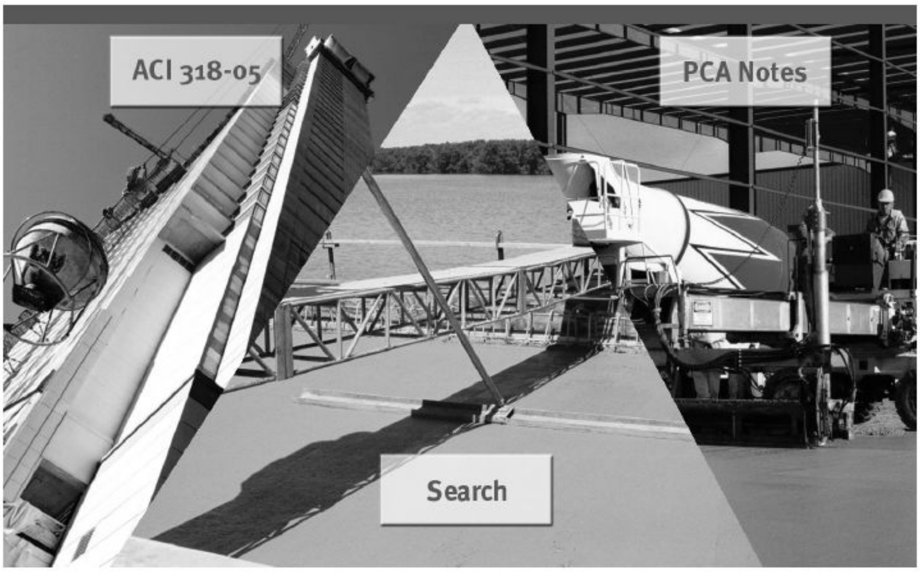
ACI 318-05

Building Code Requirements for Structural Concrete and Commentary

& PCA Notes on 318-05

American Concrete Institute®
Advancing concrete knowledge

PCA



CHAPTER 12 — DEVELOPMENT AND SPLICES OF REINFORCEMENT

CODE

12.1 — Development of reinforcement — General

12.1.1 — Calculated tension or compression in reinforcement at each section of structural concrete members shall be developed on each side of that section by embedment length, hook or mechanical device, or a combination thereof. Hooks shall not be used to develop bars in compression.

12.1.2 — The values of $\sqrt{f_c'}$ used in this chapter shall not exceed 100 psi.

COMMENTARY

R12.1 — Development of reinforcement — General

The development length concept for anchorage of reinforcement was first introduced in the 1971 code, to replace the dual requirements for flexural bond and anchorage bond contained in earlier editions. It is no longer necessary to consider the flexural bond concept, which placed emphasis on the computation of nominal peak bond stresses. Consideration of an average bond resistance over a full development length of the reinforcement is more meaningful, partially because all bond tests consider an average bond resistance over a length of embedment of the reinforcement, and partially because uncalculated extreme variations in local bond stresses exist near flexural cracks.[12.1]

The development length concept is based on the attainable average bond stress over the length of embedment of the reinforcement. Development lengths are required because of the tendency of highly stressed bars to split relatively thin sections of restraining concrete. A single bar embedded in a mass of concrete should not require as great a development length; although a row of bars, even in mass concrete, can create a weakened plane with longitudinal splitting along the plane of the bars.

In application, the development length concept requires minimum lengths or extensions of reinforcement beyond all points of peak stress in the reinforcement. Such peak stresses generally occur at the points in 12.10.2.

The strength reduction factor ϕ is not used in the development length and lap splice equations. An allowance for strength reduction is already included in the expressions for determining development and splice lengths.

Units of measurement are given in the Notation to assist the user and are not intended to preclude the use of other correctly applied units for the same symbol, such as ft or kip.

From a point of peak stress in reinforcement, some length of reinforcement or anchorage is necessary to develop the stress. This development length or anchorage is necessary on both sides of such peak stress points. Often the reinforcement continues for a considerable distance on one side of a critical stress point so that calculations need involve only the other side, for example, the negative moment reinforcement continuing through a support to the middle of the next span.

CODE

12.13.5 — Pairs of U-stirrups or ties so placed as to form a closed unit shall be considered properly spliced when length of laps are **$1.3\ell_d$**. In members at least 18 in. deep, such splices with $A_b f_{yt}$ not more than 9000 lb per leg shall be considered adequate if stirrup legs extend the full available depth of member.

COMMENTARY

R12.13.5 — These requirements for lapping of double U-stirrups to form closed stirrups control over the provisions of 12.15.

12.14 — Splices of reinforcement — General

12.14.1 — Splices of reinforcement shall be made only as required or permitted on design drawings, or in specifications, or as authorized by the engineer.

12.14.2 — Lap splices

12.14.2.1 — Lap splices shall not be used for bars larger than No. 11 except as provided in 12.16.2 and 15.8.2.3.

12.14.2.2 — Lap splices of bars in a bundle shall be based on the lap splice length required for individual bars within the bundle, increased in accordance with 12.4. Individual bar splices within a bundle shall not overlap. Entire bundles shall not be lap spliced.

12.14.2.3 — Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than the smaller of one-fifth the required lap splice length, and 6 in.

12.14.3 — Mechanical and welded splices

12.14.3.1 — Mechanical and welded splices shall be permitted.

12.14.3.2 — A full mechanical splice shall develop in tension or compression, as required, at least **$1.25f_y$** of the bar.

12.14.3.3 — Except as provided in this code, all welding shall conform to "Structural Welding Code—Reinforcing Steel" (ANSI/AWS D1.4).

R12.14 — Splices of reinforcement — General

Splices should, if possible, be located away from points of maximum tensile stress. The lap splice requirements of 12.15 encourage this practice.

R12.14.2 — Lap splices

R12.14.2.1 — Because of lack of adequate experimental data on lap splices of No. 14 and No. 18 bars in compression and in tension, lap splicing of these bar sizes is prohibited except as permitted in 12.16.2 and 15.8.2.3 for compression lap splices of No. 14 and No. 18 bars with smaller bars.

R12.14.2.2 — The increased length of lap required for bars in bundles is based on the reduction in the exposed perimeter of the bars. Only individual bars are lap spliced along the bundle.

R12.14.2.3 — If individual bars in noncontact lap splices are too widely spaced, an unreinforced section is created. Forcing a potential crack to follow a zigzag line (5 to 1 slope) is considered a minimum precaution. The 6 in. maximum spacing is added because most research available on the lap splicing of deformed bars was conducted with reinforcement within this spacing.

R12.14.3 — Mechanical and welded splices

R12.14.3.2 — The maximum reinforcement stress used in design under the code is the specified yield strength. To ensure sufficient strength in splices so that yielding can be achieved in a member and thus brittle failure avoided, the 25 percent increase above the specified yield strength was selected as both an adequate minimum for safety and a practicable maximum for economy.

R12.14.3.3 — See R3.5.2 for discussion on welding.

CHAPTER 21 — SPECIAL PROVISIONS FOR SEISMIC DESIGN

CODE

21.1 — Definitions

Base of structure — Level at which earthquake motions are assumed to be imparted to a building. This level does not necessarily coincide with the ground level.

Boundary elements — Portions along structural wall and structural diaphragm edges strengthened by longitudinal and transverse reinforcement. Boundary elements do not necessarily require an increase in the thickness of the wall or diaphragm. Edges of openings within walls and diaphragms shall be provided with boundary elements as required by 21.7.6 or 21.9.5.3.

Collector elements — Elements that serve to transmit the inertial forces within structural diaphragms to members of the lateral-force-resisting systems.

Connection — A region that joins two or more members, of which one or more is precast.

Ductile connection — Connection that experiences yielding as a result of the design displacements.

Strong connection — Connection that remains elastic while adjoining members experience yielding as a result of the design displacements.

Crosstie — A continuous reinforcing bar having a seismic hook at one end and a hook not less than 90 degrees with at least a six-diameter extension at the other end. The hooks shall engage peripheral longitudinal bars. The 90 degree hooks of two successive crossties engaging the same longitudinal bars shall be alternated end for end.

Design displacement — Total lateral displacement expected for the design-basis earthquake, as required by the governing code for earthquake-resistant design.

Design load combinations — Combinations of factored loads and forces in 9.2.

Design story drift ratio — Relative difference of design displacement between the top and bottom of a story, divided by the story height.

Development length for a bar with a standard hook — The shortest distance from the critical section (where the strength of the bar is to be developed) to the outside end of the 90 degree hook.

COMMENTARY

R21.1 — Definitions

The design displacement is an index of the maximum lateral displacement expected in design for the design-basis earthquake. In documents such as the National Earthquake Hazards Reduction Provisions (NEHRP),[21.1] ASCE 7-95, the Uniform Building Code (UBC),[21.2] the BOCA/National Building Code (BOCA)[21.3] published by Building Officials and Code Administrators International, or the Standard Building Code (SBC)[21.4] published by Southern Building Code Congress International, the design-basis earthquake has approximately a 90 percent probability of nonexceedance in 50 years. In those documents, the design displacement is calculated using static or dynamic linear elastic analysis under code-specified actions considering effects of cracked sections, effects of torsion, effects of vertical forces

CODE

21.2.4 — Concrete in members resisting earthquake-induced forces

21.2.4.1 — Specified compressive strength of concrete, f_c', shall be not less than 3000 psi.

21.2.4.2 — Specified compressive strength of lightweight concrete, f_c', shall not exceed 5000 psi unless demonstrated by experimental evidence that structural members made with that lightweight concrete provide strength and toughness equal to or exceeding those of comparable members made with normalweight concrete of the same strength.

21.2.5 — Reinforcement in members resisting earthquake-induced forces

Reinforcement resisting earthquake-induced flexural and axial forces in frame members and in structural wall boundary elements shall comply with ASTM A 706. ASTM A 615 Grades 40 and 60 reinforcement shall be permitted in these members if:

(a) The actual yield strength based on mill tests does not exceed f_y by more than 18,000 psi (retests shall not exceed this value by more than an additional 3000 psi); and

(b) The ratio of the actual tensile strength to the actual yield strength is not less than 1.25.

The value of f_{yt} for transverse reinforcement including spiral reinforcement shall not exceed 60,000 psi.

21.2.6 — Mechanical splices

21.2.6.1 — Mechanical splices shall be classified as either Type 1 or Type 2 mechanical splices, as follows:

(a) Type 1 mechanical splices shall conform to 12.14.3.2;

(b) Type 2 mechanical splices shall conform to 12.14.3.2 and shall develop the specified tensile strength of the spliced bar.

COMMENTARY

R21.2.4 — Concrete in members resisting earthquake-induced forces

Requirements of this section refer to concrete quality in frames, trusses, or walls proportioned to resist earthquake-induced forces. The maximum specified compressive strength of lightweight concrete to be used in structural design calculations is limited to 5000 psi, primarily because of paucity of experimental and field data on the behavior of members made with lightweight aggregate concrete subjected to displacement reversals in the nonlinear range. If convincing evidence is developed for a specific application, the limit on maximum specified compressive strength of lightweight concrete may be increased to a level justified by the evidence.

R21.2.5 — Reinforcement in members resisting earthquake-induced forces

Use of longitudinal reinforcement with strength substantially higher than that assumed in design will lead to higher shear and bond stresses at the time of development of yield moments. These conditions may lead to brittle failures in shear or bond and should be avoided even if such failures may occur at higher loads than those anticipated in design. Therefore, a ceiling is placed on the actual yield strength of the steel [see 21.2.5(a)].

The requirement for a tensile strength larger than the yield strength of the reinforcement [21.2.5(b)] is based on the assumption that the capability of a structural member to develop inelastic rotation capacity is a function of the length of the yield region along the axis of the member. In interpreting experimental results, the length of the yield region has been related to the relative magnitudes of ultimate and yield moments.[21.10] According to this interpretation, the larger the ratio of ultimate to yield moment, the longer the yield region. Chapter 21 requires that the ratio of actual tensile strength to actual yield strength is not less than 1.25. Members with reinforcement not satisfying this condition can also develop inelastic rotation, but their behavior is sufficiently different to exclude them from direct consideration on the basis of rules derived from experience with members reinforced with strain-hardening steel.

R21.2.6 — Mechanical splices

In a structure undergoing inelastic deformations during an earthquake, the tensile stresses in reinforcement may approach the tensile strength of the reinforcement. The requirements for Type 2 mechanical splices are intended to avoid a splice failure when the reinforcement is subjected to expected stress levels in yielding regions. Type 1 splices are not required to satisfy the more stringent requirements for Type 2 splices, and may not be capable of resisting the stress levels expected in yielding regions. The locations of

CODE

21.2.6.2 — Type 1 mechanical splices shall not be used within a distance equal to twice the member depth from the column or beam face for special moment frames or from sections where yielding of the reinforcement is likely to occur as a result of inelastic lateral displacements. Type 2 mechanical splices shall be permitted to be used at any location.

21.2.7 — Welded splices

21.2.7.1 — Welded splices in reinforcement resisting earthquake-induced forces shall conform to 12.14.3.4 and shall not be used within a distance equal to twice the member depth from the column or beam face for special moment frames or from sections where yielding of the reinforcement is likely to occur as a result of inelastic lateral displacements.

21.2.7.2 — Welding of stirrups, ties, inserts, or other similar elements to longitudinal reinforcement that is required by design shall not be permitted.

21.2.8 — Anchoring to concrete

21.2.8.1 — Anchors resisting earthquake-induced forces in structures in regions of moderate or high seismic risk, or assigned to intermediate or high seismic performance or design categories shall conform to the additional requirements of D.3.3 of Appendix D.

21.3 — Flexural members of special moment frames

21.3.1 — Scope

Requirements of 21.3 apply to special moment frame members (a) resisting earthquake-induced forces and (b) proportioned primarily to resist flexure. These frame members shall also satisfy the conditions of 21.3.1.1 through 21.3.1.4.

21.3.1.1 — Factored axial compressive force on the member, P_u, shall not exceed $A_g f_c'/10$.

21.3.1.2 — Clear span for member, ℓ_n, shall not be less than four times its effective depth.

COMMENTARY

Type 1 splices are restricted because tensile stresses in reinforcement in yielding regions can exceed the strength requirements of 12.14.3.2.

Recommended detailing practice would preclude the use of splices in regions of potential yield in members resisting earthquake effects. If use of mechanical splices in regions of potential yielding cannot be avoided, the designer should have documentation on the actual strength characteristics of the bars to be spliced, on the force-deformation characteristics of the spliced bar, and on the ability of the Type 2 splice to be used to meet the specified performance requirements.

R21.2.7 — Welded splices

R21.2.7.1 — Welding of reinforcement should be according to ANSI/AWS D1.4 as required in Chapter 3. The locations of welded splices are restricted because reinforcement tension stresses in yielding regions can exceed the strength requirements of 12.14.3.4.

R21.2.7.2 — Welding of crossing 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 added 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.

R21.3 — Flexural members of special moment frames

R21.3.1 — Scope

This section refers to beams of special moment frames resisting lateral loads induced by earthquake motions. Any frame member subjected to a factored axial compressive force exceeding $(A_g f_c'/10)$ is to be proportioned and detailed as described in 21.4.

Experimental evidence[21.11] indicates that, under reversals of displacement into the nonlinear range, behavior of continuous members having length-to-depth ratios of less than four is significantly different from the behavior of relatively slender members. Design rules derived from experience