Concrete Provisions of the 2006 International Building Code

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Chapter 19 – *Concrete* of the 2003 *International Building Code* (IBC) (International Code Council (ICC) 2003) adopted the 2002 edition of ACI 318 *Building Code Requirements for Structural Concrete* (American Concrete Institute (ACI) 2002) for concrete design and construction. In IBC Sections 1902 through 1907, portions of Chapters 2 through 7 respectively of ACI 318-02 were reproduced, with just a few amendments printed in italics. The remainder of ACI 318-02 was adopted by reference, subject to seven amendments listed in Section 1908. Section 1909 – *Structural Plain Concrete* reproduced, reformatted and rearranged portions of ACI 318-02 Chapter 22 and made two deviations from it. Section 1910 – *Seismic Design Provisions* classified shear walls into plain, detailed plain, ordinary reinforced, and special reinforced concrete, and then prescribed seismic design provisions by the Seismic Design Category as follows: one set for SDC B, a second set for SDC C, and a third set for SDC D, E, and F. Section 1913 – *Anchorage to Concrete-Strength Design* adopted ACI 318-02, Appendix D – *Anchoring to Concrete* and made one significant amendment to the Appendix D provisions. Chapter 19 of the 2003 IBC also included the following provisions not contained in ACI 318-02:

1911 – *Minimum Slab Provisions*
1912 – *Anchorage to Concrete - ASD*
1914 – *Shotcrete*
1915 – *Reinforced Gypsum Concrete*
1916 – *Concrete-filled Pipe Columns*

ACI 318-05 (ACI 2005) is the primary reference document for concrete design and construction in the 2006 *IBC* (ICC 2006). In a fairly significant change, Sections 1902 through 1907 no longer reproduce portions of Chapters 2 through 7 of ACI 318-05. The various subsections within those sections simply refer the user to the corresponding sections or subsections in Chapters 2 through 7 of ACI 318-05. This change was initiated by ACI because of concerns over the integrity of their copyright.

In another significant change to the concrete chapter, Section 1910 – *Seismic Design Provisions* has been eliminated, with the contents either incorporated in Section 1908 – *Modifications to ACI 318* or deleted as being unnecessary. Many of the provisions in Section 1910 were repeated from ACI 318, or from Section 1908. In addition, Section 1910 contained several modifications to ACI 318, which should have been in Section 1908. The expectation is that with the placement of all modifications to ACI 318 in Section 1908, ACI Committee 318 will consider the modifications to determine if they are appropriate for inclusion in the ACI 318 standard.

Significant Changes in ACI 318-05

The significant changes from the previous edition of the ACI Code (ACI 318-02) are summarized in this section. A more complete discussion of the changes has been published in the *PCI Journal*. (*See references*.) All section numbers refer to ACI 318-05.

Change of Notation

A very important change in ACI 318-05 is a thorough clean-up of the notation. This was undertaken because the Code will be easier to use if the notation is consistent throughout.

Change in Terminology

"Welded wire fabric" is now called "welded wire reinforcement". This is to maintain consistency with ASTM Specifications, where the change had been made earlier.

Chapter 9, Strength and Serviceability Requirements

1. The Ø factor of 0.75 in ACI 318-02 for flexural sections in pretensioned members where strand embedment is less than the development length (Section 12.9.1.1) is now applicable from the end of the member to the end of the transfer length. From there to the end of the development length, Ø may be increased linearly from 0.75 to 0.9. Where bonding of a strand does not extend to the end of the member, strand embedment begins at the end of the debonded length. See also Section 12.9.3 and Figure R.9.3.2.7 (a).
2. Research has shown that reinforcement with yield strengths up to 100,000 psi can be used for confinement, without any detriment to member performance. Spiral reinforcement with specified yield strengths up to 100,000 psi is therefore permitted by Section 10.9.3 of ACI 318-05.

Chapter 10, Flexure and Axial Loads

The maximum spacing of reinforcement closest to the tension force, for purposes of crack control, is given by:

$$s = 15\left(\frac{40{,}000}{f_s}\right) - 2.5c_c \le 12\left(\frac{40{,}000}{f_s}\right)$$

with f_s in psi, whereas in ACI 318-02 it was given by:

$$s = \frac{540}{f_s} - 2.5c_c \le 12\left(\frac{36}{f_s}\right)$$

with f_s in ksi. f_s is the service-level stress in the tension reinforcement and c_c is the clear cover to that reinforcement. This change reflects the higher service stresses in flexural reinforcement resulting from the load combinations introduced in the 2002 Code. f_s may now be taken equal to $0.67f_y$ (40,000 psi for Grade 60 reinforcement), whereas it could be taken as $0.6f_y$ (36,000 psi for Grade 60 reinforcement) under ACI 318-02. For this default service-level stress value, the maximum spacing limitation itself has not changed.

Chapter 11, Shear and Torsion

In a significant change that more realistically addresses thin, deep spandrel beams, which are common in precast concrete construction, Section 11.6.7 now permits the use of an alternative design procedure, the adequacy of which has been established by analysis and substantial agreement with results of comprehensive tests. Commentary Section R11.6.7 cites examples of such procedures. One cited procedure is an extension to prestressed concrete sections of the torsion procedures of pre-1995 editions of ACI 318. The fourth edition of the *PCI Design Handbook* (PCI 1992) describes the procedure.

Chapter 13, Two-Way Slab Systems

Dimensional requirements for drop panels are now applicable only when the drop panel is used to reduce the amount of negative reinforcement over a column or to reduce the minimum

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required slab thickness. A new Commentary Section R13.2.5 points out that drop panels with non-conforming dimensions may be used to increase slab shear strength.

Chapter 18, Prestressed Concrete

ACI 318-02 required prestressed two-way slab systems to be designed as Class U, which meant that f_t could be up to $7.5\sqrt{f'_c}$. ACI 318-05 restricts f_t in such slabs to $6\sqrt{f'_c}$, the same value as in ACI 318-99 and prior codes.

Chapter 21, Special Provisions for Seismic Design

1. A sentence added to Section 21.2.5 specifically prohibits the use of transverse reinforcement having specified yield strength in excess of 60 ksi in members resisting earthquake-induced forces in structures assigned to Seismic Design Category D, E, or F.

2. Sections 21.7.2.3 and 21.9.5.4 of ACI 318-02 required that all continuous reinforcement in structural walls and diaphragms must be anchored or spliced in accordance with the provisions for reinforcement in tension in Section 21.5.4. These sections were very confusing. In a most beneficial change, the requirements of Section 21.7.2.3 were modified to remove the reference to beam-column joints in Section 21.5.4. Because actual forces in longitudinal reinforcement of structural walls may exceed calculated forces, it is now required that reinforcement in structural walls be developed or spliced for f_y in tension in accordance with Chapter 12. At locations where yielding of longitudinal reinforcement is expected, 1.25 f_y is required to be developed in tension, to account for the likelihood that the actual yield strength exceeds the specified yield strength, as well as the influence of strain-hardening and cyclic load reversals. In a companion change, Section 21.9.5.4 now requires that all continuous reinforcement in diaphragms, trusses, struts, ties, chords, and collector elements be developed or spliced for f_y in tension.

3. Structural truss elements, struts, ties, diaphragm chords, and collector elements with compressive stresses exceeding $0.2f'_c$ at any section are required to be specially confined by Section 21.9.5.3. The special transverse reinforcement may be discontinued at a section where the calculated compressive stress is less than $0.15f'_c$. Stresses are calculated for factored forces using a linear elastic model and gross-section properties of the elements considered. Section 21.9.5.3 now additionally states that where design forces have been amplified to account for the overstrength of the vertical elements of the seismic-force-resisting system, as required by recent seismic code provisions, the limits of $0.2f'_c$ and $0.15f'_c$ shall be increased to $0.5f'_c$ and $0.4f'_c$, respectively.

4. In a very significant change, provisions for shear reinforcement at slab-column joints have been added in a new Section 21.11.5, to reduce the likelihood of punching shear failure in two-way slabs without beams. A prescribed amount and detailing of shear rein forcement is required unless either 21.11.5(a) or (b) is satisfied.

Section 21.11.5(a) requires calculation of shear stresses including those caused by the moment induced at a slab-column joint when subjected to the design displacement defined in Section 21.1. Section 21.11.5(b) does not require such calculation, and is based on research (Megally and Ghali 2000, Moehle 1996; *see references*.) that identifies the likelihood of punching shear failure considering interstory drift and shear due to gravity loads. The requirement, illustrated in the newly added Figure R21.11.5, can be satisfied in several ways: adding slab shear reinforcement, increasing slab thickness, designing with more lateral stiffness to decrease interstory drift, or a combination of two or more of these.

Appendix D, Anchoring to Concrete

Several significant changes have been made to the provisions of Appendix D, *Anchoring to Concrete*, as discussed in the *PCI Journal*, (*See references*).

Amendments to ACI 318-05 in 2006 IBC Sections 1902-1907

2003 IBC Chapter 19 made an exception to ACI 318-02 Section 4.2.2, requiring that in residential buildings less than four stories in height, normal-weight concrete subject to freezing and thawing, as determined from 2003 IBC Figure 1904.2.2, or deicer chemicals, must comply with the requirements of 2003 IBC Table 1904.2.2(2). Neither the figure nor the table was part of ACI 318-02. The exception, the table and the figure were adopted into the IBC from the *International Residential Code* (ICC 2003). The table mandated a minimum specified compressive strength as a function of the concrete element and exposure, but no maximum water-cementitious materials ratio. The

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figure showed the geographic regions within the U.S. mainland that were classified as having negligible, moderate and severe weather exposures for the purposes of 2003 IBC Table 1904.2.2(2). This amendment is not part of ACI 318-05, and has been maintained essentially unmodified in the 2006 IBC, except that the table is now numbered 1904.2.2.

In a provision that is not part of ACI 318-05, Section 1903.8 requires glass fiber- reinforced concrete (GFRC) and its constituent materials to be in accordance with PCI MNL 128 (PCI 2001). This modification remains unchanged from the 2003 IBC.

Amendments to ACI 318-05 in 2006 IBC Section 1908

The number of amendments in this section has grown. However, it is only an apparent increase caused primarily by two actions. One is the deletion of Section 1910 and the transfer of some amendments from there to Section 1908. Second is the split of provisions in Section 1908.1.3 into three different modifications.

1908.1.1 – Previously in Section 1910.3.1, this modification mandates continuous top and bottom reinforcement in beams of ordinary moment frames that are part of the lateral-force-resisting system of a building in Seismic Design Category (SDC) B.

1908.1.2 – Previously also in Section 1910.3.1, this modification is intended to prevent shear failure preceding flexural failure in columns of ordinary moment frames that are part of the lateral-force-resisting system of a building in SDC B, in cases where the column clear height to maximum plan dimension ratio is five or less.

1908.1.3 – This section adds or modifies definitions that are used in Chapter 19 but are not to be found in or are different from those in ACI 318-05. It represents an expansion of Section 1908.1.1 of the 2003 IBC. Four definitions have been added: those for Detailed Plain Concrete Structural Wall, Ordinary Precast Structural Wall, Ordinary Reinforced Concrete Structural Wall, and Ordinary Structural Plain Concrete Wall. The definition of Story Drift Ratio has been deleted because it is now defined in ACI 318-05.

1908.1.4 – This represents a slight modification of 2003 IBC Section 1908.1.2, which provided an interface between regions of low, moderate, and high seismic risk of ACI 318 and the SDCs of the IBC. It modifies Sections 21.2.1.2, 21.2.1.3, and 21.2.1.4 of ACI 318-05. Intermediate Precast Structural Walls have been added to the list of permitted systems in Section 21.2.1.3 (SDC C) and Section 21.2.1.4 (SDC D, E, or F).

1908.1.5 – 2003 IBC Section 1908.1.5 amended ACI 318-02 Section 21.2.5 to permit use of prestressing tendons to resist earthquake-induced forces in buildings assigned to SDC D, E or F. Four new subsections 21.2.5.1, 21.2.5.2, 21.2.5.3, and 21.2.5.4 were created. It has now been decided that Section 21.2.5.3, dealing with prestressed beams, should be a modification to ACI 318 Section 21.3.2, rather than to Section 21.2.5. Similarly, Section 21.2.5.4, dealing with anchorage of tendons, should be a modification to ACI 318 Section 21.2, rather than to Section 21.2.5. So the last two modifications are now separate Sections **1908.1.7** and **1908.1.6**, respectively. Sections 21.2.5.1, containing charging language, and 21.2.5.2, imposing a limit on the effective prestress, remain part of Section 1908.1.5.

2006 IBC Section 1908.1.5 has also added four words: "For computing shear strength" in front of the new sentence in ACI 318-05 Section 21.2.5 that requires "the value of f_{yt} for transverse reinforcement including spiral reinforcement shall not exceed 60,000 psi." This means that for the purposes of confining the compression concrete, no limit need apply on the yield strength of transverse reinforcement.

1908.1.8 – This is the same as 2003 IBC Section 1908.1.4 and modifies ACI 318-05 Section 21.7 to introduce seismic detailing requirements for wall piers.

1908.1.9 – This section, not part of the 2003 IBC, requires special precast structural walls to comply with Section 21.13.4, which is a 2006 IBC addition, in addition to complying with Sections 21.13.2 and 21.13.3. See Section 1908.1.13 below.

1908.1.10 – Previously Section 1908.1.5, this modifies ACI 318 Section 21.10.1.1 to require foundations resisting earthquake-induced forces to comply with Section 21.10 and other applicable provisions of ACI 318 *unless modified by Chapter 18 of the IBC*.

1908.1.11 – Previously in Section 1908.1.6, now in Section 1908.1.11, this modification to ACI 318-02 Section 21.11.2.2 exempts the requirement that lap splices of column reinforcement be confined to the middle half of the column height in columns that are not part of the lateral-force-resisting system (gravity columns) of a building assigned to SDC D or above, where the column is going to remain elastic under the design earthquake displacements. Applicability of this exemption is restricted to "structures where the seismic-force-resisting system does not include special moment frames."

2003 IBC Section 1908.1.6 contained another important amendment to ACI 318-02, dealing with slab-column (gravity) frames that are not part of the lateral-force-resisting system of a building assigned to SDC D or higher. The amendment stated that the deformation compatibility requirements of 2003 IBC Section 1617.6.4.3 were to be deemed satisfied by a slab-column gravity frame if it satisfied Subsections 21.11.5 through 21.11.7 added by the amendment. This modification has been deleted because ACI 318-05 has adopted a version of this modification.

1908.1.12 – Previously in Section 1910.14.2, this modification requires columns supporting discontinuous stiff members in an SDC C building to be designed using the special load combinations of Section 1605.4 and to have closely spaced full-height transverse reinforcement, extended above and below the column by specified distances.

1908.1.13 – ACI 318-02 Section 21.13.2 requires yielding to be restricted to steel elements or reinforcement in connections between wall panels, or between wall panels and the foundation in intermediate precast structural walls. 2003 IBC Section 1908.1.7, now deleted, restricted the yielding to the reinforcement. A new Section 21.13.4, added by 2006 IBC Section 1908.1.13, requires: "Except for Type 2 mechanical splices, connection elements that are designed to yield shall be capable of maintaining 80% of their design strength at the deformation induced by the design displacement."

Also, wall pier provisions, similar to those for structures in SDC D and above, have been added for structures in SDC C.

1908.1.14 – This modification was in 2003 IBC Section 1910.2.2 and contains reinforcement detailing requirements for Detailed Plain Concrete Shear Walls.

1908.1.15 – Previously in Section 1910.4.3, the IBC provisions of this section were similar but not identical to the requirements found in ACI 318-02 Section 22.10, which was silent on the use of structural plain concrete in SDC C structures.

The section now clearly states its applicability. The updated modification to ACI 318 Section 22.10 is consistent with 2003 IBC Section 1910.4.3, except as follows:

(a) In Section 22.10.1(a), the phrase "three stories or less in height" has been added to explicitly state what has always been intended. The addition of the sentence "In dwellings assigned to Seismic Design Category D or E, the height of the wall shall not exceed 8 feet, the thickness shall not be less than 7 ½ inches, and the wall shall retain no more than 4 feet of unbalanced fill." imposes a limitation not included in the 2003 IBC, but is consistent with the 2003 IRC and similar to ACI 318 Section 22.10.1(c).

(b) In Section 22.10.1 (c), Exception No. 3, the phrase "of the slab" has been added to clarify the intent.

1908.1.16 – This section modifies Section D.3.3 of ACI 318 by replacing "regions of moderate or high seismic risk" with "Seismic Design Category C, D, E, or F." Also, the requirement of Section D.3.3.4 is exempted when the minimum design strength of an anchor is at least 2.5 times the factored forces transmitted by the attachment.

Amendment to ACI 318-05 in 2006 IBC Sections 1912

In ACI 318-05, the concrete breakout strength provisions of Sections D.5.2 and D.6.2 are applicable only to anchors with diameters not exceeding 2 inch and tensile embedments not exceeding 25 inches. These restrictions are removed in the 2006 IBC through an amendment to ACI 318-05.

Conclusion

The biggest change in the concrete chapter from the 2003 to the 2006 IBC is the update of the referenced standard from ACI 318-02 to ACI 318-05. Also, Section 1910 of the 2003 IBC has been eliminated, with the contents either incorporated in Section 1908 or deleted as being unnecessary.▪

Dr. Gosh provides a more detailed look at the changes to concrete provisions of the 2006 IBC in the proceedings of the 100th Anniversary Earthquake Conference commemorating the 1906 San Francisco Earthquake, available on CD-Rom from the Earthquake Engineering Research Institute. Visit **www.eeri.org**.

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