Note to editor: The original markup was made on the 2017 edition. It was verified that the required changes are the same for the 2019 edition. Direct changes are marked in red. Notes to editor are marked in blue like this one.
CC-2250  MARKING AND IDENTIFICATION OF CONCRETE CONSTITUENTS

CC-2251  Cementitious Materials

Before leaving the place of manufacture, conveyances of bulk cementitious materials shall be sealed and tagged showing lot number, controlling specification, date of manufacture or processing, and type or class. If bag cementitious materials are used, each shipment shall be tagged with the same identification as for bulk material. All tags and markings shall be maintained with the material at site storage.

CC-2252  Aggregates

Aggregates shall be identified to show size, source, and controlling specification. The identification shall remain with the aggregate during transit and concrete plant storage.

CC-2253  Admixtures

All containers of admixtures shall be clearly marked, showing storage requirements and controlling specification. Bulk storage tanks for admixtures at batch plants shall be identified with the name of the admixture stored, the controlling specification, and the storage requirements.

CC-2300  MATERIAL FOR REINFORCING SYSTEMS

CC-2310  INTRODUCTION

(a) The material to be used for reinforcing bars for containments shall conform to ASTM A615 or A706 and the special requirements described in CC-2330.

(b) The material to be used for bar-to-bar splice sleeves in reinforcing bars shall conform to ASTM A108, A513, A519, or A576.

(c) The material to be used for reinforcing bar splice sleeves attached to liner plates or structural steel shapes shall be carbon steel conforming to one of the grades of ASTM A108, A513, A519, or A576 listed in Table D2-I-2.2.

(d) The material to be used for the heads of mechanically headed deformed bars shall conform to ASTM A108, A513, A519, or A576.

(e) Mechanically headed deformed bar assemblies shall conform to Figure CC-2310-1.

CC-2311  Mechanical Anchorage Devices

Mechanical anchorage devices shall

(a) be round or square with a smooth outer surface free of debris or irregularities.

(b) have a minimum net bearing area of 4 times the area of the bar. The net bearing area is calculated by taking the gross cross-sectional area of the head minus the nominal cross-sectional area of the bar.

The bar designations listed in this Division with the soft metric conversions in parenthesis are consistent with these ASTM standards.

CC-2330  SPECIAL MATERIAL TESTING

CC-2331  Tensile Tests

CC-2331.1  Number of Tests Required. One full-diameter tensile bar of each bar size shall be tensile tested for each 50 tons (45 Mg), or fraction thereof, of reinforcing bars produced from each heat of steel. The tensile test procedures shall be in accordance with SA-370.

CC-2331.2  Acceptance Standards. The acceptance standards shall be in conformance with the tensile requirements of ASTM A615 or ASTM A706, as applicable. If a test specimen fails to meet the tensile requirements, two additional specimens from the same heat and of the same bar size shall be tested. If either of the two additional specimens fails to meet the tensile requirements, the material represented by the tests shall not be accepted.

CC-2333  Chemical Analysis

A ladle analysis of each heat of reinforcing bar shall be made and reported in accordance with ASTM A615 or ASTM A706, as applicable.
CC-2445.2 Low Temperature Requirements. The tendon assembly shall be designed to meet the requirements of Article CC-3000 when exposed to the lowest service temperature as specified in the Construction Specification.

CC-2445.3 Electrical Isolation. Complete electrical isolation of the entire tendon shall be provided. Electrical isolation of the tendon or encapsulation shall be able to be monitored or inspected at any time.

CC-2450 SYSTEM APPROVAL TESTING
CC-2451 General
All components and system testing shall be witnessed and verified by an independent inspection and testing agency. This testing shall be completed prior to submission of post-tension drawings and other related documents to the Designer for approval. The operations of the inspection and testing agency shall be evaluated for conformance to required procedures by a nationally recognized evaluation authority.

CC-2452 Grouting Components Assembly Pressure Test
Assemble anchorage and grout cap with all required grouting attachments. Seal the opening in the anchorage where the duct connects. Condition the assembly in concrete at 150 psi (1 MPa) for 3 hr before conducting the pressure test. The assembly shall sustain internal pressure of 150 psi (1 MPa) for 5 min with no more than 15 psi (103 kPa) reduction in pressure.

CC-2453 Duct Testing
Duct and duct connections in concrete prior to prestressing steel installation shall be capable of withstanding 10 ft (3 m) of concrete fluid pressure. Duct and duct connections for use with straight preinstalled prestressing steel, installed prior to concreting, shall be capable of withstanding 5 ft (1.5 m) of concrete pressure. Duct and duct connections shall not permanently dent more than 1/8 in. (3.2 mm) under 150 lb (1 MPa) of concentrated force applied between corrugations, using No. 4 (13 mm) reinforcing bar. Apply force for 2 min and measure the dent 2 min after force removal. The duct shall have adequate longitudinal bending stiffness so that a smooth interior is maintained for grout placement.

CC-2454 System Pressure Tests
For each assembly of the post-tension system, including all sizes and configurations, assemble systems and perform the pressure test defined herein. The post-tensioning assembly includes at least one of each component required to make a tendon from grout cap to grout cap.

CC-2454.1 Grout Field Mock-Up Testing. Field mock-up testing shall be conducted to confirm the effectiveness of the grouting operation. Testing shall employ the approved grout mixture, mixing and installation procedures, duct materials, and duct configurations that represent the most critical tendon arrangements (greatest height change and length) anticipated for the project. Grouted duct work shall be destructively examined for a complete encapsulation of tendons and complete filling of duct cavities per a procedure approved by the Designer.

CC-2460 PERFORMANCE TESTS
CC-2461 General Requirements
A series of performance tests shall be conducted to qualify the tendon system for use in the concrete containment. The required tests are designed to demonstrate that the combination of materials for the tendon system is adequate and to assess the overall strength and integrity of the tendon system. These tests of the tendon system are in addition to the tests of the separate tendon system components required by CC-2440.

CC-2462 Material to Be Used for Performance Tests
The materials to be used for the performance test tendons shall be those that the tendon Manufacturer proposes using for production tendons. All of the actual materials used and the necessary dimensions shall be documented on a form the same as or similar to that shown in Figure CC-2462-1.

CC-2463 Type and Number of Performance Tests
CC-2463.1 Static Tensile Test. The Construction Specification shall specify the number of static tensile tests (not less than two) to be conducted to destruction so that the following information may be obtained:
(a) yield strength (or proof stress)
(b) ultimate tensile strength
(c) elongation [over 100 in. (2 500 mm) minimum gage length]
(d) number of failed wires or strands
The results shall comply with the requirements of CC-2462.

CC-2463.2 High Cycle Dynamic Tensile Test. One high cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 500,000 cycles of stress variation from 60% to 66% of the minimum specified ultimate tensile strength of the tendon. One cycle is defined as an increase from the lower load to the higher load and return.

CC-2463.3 Low Cycle Dynamic Tensile Test. One low cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 50 cycles of stress variation from 40% to 80% of the minimum
(b) When \( v_{ut} \) is less than or equal to \( v_{ct} \), no reinforcing is required.

(c) Where \( v_{ut} \) is greater than \( v_{ct} \), the entire shear stress shall be resisted by reinforcing that is within the plane of the wall and normal to the failure surface. Such reinforcing shall be designed by the following equation:

\[
A_{vt} = \frac{V_{ut}(2\pi r)}{f_y} \tag{21}
\]

where

- \( t = \) concrete thickness
- \( \mu = \) a coefficient of friction that shall be taken equal to 1.0 when the failure surface is concrete to concrete and 0.7 when the failure surface is concrete to steel

(d) \( A_{vt} \) [in.\(^2\) (mm\(^2\))] shall be distributed uniformly around the failure surface and shall be fully developed by embedment or mechanical means on either side of the failure surface. Uniformly distributed shall be taken as requiring at least eight approximately equally spaced bars crossing the failure surface.

(e) \( v_{ut} \) shall not exceed 0.2\( f'_c \) nor 800 psi (5.5 MPa).

## CC-3522 Service Load Design

The same requirements stated in CC-3521 shall be used in designing shear reinforcement for service loads with the following modifications:

(a) Equation CC-3521.2.1(16) shall be replaced by

\[
v = \frac{V}{bd} \tag{1}
\]

(b) The reinforcement steel stress allowable from CC-3432.1 shall replace \( f_y \) in eqs. CC-3521.2.3(a)(17) through CC-3521.2.3(b)(2)(19).

(c) The reinforcing steel stress allowable from CC-3432.1 shall replace \( 0.9f_y \) in eqs. CC-3521.1.1(a)(12) through CC-3521.1.1(b)(1)(14).

(d) \( V_u \) in eqs. CC-3521.1.1(a)(12) through CC-3521.1.1(b)(1)(14) shall be replaced by \( V \).

(e) The maximum tangential shear stress provided by orthogonal reinforcement and limiting maximum tangential shear stresses shall be 50% of the values given for factored loads in CC-3521.1.1(b).

(f) Equation CC-3521.1.2(b)(15) shall be replaced by

\[
v \leq 0.5v_c \tag{15}
\]

(g) The requirements of CC-3521.3 shall be used for peripheral shear design for service loads with the following modifications:

1. The nominal shear stress shall be calculated by

\[
v = \frac{V}{bd} \tag{16}
\]

2. Shear stress \( v_c \) shall be calculated in accordance with CC-3431.3.

3. When \( v \) is greater than \( v_{ct} \), the excess shear force corresponding to \( v - v_{ct} \) shall be resisted by shear reinforcement designed in accordance with (b) above. \( v - v_{ct} \) shall be determined as follows:

   (a) \( v \) shall not exceed the greater of \( 3\sqrt{f'_c} (0.25\sqrt{f'_c}) \) or 1.5\( v_c \) when \( v_c \) is calculated in accordance with CC-3431.3.

   (b) The shear stress \( v_c \) carried by the concrete at any section shall not exceed the greater of \( \sqrt{f'_c} (0.083\sqrt{f'_c}) \) or \( 0.5v_c \) when \( v_c \), calculated in accordance with CC-3431.3, is greater than or equal to \( \sqrt{f'_c} (0.083\sqrt{f'_c}) \). When \( v_c \) is less than \( \sqrt{f'_c} (0.083\sqrt{f'_c}) \), the value of \( v_c \), calculated in accordance with CC-3431.3, shall be used.

(b) Torsional shear provisions for Service Load Design shall be as follows:

1. \( v_{ct} \) shall be calculated in accordance with CC-3431.3 and the reinforcement steel stress allowable from CC-3432.1 shall replace \( f_y \) in eq. CC-3521.4(c)(21).

2. In eq. CC-3521.4(a)(20), \( v_t \) and \( T \) shall be substituted for \( v_{ut} \) and \( T_u \), respectively.

3. In eq. CC-3521.4(c)(21), \( v_t \) shall be substituted for \( v_{ut} \).

4. The limits on \( v_t \) shall be calculated in accordance with CC-3431.3.

## CC-3530 Reinforcing Steel Requirements

### CC-3531 General

The following requirements shall govern design of the reinforcing steel:

(a) The reinforcing steel shall be designed with consideration of placement tolerances specified herein and in the Construction Specification.

(b) The following paragraphs relate to all load combinations in Table CC-3230-1.

### CC-3532 Reinforcing Steel Splicing and Development

(a) Splices of reinforcement shall be made only as required or permitted on the Design Drawings or in the Construction Specification.

(b) Lap splices shall not be used for bars larger than No. 11 (D36). Lap splices of bundled bars shall be based on the lap splice length required for individual bars of the same size as the bars spliced. Individual bar splices within a bundle shall not overlap. Entire bundles shall not be lap spliced. Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required length of lap nor more than 6 in. (150 mm).

(c) Where a non-prestressed reinforcement bar splice must be located in a region where tension is predicted in a direction perpendicular to the bar to be spliced, only a positive mechanical splice or a welded butt splice shall
be used, unless calculations or tests of the selected splice detail are made to demonstrate that there is an adequate transfer of force. These provisions do not apply to nominal temperature reinforcement.

(d) The values of $\sqrt{f_c}$ shall not exceed 100 psi (0.69 MPa).

(e) Mechanical splices shall be staggered if the strain measured over the full length of the splice (at 0.9 yield) exceeds that of a bar that is not mechanically spliced by more than 50%. If staggered mechanical splices are required, no more than $\frac{1}{4}$ of the bars shall be spliced in one plane normal to the bars, and the mechanical splices shall be staggered at least 30 in. (760 mm).

**CC-3532.1 Tension Splices.**

**CC-3532.1.1 Classification of Tension Lap Splices.**
The minimum length of lap for tension lap splices shall be as follows:

(a) Class A splices: $1.0l_d$

(b) Class B splices: $1.3l_d$

The tensile development length $l_d$ to develop $f_y$ is as given in CC-3532.1.2.

**CC-3532.1.2 Development Length.**

(a) Reinforcing steel which must terminate in a location where biaxial tension is predicted, such as at penetrations, shall be anchored by hooks, bends, or by positive mechanical anchorage in such a manner that the force in the terminated bar is adequately transferred to other reinforcement. Bar development lengths at such locations shall be increased by at least 25% over those permitted for uniaxial tension. Mechanical devices for end anchorage shall be qualified by testing to be capable of developing at least 125% of the specified minimum yield strength of the bar. Mechanical anchorage devices listed in CC-4331.3(a) through CC-4331.3(e) are allowed as end anchorage. These devices shall be in accordance with the provisions of CC-2310 and shall be qualified by testing per CC-4330. These special precautions are not required for nominal temperature reinforcement.

(b) Where bars no longer required to carry load are terminated in areas of biaxial tension, the bar development lengths shall be increased at least 25% over that required for areas of uniaxial tension, provided that biaxial tension forces are carried by other reinforcement. This requirement does not apply to nominal temperature reinforcement.

(c) The calculated tension in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof. For bars in tension, hooks may be used in developing the bars. If mechanical devices are used in whole or in part for end anchorage, the system shall be qualified by testing to be capable of developing at least 125% of the specified minimum yield strength of the bar and shall be in accordance with CC-2310 and CC-4330. Mechanical anchorage devices for end anchorage are limited to only the processes listed in CC-4331.3(a) through CC-4331.3(e).

(d) Tension reinforcement may be anchored by bending it across the section and either making it continuous with the reinforcement on the opposite face of the section, or anchoring it there by any mechanical device capable of developing at least 125% of the specified minimum yield strength of reinforcement.

(e) The critical sections for development of reinforcement are at points of maximum stress and at points where adjacent reinforcement terminates or is bent.

(f) Reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the section or 12 bar diameters, whichever is greater. The extension need not exceed 5 ft (1.5 m) if shear reinforcement is provided in the same area.

(g) Continuing reinforcement shall have an embedment length not less than the development length $l_d$ beyond the point where bent or terminated reinforcement is no longer required to resist flexure or tension.

(h) Reinforcement shall not be terminated in a tension zone unless one of the following conditions is satisfied.

(1) The shear at the cutoff point shall not exceed two-thirds that permitted, including the shear strength of furnished radial reinforcement.

(2) Stirrup area in excess of that required for shear and torsion is provided along each terminated bar over a distance from the termination point equal to three-fourths the effective depth of the member. The excess stirrups shall be proportioned such that $(A_{s_v}/b_{ws})\times f_y$ is not less than 60 psi (0.4 MPa), where $A_{s_v}$ is the area of the area of bars cut off to the total area of bars at the section.

(3) For No. 11 (D36) and smaller bars, the continuing bars provide double the area required for flexure at the cutoff point and the shear does not exceed three-fourths that permitted.

(i) The development length $l_{d,v}$ in inches, shall be computed as the product of the basic development length of (1) below and the applicable modification factor or factors of (2) below, but $l_{d,v}$ shall be not less than 12 in. (300 mm)

(1) The basic development length shall be as follows:

(1) For No. 6 (D19) and smaller bars

(U.S. Customary Units)

$$l_d = \frac{3}{40} \times \frac{f_y}{\sqrt{f_c}} \times \frac{0.8}{\left(\frac{c_h + K_{tr}}{d_b}\right)}$$

where:

- $f_y$: Yield stress of the bar
- $f_c$: Compressive strength of concrete
- $c_h$: Embedment length
- $K_{tr}$: Tension modification factor
- $d_b$: Diameter of bar
For No. 7 (D22) and larger bars

\[ l_d = \left( \frac{f_y}{1.1f'c} \times \frac{0.8}{K_{tr}} \right) d_b \]

\(-b\) For No. 7 (D22) and larger bars

\[ l_d = \left( \frac{3}{40} \times \frac{f_y}{f'c} \times \frac{1}{\left( \frac{c_b + K_{tr}}{d_b} \right)} \right) d_b \]

\[ K_{tr} = \frac{4A_{tr}}{sn} \quad \text{(U.S. Customary and SI Units)} \]

It is permitted to use \( K_{tr} = 0 \) as a design simplification even if transverse reinforcement is present.

\[ A_{tr} = \text{total cross-sectional area of all transverse reinforcement that is within the spacing } s \text{ and that crosses the potential plane of splitting through the reinforcement being developed, in.}^2 \text{ (mm}^2) \]

\[ c_b = \text{smaller of the distance from center of a bar to nearest concrete surface or one-half the center-to-center spacing of bars being developed, in. (mm)} \]

\[ K_{tr} = \text{transverse reinforcement index} \]

\[ n = \text{number of bars being spliced or developed along the plane of splitting} \]

\[ s = \text{maximum center-to-center spacing of transverse reinforcement within } l_d, \text{ in. (mm)} \]

Development length of individual bars within a bundle, in tension or compression, shall be that for the individual bar, increased 20% for a three-bar bundle and 33% for a four-bar bundle.

For determining the appropriate confinement term, a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area and having a centroid that coincides with that of the bundled bars.

(2) For horizontal reinforcement, the basic development length shall be multiplied by 1.3 if more than 12 in. (300 mm) of concrete is placed below the reinforcement during the concrete placement that embeds the reinforcement in the section. For the purpose of these requirements, reinforcement is considered to be horizontal if the angle the reinforcement makes with the horizontal plane is 30 deg or less.

(3) The basic development length may be reduced by the ratio of (area required) / (area provided), except where anchorage or development for \( f_y \) is specifically required.

CC-3532.1.3 Splices in Region of Maximum Tensile Stress. Splices in regions of maximum tensile stress should be avoided. Where such splices must be used, they shall be mechanically spliced in accordance with CC-4333, welded butt splice in accordance with CC-4334, or Class B lap spliced in accordance with CC-3532.1.1.

CC-3532.1.4 Splices Away From Regions of Maximum Tensile Stress. Splices away from regions of maximum tensile stress (maximum computed stress less than 0.5\( f_y \)) shall be mechanically spliced in accordance with CC-4333, welded butt spliced in accordance with CC-4334, or lap spliced in accordance with CC-3532.1 as follows:

(a) if no more than one-half of the bars are lap spliced within a required lap length — Class A

(b) if more than one-half of the bars are lap spliced within a required lap length — Class B

CC-3532.1.5 Splices in Tension Tie Members. Splices shall be made with a welded butt splice in accordance with CC-4334 or a positive mechanical connection in accordance with CC-4334 and be staggered at least 1.3\( l_d \).

CC-3532.1.6 Bars of Different Sizes. When bars of different size are lap spliced in tension, splice length shall be the tension lap splice length of the larger bar.

CC-3532.2 Compression Splices.

CC-3532.2.1 General. Splices in compression may be lap or butt spliced. Lap splices shall meet the requirements of CC-3532.2.2 and butt splices (welded or mechanical) shall meet the requirements of CC-4333 or CC-4334.

CC-3532.2.2 Lap Splices. The minimum length of a lap splice in compression shall be the development length in compression \( l_{dc} \) in accordance with CC-3532.2.3 but not less, in inches, than 0.0005\( f_y d_b \) (in mm, than 0.0725\( f_y d_b \)) for \( f_y \) of 60,000 psi (420 MPa) or less or (0.0009\( f_y - 24 \))\( d_b \) [SI Units: (0.13\( f_y - 24 \))\( d_b \)] for \( f_y \) greater than 60,000 psi (420 MPa) but not less than 12 in. (300 mm). When bars of different size are lap spliced in compression, splice length shall be the larger of \( l_{dc} \) of the larger bar and compression lap splice length of the smaller bar. Lap splices of No. 14 (D43) and No. 18 (D57) bars to No. 11 (D36) and smaller bars shall be permitted.
CC-3532.2.3 Development Length for Bars in Compression.

(a) The calculated compression in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof.

(b) The development length \( l_{dc} \) for bars in compression shall be computed as \( 0.02f_yd_b / f'c \) but shall not be less than 0.00036 \( f_yd_b \) or 8 in. (200 mm). \( l_{dc} \) may be modified by a reduction factor equal to \( (A_x \text{ required})/(A_x \text{ provided}) \).

(c) Hooks and heads for mechanical devices for end anchorage shall not be considered effective in developing bars in compression.

CC-3532.3 Development of Standard Hooks in Tension.

(a) Development length \( l_{dh} \), in inches, for deformed bars in tension terminating in a standard hook (CC-4321) shall be computed from (b) below and the applicable modification factor or factors of (c) below, but \( l_{dh} \) shall not be less than 8 \( d_b \) or 6 in. (150 mm), whichever is greater.

(b) Development length \( l_{dh} \) for a hooked bar shall be \( 0.02f_yd_b / f'c \) (in.) \([\text{SI Units: mm}]floor \)

(c) Development length \( l_{dh} \) shall be multiplied by applicable factor or factors as follows:

(1) For No. 11 bar (B36) and smaller, side cover normal to plane of hook not less than 2 1/2 in. (64 mm), for 90 deg hook, cover on bar extension beyond hook not less than 2 in. (50 mm): 0.7.

(2) For 90 deg hooks of No. 11 (B36) and smaller bars that are either enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than 3 \( d_b \) along \( l_{dh} \) or enclosed within ties or stirrups parallel to the bar being developed, spaced not greater than 3 \( d_b \) along the tail extension of the hook plus bend: 0.8.

(3) For 180 deg hooks of No. 11 (B36) and smaller bars that are enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than 3 \( d_b \) along \( l_{dh} \): 0.8.

In (2) and (3) above, \( d_b \) is the diameter of the hooked bar, and the first tie or stirrup shall enclose the bent portion of the hook, within 2 \( d_b \) of the outside of the bend.

(4) Where anchorage or development for \( f_y \) is not specifically required, reinforcement in excess of that required by analysis: \( (A_x \text{ required})/(A_x \text{ provided}) \).

(d) For bars being developed by a standard hook at discontinuous ends of members with both side cover and top (or bottom) cover over hook less than 2 1/2 in. (64 mm), hooked bar shall be enclosed within ties or stirrup ties spaced along the full development length \( l_{dh} \) not greater than 3 \( d_b \), where \( d_b \) is diameter of hooked bar. For this case, factor of (c)(2) and (c)(3) above shall not apply.

CC-3532.4 Development of Mechanically Headed Deformed Bars In Tension.

(a) Development length for mechanically headed deformed bars in tension, \( l_{dt} \), shall be determined from (c).

(b) Use of mechanical anchorage devices to develop deformed bars in tension shall be limited to the following conditions:

(1) Specified yield strength of the reinforcing steel, \( f_y \), shall not exceed 60,000 psi (420 MPa).

(2) Bar size shall not exceed #11 (B36).

(3) Concrete shall be normal weight.

(4) Net bearing area of head, \( A_{p,net} \), shall not be less than 4 \( a_b \), where \( A_b \) is defined as the nominal area of the deformed reinforcing bar.

(5) Clear spacing between bars shall not be less than 4 \( d_b \) when measured from bar to bar, not including the head, where \( d_b \) is defined as the nominal bar diameter of the deformed reinforcing bar.

(6) Clear cover for bar shall not be less than 2 \( d_b \) when measured from the bar, not the head.

(c) The development length for mechanically anchored headed deformed bars in tension shall be calculated by

\[
l_{dt} = \left[ \frac{0.016f_y}{f'c} \right] d_b
\]

where

\( l_{dt} \) = development length in tension of the headed deformed bar, measured from the critical section to the bearing face of No. 11 (B36), size No. 14 (43) and No. 18 (57).

NOTE: Critical section for development of the mechanically headed deformed bars is defined in CC-3532.1.2(e).

The value of \( f'c \) used to calculate \( l_{dt} \) shall not exceed 6,000 psi (42 MPa). Length \( l_{dt} \) shall not be less than the larger of 8 \( d_b \) and 6 in. (152 mm).

(d) Mechanically anchored headed deformed bars in size #14 (D43) and #18 (D57) may be used, provided that test data is presented indicating that the system is capable of developing at least 125% of the specified minimum yield strength of the reinforcing steel. The Designer shall proportion deformed headed bar concrete anchorage and investigate the need for supplemental reinforcing steel so the required reinforcing bar force is reached before either a concrete pullout cone or side blowout failure occurs. The deformed headed bar shall be in accordance with CC-2310. Development of reinforcement shall be permitted to consist of a combination...
of mechanical anchorage and additional embedment length of reinforcement between the critical section and the mechanical device.

**CC-3533 Reinforcing Steel Anchorage**

**CC-3533.1 Anchorage of Radial Shear Reinforcement.**

(a) Radial shear reinforcement shall be carried as close to the compression and tension surfaces of the section as cover requirements and the proximity of other steel will permit. The ends shall be anchored by one of the following means:

1. A standard hook plus an effective embedment of 0.5\(d_t\); the effective embedment of a stirrup leg shall be taken as the distance between the mid-depth of the member \(d/2\) and the start of the hook (point of tangency)
2. Embedment on the compression side of mid-depth \(d/2\) for a full-development length \(l_d\) but not less than 24 bar diameters
3. Bending around the membrane reinforcement through at least 135 deg (2.36 rad); hooking or bending stirrups around the membrane reinforcement shall be considered effective anchorage
4. A mechanically headed deformed bar per CC-2311 plus an effective embedment of 0.5\(d_t\) in accordance with CC-3532.4; the effective embedment of a stirrup leg shall be taken as the distance between the mid-depth of the member \(d/2\) and the bearing face of the head

(b) Between the anchored ends, each bend in the continuous portion of a transverse simple U- or multiple U-stirrup shall enclose a longitudinal bar.

(c) Bars bent to act as section reinforcement shall, in a region of tension, be continuous with the main reinforcement and in a compression zone shall be anchored on the compression side of mid-depth as specified for development length in CC-3532.2.3 for that part of \(f_y\) that is needed to satisfy eq. CC-3521.2.3(b)(2)(19).

(d) Pairs of U-stirrups so placed as to form a closed tie shall be considered properly spliced when the laps are each 1.3\(d_t\).

**CC-3534 Reinforcing Steel Cover and Spacing Requirements**

**CC-3534.1 Cover.** The following minimum concrete cover shall be provided for reinforcing bars, prestressing tendons, or products:

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Minimum Cover (in. or mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast against and permanently exposed to earth</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Exposed to earth or weather:</td>
<td></td>
</tr>
<tr>
<td>No. 6 through No. 18 bars</td>
<td>2 (50)</td>
</tr>
<tr>
<td>No. 6 bars, 5/8 in. and smaller</td>
<td>1 1/2 (38)</td>
</tr>
<tr>
<td>Not exposed to weather or in contact with the</td>
<td></td>
</tr>
<tr>
<td>ground: Principal reinforcement, ties, and stirrups</td>
<td>1 1/2 (38)</td>
</tr>
<tr>
<td>Other reinforcement</td>
<td>1 (25)</td>
</tr>
</tbody>
</table>

For bar bundles, the minimum cover shall equal the equivalent diameter of the bundle but need not be more than 2 in. (50 mm) or the tabulated minimum, whichever is greater.

(b) The concrete cover shall be established by considering the placing tolerances of the formwork and reinforcement. The minimum concrete cover specified in (a) above shall not be reduced by the placing tolerances of the formwork and reinforcement.

**CC-3534.2 Spacing.** The clear distance between parallel bars in a layer shall not be less than the nominal diameter of the bars, nor 1/5 times the maximum size of the coarse aggregate, nor 1 in. (25 mm). The clear distance between parallel layers shall not be less than 1 3/8 in. (35 mm). The clear distance limitation between bars shall also apply to the clear distance between a contact (lap) splice and adjacent splices or bars.

**CC-3535 Concrete Crack Control**

(a) When an expected crack formation is so located that critical elements of the containment, such as anchor zone concrete, buttresses, ring girders, and large opening edges, may be weakened, bonded nonprestressed reinforcement shall be provided to carry the total tensile force in the concrete.

(b) Nonprestressed reinforcement shall be provided in the containment shell to control surface and membrane cracking from the effects of shrinkage, temperature, and membrane tension. The area of such reinforcement in each direction at each face of the concrete shall be a minimum of 0.0020 times the gross cross-sectional area of the section. This requirement may be met in whole or in part by reinforcement otherwise required to resist calculated loads. An integral steel liner, if provided, may be included to satisfy the requirement for inside face reinforcement. Reinforcing bars considered as face reinforcement shall not be more than one-fifth of the total section thickness from the concrete face.

(c) For basement structures, the ratio of nonprestressed reinforcement area to gross concrete cross-sectional area shall be not less than 0.0018 in each direction, unless the area of reinforcement provided at each face is at least one-third greater than that required by analysis.

Nonprestressed reinforcement for crack control shall not be spaced farther apart than 18 in. (450 mm).

**CC-3536 Curved Reinforcement**

All forces imposed by curved reinforcement shall be considered in the design of local areas such as around penetrations.
splices, and threaded splices in thread deformed reinforcing bars. For taper threaded splices and cold roll formed parallel threaded splices and headed bar systems, one of the six specimens shall be tested at 20°F (−7°C) or less. Two additional specimens may be tested at 20°F (−7°C) or less for taper threaded splices and cold roll formed parallel threaded splices and mechanically headed deformed bar systems to waive the tensile test requirements of production splice and mechanically headed deformed bar samples at 20°F (−7°C) or less required by CC-4333.5.4. A tensile test on a specimen from the same bar used for the spliced and mechanically headed deformed bar specimens shall be performed to establish actual tensile strength. The average tensile strength of the splices and mechanically headed deformed bars shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength. The tensile strength of an individual splice and mechanically headed deformed bar system shall not be less than 125% of the specified minimum yield strength of the reinforcing bar. Each individual test report on the splice, mechanically headed deformed bar, and unspliced specimen shall include at least the following information:

(1) tensile strength
(2) total elongation
(3) load–extension curve to the smaller of 2% strain or the strain of 125% of the specified minimum yield strength of the reinforcing bar

The gage length for each pair of spliced and unspliced specimens shall be the same, and equal to the length of splice sleeve, plus not less than 1 bar diameter nor more than 3 bar diameters at each end. The minimum length of a mechanically headed deformed bar test specimen shall be the greater of 10 in. (250 mm) or ten times the nominal diameter of the bar. For taper threaded and cold roll formed parallel threaded and mechanically headed deformed bar systems, the splice and mechanically headed deformed bar specimens being tested at 20°F (−7°C) or less shall be cold soaked for a minimum of 24 hr prior to testing at a temperature equal to or less than the temperature required for this test. The test temperature at the root of the critical thread shall be 20°F (−7°C) or less and maintained until the specimen reaches yield level load.

(b) Cyclic Tensile Tests. Three specimens of the bar-to-bar splice and three specimens of the bar-to-head attachment for each reinforcing bar size [and grade for taper threaded systems, cold roll formed parallel threaded systems, and threaded sleeves or mechanical anchorage devices (heads) in thread deformed reinforcing bar], splice type, and head type to be used in construction shall be subjected to a low cycle tensile test. Each specimen shall withstand 100 cycles of stress variation from 5% to 90% of the specified minimum yield strength of the reinforcing bar. One cycle is defined as an increase from the lower load to the higher load and return.

(c) Slip test. Two of the six static tensile test mechanical splice samples noted in (a) shall be evaluated for slip prior to completing the static tensile test given in (a). The slip test shall be conducted in accordance with the ASTM A1034 slip test procedure to a predetermined load equal to one-half the specified yield strength (0.5fy) of the reinforcing steel bar. After completion of the test cycle, the measured slip shall not exceed the total slip specified in Table CC-4333.2.3-1. If only one of the two samples meets the slip acceptance criteria, a retest may be allowed in which all remaining static tensile test specimens shall be evaluated for slip prior to static tensile testing and shall meet the slip acceptance criteria, otherwise the splices shall be rejected.

CC-4333.2.4 Essential Variables. The performance tests must be completely reconducted when any of the applicable changes listed below are made. Changes other than those listed may be made without the necessity for repeating the performance tests.

(a) for all splice and mechanically headed deformed bar systems
(1) a change in splice sleeve material or grade, or head material or grade
(2) a reduction in the cross-sectional area of the splice sleeve or mechanical anchorage device
(3) a reduction in the bar engagement length
(4) an increase in reinforcing bar grade
(5) a change in mechanical anchorage device (head) geometry

(b) for sleeve with ferrous filler metal splices and mechanically headed deformed bar systems with filler metal, a change in the filler metal

c) for taper threaded splices and mechanically headed deformed bar systems with taper threads
(1) a change in thread geometry
(2) a change in torque

d) for swaged splices and cold swaged mechanically headed deformed bar systems
(1) a change in swaging pressure
(2) a change in swaging device
(3) a change in thread geometry
(4) a change in outside or inside diameter of sleeve, mechanical anchorage device

<table>
<thead>
<tr>
<th>Reinforcing Bar Size</th>
<th>Total Slip, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4, No. 6</td>
<td>0.020 (0.51)</td>
</tr>
<tr>
<td>No. 7, No. 9</td>
<td>0.026 (0.67)</td>
</tr>
<tr>
<td>No. 10 to No. 11</td>
<td>0.036 (0.91)</td>
</tr>
<tr>
<td>No. 12</td>
<td>0.048 (1.22)</td>
</tr>
<tr>
<td>No. 18</td>
<td>0.060 (1.52)</td>
</tr>
</tbody>
</table>
The method of testing specimens shall conform to the requirements in AWS D1.4, subclause 6.2.4.

**D2-VIII-1535 Method of Testing Specimens**

The method of testing specimens shall conform to the requirements in AWS D1.4, subclause 6.2.5.

**D2-VIII-1536 Test Results Required**

The method of testing specimens shall conform to the requirements in AWS D1.4, subclause 6.2.6.

**D2-VIII-1540 WELDER AND WELDING OPERATOR PERFORMANCE QUALIFICATION**

The qualification for welders and welding operators shall conform to the requirements for direct butt and T-Joint welds of AWS D1.4, subclause 6.3, unless noted otherwise.

**D2-VIII-1541 Base Metal**

The base metal used shall comply with CC-2310.

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**Table D2-VIII-1541**

<table>
<thead>
<tr>
<th>Carbon Equivalent Range, %</th>
<th>Size of Reinforcing Bar</th>
<th>Interpass Temperature, °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40 max</td>
<td>Up to 11 (36), incl.</td>
<td>None [Note (4)]</td>
</tr>
<tr>
<td></td>
<td>14 (43) and 18 (57)</td>
<td>50 (10)</td>
</tr>
<tr>
<td>Over 0.40–0.45, incl.</td>
<td>Up to 11 (36), incl.</td>
<td>None [Note (4)]</td>
</tr>
<tr>
<td></td>
<td>14 (43) and 18 (57)</td>
<td>100 (38)</td>
</tr>
<tr>
<td>Over 0.45–0.55, incl.</td>
<td>Up to 6, incl.</td>
<td>None [Note (4)]</td>
</tr>
<tr>
<td></td>
<td>7 (22) to 11 (36), incl.</td>
<td>50 (10)</td>
</tr>
<tr>
<td></td>
<td>14 (43) and 18 (57)</td>
<td>200 (95)</td>
</tr>
<tr>
<td>Over 0.55–0.65, incl.</td>
<td>Up to 6 (19), incl.</td>
<td>100 (38)</td>
</tr>
<tr>
<td></td>
<td>7 (22) to 11 (36), incl.</td>
<td>200 (95)</td>
</tr>
<tr>
<td></td>
<td>14 (43) and 18 (57)</td>
<td>300 (150)</td>
</tr>
<tr>
<td>Over 0.65–0.75, incl.</td>
<td>Up to 6 (19), incl.</td>
<td>300 (150)</td>
</tr>
<tr>
<td></td>
<td>7 (22) to 18 (57), incl.</td>
<td>400 (200)</td>
</tr>
<tr>
<td>Over 0.75</td>
<td>Up to 6 (19), incl.</td>
<td>300 (150)</td>
</tr>
<tr>
<td></td>
<td>7 (22) to 18 (57), incl.</td>
<td>500 (260)</td>
</tr>
</tbody>
</table>

**NOTES:**

1. When reinforcing steel is to be welded to liner plates or other steels permitted by Table D2-I-2.2, the preheat and interpass requirements of both steels shall be considered. The minimum preheat and interpass requirement to apply in this situation shall be the higher requirement of the two materials being joined. When welding reinforcing steel to quenched and tempered steels, the preheat and interpass requirements for both materials must be satisfied or welding shall not be used.

2. Welding is not permitted when the ambient temperature is lower than 0°F (−18°C). When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar, for not less than 6 in. (150 mm) each side of the joint, shall be at or above the specified minimum temperature. Preheat and interpass temperatures must be sufficient to prevent crack formation.

3. After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.

4. When the base metal is below 32°F (0°C), preheat the base metal to at least 70°F (20°C) and maintain this minimum temperature during welding.

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**D2-VIII-1542 Welding Procedure**

The welder or the welding operator shall follow the Welding Procedure Specification.

**D2-VIII-1543 Retests**

If a welder or welding operator fails to meet the qualification requirements of one or more test welds, a retest may be allowed under the following conditions:

(a) An immediate retest may be made consisting of two test welds of each type on which the welder or welding operator failed. All test specimens shall meet all requirements for all such welds.

(b) A retest may be made provided there is evidence that the welder or welding operator has had further training or practice. A complete retest shall be made in this case.

(c) If the Inspector has reason to doubt the qualifications of a welder or welding operator, he may require retest.

**D2-VIII-1544 Period of Effectiveness**

The welder’s or welding operator’s qualifications specified in this Code shall remain in effect indefinitely unless
D2-VIII-1620  RADIOGRAPHIC EXAMINATION

D2-VIII-1621  Extent and Procedure Requirements

One joint selected at random from each 25 direct butt production joints made by each welder shall be radio- graphed from two mutually perpendicular directions. The radiographic examination procedure shall be in accordance with D2-VIII-1620. Ultrasonic inspection of direct butt joints in deformed reinforcing bars is not considered feasible except by highly specialized techniques and is not recommended.

D2-VIII-1621.1  Radiographic Examination of Direct Butt Joints. The radiographic examination of direct butt joints shall conform to the requirements of AWS D1.4, subclause 7.9.

D2-VIII-1622  Acceptance Standards

Welds shall be free of any type of crack or zone of incomplete fusion or penetration. All craters shall be filled to the full cross section of the weld.

Direct butt splices inspected by radiography shall have a maximum dimension of any single porosity or fusion type discontinuity or the sum of the maximum dimensions of all porosity or fusion type discontinuities not exceeding the limits given in Table D2-VIII-1620-1.

Undercutting deeper than \( \frac{1}{32} \) in. (0.8 mm) shall not be allowed, regardless of the direction of stress, except that at points where welds intersect the raised pattern of deformations, undercutting less than \( \frac{1}{16} \) in. (1.5 mm) deep shall be acceptable. Welds shall be free of all overlaps.

Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(a) any zone of incomplete fusion, crack, or lack of penetration

(b) any other indication which is greater than the limits of Table D2-VIII-1620-1

D2-VIII-1622.1  Radiographic Interpretation. All radiographs shall be interpreted in conformance to the requirements of AWS D1.4, subclause 7.9.3.

D2-VIII-1623  Reexamination

(a) If any of the welded joints are found unacceptable, they shall be replaced and reexamined. Two additional joints from the same group, preferably one on either side of the unacceptable joint, shall also be subject to radiographic examination. If these joints meet the acceptance criteria, all of the remaining joints out of that group of 25 shall be considered acceptable, subject to continuing joint performance tests.

(b) If any of the additional joints do not meet the acceptance criteria, all remaining joints of that group shall be examined and any unacceptable joints shall be rejected. The operator shall then be requalified in accordance with D2-VIII-1540.

---

<table>
<thead>
<tr>
<th>Customary Unit</th>
<th>Sum of Discontinuity Dimensions, in. (mm)</th>
<th>Single Discontinuity Dimension, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (25)</td>
<td>( \frac{3}{16} ) (5)</td>
<td>( \frac{3}{8} ) (3)</td>
</tr>
<tr>
<td>9 (29)</td>
<td>( \frac{3}{16} ) (5)</td>
<td>( \frac{3}{8} ) (3)</td>
</tr>
<tr>
<td>10 (32)</td>
<td>( \frac{1}{4} ) (6)</td>
<td>( \frac{3}{8} ) (3)</td>
</tr>
<tr>
<td>11 (36)</td>
<td>( \frac{1}{4} ) (6)</td>
<td>( \frac{3}{16} ) (5)</td>
</tr>
<tr>
<td>14 (43)</td>
<td>( \frac{5}{16} ) (8)</td>
<td>( \frac{3}{16} ) (5)</td>
</tr>
<tr>
<td>18 (57)</td>
<td>( \frac{3}{16} ) (11)</td>
<td>( \frac{1}{4} ) (6)</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Acceptance criteria for bar size numbers less than No. 8 (25) shall be established by the Designer.
NONMANDATORY APPENDIX D2-F
REINFORCEMENT FABRICATION AND PLACING TOLERANCES

ARTICLE D2-F-1000
REINFORCEMENT FABRICATION AND PLACING TOLERANCES

D2-F-1100 SCOPE

The dimensional tolerances as given herein are a general guide for the fabrication and placing of reinforcement. These tolerances are established as guides and further considerations shall be given to the fabrication, placing of reinforcement, concrete placement, and formwork tolerances when determining the tolerance requirements for the Construction Specification.

D2-F-1200 FABRICATION TOLERANCES

D2-F-1210 GENERAL

The fabrication tolerances provided herein are industry standards. The designer shall give consideration to the configuration and location of the bars in the structure when developing fabrication tolerances in the Construction Specification.

D2-F-1220 FABRICATION TOLERANCES FOR BAR SIZES #3 (10) THROUGH #11 (36)

Bar sizes #3 (10) through #11 (36) shall be fabricated to meet the tolerances shown in Figure D2-F-1220-1 for the bend types shown.

D2-F-1230 FABRICATION TOLERANCES FOR BAR SIZES #14 (43) AND #18 (57)

Bar sizes #14 (43) and #18 (57) shall be fabricated to meet the tolerances shown in Figure D2-F-1230-1 for the bend types shown.

D2-F-1300 PLACING TOLERANCES

D2-F-1310 GENERAL

The placing of reinforcement shall be controlled to ensure that the requirements of the design are satisfied; the proper quantity of reinforcement shall be placed such that the design loads are resisted by properly developed reinforcement and concrete can be properly placed and consolidated. The requirements provided herein shall be considered guidelines. Special design requirements shall also be considered in developing the Construction Specification.

D2-F-1320 LOCATION OF REINFORCEMENT

(a) Reinforcement shall be placed within a tolerance of plus or minus one-half the nominal rebar spacing shown on the design drawings, except as stated in (b) and (c) below. In any given run of bars (not to exceed section thickness in length), the total quantity of bars required by design shall be provided (see Figure D2-F-1320-1).

(b) The reduction of depth \( d \) shall not exceed 0.05\( d \) or 2 in. (50 mm).

(c) The clear distance between reinforcing steel and steel liner shall not be less than 2 in. (50 mm).

D2-F-1330 SPACING

Acceptable spacing tolerances may vary depending on the size and configuration of the structure, the rebar pattern, and the largest size of aggregate to be used. Acceptable tolerances shall ensure proper placing and consolidation of concrete and take into account the design requirements in D2-F-1320.
Figure D2-F-1220-1
Standard Fabricating Tolerances for Bar Sizes #3 (10 mm) Through #11 (35 mm)
Figure D2-F-1220-1
Standard Fabricating Tolerances for Bar Sizes #3 (10 mm) Through #11 (35 mm) (Cont’d)

GENERAL NOTES:
(a) Entire shearing and bending tolerances are customarily absorbed in the extension past the last bend in a bent bar.

No. 3 (10) Through No. 11 (36)
GENERAL NOTES (CONT'D):

(b) Angular Deviation: maximum ±21/2 deg or ±11/2 in./ft (±38 mm/305 mm) on all 90 deg hooks and bends. Saw cut both ends: overall length ±1/2 in. (±13 mm). All tolerances single plane and as shown.

(c) Tolerances for Types S1–S9, T1–T9 apply to bar sizes #3–#5 inclusive only.

(d) Tolerance Symbols

1. = bar sizes #3 (10 mm), #4 (13 mm), #5 (16 mm): ±1/2 in. (±13 mm) [gross length <12 ft-0 in. (<3.66 m)]
2. = bar sizes #3 (10 mm), #4 (13 mm), #5 (16 mm): ±1/2 in. (±13 mm) [gross length ≥12 ft-0 in. (≥3.66 m)]
3. = bar sizes #6 (19 mm), #7 (22 mm), #8 (25 mm): ±1 in.
4. = ±1/2 in. (±13 mm)
5. = ±1.5% × 0 dimension, ±2 in. (±50 mm) min.
6. = diameter ≤30 in. (≤750 mm) ±1/2 in. (±13 mm)
7. = diameter <30 in. (<750 mm) ±1/2 in. (±13 mm)

NOTE:

(1) Dimensions on this line are to be within tolerance shown but are not to differ from the opposite parallel dimension by more than 1/2 in. (13 mm).
Figure D2-F-1230-1
Standard Fabricating Tolerances for Bar Sizes #14 (43 mm) and #18 (57 mm)

*Straight

1.  

2.  

3.  

4.  

5.  

6.  

7.  

8.  

9.  

10.  

11.  

12.  

13.  

14.  

15.  

16.  

17.  

18.  

19.  

20.  

21.  

Typical angular deviation – all 90 deg hooks and bends shown.

Maximum deviation from "square" to the end 12 in. (300 mm) of the bar shall be 4 deg for tension splice (saw cut ends only).
General Notes:

(a) Tolerance Symbols

<table>
<thead>
<tr>
<th>No. 14 (43 mm)</th>
<th>No. 18 (57 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 = plus or minus</td>
<td>2(\frac{1}{2}) in. (60 mm)</td>
</tr>
<tr>
<td>8 = plus or minus</td>
<td>2 in. (50 mm)</td>
</tr>
<tr>
<td>9 = plus or minus</td>
<td>1(\frac{1}{2}) in. (40 mm)</td>
</tr>
<tr>
<td>10 = (\pm \frac{2}{3}) \times 0 dimensions</td>
<td>(\pm \frac{1}{2}) in. ((\pm 60) mm) min. [saw cut bends: overall length (\pm \frac{1}{2}) in. ((\pm 13) mm)]</td>
</tr>
</tbody>
</table>

(b) Angular Deviation: maximum \(\pm \frac{2}{3}\) deg or \(0 \pm \frac{1}{2}\) in./ft (0.04 mm/mm) on all 90 deg hooks and bends.