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A Consolidated Guide

ACI 318 Provisions and ASTM References for Specifying WWR

For architects, engineers, contractors and others who intend to use or are considering the use of high performance, lightweight, cost-efficient welded wire reinforcement (WWR), this publication contains key code provisions concerning wire and WWR for reinforced concrete design.

The reference can be used as a guide for design expressions, approved ASTM material references and commentary to assist in the design of WWR in concrete structures. The various chapters and sections that reference wire and WWR are taken from the current ACI 318 Building Code for Structural Concrete and Commentary*. Refer to the ACI Code for complete documentation and commentary on specific sections. Permission to reprint these data has been granted by the American Concrete Institute.

KEY CODE UPDATES OR CHANGES MADE IN RECENT YEARS:

1. Supported or suspended structural slabs with minimum steel reinforcement can be found in Chapter 7. An expression exists to substitute high strength WWR over 60 ksi yield strength - See Chapters 3 and 7. All ASTM Standard references noted throughout the Code, covering structural wire and WWR include a supplement allowing up to 80 ksi reinforcement. Note the ACI 318 code at present does not cover structural slabs on ground. Refer to other WRI references for the design procedures of structural slabs on ground.

2. The latest Code provisions for confinement and shear reinforcement can be found in Chapters 11. The Code now recognizes shear reinforcement up to 80,000 psi yield strength for deformed WWR. It has recognized up to 80,000 psi yield strength in flexure for many years and is stated in Chapter 9.

3. Wall reinforcement provisions and minimum requirements can be found in Chapters 14 and 21. Chapter 14 refers to steel ratio requirements for both rebar and WWR. Both reinforcing materials can be specified. See Special Provisions for Seismic Design in Chapter 21. Higher ratios of reinforcement are required in Chapter 21. Section 21.1.1.8 states that other structural materials or structural systems not previously recognized are approved if research data shows evidence of meeting strength and toughness equal to or exceeding Chapter 21 requirements.

4. Epoxy-coated welded wire reinforcement is now recognized by the Code in Chapters 3 and 12. Statements have been added to include the reference of ASTM A 884 for the coated reinforcement. Also testing is referenced in Chapter 12 which shows that no additional splice lengths are necessary over un-coated WWR. The welded intersections of WWR provide sufficient bond strength to resist shear stresses. Research work by the University of Texas on the subject is referenced in the Code. It can be found in the commentary of Chapter 12, R12.7 - Also see the footnote reference 12.11 in the back of the Code.

5. In future Codes the largest cold worked wire size will be increased to a W45 or D45 (3/4" diameter) wire sizes. See Section 3.5.3.7 for special requirements of development and splice design. The size wire is now available by some WRI producer plants.

6. Recent research work on high strength wire with high ductility is now noted in Chapter 11, R11.5.2. The research papers are listed near the back of the Code as 11.18, 11.19 & 11.20. As a reminder, these references can be considered for projects that fall in the category of special provisions as described in #3 above.

**The provisions in this Tech Fact can be found in ACI 318-02. This Tech Fact may be inserted in the WRI Structural Detailing Manual section and will be updated as future Codes are published.*

The last page has a listing of applicable ASTM Standards for wire and WWR.

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PROVISIONS OF ACI 318* BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE WHICH APPLY TO WELDED WIRE REINFORCEMENT

Welded plain wire reinforcement (WWR) and welded deformed wire reinforcement are both defined in ACI 318, Section 2.2, as Deformed Reinforcement. Since welded wire reinforcement is supplied in sheets or mats instead of individual bars, additional descriptive provisions are necessary and are found in Section 2. Wire Reinforcement Institute's publications are available for areas of reinforcement with various strengths, as well as development and splice lengths for different styles.

For the convenience of architects and engineers, some provisions related to WWR are reprinted from ACI 318 and will be referred to by code chapters and pertinent sections in this manual. Some metric data and formulas are presented in the Wire Reinforcement Institutes Manual of Standard Practice, Structural Welded Wire Reinforcement, copyright, 1999.

CHAPTERS OF ACI 318-08 FOR WELDED WIRE REINFORCEMENT:

CHAPTER 1 - CONCRETE ON STEEL DECK

1.1.8 - Concrete on steel deck

1.1.8.1 - Design and construction of structural concrete slabs cast on stay-in-place, noncomposite steel deck are governed by the Code.

1.1.8.2 - This Code does not govern the composite design of structural concrete slabs cast on stay-in-place, composite steel deck. Concrete used in the construction of such slabs shall be governed by Chapters 1 through 6 of this Code, where applicable. Portions of such slabs designed as reinforced concrete governed by this Code.

"Standard Practice for the Construction and Inspection of Composite Slabs" (ANSI/ASCE 9).[1.12] Reference 1.13 also provides guidance for design of composite slabs on steel deck. The design of negative moment reinforcement to make a slab continuous is a common example where a portion of the slab is designed in conformance with the Code.

CHAPTER 3 - MATERIALS

3.5 - Steel reinforcement

3.5.3 - Deformed reinforcement

3.5.3.5 - Deformed wire for concrete reinforcement shall conform to "Specifications for Steel Wire, Deformed, for Concrete Reinforcement" (ASTM A 496), except that wire shall not be smaller than size D4 and for wire with a specified yield strength f_y exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi.

3.5.3.6 - Welded plain wire reinforcement for concrete shall conform to "Specification for Steel Welded Wire Reinforcement , Plain, for Concrete" (ASTM A 185), except that for wire with a specified yield strength fy exceeding 60,000 psi, f_y shall be the stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi. Welded intersections shall not be spaced farther apart than 12 in. in direction of calculated stress, except for wire reinforcement used as stirrups in accordance with 12.13.2.

3.5.3.7 - Welded deformed wire reinforcement for concrete shall conform to "Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete Reinforcement" (ASTM A 497), except that for wire with a specified yield strength fy exceeding 60,000 psi, f_y shall be stress corresponding to a strain of 0.35 percent if the yield strength specified in the design exceeds 60,000 psi. Welded intersections shall not be spaced father apart than 16 in. in direction of calculated stress, except for wire reinforcement used as stirrups in accordance with 12.13.2.

3.5.3.9 - Epoxy - Coated wires and WWR shall comply with ASTM A 884.

3.8 - Standards cited in this code

3.8.1 - Standards of the American Society for Testing and Materials referred to in this code are listed below, and are declared part of this code:

A 82 Standard Specification for Steel Wire, Plain, for Concrete Reinforcement

A 185 Standard Specification for Steel Welded Wire Reinforcement*, Plain, for Concrete

A 496 Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement

A 497 Standard Specification for Steel Welded Wire Reinforcement*, Deformed, for Concrete

A 884 Standard Specification for Epoxy - Coated Steel Wire and Welded Wire for Reinforcement

A1022 Standard Specifications for Stainless Steel Wire & Welded Wire for Concrete Reinforcement

CHAPTER 7 - DETAILS OF REINFORCEMENT

7.2 - Minimum bend diameters

7.2.3 - Inside diameter of bends in welded wire reinforcement (plain or deformed) for stirrups and ties shall not be less than $4d_b$ for deformed wire larger than D6

** Expressions or factors being considered for change in future codes.*

and $2d_b$ for all other wires. Bends with inside diameter of less than $8d_b$ shall not be less than $4d_b$ from nearest welded intersection.

7.5.3 - Welded wire reinforcement (with wire size not greater than W5 or D5) used in slabs not exceeding 10 ft. in span may be curved from a point near the top of slab over the support to a point near the bottom of slab at midspan, provided such reinforcement is either continuous over, or securely anchored at support.

7.6 - Spacing limits for reinforcement

7.6.5 - In walls and slabs other than concrete joist construction, primary flexural reinforcement shall not be spaced farther apart than 3 times the wall or slab thickness, nor 18 in.

7.10.5 - Ties
Tie reinforcement for compression members shall conform to the following:

7.10.5.1 - All nonprestressed bars shall be enclosed by lateral ties, at least #3 in size for longitudinal bars #10 or smaller, and at least #4 in size for #11, $14, #18, and bundled longitudinal bars. Deformed wire or welded wire reinforcement of equivalent areas is allowed.

7.10.5.2 - Vertical spacing of ties shall not exceed 16 longitudinal bar diameters, 48 tie bar or wire diameters, or least dimension of the compression member.

7.11 - Lateral reinforcement for flexural members

7.11.3 - Closed ties or stirrups shall be formed in one piece by overlapping standard stirrup or tie and hooks around a longitudinal bar, or formed in one or two pieces lap spliced with a Class B splice (lap of 1.3 ℓ_d), or anchored in accordance with 12.13.

7.12 - Shrinkage and temperature reinforcement

7.12.1 - Reinforcement for shrinkage and temperature stresses normal to flexural reinforcement shall be provided in structural slabs where the flexural reinforcement extends in one direction only.

7.12.2.1 - Area of shrinkage and temperature reinforcement shall provide at least the following ratios of reinforcement area to gross concrete area, but not less than 0.0014:

(a) Slabs where Grade 40 or 50 deformed bars are used 0.0020

(b) Slabs where Grade 60 deformed bars or welded wire reinforcement are used 0.0018

(c) Slabs where reinforcement with yield stress exceeding 60,000 psi measured at a yield strain of 0.35 percent is used . . . . $\frac{0.0018 \times 60{,}000}{f_y}$

7.12.2.2 - Shrinkage and temperature reinforcement shall not be spaced farther apart than 5 times the slab thickness, nor 18 in.

7.12.2.3 - At all sections where required, reinforcement for shrinkage and temperature stresses shall develop the specified yield strength f_y in tension in accordance with Chapter 12.

Note - For additional details of WWR refer to ACI 318-95, Chapter 7.

CHAPTER 9- STRENGTH AND SERVICEABILITY REQUIREMENTS

9.4 - Design strength for reinforcement

The values of f_y and f_{yt} used in design calculations shall not exceed 80,000 psi, except for prestressing steel and for transverse reinforcement in 10.9.3 and 21.1.5.4

CHAPTER 11 - SHEAR AND TORSION

11.4 - Shear strength provided by shear reinforcement

11.4.1 - Types of shear reinforcement

11.4.1.1 - Shear reinforcement may consist of:
(a) Stirrups perpendicular to axis of member.
(b) Welded wire reinforcement with wires located perpendicular to axis of member.
(c) Spirals, circular ties, or hoops.

11.4.1.2 - For nonprestressed members, shear reinforcement may also consist of:
(a) Stirrups making an angle of 45 degrees or more with longitudinal tension reinforcement.
(b) Longitudinal reinforcement with bent portion making an angle of 30 degrees or more with the longitudinal tension reinforcement.
(c) Combinations of stirrups and bent longitudinal reinforcement.

11.4.2 - The values f_y and f_{yt} used in design of shear reinforcement shall not exceed 60,000 psi, except the value shall not exceed 80,000 psi welded deformed wire reinforcement.

11.4.4 - Stirrups and other bars or wires used as shear reinforcement shall extend to a distance d from extreme compression fiber and shall be anchored at both ends according to 12.13 to develop the design yield strength of reinforcement.

11.4.5 - Spacing limits for shear reinforcement

11.4.5.1 - Spacing of shear reinforcement placed perpendicular to axis of member shall not exceed d/2 in nonprestressed members or 0.75h in prestressed members, nor 24 in.

11.5 - Designed for torsion

11.5.3.4 - Design yield strength of torsion reinforcement shall not exceed 60,000 psi.

11.5.4 - Details of torsion reinforcement

11.5.4.1 - Torsion reinforcement shall consist of longitudinal bars or tendons and one or more of the following:

(a) Closed stirrups or closed ties, perpendicular to the axis of the member;
(b) A closed cage of welded wire reinforcement with transverse wire perpendicular to the axis of the member;
(c) In nonprestressed beams, spiral reinforcement.

11.5.4.2 - Transverse torsinal reinforcement shall be anchored by one of the following;
(a) A 135-degree standard hook or seismic hook as defined in 2.2, around a longitudinal bar;
(b) According to 12.13.2.1, 12.13.2.2 or 12.13.2.3 in regions where the concrete surrounding the anchorage is restrained against spalling by a flange or slab or similar member.

11.5.6 - Spacing limits for torsion reinforcement

11.5.6.1 - The spacing of transverse torsion reinforcement shall not exceed the smaller of $p_h/8$ or 12 in.

11.5.6.2 - The longitudinal reinforcement required for torsion shall be distributed around the perimeter of the closed stirrups with a maximum spacing of 12 in. The longitudinal bars or tendons shall be inside the stirrups. There shall be at least one longitudinal bar or tendon in each corner of the stirrups. Longitudinal bars shall have a diameter at least 0.042 times the stirrup spacing, but not less than 3/8 in.

11.6.8.1 - Spacing of closed stirrups shall not exceed the smaller of $(x_1 + y_1)/4$, or 12 in.

11.6.8.2 - Spacing of longitudinal bars, not less than #3, distributed around the perimeter of the closed stirrups, shall not exceed 12 in. At least one longitudinal bar shall be placed in each corner of the closed stirrups. #3 distributed around the perimeter of the closed stirrups, shall not exceed 12 in.

CHAPTER 12 - DEVELOPMENT AND SPLICES OF REINFORCEMENT

12.1 - Development of reinforcement - General

12.1.1 - Calculated tension or compression in reinforcement at each section of reinforced concrete members shall be developed on each side of that section by embedment length, hook or mechanical device or a combination thereof. Hooks may be used in developing bars in tension only.

12.2 - Development of deformed bars and deformed wire in tension

12.2.1 - Development length for deformed bars and deformed wire in tension, ℓ_d, shall be determined from either 12.2.2 or 12.2.3 and applicable modification factors of 12.2.4 and 12.2.5, but ℓ_d shall not be less than 12 in.

12.2.2 - For deformed bars or deformed wire, ℓ_d shall be as follows:

	No. 6 and smaller bars and deformed wires	No. 7 and larger bars
Clear spacing of bars or wires being developed or spliced not less than d_b, clear cover not less than d_b, and stirrups or ties throughout ℓ_d not less than the Code minimum or Clear spacing of bars being developed or spliced not less than $2d_b$ and clear cover not less than d_b	$\left(\frac{f_y \Psi_t \Psi_e}{25\lambda\sqrt{f'_c}}\right)d_b$	$\left(\frac{f_y \Psi_t \Psi_e}{20\lambda\sqrt{f'_c}}\right)d_b$
Other Cases	$\left(\frac{3f_y \Psi_t \Psi_e}{50\lambda\sqrt{f'_c}}\right)d_b$	$\left(\frac{3f_y \Psi_t \Psi_e}{40\lambda\sqrt{f'_c}}\right)d_b$

12.2.3 - For deformed bars or deformed wire, ℓ_d shall be:

$$\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_y\psi_t\psi_e}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b \qquad (12\text{-}1)$$

in which the confined term $(c_b + K_{tr})/d_b$ shall not be taken greater than 2.5, and

$$K_{tr} = \frac{40A_{tr}}{sn} \qquad (12\text{-}2)$$

where ***n*** is the number of bars or wires being spliced or developed along the plane of splitting. It shall be permitted to use K_{tr} = 0 as a design simplification even if transverse reinforcement is present.

12.2.4 - The factors used in the expressions for development of deformed bars and deformed wires in tension in 12.2 are as follows:

(a) Where horizontal reinforcement is placed such that more than 12 in. of fresh concrete is cast below the development length or splice, ψ_t = 1.3. For other situations, ψ_t = 1.0

(b) For epoxy-coated or wires with cover less than $3d_b$, or clear spacing less than $6d_b$, ψ_e =1.5. For all other epoxy-coated bars or wires, ψ_e = 1.2. For uncoated and zinc-coated (galvanized) reinforcement, ψ_e = 1.0.

However, the product $\psi_t\ \psi_e$ need not be greater than 1.7.

(c) For No. 6 and smaller bars and deformed wires,ψ_e = 0.8. No. 7 and larger bars, ψ_s = 1.0

(d) Where lightweight concrete is used λ not exceed 0.75 unless is f_{ct} specified (see 8.6.1). Where normal-weight concrete is used, λ = 1.0.

12.3 - Development of deformed bars in compression

12.3.1 - Development length for deformed bars and deformed wire in compression, ℓ_{dc} shall be determined from 12.3.2 and applicable modification factors of 12.3.3, but ℓ_{dc} shall be not less than 8 in.

12.3.2 - For deformed bars and deformed wire, ℓ_{dc} shall be taken as the larger of and $(0.0003f_y)d_b$, with λ as given in 12.2.4(d) and the constant 0.0003 carries the unit of in.^{2}/lb.

12.3.3 - Length ℓ_{dc} in 12.3.2 shall be permitted to be multiplied by applicable factors for:

(a) Reinforcement in excess of that required by analysis. . . . . . .(A_s required)/A_s provided)

(b) Reinforcement enclosed within spiral reinforcement not less than 1/4 in. diameter and not more than 4 in. pitch or within No. 4 ties in conformance with 7.10.5 and spaced not more than 4 in. on center 0.75

12.7 - Development of welded deformed wire reinforcement in tension

12.7.1 - Development length for welded deformed wire reinforcement in tension, ℓ_d, measured from the point of critical section to the end of wire shall be computed as the product of ℓ_d, from 12.2.2 or 12.2.3, times welded deformed wire reinforcement factor, ψ_w, from 12.7.2 or 12.7.3. It shall be permitted to reduce ℓ_d in accordance with 12.2.5 when applicable, but ℓ_d shall not be less than 8 in. except in computation of lap splices by 12.18. When using ψ_w from 12.7.2, it shall be permitted to use an epoxy-coated factor ψ_w of 1.0 for epoxy-coated welded wire reinforcement in 12.2.2 and 12.2.3.

12.7.2 - For welded deformed wire reinforcement with at least one cross wire within the development length and not less than 2 in. from the point of the critical section, the wire reinforcement factor shall be the greater of:

$$\left(\frac{f_y - 35{,}000}{f_y}\right) \quad \text{or} \quad \left(\frac{5d_b}{s_w}\right)$$

but need not be taken greater than 1.

12.7.3 - For welded deformed wire reinforcement with no cross wires within the development length or with a single cross wire less than 2 in. from the point of the critical section, ψ_w shall be taken as 1.0, and the development length shall be determined as for deformed wire.

12.7.4 - When any plain wires are present in the deformed wire reinforcement in the direction of the development length, the reinforcement shall be developed in accordance with 12.8.

12.8 - Development of welded plain wire reinforcement in tension.

Yield strength of welded plain wire reinforcement shall be considered developed by embedment of two cross wires with the closer cross wire not less than 2 in. from the point of the critical section. However, ℓ_d, shall not be less than

$$\ell_d = 0.27\frac{A_b}{s}\frac{f_y}{\lambda\sqrt{f'_c}} \qquad (12\text{-}3)$$

where ℓ_d is measured from the point of the critical section to the outermost crosswire, s is the spacing between the wires to be developed, and λ as given in 12.2.4(d). Where reinforcement provided is in excess of that required, ℓ_d may be reduced in accordance with 12.2.5. Length, ℓ_d , shall not be less than 6 in. except in computation of lap splices by 12.19.

except that when reinforcement provided is in excess of that required, this length may be reduced in accordance with 12.2.5. ℓ_d shall not be less than 6 in. except in computation of lap splices by 12.19.

12.13 - Development of web reinforcement

12.13.2 - Ends of single leg, simple U-, or multiple U-stirrups shall be anchored by one of the following means:

12.13.2.1 - For #5 bar and D31 wire, and smaller, and for #6, #7, and #8 bars with f_y of 40,000 psi or less, a standard hook around longitudinal reinforcement.

12.13.2.2 - For #6, #7, and #8 stirrups with fy greater than 40,000 psi, a standard stirrup hook around a longitudinal bar plus an embedment between midheight of the member and the outside end of the hook equal to or greater than $0.014 d_b f_y / \sqrt{f'_c}$

12.13.2.3 - For each leg of welded plain wire reinforcement forming simple U-stirrups, either:

(a) Two longitudinal wires spaced at a 2 in. spacing along the member at the top of the U.

(b) One longitudinal wire located not more than d/4 from the compression face and a second wire closer to the compression face and spaced not less than 2 in. from the first wire. The second wire may be located on the stirrup leg beyond a bend, or on a bend with an inside diameter of bend not less than 8db.

12.13.2.4 - For each end of a single leg stirrup of welded plain or deformed wire reinforcement, two longitudinal wires at a minimum spacing of 2 in. and with the inner wire at least the greater of d/4 or 2 in. from middepth of member d/2. Outer longitudinal wire at tension face shall not be farther from the face than the portion of primary flexural reinforcement closest to the face.

12.15 - Splices of deformed bars and deformed wire in tension

12.15.1 - Minimum length of lap for tension lap splices shall be as required for Class A or B splice, but not less than 12 in., where:

Class A splice . . . . $1.0\ell_d$
Class B splice . . . . $1.3\ell_d$

where ℓ_d is the tensile development length for the specified yield strength f_y in accordance with 12.2 without the modification factor of 12.2.5.

12.15.2 - Lap splices of deformed bars and deformed wire in tension shall be Class B splices except that Class A splices are allowed when: (a) the area of reinforcement provided is at least twice that required by analysis over the entire length of the splice, and (b) one-half or less of the total reinforcement is spliced within the required lap length.

12.18 - Splices of welded deformed wire in tension.

12.18.1 - Minimum length of lap for lap splices of welded deformed wire reinforcement measured between the ends of each reinforcement sheet shall be not less than $1.3\ell_d$ nor 8 in., and the overlap measured between outermost cross wires of each reinforcement sheet shall not be less than 2 in. ℓ_d shall be the development length for the specified yield strength f_y in accordance with 12.7.

12.18.2 - Lap splices of welded deformed wire reinforcement, with no cross wires within the lap splice length, shall be determined as for deformed wire.

12.18.3 - Where any plain wires, or deformed wires larger than D-31, are present in welded deformed reinforcement in the direction of the lap splice or where welded deformed wire reinforcement, the reinforcement is lap spliced to welded plain wire reinforcement, the reinforcement shall be lap spliced in accordance with 12.19.

12.19 - Splices of welded plain wire reinforcement in tension. Minimum length of lap for lap splices of welded plain wire reinforcement shall be in accordance with the following.

12.19.1 - When area of reinforcement provided is less than twice that required by analysis at splice location, length of overlap measured between outermost cross wires of each reinforcement sheet shall be not less than one spacing of cross wires plus 2 in., nor less than $1.5\ell_d$, nor 6 in. ℓ_d shall be the development length for the specified yield strength f_y in accordance with 12.8.

12.19.2 - When area of reinforcement provided is at least twice that required by analysis at splice location, length of overlap measured between outermost cross wires of each reinforcement sheet shall be not less than $1.5\ell_d$, nor 2 in. ℓ_d shall be the development length for the specified yield strength f_y in accordance with 12.8.

CHAPTER 14 - WALLS

14.2 - General

14.2.7 - Quantity of reinforcement and limits of thickness required by 14.3 and 14.5 are waived where structural analysis shows adequate strength and stability.

14.3 - Minimum reinforcement

14.3.1 - Minimum vertical and horizontal reinforcement shall be in accordance with 14.3.2 and 14.3.3 unless a greater amount is required for shear by 11.9.8 and 11.9.9.

14.3.2 - Minimum ratio of vertical reinforcement area to gross concrete area shall be:

(a) 0.0012 for deformed bars not larger than #5 with a specified yield strength not less than 60,000 psi, or

(b) 0.0015 for other deformed bars, or

(c) 0.0012 for welded wire reinforcement not larger than W31 or D31.

14.3.3 - Minimum ratio of horizontal reinforcement area to gross concrete area shall be:

*(a) 0.0020 for deformed bars not larger than #5 with a specified yield strength not less than 60,000 psi, or

(b) 0.0025 for other deformed bars, or

(c) 0.0020 for welded wire reinforcement (plain or deformed) not larger than W31 or D31.

14.3.4 - Walls more than 10 in. thick, except basement walls, shall have reinforcement for each direction placed in two layers parallel with faces of wall in accordance with the following:

(a) One layer consisting of not less than 1/2 and not more than 2/3 of total reinforcement required for each direction shall be placed not less than 2 in.

nor more than 1/3 the thickness of wall from exterior surface.

(b) The other layer, consisting of the balance of required reinforcement in that direction, shall be placed not less than 3/4 in. nor more than 1/3 the thickness of wall from interior surface.

14.3.5 - Vertical and horizontal reinforcement shall not be spaced further apart than three times the wall thickness, nor 18 in.

14.3.6 - Vertical reinforcement need not be enclosed by lateral ties if vertical reinforcement area is not greater than 0.01 times gross concrete area, or where vertical reinforcement is not required as compression reinforcement.

14.3.7 - In addition to the minimum reinforcement required by 14.3.1, not less than two No. 5 bars in walls having two layers of reinforcement in both directions and one No. 5 bar in walls having a single layer of reinforcement in both directions shall be provided around window, door, and similar sized openings. Such bars shall be anchored to develop f_y in tension at the corners of the openings.

CHAPTER 21 - EARTHQUAKE-RESISTENT STRUCTURES

21.1 - General requirements

21.1.1 - Scope

21.1.1.1 - Chapter 21 contains special requirements for design and construction of reinforced concrete members of a structure for which the design forces, related to earth- quake motions, have been determined on the basis of energy dissipation in the nonlinear range of response.

21.1.1.2 - All structures shall be assigned to a seismic design category (SDC) in accordance with 1.1.9.1 - Provisions for Earthquake resistance.

21.1.1.3 - All members shall satisfy requirements of Chapters 1 to 19 and 22. Structures assigned to SDC B, C, D, E, or F also shall satisfy 21.1.1.4 through 21.1.1.8, as applicable.

21.1.1.4 - Structures assigned to SDC B shall satisfy 21.1.2.

21.1.1.5 - Structures assigned to SDC C shall satisfy 21.1.2 and 21.1.8 as applicable.

21.1.1.6 - Structures assigned to SDC D, E, or F shall satisfy 21.1.2, 21.1.8 and 21.11 through 21.13.

21.1.1.7 - Structures systems designed as part of the seismic-force-resisting system shall be restricted to those designated by the legally adopted general building code of which this Code forms a part, or determined by other authority having jurisdiction in areas without a legally adopted building code. Except for SDC A, for which Chapter 21 does not apply, the following provisions shall be satisfied for each structural system designated as part of the seismic-force-resisting system, regardless of the SDC:

(a) Ordinary moment frames shall satisfy 21.2
(b) Ordinary structural walls need not satisfy any provisions in Chapter 21.
(c) Intermediate moment frames satisfy 21.3
(d) Intermediate precast walls shall satisfy 21.4.
(e) Special moment frames shall satisfy 21.5 through 21.8.
(f) Special structural walls shall satisfy 21.9
Special precast structural walls shall satisfy 21.10

All special moment frames and special structural walls shall also satisfy 21.1.3 through 21.1.7

21.1.1.8 - A reinforced concrete structural system not satisfying the requirements of this chapter is allowed if it is demonstrated by experimental evidence and analysis that the proposed system will have strength and toughness equal to or exceeding those provided by a comparable monolithic reinforced concrete structure satisfying this chapter.

21.1.7.2 - Welding of stirrups, ties, inserts, or other similar elements to longitudinal reinforcement required by design shall not be permitted.

R21.1.7.2 - Welding or tack-welding or cross reinforcing bars can lead to local embrittlement of the steel. If welding of crossing bars is used to facilitate fabrication or placement of reinforcement, it should be done only on bars for such purposes. The prohibition of welding crossing reinforcing bars does not apply to bars that are welded with welding operations under continuous, competent control as in the manufacture of welded wire reinforcement.

21.5.3 - Transverse reinforcement

21.3.3.1 - Hoops shall be provided in the following regions of frame members:

(a) Over a length equal to twice the member depth measured from the face of the supporting member toward midspan, at both ends of the flexural member.

(b) Over lengths equal to twice the member depth on both sides of a section where flexural yielding is likely to occur in connection with inelastic lateral displacements of the frame.

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21.5.3.2 - The first hoop shall be located not more than 2 in. from the face of a supporting member. Spacing of the hoops shall not exceed the smallest of (a), (b), (c), (d):

(a) *d*/4;
(b) eight times the diameter of the smallest longitudinal bars;
(c) 24 times the diameter of the hoop bars; and
(d) 12 in.

21.5.3.3 - Where hoops are required, longitudinal bars on the perimeter shall have lateral support conforming to 7.10.5.3.

21.5.3.4 - Where hoops are not required, stirrups shall be spaced at no more than *d*/2 throughout the length of the member.

21.5.3.5 - Stirrups or ties required to resist shear shall be hoops over lengths of members in 21.5.3.1.

21.3.3.6 - Hoops in flexural members are shall be permitted to be made up of two pieces of reinforcement: a stirrup having seismic hooks at both ends and closed by a crosstie. Consecutive crossties engaging the same longitudinal bar shall have their 90-degree hooks at opposite sides of the flexural member. If the longitudinal reinforcing bars secured by the crossties are confined by a slab only on one side of the flexural frame member, the 90-degree hooks of the crossties shall be placed on that side.

21.9 - Special structural walls and coupling beams.

21.9.1 - Scope
Requirements of 21.9 apply to special structural walls, cast-in-place or precast, and coupling beams forming part of seismic-force-resisting system. Special structural walls constructed using precast concrete shall also comply with 21.10

21.9.2 - Reinforcement

21.9.2.1 - The distributed reinforcement ratios, ρ_ℓ, and ρ_t for structural walls shall not be less than 0.0025, except that if V_u does not exceed $A_{cv}\lambda\sqrt{f'_c}$, ρ_ℓ, and ρ_t shall be permitted to be reduced to the values required in 14.3. Reinforcement spacing each way in structural walls and diaphragms shall not exceed 18 in. Reinforcement contributing to V_u shall be continuous and shall be distributed across the shear plane.

21.9.2.2 - At least two curtains of reinforcement shall be used in a wall if exceeds V_u $2A_{cv}\lambda\sqrt{f'_c}$.

* *Expressions or factors being considered for change in future codes.*

***The constant carries the unit of in.²/lb.*

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A Listing of
ASTM Standards Applicable to Wire and WWR

A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement

A 123 Specification for Zinc (Hot-Dip) Coatings on Iron and Steel Products

A 185 Specification for Steel Welded Wire, Plain, for Concrete Reinforcement

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement

A 497 Specification for Steel Welded Wire, Deformed, for Concrete Reinforcement

A 641 Specification for Zinc-Coated (Galvanized) Carbon Steel Wire

A 700 Practices for Packaging, Marking and Loading Methods for Steel Products

A 884 Specification for Epoxy-Coated Steel Wire and Welded Wire for Reinforcement

A 933 Specification for Vinyl (PVC) Coated Steel Wire and Welded Wire for Reinforcement

A 1022 Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement