) **Addition of Cement.** Cement may be added, except to class P concrete, provided that:

- (1) The amount of cement added does not exceed 55.7 kg/m³ more than the mix design or a total of 418 kg/m³, unless otherwise DESIGNATED IN THE SPECIAL PROJECT SPECIFICATIONS.
- (2) The maximum allowable mixing time (or number of drum revolutions) is not exceeded.
- (3) Concrete is remixed for at least half of the minimum mixing time (or number of drum revolutions).

(c) **Adjustment for Percent Entrained Air.** Vary the amount of air-entraining admixture used in each batch as necessary from that given in the approved mix design to produce concrete with the percent entrained air specified in table 552-1.

552.12 Temperature and Weather Conditions. Maintain the temperature of the concrete mixture just before placement between 10 °C and 32 °C; except maintain the concrete for bridge decks between 10 °C and 25 °C.

(a) **Cold Weather.** Cold weather is defined as any time during the concrete placement or curing period that the ambient temperature at the worksite drops

below 2 °C or the ambient temperature at the site drops below 10 °C for a period of 12 hours or more.

When cold weather is reasonably expected or has occurred within 7 days of anticipated concrete placement, submit a detailed plan for producing, transporting, placing, protecting, curing, and temperature monitoring of concrete during cold weather. Include procedures for accommodating abrupt changes in weather conditions. Do not commence placement until plan is approved. Approval of an acceptable plan will take at least 1 day.

Before commencing cold weather concreting, have all material and equipment required for protection available at or near the project and subject to the approval of the CO.

Remove all snow, ice, and frost from the surfaces, including reinforcement and subgrade, against which the concrete is to be placed. Ensure that the temperature of any surface that will come into contact with fresh concrete is at least 2 °C and is maintained at a temperature of 2 °C or above during the placement of the concrete.

Place heaters and direct ducts so as not to cause concrete drying or fire hazards. Vent exhaust flue gases from combustion heating units to the outside of any enclosures. Heat the concrete components in a manner that is not detrimental to the mix. Do not heat cement or permit the cement to come into contact with aggregates that are hotter than 40 °C. Ensure that concrete at the time of placement is of uniform temperature and free of frost lumps. Do not heat aggregates with a direct flame or on sheet metal over fire. Do not heat fine aggregate by direct steam. Do not add salts to prevent freezing.

Provide heat within the housing by steam or hot air. Maintain a humid condition within the housing during the heating period. Do not use stoves or open-burning salamanders within the housing.

Do not use any heating method that will endanger forms, falsework, or any part of the structure, or that will subject the concrete to drying out or other injury due to excessive temperatures. Do not allow the concrete deck surface temperature to exceed 32 °C throughout the curing period.

Maintain a reasonably uniform temperature within the enclosure throughout the curing period.

Provide adequate fire protection when heating is in progress, and maintain watchmen or other attendants to keep heating units in continuous operation.

Furnish and place continuously recording surface temperature measuring devices that are accurate within ± 1 °C.

Make outside air temperature recordings at the same time that recordings are made within the enclosure. Provide a copy of temperature records to the CO.

During cold weather, protect the concrete for at least 7 days at or above the minimum temperatures shown in table 552-4.

Table 552-4.—Cold weather concrete surface temperatures.

Concrete Surface Temperatures	Minimum Section Size Dimension (mm)			
	< 300	300–900	900–1,800	> 1,800
Minimum temperature during protection period	13 °C	10 °C	7 °C	4 °C
Maximum allowable temperature drop in any 24-hour period after end of protection	28 °C	22 °C	17 °C	11 °C

When pozzolan or fly ash cement is used, adjust the required period of controlled temperature and moisture as follows:

Percentage of Cement Replaced by Weight	Required Period of Controlled Temperature and Moisture
10%	9 days
10–15%	10 days
16–20%	11 days

The above requirement for an extended period of controlled temperature and/or moisture may be waived if a compressive strength of 65 percent of the specified 28-day strength is achieved in 7 days.

At the end of the protection period, allow the concrete to cool gradually over 24 hours at a rate not to exceed the maximum values shown in table 552-4. All protection may be removed when the concrete surface temperature is within 15 °C of the ambient air temperature.

If the concrete temperatures cannot be maintained within the limits specified in table 552-4 through insulated forms or blankets, enclose each section of the structure with adequate housing before placing the concrete in the section.

Make the protective housing of sufficient size to allow all concrete placing and finishing operations for any one placement to proceed under cover without hindrance. However, to facilitate the placement of concrete, install the covering material immediately after depositing the concrete. Construct the housing to be weathertight and in a manner that will ensure that specified temperatures will be maintained uniformly throughout the enclosure during the protection period.

When housing of the structure is not initially installed, but may be subsequently required in accordance with the specifications, protect structural concrete in bridge decks or similar thin sections with insulating blankets or other methods approved by the CO. Ensure that the curing method prevents moisture loss on all exposed surfaces, including those protected by insulating blankets.

Provide insulation that consists of bats or blankets of fiberglass, rock wool, balsam wool, insulation boards, or other approved material.

Completely encase the bats or blankets in suitable wind- and water-resistant covers that are fastened securely to wood forms between the studs and walls, with edges and ends sealed to the framing to minimize heat loss. Attach insulation to steel forms by adhesive or other approved methods. Cover ribs and flanges of steel forms with insulating blankets or separate strips of insulation. Ensure that the edges and corners of concrete are well insulated. Protect horizontal surfaces of concrete with a layer of the insulating material securely fastened in place. Protect the tops of placements, such as bridge decks and similar flat slab sections, with tarpaulins over the insulation. Cover large insulating blankets around and securely fasten in place for curing concrete columns cast in prefabricated forms and similar concrete items. Seal all joints in the blankets with tape.

Use electric heating blankets and other suitable materials instead of insulated blankets or bats only when specifically approved by the CO for each application.

Assume entire responsibility for the proper protection and final satisfactory condition of all concrete placed during cold weather or exposed to cold weather within the required protection period. Remove and replace any concrete that has been frozen or damaged due to other causes.

(b) Hot Weather. Hot weather is defined as any time during the concrete placement that the ambient temperature at the work site is above 35 °C.

In hot weather, cool all surfaces that will come in contact with the mix to below 35 °C. Cool by covering with wet burlap or cotton mats, fog spraying with water, covering with protective housing, or using other approved methods.

Immediately prior to and during placement, maintain concrete at a temperature not to exceed 35 °C; but ensure that bridge superstructure (deck) concrete does not exceed a temperature of 25 °C.

When placing concrete deck slabs, if the air temperature near the slab's surface is expected to rise above 25 °C, schedule operations so that finishing of the top of the slab is completed before this occurs, or use hot-weather concreting practices to maintain the deck surface temperature at 25 °C or less until finishing is completed.

Maintain concrete temperature by using any combination of the following methods:

- (1) Shade the material storage areas or production equipment.
- (2) Cool aggregate by sprinkling.
- (3) Cool aggregate and/or water by refrigeration or replace a portion or all of the mix water with flaked or crushed ice to the extent that the ice will completely melt during mixing of the concrete.

(c) **Evaporation.** When placing concrete in bridge decks or other exposed slabs, limit the expected evaporation rate to less than 0.5 kg/m²/h, as determined by figure 552-1 or the following:

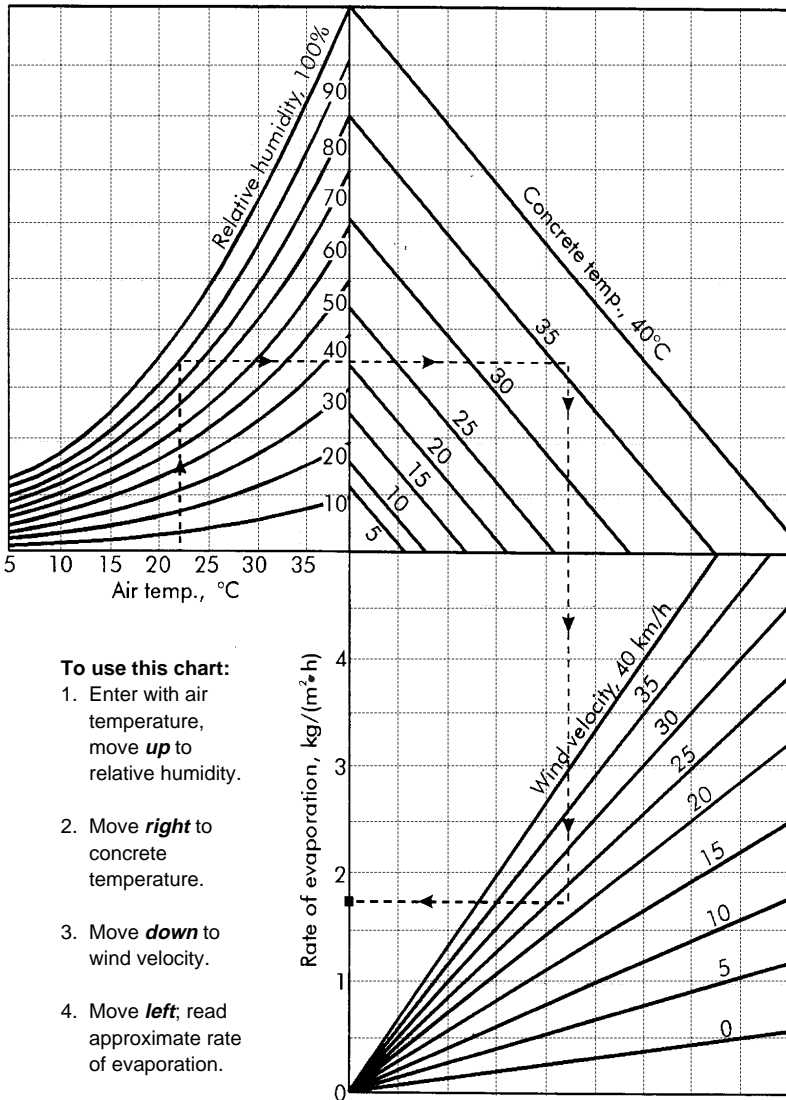
$$EVAP = \frac{1 + 0.2374WV}{2906} \times \left[CT^2 - 4.762CT + 220.8 - RH \times \left[\frac{AT^3 + 127.8AT^2 + 665.6AT + 34,283}{20415} \right] \right]$$

where

- EVAP* = evaporation rate (kg/m²/h)
- WV* = wind velocity (km/h)
- RH* = relative humidity (%)
- AT* = air temperature (°C)
- CT* = concrete temperature (°C)

When necessary, take one or more of the following actions:

- (1) Construct windbreaks or enclosures to effectively reduce the wind velocity throughout the area of placement and for a period of 12 hours following completion of deck placement or until the evaporation rate is less than 0.5 kg/m²/h.
- (2) Use fog sprayers upwind of the placement operation to effectively increase the relative humidity.
- (3) Reduce the temperature of the concrete in accordance with Subsection 552.12(b).



Note: Example shown by dashed lines is for an air temperature of 22.5 °C, relative humidity of 90 percent, concrete temperature of 36 °C, and wind velocity of 22.5 km/h. This results in a rate of evaporation of 1.75 kg/m²/h.

Figure 552-1.—Evaporation rate of surface moisture.

(d) Rain. At all times during and immediately after placement, protect the concrete from rain.

552.13 Handling & Placing Concrete. Perform the work specified in Section 206. Construct reinforcing steel, structural steel, bearing devices, joint material, and miscellaneous items in accordance with the appropriate sections.

(a) General. Use falsework and forms in accordance with Section 562. Handle, place, and consolidate concrete using methods that will not cause segregation and will result in dense, homogeneous concrete that is free of voids and rock pockets. Use placement methods that do not cause displacement of reinforcing steel or other material that is embedded in the concrete. Place and consolidate concrete before initial set. Do not retemper concrete by adding water to the mix except as provided for in Subsection 552.11.

Do not place concrete until the forms, all embedded material, and the adequacy of the foundation material have been inspected and approved by the CO.

Remove all mortar, debris, and foreign material from the forms and reinforcing steel before commencing placement. Thoroughly moisten the forms and subgrade immediately before concrete is placed against them. Temporary form spreader devices may be left in place until concrete placement precludes their need. Remove them when no longer needed.

Place concrete continuously without interruption between planned construction or expansion joints. Ensure that the delivery rate and placing sequence and methods are such that fresh concrete is always placed and consolidated against previously placed concrete before initial set has occurred in the previously placed concrete. Do not allow the time between the placement of successive batches to exceed 30 minutes (20 minutes under hot weather conditions).

During and after placement of concrete, do not damage previously placed concrete or break the bond between the concrete and reinforcing steel. Keep workers off fresh concrete. Do not support platforms for workers and equipment directly on reinforcing steel. After the concrete is set, do not disturb the forms or reinforcing bars that project from the concrete until it is of sufficient strength to resist damage.

Five to 10 working days before placing concrete in a cast-in-place bridge deck, hold a preplacement conference to discuss the construction procedures, personnel, and equipment to be used. At this time, provide full details on plans for the placement operation, including finishing machine data, workforce, contingency plans, concrete delivery, and other information requested by the CO.

(b) *Sequence of Placement.* Observe the following sequence of placement:

(1) *Substructures.* Do not place loads on finished bents, piers, or abutments until concrete strength cylinder tests from the same concrete cured under the same conditions as the substructure element indicate that all concrete has at least 80 percent of its required 28-day compressive strength.

(2) *Vertical Members.* For vertical members more than 5 m in height, allow the concrete to set for at least 4 hours before placing concrete for integral horizontal members. For vertical members less than 5 m in height, allow the concrete to set for at least 30 minutes. Do not apply loads from horizontal members until the vertical member has attained its required strength.

(3) *Superstructures.* Do not place concrete in the superstructure until substructure forms have been stripped sufficiently to determine the acceptability of the supporting substructure concrete. Do not place concrete in the superstructure until the substructure has attained the required strength.

Place concrete for T-beams in two separate operations. Wait at least 5 days after stem placement before placing the top deck slab concrete.

Concrete for box girders may be placed in two or three separate operations consisting of bottom slab, girder webs, and top slab, or as SHOWN ON THE DRAWINGS. However, place the bottom slab first, and do not place the top slab until the girder webs have been in place for at least 5 days.

(4) *Arches.* Place concrete in arch rings so that the centering is loaded uniformly and symmetrically.

Place centering upon approved jacks to provide means of correcting any slight settlement that may occur after concrete placement has begun. Make any adjustments made necessary by settlement before the concrete has taken its initial set.

(5) *Box Culverts.* Place the base slab of box culverts and allow to set 24 hours before the remainder of the culvert is constructed. For sidewall heights of 1.5 m or less, the sidewalls and top slab may be placed in one continuous operation. For sidewalls greater than 1.5 m but less than 5 m in height, allow sidewall concrete to set at least 30 minutes before placing concrete in the top slab. For sidewalls 5 m or higher, allow sidewall concrete to set at least 12 hours before placing concrete in the top slab.

(6) *Precast Elements.* Place and consolidate concrete so that shrinkage cracks are not produced in the member.

(c) **Placing Methods.** Use equipment of sufficient capacity, and ensure that it is designed and operated to prevent mix segregation and mortar loss. Do not use equipment that causes vibrations that could damage the freshly placed concrete. Do not use equipment with aluminum parts that come in contact with the concrete. Remove set or dried mortar from inside surfaces of placing equipment.

Place concrete as near as possible to its final position. Do not place concrete in horizontal layers greater than 0.5 m thick. Do not exceed the vibrator capacity to consolidate and merge the new layer with the previous layer. Do not place concrete at a rate that, when corrected for temperature, exceeds the design loading of the forms.

Do not drop unconfined concrete more than 2 m. Concrete may be confined by using a tube fitted with a hopper head or other approved device that prevents mix segregation and mortar spattering. This does not apply to cast-in-place piling when concrete placement is completed before initial set occurs in the concrete placed first.

In thin sections where there is not sufficient space inside the form to place by chute, place concrete through form windows.

Operate concrete pumps so that a continuous stream of concrete without air pockets is delivered at the tube discharge. Do not use conveyor belt systems longer than 170 m when measured from end to end of the total belt assembly. Arrange the belt assembly so that each section discharges into a vertical hopper to the next section without mortar adhering to the belt. Use a hopper, chute, and deflectors at the discharge end of the conveyor belt system to cause the concrete to drop vertically.

Arrange the equipment so that no vibrations result that might damage freshly placed concrete.

(d) **Consolidation.** Provide sufficient hand-held internal concrete vibrators suitable for the conditions of concrete placement. Ensure that the vibrators meet requirements shown in table 552-5. Provide rubber-coated vibrators when epoxy-coated reinforcement is used.

Table 552-5.—Hand-held vibratory requirements.

Head Diameter (mm)	Frequency (vibrations/min)	Radius of Action (mm)
19–38	10,000–15,000	75–125
32–64	9,000–13,500	125–255
50–89	8,000–12,000	180–485

Provide a sufficient number of vibrators to consolidate each batch as it is placed. Provide a spare vibrator at the site in case of breakdown. Use external form vibrators only when the forms have been designed for external vibration and when internal vibration is not possible.

Consolidate all concrete by mechanical vibration immediately after placement. Manipulate vibrators to thoroughly work the concrete around reinforcement, embedded fixtures, corners, and angles in the forms. Do not cause segregation. Do not consolidate concrete placed underwater. Supplement vibration with spading, as necessary, to provide smooth surfaces and dense concrete along form surfaces, in corners, and at locations impossible to reach with the vibrators.

Vibrate the concrete at the point of deposit and at uniformly spaced points not farther apart than one and one-half times the radius over which the vibration is visibly effective. Insert vibrators so that the affected vibrated areas overlap. Do not use vibrators to move concrete. Insert vibrators vertically, and slowly withdraw them from the concrete. Vibrate long and intensely enough to thoroughly consolidate the concrete, but not to cause segregation. Do not vibrate at any one point long enough to cause localized areas of grout to form. Do not vibrate reinforcement.

(e) Underwater Placement. Underwater placement of concrete is permitted only for seal concrete and drilled shafts. Perform underwater placement only in the presence of the CO. If other than seal concrete is used, increase the minimum cement content by 10 percent. Use tremies, concrete pumps, or other approved methods for placement. Do not place concrete in running water.

(1) Tremies. Use watertight tremies with a diameter of 250 mm or more. Fit the top with a hopper. Use multiple tremies as required. Make tremies capable of being rapidly lowered to retard or stop the flow of concrete and to permit free movement of the discharge end over the entire surface of the cement.

At the start of concrete placement, seal the discharge end and fill the tremie tube with concrete. Keep the tremie tube full of concrete to the bottom during placement, and keep the discharge end completely submerged in the concrete at all times. If water enters the tube, withdraw the tremie and reseal the discharge end. Maintain continuous concrete flow until the placement is completed.

(2) Concrete Pumps. Use pumps with a device at the end of the discharge tube to seal out water while the tube is first being filled with concrete. When concrete flow is started, keep the end of the discharge tube full of concrete and below the surface of the deposited concrete until placement has been completed.

Place underwater concrete continuously from start to finish in a compact mass. Place each succeeding layer of concrete before the preceding layer has taken

initial set. Use more than one tremie or pump as necessary to ensure compliance with this requirement. Keep the concrete surface as horizontal as practicable. Do not disturb after placement. Maintain still water at the point of deposit.

Dewater after test specimens cured under similar conditions indicate that the concrete has sufficient strength to resist the expected loads. Remove all laitance or other unsatisfactory material from the exposed concrete.

(f) Concrete Railings & Parapets. Use smooth, tight-fitting, rigid forms. Neatly miter corners. Place concrete railings and parapets after the centering or falsework for the supporting span is released. Remove forms without damaging the concrete. Finish all corners to be true, clean-cut, and free from cracks, spalls, or other defects.

Cast precast railing members in mortar-tight forms. Remove precast members from molds as soon as the concrete has sufficient strength to be self-supporting. Protect edges and corners from chipping, cracking, and other damage. Cure in accordance with Subsection 552.17(b). The curing period may be shortened, as approved, by using moist heat and/or type III cement or water-reducing agents.

552.14 Construction Joints. Provide construction joints at locations as SHOWN ON THE DRAWINGS. Written approval is required for any additional construction joints.

At horizontal construction joints, place gage strips inside the forms along all exposed faces to produce straight joint lines. Clean and saturate construction joints before placing fresh concrete. Keep joints saturated until adjacent fresh concrete is placed. Immediately before placing new concrete, draw forms tight against previously placed concrete. Where accessible, thoroughly coat the existing surface with a very thin coating of cement mortar. Extend reinforcing bars across construction joints.

552.15 Expansion & Contraction Joints. Form expansion and contraction joints as follows:

(a) Open Joints. Form open joints with a wooden strip, metal plate, or other approved material. Remove the joint-forming material without chipping or breaking the corners of the concrete. Do not extend reinforcement across an open joint.

(b) Filled Joints. Cut premolded expansion joint filler to the shape and size of the surface being jointed. Secure the joint filler on one surface of the joint using galvanized nails or other acceptable means so that it will not be displaced by the concrete. Splice in accordance with the manufacturer's recommendations. After form removal, neatly cut and remove all concrete or mortar that has sealed across the joint. Fill all joint gaps 3 mm or wider with hot asphalt or other approved filler. Place all necessary dowels, load transfer devices, and other devices as SHOWN ON THE DRAWINGS or as directed.

(c) **Steel Joints.** Fabricate plates, angles, or other structural shapes accurately to conform to the concrete surface. Set joint opening to conform to the ambient temperature at the time of concrete placement and as SHOWN ON THE DRAWINGS. Securely fasten the joints to keep them in correct position. Maintain an unobstructed joint opening during concrete placement.

(d) **Water Stops.** Construct water stops in accordance with Section 712 and as SHOWN ON THE DRAWINGS.

(e) **Compression Joint Seals.** Use one-piece compression joint seals for transverse joints and the longest practicable length for longitudinal joints. Clean and dry joints and remove spalls and irregularities. Apply a lubricant-adhesive as a covering film to both sides of the seal immediately before installation. Compress the seal and place it in the joint as recommended by the manufacturer. Make sure the seal is in full contact with the joint walls throughout its length.

Remove and discard all seals that are twisted, curled, nicked, or improperly formed. Remove and reinstall joint seals that elongate more than 5 percent of their original length when compressed. Remove all excess lubricant-adhesive before it dries.

(f) **Elastomeric Expansion Joint Seal.** Install the joint in accordance with the manufacturer's recommendations and the SPECIAL PROJECT SPECIFICATIONS, or as SHOWN ON THE DRAWINGS.

552.16 Finishing Plastic Concrete. Strike off concrete surfaces that are not placed against forms. Float finish the concrete surface. Remove any laitance or thin grout. Carefully tool all nonchamfered edges with an edger. Leave edges of joint filler exposed.

Protect the surface from rain damage.

Finish all concrete surfaces used by traffic to a skid-resistant surface.

(a) **Striking Off & Floating.** For bridge decks or top slabs of structures serving as finished pavements, use an approved power-driven finishing machine equipped with oscillating screed. If approved, use hand-finishing methods for irregular areas where the use of a machine is impractical.

Limit placement of concrete to that which can be properly finished before the beginning of initial set. Never allow concrete to be placed more than 2.5 m ahead of the finishing machine.

Strike off all surfaces using equipment supported by and traveling on screed rails or headers. Do not support rails within the limits of the concrete placement without approval.

Set rails or headers that can be readily adjusted for elevation on nonyielding supports so the finishing equipment operates without interruption over the entire surface being finished. Extend rails beyond both ends of the scheduled concrete placement a sufficient distance to enable the finishing machine to finish the concrete being placed.

Set rails the entire length of steel girder superstructures.

Use rails or headers that are of a type that can be installed so that no springing or deflection will occur under the weight of the finishing equipment.

Adjust rails, headers, and strike-off equipment to the required profile and cross section, allowing for anticipated settlement, camber, and deflection of falsework.

Before beginning delivery and placement of concrete, operate the finishing machine over the entire area to be finished to check for excessive rail deflections, proper deck thickness, and reinforcing steel cover, and to verify proper operation of equipment. Make necessary corrections before concrete placement begins. Obtain approval to begin deck concrete placement.

Schedule delivery and placement of concrete so as to permit all placement and finishing operations to be completed during daylight hours, unless otherwise approved in advance by the CO.

Place concrete bridge decks continuously along the full length of the structure or superstructure unit, unless otherwise SHOWN ON THE DRAWINGS or approved in writing by the CO. Provide sufficient material, equipment, and manpower to complete bridge deck placement at a minimum rate of 6 m per hour, unless otherwise SHOWN ON THE DRAWINGS.

Should settlement or other unanticipated events occur that would prevent obtaining a bridge deck meeting the requirements of this specification, discontinue placing deck concrete until corrective measures are taken. If satisfactory measures are not taken prior to initial set of the concrete in the affected area, discontinue all placing of concrete and install a bulkhead at a location approved by the CO. Remove all concrete in place beyond the bulkhead.

After placing the concrete, operate the finishing machine over the concrete as needed to obtain the required profile and cross section. Keep a slight roll of excess concrete in front of the cutting edge of the screed at all times. Maintain this excess of concrete to the end of the pour or form and then remove and waste it. Adjust rails or headers as necessary to correct for unanticipated settlement or deflection.

Remove rail supports embedded in the concrete to at least 50 mm below the finished surface, and fill and finish any voids with fresh concrete. Finish the surface with a float, roller, or other approved device as necessary to remove all local irregularities.

Remove all excess water, laitance, or foreign material brought to the surface using a squeegee or straightedge drawn from the center of the slab towards either edge. Do not apply water to the surface of the concrete during finishing operations.

Following the completion of the strike-off, float the roadway slab surface to a smooth, uniform surface by means of floats 3 m or more in length. Use floats to remove roughness and minor irregularities left by the strike board or finishing machine and to seal the concrete surface. Do not permit excessive working of the concrete surface. Ensure that each transverse pass of the float overlaps the previous pass by a distance equal to at least one-half the length of the float.

Operate hand-operated float boards from transverse finishing bridges. Provide finishing bridges that completely span the roadway area being floated. Provide a sufficient number of finishing bridges to permit operation of the floats without undue delay and to permit inspection of the work. Use at least two transverse finishing bridges when hand-operated float boards are used, unless otherwise approved by the CO.

Provide finishing bridges that are of rigid construction, free of wobble and spring when used by the operators of longitudinal floats, and easily moved.

(b) Straightedging. Check all slab and sidewalk surfaces in the presence of the CO. Check the entire surface parallel to the centerline of the bridge with a 3-m metal straightedge. Overlap the straightedge at least one-half the length of the previous straightedge placement.

Correct deviations in excess of 3 mm from the testing edge of the straightedge. For deck surfaces that are to receive an overlay, correct deviations in excess of 6 mm.

(c) Texturing. Produce a skid-resistant surface texture on all driving surfaces by grooving. Use grooved, sidewalk, and troweled and brushed finishes, or a combination thereof, for other surfaces as required.

(1) Grooved Finish. Use a float with a single row of fins or an approved machine designed specifically for sawing grooves in concrete pavements. Space fins 13 to 20 mm on centers. Make the grooves 2 to 5 mm wide and 3 to 5 mm deep. Groove perpendicular to the centerline without tearing the concrete surface or loosening surface aggregate.

If grooves are sawn, cut the grooves 5 mm wide at a spacing of 15 to 25 mm.

On bridge decks, discontinue grooving 300 mm from the curb face and provide a longitudinal troweled finish on the surface of gutters.

(2) Sidewalk Finish. Strike off the surface using a strike board, and then float the surface. Use an edging tool on edges and expansion joints. Broom the surface using a broom with stiff bristles. Broom perpendicular to the centerline from edge to edge, with adjacent strokes slightly overlapped. Produce regular corrugations not more

than 3 mm in depth without tearing the concrete. While the concrete is plastic, correct porous spots, irregularities, depressions, small pockets, and rough spots. Groove contraction joints at the required interval using an approved grooving tool.

(3) *Troweled & Brushed Finish.* Use a steel trowel to produce a slick, smooth surface free of bleedwater. Brush the surface with a fine brush using parallel strokes.

(4) *Exposed Aggregate Finish.* Strike off the surface using a strike board and then float the surface. Use an edging tool on all transverse and longitudinal joints that are against forms or existing pavement. Do not edge transverse joints in a continuous pour or longitudinal joints in a continuous dual-lane pour.

As soon as the concrete hardens sufficiently to prevent particles of gravel from being dislodged, broom the surface. Use stiff brushes approved by the CO. Exercise care to prevent marring of the surface and cracking or chipping of slab edges or joints. If approved by the CO, apply a light spray of retardant to the unfinished surface to facilitate this work.

First, broom transversely across the pavement. Pull the loosened semistiff mortar entirely off the pavement. Remove the mortar from all adjacent pavements. Then broom parallel to the pavement centerline. Continue this operation until a sufficient amount of coarse aggregate is exposed. Other methods of aggregate exposure, such as using a water spray attachment on a special exposed aggregate broom, will be permitted if satisfactory results are demonstrated.

After curing according to Subsection 501.10, wash the surface with brush and water to remove all laitance and cement from the exposed coarse aggregate.

(d) *Surface Underneath Bearings.* Finish all bearing surfaces to within 5 mm of plan elevation. When a masonry plate is to be placed directly on the concrete or on filler material less than 5 mm thick, finish the surface with a float to an elevation slightly above plan elevation. After the concrete is set, grind the surface as necessary to provide a full and even bearing.

When a masonry plate is to be set on filler material between 5 and 15 mm thick, finish the surface with a steel trowel. Finish or grind the surface so that it does not vary from a straightedge in any direction by more than 2 mm.

When a masonry plate is to be set on filler material greater than 15 mm thick or when an elastomeric bearing pad is to be used, finish the surface to a plane surface free of ridges.

When required under a masonry plate or elastomeric bearing pad, use mortar in the proportions of 1 part Portland cement and 1-1/2 parts clean sand. Thoroughly mix sand and cement before adding water. Mix only enough mortar for immediate use.

Discard mortar that is more than 45 minutes old. Do not retemper mortar. Cure mortar at least 3 days, and do not apply loads to mortar for at least 48 hours. Do not mix and use mortar during freezing conditions. Ensure that mortar sand conforms to AASHTO M 45. Proprietary products may be used with approval.

(e) Surface Underneath Waterproofing Membrane Deck Seal. Ensure that surfaces that are to be covered with a waterproofing membrane deck seal are not coarse textured, but rather finished to a smooth surface that is free of ridges and other projections.

552.17 Curing Concrete. Begin curing immediately after the free surface water has evaporated and the finishing is complete. If the surface of the concrete begins to dry before the selected cure method can be implemented, keep concrete surface moist using a fog spray without damaging the surface. Unless otherwise approved by the CO, provide fogging equipment for all deck placement operations.

Use fogging equipment capable of applying water to the concrete in the form of a fine mist in sufficient quantity to curb the effects of rapid evaporation of mixing water from the concrete on the deck. Obtain approval by the CO in advance for fogging nozzles and water supply methods. Produce a true mist that will not harm the surface finish of fresh concrete. Apply the mist at the times and in the manner approved by the CO.

Keep surfaces to be rubbed moist after forms are removed. Cure immediately following the first rub.

Cure the top surfaces of bridge decks using the liquid membrane curing compound method, combined with either the water method or the waterproof cover method. Apply liquid membrane curing compound immediately after finishing. Apply a water method or the waterproof cover method within 4 hours after finishing.

Cure all concrete for at least 7 consecutive days. When pozzolan or fly-ash-modified cement is used, extend the required period of controlled moisture, as called for in Subsection 552.12.

(a) Forms-in-Place Method. For formed surfaces, leave the forms in place without loosening. If forms are removed during the curing period to facilitate rubbing, strip forms only from areas able to be rubbed during the same shift. During rubbing, keep the surface of the exposed concrete moist. After the rubbing is complete, continue curing process using the water method or by applying a clear curing compound (type 1 or type 1-D) for the remainder of the curing period.

(b) Water Method. Keep the concrete surface continuously wet by ponding, spraying, or covering with material that is kept continuously and thoroughly wet. Covering material may consist of cotton mats, multiple layers of burlap, or other approved material that does not discolor or otherwise damage the concrete. Do not cure concrete underwater if the temperature of the water is less than 2 °C.

Cover the wet concrete surface with a waterproof sheet material that prevents moisture loss from the concrete.

Use widest sheets practical. Lap adjacent sheets at least 150 mm and tightly seal all seams with pressure-sensitive tape, mastic, glue, or other approved methods. Secure all material so that wind will not displace it. Immediately repair sheets that are broken or damaged.

(c) Liquid Membrane Curing Compound Method. Do not use the liquid membrane method on surfaces to receive a rubbed finish. Use on construction joint surfaces is permitted only if the compound is removed from the concrete and the reinforcing steel by sandblasting before placement of concrete against the joint.

Use type 2 white-pigmented liquid membrane only on the top surfaces of bridge decks or on surfaces not exposed to view in the completed work. Use type 1 or 1-D clear curing compounds on other surfaces.

Mix membrane curing solutions containing pigments before use. Continue to agitate during application. Use equipment capable of producing a fine spray. Apply the curing compound at a minimum rate of 0.25 L/m² in one or two uniform applications. If the solution is applied in two applications, follow the first application with the second application within 30 minutes and apply at right angles to the first application.

If the membrane is damaged by rain or other means during the curing period, immediately apply a new coat over the damaged areas.

552.18 Finishing Formed Concrete Surfaces. Remove and replace or repair, as approved, all rock pockets or honeycombed concrete.

Provide a class 1 finish to all formed concrete surfaces, unless another finish is SHOWN ON THE DRAWINGS or called for in the SPECIAL PROJECT SPECIFICATIONS.

Finish sound formed concrete surfaces as shown below.

(a) Class 1—Ordinary Surface Finish. Finish the following surfaces with a class 1, ordinary surface finish:

- (1) Undersurfaces of slab spans, box girders, filled spandrel arch spans, and the roadway deck slab between superstructure girders.
- (2) Inside vertical surfaces of exterior superstructure girders and all vertical surfaces of interior girders.

- (3) Surfaces to be buried and culvert surfaces above finished ground that are not visible from the traveled way or a walkway.

Begin finishing as soon as the forms are removed. Remove fins and irregular projections from all surfaces that are exposed or will be waterproofed. Remove bulges and offsets with carborundum stones or discs. Remove localized poorly bonded rock pockets or honeycombed concrete and replace with sound concrete or packed mortar in an approved manner. Cut back at least 25 mm beneath the concrete surface all projecting wire or other devices used to hold forms in place.

Clean and point all form tie cavities, holes, depressions, voids, broken corners and edges, and other defects. Saturate the area with water. Finish the area with mortar that is less than 1 hour old. After the mortar is set, rub it (if required) and continue curing. Match exposed surfaces to surrounding concrete.

Carefully tool and remove free mortar and concrete from construction and expansion joints. Leave joint filler exposed for its full length with clean, true edges.

Rub or grind bearing surfaces on piers and abutments to the specified elevation and slope.

For patching large or deep areas, add coarse aggregate to the patching material and take special precautions to ensure a dense, well-bonded, and properly cured patch. Areas of honeycomb that exceed 2 percent of the surface area of a structural element may be considered sufficient cause for rejection of the structural element.

Cure mortar patches in accordance with Subsection 552.17.

If the final finished surface is not true and uniform, rub it in accordance with Subsection 552.18(b).

(b) Class 2—Rubbed Finish. Finish the following surfaces with a class 2 rubbed finish:

- (1) All surfaces of bridge superstructures, except those surfaces designated to receive a class 1 or other finish.
- (2) All surfaces of bridge piers, piles, columns and abutments, and retaining walls above finished ground and to at least 300 mm below finished ground.
- (3) All surfaces of open spandrel arch rings, spandrel columns, and abutment towers.
- (4) All surfaces of pedestrian undercrossings, except floors and surfaces to be covered with earth.

- (5) Surfaces above finished ground of culvert headwalls and endwalls when visible from the traveled way or walkway.
- (6) Inside surfaces of culvert barrels higher than 1 m that are visible from the traveled way. Finish for a distance inside the barrel at least equal to the height of the culvert.
- (7) All surfaces of railings.

Complete a class 1 finish in accordance with Subsection 552.18(a). Saturate the concrete surface with water. Rub the surface with a medium-coarse carborundum stone using a small amount of mortar on its face. Use mortar composed of cement and fine sand mixed in the same proportions as the concrete being finished. Continue rubbing until form marks, projections, and irregularities are removed and a uniform surface is obtained. Leave the paste produced by this rubbing in place.

After other work that could affect the surface is completed, rub with a fine carborundum stone and water until the entire surface has a smooth texture and uniform color. After the surface has dried, rub it with burlap to remove loose powder. Leave it free from all unsound patches, paste, powder, and objectionable marks.

(c) **Class 3—Tooled Finish.** Let the concrete set for at least 14 days or longer if necessary to prevent the aggregate particles from being “picked” out of the surface. Use air tools such as a bush hammer, pick, or crandall. Chip away the surface mortar and break the aggregate particles to expose a grouping of broken aggregate particles in a matrix of mortar.

(d) **Class 4—Sandblasted Finish.** Let the concrete set for at least 14 days. Protect adjacent surfaces that are not to be sandblasted. Sandblast the surface with hard, sharp sand to produce an even fine-grained surface in which the mortar is cut away, leaving the aggregate exposed.

(e) **Class 5—Wire Brushed or Scrubbed Finish.** Begin as soon as the forms are removed. Scrub the surface with stiff wire or fiber brushes using a solution of muriatic acid. Mix the solution in the proportion of 1 part acid to 4 parts water. Scrub until the cement film or surface is completely removed and the aggregate particles are exposed. Leave an even pebbled texture with the appearance of fine granite to coarse conglomerate, depending upon the size and grading of aggregate. Wash the entire surface with water containing a small amount of ammonia.

(f) **Class 6—Color Finish.** Build a sufficient number of 0.5 x 1-m concrete color sample panels to obtain a color acceptable to the CO. Protect the approved color sample panel at all times during the work. Color all designated surfaces to match the color of the approved sample.

Complete a class 1 finish in accordance with Subsection 552.18(a). Do not apply the color finish until all concrete placement for the structure is complete. Remove all dust, foreign matter, form oil, grease, and curing compound with a 5-percent solution of trisodium phosphate, and then rinse the concrete surface with clean water.

Use paper, cloth, or other means to protect surfaces not to be color finished. Apply the finish to a dry concrete surface when the surface temperature is 4 °C or higher and the air temperature in the shade is anticipated to be 4 °C or higher during the 24 hours following application.

Apply the color finish in accordance with the manufacturer's recommendations. Spray, brush, or roll on the first coat of penetrating sealer and color base. Spray, brush, or roll on the finish coat after the first coat has thoroughly dried. Apply finish to provide a uniform, permanent color, free from runs and sags to the surfaces.

Clean concrete areas not intended to be covered by the finish using an approved method.

552.19 Concrete Anchorage Devices. Use chemical, grouted, or cast-in-place concrete anchorage devices for attaching equipment or fixtures to concrete.

Furnish the following for approval:

- (a) Concrete anchorage device sample.
- (b) Manufacturer's installation instructions.
- (c) Material data and certifications.

Fabricate all metal parts of the anchorage devices from stainless steel or from steel protected with a corrosion-resistant metallic coating that does not react chemically with concrete. Supply anchorage devices complete with all hardware.

For chemical or grouted anchors, conduct a system approval test on one anchor at the jobsite, not to be incorporated in the work. Conduct a static load test in accordance with ASTM E 488. Demonstrate that the anchorage device will withstand a sustained direct tension test load not less than the values shown in table 552-5 for a period of at least 48 hours with movement not to exceed 1 mm. Also demonstrate that, when loaded to failure, the anchorage device demonstrates a ductile failure of the anchor steel, not a failure of the chemical, grout, or concrete.

Install concrete anchorage devices as recommended by the device manufacturer and so that the attached equipment or fixtures will bear firmly against the concrete. Torque installed nuts to the values specified in table 552-6, unless

Table 552-5.—Sustained load test values.

Anchorage Device Stud Size	Tension Test Load (kN)
M20	24.0
M16	18.3
M12	12.7
M8	7.1

Table 552-6.—Torque for anchorage devices.

Anchorage Device Stud Size	Torque (N•m)
M20	180
M16	130
M12	80
M8	30

otherwise specified in the manufacturer's instructions. Set bearing anchor bolts in accordance with the requirements specified in Section 564.

In the presence of the CO, proof load a random sample of at least 10 percent of the anchors to 90 percent of the yield stress of the steel. If any anchor fails, reset the failed anchor and proof torque the reset anchor and 100 percent of all remaining anchors. The proof load may be applied by torquing against load indicator washers, applying direct tension load to the anchor, or some other method approved by the CO. After proof loading, release the load on the anchor and retighten to the load specified in table 552-6, or in accordance with the manufacturer's instructions.

552.20 Loads on New Concrete Structures. Do not allow vehicles or construction equipment on any span until concrete in the entire superstructure has attained its design compressive strength and has been in place 21 days.

Do not place any loads on finished piers, bents, or abutments until tests on concrete cylinders cast from the same concrete and cured under the same conditions indicate that the concrete has obtained at least 80 percent of the specified minimum 28-day concrete compressive strength. This restriction does not apply to placement of upper lifts for substructure elements cast in stages.

For posttensioned concrete structures, do not allow vehicles weighing more than 2,000 kg on any span until the prestressing steel for that span is tensioned, grouted, and cured. Vehicles weighing less than 2,000 kg may be permitted on a span, provided the weight of the vehicle was included in the falsework design.

Permit no public traffic on the bridge until approaches, curbs, bridge rail, and object markers are completed and in place.

Erect barricades at each end of the bridge span upon completion of the deck concreting if road approaches allow vehicles to drive directly onto the structure. Locate barricades so as to physically prevent vehicular access to the bridge. Do not remove barricades until the structure is open to public traffic as approved by the CO.

Measurement

552.21 Method. Use the method of measurement that is DESIGNATED IN THE SCHEDULE OF ITEMS.

Measure structural concrete by the cubic meter or lump sum. Measure in accordance with the neat lines of the structure as SHOWN ON THE DRAWINGS, except as altered by the CO to fit field conditions. Make no deduction for the volume occupied by reinforcing steel, anchors, weep holes, piling, or pipes less than 200 mm in diameter. Do not include the volume of fillet less than 150 mm on a side or the varying thickness haunches between prefabricated girder and bridge decks.

Payment

552.22 Basis. The accepted quantities will be paid for at the contract unit price for each PAY ITEM DESIGNATED IN THE SCHEDULE OF ITEMS.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
552 (01) Structural concrete, class ____	Cubic Meter
552 (02) Structural concrete, class ____	Lump Sum
552 (03) Structural concrete, class ____, for _____ <i>Description</i>	Cubic Meter
552 (04) Structural concrete, class ____, for _____ <i>Description</i>	Lump Sum

Section 553—Prestressed Concrete

Description

553.01 Work. Prestress precast or cast-in-place concrete by furnishing, placing, and tensioning prestressing steel. Manufacture, transport, store, and install all precast prestressed members except piling.

Furnish prestressed members complete, including all concrete, prestressing steel, bar reinforcing steel, and incidentals in connection therewith.

Materials

553.02 Requirements. Furnish material that conforms to specifications in the following sections and subsections:

Elastomeric Bearing Pads	717.10
High-Strength Nonshrink Grout	701.02
Low-Strength Grout	701.03
Mortar	701.04
Prestressing Steel	709.03
Reinforcing Steel	554
Sealants, Fillers, Seals, & Sleeves	712.01
Structural Concrete	552
Structural Steel	717.01

Use class P concrete in prestressed members unless otherwise SHOWN ON THE DRAWINGS. Design the concrete mix in accordance with Subsection 552.03 with a 28-day design compressive strength as SHOWN ON THE DRAWINGS. Do not permit lightweight concrete unless otherwise SHOWN ON THE DRAWINGS.

Construction

553.03 Method Approval. Notify the CO a minimum of 10 days prior to fabrication of any prestressed members.

Inspect all prestressed concrete members by one of the following methods, unless otherwise SHOWN ON THE DRAWINGS or in the SPECIAL PROJECT SPECIFICATIONS:

- Use the quality control engineer of a plant certified by the Prestressed Concrete Institute (PCI). Submit a copy of the transmittal letter of the latest PCI inspection with the shop drawings. Furnish a copy of all testing and inspection reports to the CO upon delivery of the members to the jobsite.
- Use an independent licensed professional engineer experienced in prestressed concrete girder inspection to certify that the prestressed members were built in accordance with the drawings and specifications. Furnish, along with the certification, a copy of all testing and inspection reports to the CO upon delivery of the members to the jobsite.

Ensure that dimensional tolerances for prestressed girders are as given in division 5, section 5 of PCI manual 116-77 ("Manual for Quality Control: Precast Prestressed Concrete Products," Prestressed Concrete Institute, Chicago, Illinois).

Perform prestressing by pretensioning methods. Submit four copies of shop drawings for prestressed members and one copy of reproducible detailed drawings of the method, material, and equipment proposed for approval at least 21 days before starting prestressing.

Show the following:

- (a) Method and sequence of stressing.
- (b) Complete specifications, details, and test results for the prestressing steel and anchoring devices.
- (c) Anchoring stresses.
- (d) Arrangement of the prestressing steel in the members to include the strand pattern at midspan and at centerspan of bearing; and the location of total strand center of gravity at midspan, at hold-down points, at quarter points, and at centerline of bearing.
- (e) Tendon elongation calculations for jacking procedures to be used, to include the calibration curve for the gauge and jacking system, the stress-strain curve for the prestressed strands, and the pressure gauge readings.
- (f) Number, spacing, and method of draping pretensioned strands.
- (g) The prestressing bed layout and overall length between grips at fixed and jacking ends, and the type of equipment to be used.
- (h) Other substantiating calculations for the prestressing method.

- (i) Certification of wire or strand taken in accordance with Subsection 709.03.
- (j) Concrete mix design.

Provide the signature and seal of a licensed professional engineer on all shop drawings and calculations prepared for fabrication of prestressed members.

The CO will review mix designs and approve shop drawings prior to fabrication of prestressed members.

553.04 Prestressing Steel. Use prestressing steel that is bright and free of corrosion, dirt, grease, wax, scale, rust, oil, or other foreign material that may prevent bond between the steel and the concrete. Do not use prestressing steel that has sustained physical damage or is pitted.

One approved splice per pretensioning strand is permitted if the splice is between members in the casting bed. Splice so the strands have the same “twist” or “lay.”

Do not weld or ground welding equipment on forms or other steel in the member after the prestressing steel is installed.

Allow a seven-wire strand with one broken wire to remain in the member, provided it is within the following limits:

For members with:

- (a) Less than 20 strands, no wire breaks permitted.
- (b) 20 to 39 strands, one wire break permitted.
- (c) 40 to 59 strands, two wire breaks permitted.
- (d) 60 or more strands, three wire breaks permitted.

Remove and replace all strands that exceed the permissible number of wire breaks. Remove any strand that has one or more than one broken wire. Securely wrap the broken ends of any wire breaks that are permitted to remain in the member with tie wire to prevent raveling.

553.05 Concrete. Construct prestressed concrete in accordance with Section 552. Construct reinforcing steel in accordance with Section 554.

Ensure that threaded inserts develop the full tensile strength of bars or bolts they secure. Unless otherwise SHOWN ON THE DRAWINGS, provide lifting devices of adequate strength to safely lift the girders within 600 mm of the girder ends.

Straighten wires, wire groups, parallel-lay cables, and any other prestressing elements to ensure proper position in the enclosures. Provide suitable horizontal and vertical spacers, if required, to hold the wires in position.

Do not place concrete in the forms until the placement of reinforcing steel, prestressing steel, ducts, bearing plates, and other embedded material is approved. Place and vibrate concrete with care to avoid displacing the embedded material.

Rough cast the top surface of members against which concrete will be cast.

Determine the strength of precast concrete required prior to release of pretensioned strands by tests on cylinders cast and cured under conditions in which the time-temperature relationship of the cylinder will simulate as nearly as possible that obtained during the curing of the structural member. When the forms are heated by steam or hot air, place the cylinder in the lowest heat zone during the curing period. When forms are heated by some other means, provide a recording of the time-temperature relationship of the test cylinder for comparison with that of the prestressed unit.

Mold, cure, and test the cylinders in accordance with AASHTO T 126 and T 22 for 28-day test cylinders, and AASHTO T 23 for test cylinders cured with the members. When accelerated curing methods are used, allow the cylinders to cool for at least one-half hour prior to capping, and allow caps of sulfur compound to cure one-half hour before testing.

Table 553-1.—Prestressed members (from the same placements).

Number of Members/Day	Release Test Cylinders Taken ^a	Minimum Cylinders Broken (Release Test)	28-Day Strength Test Cylinders Taken and Broken ^a
1	3	2	3
2	3	1 per beam	4 ^b
3	3 ^c	1 per beam	6 ^b
4	4 ^c	1 per beam	8 ^b
5	5 ^c	1 per beam	10 ^b
6	6 ^c	1 per beam	12 ^b
7	7 ^c	1 per beam	14 ^b
8	8 ^c	1 per beam	16 ^b

a. Assumes all concrete is air-entrained or nonair-entrained. If both types of concrete are used in the same member, the number of test cylinders listed shall be taken from the air-entrained concrete, and the same number of test cylinders shall be taken from the nonair-entrained concrete.

b. Two test cylinders taken from each member.

c. One test cylinder taken from each member.

As a minimum, take the numbers of test cylinders shown in table 553-1. Take more cylinders if the CO judges it necessary.

Cure the girder in a saturated atmosphere of at least 90 percent relative humidity. Cure time may be shortened by heating the outside of impervious forms with radiant heat, convection heat, conducted steam, or hot air.

Apply radiant heat by means of pipes circulating steam, hot oil, hot water, or electric heating elements. Inspect casting beds to ensure uniform heat application. Use a suitable enclosure to contain the heat. Minimize moisture loss by covering all exposed concrete surfaces with plastic sheeting or liquid membrane curing compound in accordance with Subsection 552.17. Sandblast curing compound from all surfaces to which concrete will be bonded.

When using steam, envelop the entire surface with saturated steam. Completely enclose the casting bed with a suitable type of housing, tightly constructed to prevent the escape of steam and exclude outside air. Use steam at 100 percent relative humidity. Do not apply the steam directly to the concrete.

When using hot air, the CO will approve the method to envelop and maintain the girder in a saturated atmosphere. Never allow dry heat to touch the girder surface.

For all heat curing methods:

- (a) Keep all unformed girder surfaces in a saturated atmosphere throughout the curing time.
- (b) Embed a thermocouple linked with a thermometer accurate to ± 3 °C 150 to 200 mm from the top or bottom of the girder on its centerline and near its midpoint.
- (c) Monitor with a recording sensor (accurate to ± 3 °C) arranged and calibrated to continuously record, date, and identify concrete temperature throughout the heating cycle.
- (d) Make this temperature record available to the CO.
- (e) Heat concrete to no more than 38 °C during the first 2 hours after placing concrete, and then increase no more than 14 °C per hour to a maximum of 80 °C.
- (f) After curing is complete, cool concrete no more than 14 °C per hour to 38 °C.

- (g) Keep the temperature of the concrete above 15 °C until the girder reaches release strength.
- (h) Do not expose the girders to temperatures below freezing until the specified 28-day strength has been achieved.
- (i) To prevent cracking of members, detension strands and transfer their stress to the concrete immediately upon attainment of required release strengths and before the members have been allowed to dry and cool. Should this be impractical, keep the members covered and moist, and hold at a minimum temperature of 15 °C until strands are detensioned.

Cure precast pretensioned members until the concrete has attained the required release compressive strength. The average strength of two test cylinders shall be greater than the minimum required strength. Ensure that the individual strength of any one cylinder is not more than 5 percent below the required strength.

Steam-cure curbs and diaphragms cast after the prestress member has been cured for a minimum of 12 hours at 38 °C to 71 °C or moist-cured for a minimum of 3 days in accordance with Subsection 552.17.

Provide a class 2 rubbed finish to the exterior surface of the exterior girders and the bottom flanges of all girders, as specified in Subsection 552.18(b), unless otherwise SHOWN ON THE DRAWINGS. Provide a class 1 ordinary surface finish to the rest of the girders, as specified in Subsection 552.18(a).

Finish portions of prestressed members that will serve as bridge decks, as provided in Subsection 552.16(c)(1) or (2), as appropriate, or as SHOWN ON THE DRAWINGS.

With the approval of the CO, repair rock pockets and other minor deficiencies of a nonstructural nature in the girders. Reject any girders that are repaired without the approval of the CO, regardless of the extent of the repair work.

553.06 Tensioning. Stress strands only when an inspector (see Subsection 553.03) is present. Record the pretensioning gauge pressures and measured strand elongations, and provide a copy to the CO.

Use hydraulic jacks to tension prestressing steel. Use a pressure gage or load cell for measuring jacking force.

Calibrate measuring devices at least once every 6 months, or if they appear to be giving erratic results. Calibrate the jack and gage as a unit, with the cylinder extension in the approximate position to be at final jacking force. Keep a certified calibration chart with each gage.

If a pressure gage is used, do not gage loads less than one-quarter or more than three-quarters of the total graduated capacity of the gage, unless calibration data clearly establishes consistent accuracy over a wider range. Use a pressure gage with an accurate reading dial at least 150 mm in diameter.

Measure the force induced in the prestressing steel using jacking gages, and take elongation measurements of the prestressing steel. If there is a discrepancy of more than 7 percent between the jacking force and the expected elongation, check the entire operation, determine the reasons for the discrepancy, and correct before proceeding. Recalibrate jacking gages if their readings do not agree within 5 percent of each other. If the jacking system is equipped with an automatic release valve that closes when the required prestressing force is reached, strand elongation measurements are only required for the first and last tendon tensioned and for at least 10 percent of the remaining tendons.

If a load cell is used, do not use the lower 10 percent of the manufacturer's rated capacity of the load cell to determine the jacking force.

Do not exceed a temporary tensile stress in prestressing steel of 80 percent of the specified minimum ultimate tensile strength of the prestressing steel. Anchor prestressing steel at an initial stress that will result in the retention of a working stress after all losses of not less than those required.

For pretensioned members, do not allow the initial release stress after seating and before other losses to exceed 70 percent of the specified minimum ultimate tensile strength of the prestressing steel for stress-relieved strands, and 75 percent for low-relaxation strands. For posttensioned members, do not allow the initial release stress after seating to exceed 70 percent of the specified minimum ultimate tensile strength of the prestressing steel.

553.07 Pretensioned Members. Cast pretensioned members to the tolerances shown in table 553-2.

Cast pretensioned members in commercial prestressing plants that are PCI-Certified Plants in Product Group B—Bridges, category B3 (Prestressed Straight Strand Bridge Members) or category B4 (Prestressed Draped Strand Bridge Members), as applicable to the members to be manufactured.

(a) **Prestressing Steel.** Protect prestressing steel placed in the stressing bed from contamination and corrosion if the stressing bed will be exposed to weather for more than 36 hours before encasement in concrete.

Table 553-2.—Prestressed concrete member tolerances.

Description	Tolerance
Precast girders with cast-in-place decks: ^a	
Length	± 10 mm/10 m, ± 25 mm max.
Width (overall)	+ 10 mm, - 5 mm
Depth (overall)	+ 15 mm, - 5 mm
Depth (flanges)	- 5 mm
Width (web)	+ 10 mm, - 5 mm
Sweep ^b	3 mm/3 m
Variation from end squareness or skew	± 15 mm/m, ± 25 mm max.
Camber variation from design camber	± 3 mm/3 m ± 15 mm, max. > 25 m length ± 25 mm, max. > 25 m length
Position of strands:	
Individual	± 5 mm—bundled
Bundled	± 15 mm
Position from design location of deflection points for deflected strands	± 500 mm
Position of plates other than bearing plates	± 25 mm
Position of bearing plates	± 15 mm
Tipping and flushness of plates	± 5 mm
Tipping and flushness of bearing plates	± 5 mm
Position of inserts for structural connections	± 15 mm
Position of handling devices:	
Parallel to length	± 150 mm
Transverse to length	± 25 mm
Position of stirrups:	
Longitudinal spacing	± 50 mm
Projection above top	± 20 mm
Local smoothness ^c	± 6 mm in 3 m, any surface

a. AASHTO I Beams and Bulb Tee Girders.

b. Variation from straight line parallel to centerline of member.

c. Does not apply to top surface left rough to receive a topping or to visually concealed surfaces.

Free all strands of kinks or twists. Accurately hold prestressing steel in position, and tension in accordance with Subsection 553.06. Do not allow strands to unwind more than one turn. Keep a record of the jacking force and elongation measurements after the strands are tensioned to 20 percent of final jacking force.

Tension prestressing steel to the required stress. Include in elongation computations strand anchorage slippage, splice slippage, horizontal movement of abutments, and prestressing steel temperature changes between the time of tensioning and the time when the concrete takes its initial set.

Table 553-2.—Prestressed concrete member tolerances (cont.).

Description	Tolerance
Precast girders used in multibeam decks: ^d	
Length	± 20 mm
Width (overall)	± 5 mm
Depth (overall)	± 5 mm
Depth (top flange)	± 15 mm
Depth (bottom flange)	+ 15 mm, - 5 mm
Width (web)	± 10 mm
Sweep ^e –	
Up to 12-m member length	± 5 mm
12- to 18-m member length	± 10 mm
Greater than 18-m member length	± 15 mm
Variation from end squareness or skew:	
Horizontal	± 10 mm/m
Vertical	± 15 mm max.
Camber variation from design camber	± 3 mm/3 m, ± 15 mm max.
Differential camber between adjacent members of the same design	6 mm/3 m, 20 mm max.
Position of strands:	
Individual	± 5 mm
Bundled	± 5 mm
Position from design location of deflection points for deflected strands	500 mm
Position of plates other than bearing plates	± 25 mm
Tipping and flushness of plates	± 5 mm
Position of inserts for structural connections:	± 15 mm
Position of handling devices:	
Parallel to length	± 150 mm
Transverse to length	± 25 mm

d. Box beams, slabs, decked bulb tee, and multistern girders.

e. Variation from straight line parallel to centerline of member.

Maintain the prestress bed forms, strands, and reinforcement bar temperature within 14 °C of the temperature of the concrete to be placed in the forms. Support strands with rollers at points of direction change when strands are tensioned in a draped position. Use free-running rollers with minimal friction. Initially, when strands are tensioned and then pulled into the draped position, tension to no more than the required tension minus the increased tension due to forcing the strand to a draped profile. If the load in a draped strand at the dead end, as determined by elongation measurements, is less than 95 percent of the jack load, tension the strand from both ends of the bed. Make the load, as computed from the sum of elongations produced by jacking at both ends, agree within 5 percent of the jack load.

Table 553-2.—Prestressed concrete member tolerances (cont.).

Description	Tolerance
Precast girders used in multibeam decks, position of stirrups:	
Longitudinal spacing	± 25 mm
Projection above top	+ 5 mm, – 20 mm
Tipping of beam seat bearing area	± 5 mm
Position of dowel tubes	± 15 mm
Position of tie rod tubes:	
Parallel to length	± 15 mm
Vertical	± 10 mm
Position of slab void:	
End of void to center of tie hole	± 15 mm
Adjacent to end block	± 25 mm
Local smoothness ^f	± 5 mm in 3 m, any surface
Posttension members:	
Position of posttensioning ducts	± 5 mm
Position of tendon anchorage bearing plates	± 5 mm

f. Does not apply to top surface left rough to receive a topping or to visually concealed surfaces.

Within 3 hours before placing concrete, check the tension on all prestressing steel strands. The method and equipment for checking the loss of prestress shall be subject to approval by the CO. If strands are tensioned individually, check each strand for loss of prestress. Retension to the original computed jacking stress all strands that show a loss of prestress in excess of 3 percent. If strands are tensioned in a group, check the entire group for loss of prestress. Release and retension the entire group if the total prestress shows a loss in excess of 3 percent, or if any individual strand appears significantly different from the rest of the strands in the group.

(b) Releasing Steel. Release the prestress load to the concrete after the concrete has attained its required release compressive strength. Do not expose the concrete to temperatures below freezing for at least 7 days after casting. Cut or release strands such that lateral eccentricity of the prestress force will be minimized. Cut prestress steel off flush with the end of the member unless otherwise SHOWN ON THE DRAWINGS.

553.08 Storing, Transporting, & Erecting. Do not ship prestressed concrete members until concrete cylinder tests manufactured of the same concrete and cured under the same conditions as the members indicate that the concrete in each member has attained the minimum required design strength and is at least 14 days old.

Store, transport, and erect precast and prestressed girders, slab units, and box units in the upright position with the points of support and directions of the reactions, with respect to the member, approximately the same as when the member is in its final position, unless otherwise shown on approved shop drawings. Prevent cracking or damage during storage, hoisting, and handling of the precast units. Replace units damaged by improper storage or handling.

Store, transfer, and erect precast prestressed concrete piling in accordance with the requirements for precast concrete piling specified in Section 551. Place other precast prestressed structural members in the structure as SHOWN ON THE DRAWINGS and in accordance with the SPECIAL PROJECT SPECIFICATIONS.

553.09 Erecting & Placement of Multibeam Members. Advise the CO a minimum of 48 hours before prestressed girders for multibeam bridges are to be field welded, and before any field grout or mortar is to be placed.

Adjust, if necessary, multibeam girders by using galvanized steel shims the same length and width as the bearing pad or plate. Allow no more than 5 mm vertical difference between top of adjacent beam edges at each end of the span. When an asphalt wearing surface or cast-in-place deck is to be placed on top of the prestressed beams, allow a vertical tolerance of only 15 mm. Do not load beams to make them assume the same camber as an adjacent beam.

Perform abrasive blasting on the keyway surfaces of all multibeam prestressed concrete members to provide a new and clean concrete surface that is free of carbonated concrete and other contaminants, and to expose parts of the large aggregate beneath the concrete paste.

Use high-pressure water blasting (20.7 kPa or more) to remove all debris and loosened paste in the keyways immediately prior to placing mortar. Remove all free-standing water and allow keyways to completely surface dry. Test for the presence of carbonated concrete when directed by the CO or called for by the SPECIAL PROJECT SPECIFICATIONS. Repeat abrasive blasting and water washing as needed if tests indicate the presence of carbonated concrete.

Use mortar in keyways between multibeam members and to patch defects, blockouts, or other areas on the concrete roadway portion of the structure 25 mm or more in depth and over 25 mm in width. Patch smaller areas on the concrete roadway with grout.

Maintain air and concrete keyway temperatures between 7 °C and 30 °C before placing mortar. Maintain the temperature within these limits until mortar placement and application of curing method is completed.

Use grout on all anchor bolts and dowels to make all repairs.

Require air and concrete temperatures for grout placement to be the same as required for mortar. Thoroughly saturate the areas to be grouted with water and remove all free-standing water just prior to grout placement.

Strike off exposed grout surfaces flush with the same surface texture finish as the surrounding concrete as soon as the grout has set sufficiently. Cure the exposed surface as specified in Subsection 552.17. When artificial means are used to control the curing temperature of the mortar or grout, as during hot or cold weather, the CO will approve the method in advance. Use combustion heaters only if fully vented outside their enclosure. Store all dry mortar materials and mixing and placing equipment such that their temperature is above freezing. Warm mixing water to provide mortar or grout at desired temperature, but ensure that it is at 30 °C or less when mixed with the dry materials. Use ice as part of the mixing water provided it is completely melted prior to the introduction of the water to the dry materials.

Ensure that patching mortar and grout are the same color as the parent concrete.

Ensure that all field welding meets the requirements specified in Section 555. When welding or burning on precast members, attach the ground lead directly to the base metal; reject any precast prestressed member used as a conductor for the ground, and replace the member without compensation.

553.10 Painting Steel. Use a wire brush or abrasive blast to remove all dirt and residue not firmly bonded to the metal or concrete surfaces. Clean and paint the exposed ends of the prestress steel, posttension anchor head assemblies, and a 25-mm strip of adjoining concrete.

Mix zinc-rich paint conforming to Federal Specifications and Standards (FSS) TT-P-641. Work the paint into all voids in the prestressing tendons. Apply one thick coat to surfaces that will be covered with concrete. Apply two coats to surfaces not covered with concrete.

Measurement

553.11 Method. Use the method of measurement that is DESIGNATED IN THE SCHEDULE OF ITEMS.

Measure precast prestressed structural concrete members by the each or by the meter.

Measure prestressed piling under Section 551.

Payment

553.12 Basis. The accepted quantities will be paid for at the contract unit price for each PAY ITEM DESIGNATED IN THE SCHEDULE OF ITEMS.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
553 (01) Precast prestressed concrete structural members, _____ <i>Description</i>	Each
553 (02) Precast prestressed concrete structural members, _____ <i>Description</i>	Meter

Section 553A—Precast Concrete Structures

Description

553A.01 Work. Construct precast concrete members. In addition, manufacture, test materials for, transport, store, and install all precast concrete portions except piling, and perform all necessary grouting, welding, or other connections. Furnish precast concrete members complete and in place, including all concrete reinforcing steel and incidentals connected therewith.

Materials

553A.02 Requirements. Provide materials that meet the requirements specified in the following subsections:

Elastomeric Bearing Pads	717.10
High-Strength Nonshrink Grout	701.02
Low-Strength Grout	701.03
Mortar	701.04
Reinforcing Steel	709.01
Sealants, Fillers, Seals, & Sleeves	712.01
Structural Concrete	552.02
Structural Steel	717.01

Provide precast concrete members of the size, shape, strength, air content, and finish that are SHOWN ON THE DRAWINGS.

Perform all sampling, testing, and inspection necessary to ensure quality control of the component materials and the concrete. Sample and test for quality control and acceptance testing in accordance with the AASHTO or ASTM test methods prescribed in Section 552.

Maintain adequate records of all inspections and tests. Keep records that indicate the nature and number of observations made, the number and type of deficiencies found, the quantities approved and rejected, and the nature of any corrective action taken.

Sample and test every batch (100 percent sampling and testing) for air content and slump at the start of concrete production. Random sampling and testing for air content and slump at the rate of one for every five successive batches may be substituted for 100 percent sampling and testing if the test results for three

successive batches are within the specification limitations for air content or slump; but reinstate 100 percent sampling and testing if a test result for any random sample is outside the specification limitations for either air content or slump.

Make compression tests to determine the minimum strength requirements on cylinders. Make a minimum of four cylinders from each day's production, and cure them in the same manner as the precast units. Use testing methods in accordance with AASHTO T 22.

Furnish, or have the supplier furnish, a Certificate of Compliance to the CO certifying that the above materials comply with the applicable specifications. In addition, furnish to the CO a copy of all test results performed by the Contractor or supplier that are necessary to ensure compliance.

Construction

553A.03 Performance. Construct precast concrete structural members in accordance with the following sections and subsections, as applicable:

Erecting and Placement of Multibeam Members	553.09
Reinforcing Steel	554
Storing, Transporting, & Erecting	553.08
Structural Concrete	552

Submit four sets of shop drawings to the CO for approval, including the concrete mix design for each class of concrete proposed for use, a minimum of 21 days before fabrication of the precast member(s).

553A.04 Casting Yard. The precasting of concrete structural members may be done at a casting yard location selected by the Contractor.

553A.05 Handling, Transporting, & Erecting. Provide additional reinforcement, as needed, to meet the requirements of handling, transporting, and erecting precast members.

Measurement

553A.06 Method. Use the method of measurement that is DESIGNATED IN THE SCHEDULE OF ITEMS.

Each member will include the concrete, reinforcement steel, anchorages, plates, nuts, and other material contained within or attached to the unit.

Payment

553A.07 Basis. The accepted quantities will be paid for at the contract unit price for each PAY ITEM DESIGNATED IN THE SCHEDULE OF ITEMS.

<u>Pay Item</u>	<u>Pay Unit</u>
553A (01) Precast concrete member, _____ <i>Description</i> Each
553A (02) Precast concrete structure, _____ <i>Description</i> Lump Sum

Section 554—Reinforcing Steel

Description

554.01 Work. Furnish and place reinforcing steel.

Materials

554.02 Requirements. Furnish material that conforms to specifications in the following subsections:

Reinforcing Steel 709.01

Construction

554.03 Order Lists. When SHOWN ON THE DRAWINGS or in the SPECIAL PROJECT SPECIFICATIONS, submit all order lists and bending diagrams to the CO for approval. Approval does not relieve the Contractor of responsibility for the accuracy of the lists and diagrams. Do not order material until the lists and diagrams are approved.

Do not fabricate vertical reinforcement in columns, walls, piers, and shafts until footing elevations are established in the field, unless otherwise SHOWN ON THE DRAWINGS or in the SPECIAL PROJECT SPECIFICATIONS.

554.04 Identification. Ship bar reinforcement in standard bundles tagged and marked in accordance with the “Manual of Standard Practice” by the Concrete Reinforcing Steel Institute (CRSI).

554.05 Bending. Fabricate reinforcing bars in accordance with ACI SP 66. Cold bend all reinforcing bars that require bending. Limit the overall height or drop bending tolerance of deck truss bars to + 0 mm or – 6 mm. Do not bend bars partially embedded in concrete except as SHOWN ON THE DRAWINGS or otherwise permitted.

When the dimensions of hooks or the diameter of bends is not SHOWN ON THE DRAWINGS, provide standard hooks conforming to ACI SP 66.

554.06 Protection of Material. Store reinforcing steel above the ground on platforms, skids, or other supports. Protect from physical damage, rust, and other surface deterioration.

Use reinforcing steel only when the surface is clean and the minimum dimensions, cross-sectional area, and tensile properties conform to the physical requirements for the size and grade of steel specified.

Do not use reinforcing steel that is cracked, laminated, or covered with dirt, rust, loose scale, paint, grease, oil, or other deleterious material.

554.07 Epoxy-Coated Reinforcing Steel. Support coated bars on padded contact areas. Pad all bundled bands. Lift with a strong back, multiple supports, or a platform bridge. Prevent bar-to-bar abrasion. Do not drop or drag bundles.

Before placement, inspect coated bars for damage to the coating. Patch all defects in the coating that are discernible to the unaided eye with a prequalified patching/repair material, in accordance with AASHTO M 284M. Clean areas to be patched by removing all surface contaminants and damaged coating. Roughen the area to be patched before applying the patching material. Where rust is present, remove the rust by blast cleaning or power-tool cleaning immediately before applying the patching material.

Promptly treat the bar in accordance with the resin manufacturer's recommendations and before detrimental oxidation occurs. Overlap the patching material onto the original coating for 50 mm or as recommended by the manufacturer. Provide a minimum 200- μ m dry film thickness on the patched areas.

Take necessary steps to minimize damage to the epoxy coating of installed bars. Clean and patch any damage to the coating noted after installation, as described above.

Field repairs will not be allowed on bars that have severely damaged coatings. Replace bars with severely damaged coatings. A severely damaged coating is defined as a coating with a total damaged area in any 0.5-m length of bar that exceeds

5 percent of the surface area of that portion of the bar. Coat mechanical splices after splice installation in accordance with AASHTO M 284M for patching damaged epoxy coatings.

554.08 Placing & Fastening. Support the bars on precast concrete blocks or metal supports in accordance with the CRSI "Manual of Standard Practice of the Concrete Reinforcing Steel Institute." Attach concrete block supports to the supported bar with 2-mm wire cast in the center of each block. Use class 1 (plastic-protected) or class 2, type B (stainless-steel-protected) metal supports in contact with exposed concrete surfaces. Use stainless steel conforming to ASTM A 493, type 430. Coat chairs, tie wires, and other devices used to support, position, or fasten epoxy-coated reinforcement with a dielectric material. Do not use plastic, wood, aluminum, brick, or rock supports.

Space slab bar supports no more than 1.2 m apart transversely or longitudinally. Do not use bar supports either directly or indirectly to support runways for concrete buggies or other similar construction loads.

Space parallel bars within 38 mm of the required location. Do not accumulate spacing variations. Ensure that the average of any two adjacent spaces does not exceed the required spacing.

Provide 50 mm clear cover for all reinforcement except as otherwise SHOWN ON THE DRAWINGS.

Place reinforcing steel in deck slabs within 6 mm of the vertical plan location. Tie bridge deck reinforcing bars together at all intersections, except where spacing is less than 300 mm in both directions, in which case alternate intersections may be tied. Check the clear cover over deck-reinforcing steel using a template before placing deck concrete. Replace damaged supports.

Tie every reinforcing-steel intersection at the outside edges of decks, in top mats of footings, and in all precast and/or prestressed concrete units.

Tie bundle bars together at intervals not exceeding 2 m. Do not bundle bars unless the location and splice details are specified.

Do not place concrete in any member until the placement of the reinforcement is approved by the CO. Concrete placed without approval may be rejected, and the Contractor may be required to remove it without compensation.

554.09 Splices. Splicing, except as SHOWN ON THE DRAWINGS, is not permitted without approval. Provide lap lengths as SHOWN ON THE DRAWINGS or in accordance with the latest edition of "Standard Specifications for Highway Bridges," published by AASHTO.

Splice reinforcing bars only where SHOWN ON THE DRAWINGS. Do not place slab bar mechanical splices adjacent to each other.

Make lapped splices by placing the reinforcing bars in contact and wiring them together with at least three ties to maintain the alignment and position of the bars.

If welding of reinforcing steel is permitted, ensure that the welds conform to AWS D 1.4. Do not weld reinforcing steel if the chemical composition of the steel exceeds the percentages shown in table 554-1.

Use welders that are currently certified. When required, test each weld using magnetic particle, radiography, or other nondestructive inspection techniques.

Table 554-1.—Reinforcing steel components.

Chemical Composition	Percent
Carbon	0.30
Manganese	1.50
Carbon equivalent	0.55

Do not tack-weld reinforcing steel.

Mechanical couplers may be used in lieu of welding, if approved. Use couplers with a strength that is at least 125 percent of the required yield strength of the reinforcing steel.

If welded wire fabric is shipped in rolls, straighten into flat sheets before placing. Splice sheets of mesh or bar mat reinforcement by overlapping not less than 1 mesh width plus 50 mm. Securely fasten at the ends and edges.

Measurement

554.10 Method. Use the method of measurement that is DESIGNATED IN THE SCHEDULE OF ITEMS.

Measure reinforcing steel by the kilogram or by the lump sum, excluding laps added for the Contractor’s convenience.

Payment

554.11 Basis. The accepted quantities will be paid for at the contract unit price for each PAY ITEM DESIGNATED IN THE SCHEDULE OF ITEMS.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
554 (01) Reinforcing steel	Kilogram
554 (02) Epoxy-coated reinforcing steel	Kilogram
554 (03) Reinforcing steel	Lump Sum