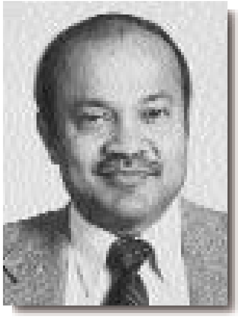
Provisions Related to Structural Design and Concrete of the 2003 IBC and NFPA Building Code

This article provides an overview of the differences in structural design and concrete-related provisions of the two latest model codes: the 2003 International Building Code, published in February 2003, and the 2003 NFPA 5000 Building Construction and Safety Code, published in August 2002.



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The structural chapters of the 2003 International Building Code[1] (IBC, Fig. 1) and 2003 NFPA 5000 Building Construction and Safety Code[2] (Fig. 2), are:

- IBC Chapter 16 and NFPA Chapter 35, Structural Design
- IBC Chapter 17, Structural Tests and Special Inspections, and NFPA Chapter 40, Quality Assurance During Construction
- IBC Chapter 18, Soils and Foundations, and NFPA Chapter 36, Soils, Foundations, and Retaining Walls
- IBC Chapter 19 and NFPA Chapter 41, Concrete
- IBC Chapter 20 and NFPA Chapter 42, Aluminum
- IBC Chapter 21 and NFPA Chapter 43, Masonry
- IBC Chapter 22 and NFPA Chapter 44, Steel
- IBC Chapter 23 and NFPA Chapter 45, Wood

The scope of this article is limited to Chapters 16 through 19 of the IBC, and the corresponding chapters of the NFPA 5000 Code.

A key difference between the two sets of structural provisions is the extent to which they rely on adopting standards by reference. NFPA 5000 (2003) relies almost entirely on adoption by reference, whereas the 2003 IBC relies less heavily on such adoption, although from the 2000 to the 2003 edition of the IBC, this reliance has increased. For example, NFPA 5000 (2003) refers to ASCE 7-02 Minimum Design Loads for Buildings and Other Structures[3] for almost all of its seismic design requirements, whereas the 2003 IBC still retains some of the seismic design requirements in the Code itself. The 2000 IBC contained complete seismic design provisions.

NFPA 5000 (2003) includes an Annex A which is not part of the requirements, but is included for informational purposes only. If an asterisk appears next to a section number, then the code user is directed to Annex A for supplemental information. The IBC does not have anything comparable to this feature primarily because much of the information in NFPA 5000 Annex A is included within the IBC text itself.

NFPA 5000 (2003) includes a reference in brackets following the code text that has been extracted from a referenced standard. Information about the referenced standard, including the edition, can be found in NFPA Chapter 2 and Annex D. The IBC does not

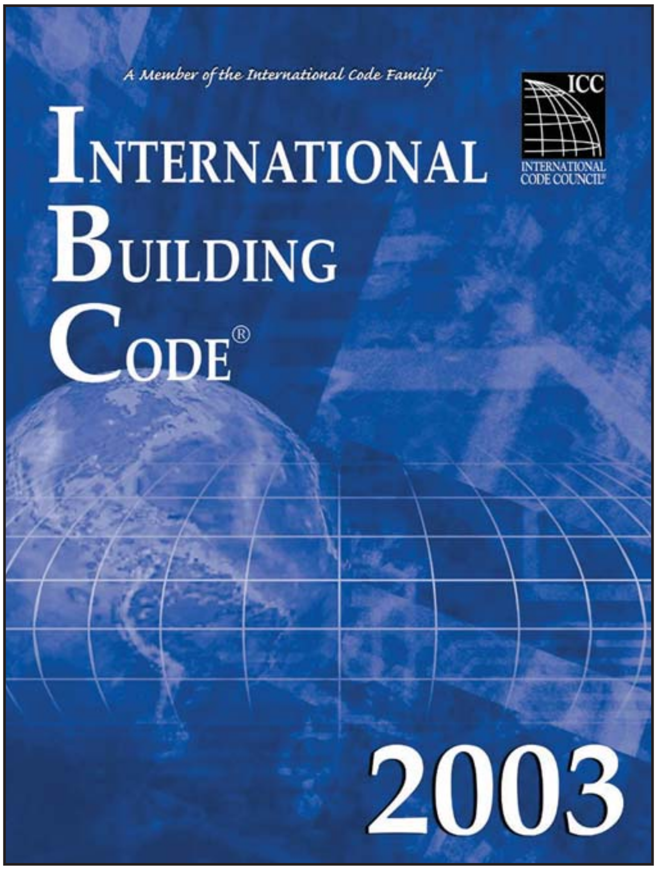

Fig. 1. The 2003 International Building Code.

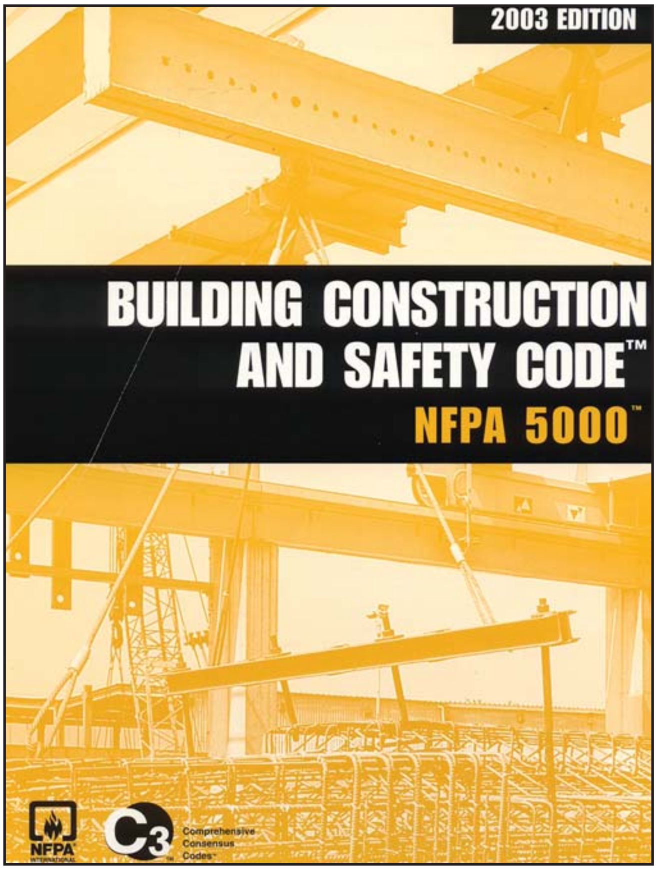

Fig. 2. The 2003 NFPA 5000 Building Construction and Safety Code.

indicate if text has been extracted from a reference standard. Information about standards referenced in the IBC, including the edition, can be found in IBC Chapter 35.

STRUCTURAL DESIGN

Load Combinations

Load combinations are set forth in Section 1605 of the 2003 IBC, whereas NFPA 5000 (2003) references Section 2 of ASCE 7-02 for load combinations.

The strength design load combinations are the same in the two codes, except that the IBC increases the snow load factor from 0.2 to 0.7, in the gravity plus seismic load combination, for roof configurations that do not shed snow.

The IBC has two sets of ASD load combinations, whereas ASCE 7-02, referenced in NFPA 5000 (2003), has only one. ASCE 7-02 ASD load combinations look different from the IBC basic ASD load combinations; however, they are different in appearance only, not in substance.

ASCE 7-02, referenced in NFPA 5000 (2003), has load combinations including atmospheric ice loads that are not to be found in the IBC.

In designs using special seismic load combinations, the IBC allows design strengths to be increased by a factor of 1.7 when ASD is used, compared to a factor of 1.2 in ASCE 7-02.

ASCE 7-02 requires that the strength and stability of a structure be checked to ensure that it is capable of withstanding the effects of extraordinary events such as fires, explosions, and vehicular impact. No similar requirements are given in the IBC. Building codes have traditionally addressed the fire issue by requiring that certain structures have fire resistance rated construction. The statement concerning explosions and vehicular impact has traditionally been ignored.

Live Loads

NFPA 5000 (2003) references ASCE 7-02 for live loads, while the live loads in the 2003 IBC are essentially the same as those of ASCE 7-02.

While NFPA 5000 has adopted live load reduction based on ASCE 7-02, IBC 2003 has live load reduction based on ASCE 7-02 as well as alternative live load reduction based on the 1997 UBC.

Live load reduction based on ASCE 7-02 is modified in significant respects in IBC 2003. ASCE 7-02 limits the tributary area, A_T, for one-way slabs to an area defined by the slab span times a width normal to the span of 1.5 times the slab span. The 2003 IBC does not have this limitation; instead, the IBC basically prohibits live load reduction in one-way slabs (there is an exception to this, which is of little practical consequence).

Neither ASCE 7-02 nor IBC 2003 allows a reduction in live load in passenger vehicle garages, except that live loads on members supporting two or more floors are permitted to be reduced by a maximum of 20 percent. The 2003 IBC further stipulates that the live load must not be taken less than that calculated on the basis of the live load element factor, K_{LL}, and the tributary area, A_T.

Alternate floor live load reduction of the 2003 IBC, adapted from the 1997 UBC, does not impose limitations on live load reduction for one-way slabs and parking structures. Up to 40 percent reduction is allowed for horizontal members, and up to 60 percent for vertical members.

The above raises an important and interesting issue. The uniform live load for garages (passenger vehicles only) has been reduced from 50 to 40 psf (2.40 to 1.92 kPa) from ASCE 7-98 to ASCE 7-02. Under the alternate live load reduction provision of IBC 2000, a parking garage floor could be designed for a reduced live load of 30 psf (0.6 × 50 psf) [1.44 kPa], whereas under the ASCE live load reduction provisions, the same floor had to be designed for a full design live load of 50 psf (2.40 kPa).

Now that the 2003 IBC would permit the above floor to be designed for a live load of 40 psf (1.92 kPa), can the floor be designed for a reduced live load of 24 psf (0.6 × 40 psf) [1.15 kPa] under the alternate live load reduction provision? The author does not believe that anything below 30 psf (1.44 kPa) is warranted, although the letter of the code may permit that.

Soil Lateral Loads

The 2003 IBC and NFPA 5000 Code (2003) prescribe soil lateral loads for use in designing basement walls and retaining walls that are essentially identical. In some cases, the lateral loads are different from those in ASCE 7-02. NFPA 5000 specifies that unless drainage is provided, the hydrostatic load of the water pressure must be assumed equal to the wall height; IBC 2003 does not mention this specifically. NFPA references NCMA's Design Manual for Segmented Retaining Walls,[4] which is not referenced in the IBC.

Earthquake Loads

When allowable stress design is used for proportioning foundations, the 2003 IBC allows certain liberalizations that are not permitted in ASCE 7-02, referenced in NFPA 5000 (2003).

IBC 2003 requires that any small portion of a structure shall be tied to the remainder of the structure with connections capable of resisting F_p equal to 0.05 times the weight of the smaller portion. ASCE 7-02, referenced in NFPA 5000 (2003) has changed the 5 percent to $0.133S_{DS} \geq 5$ percent, resulting in greater design forces where S_{DS} is greater than approximately 0.375.

The 2003 IBC permits the Seismic Design Category determination to be based on S_{DS} alone [Table 1616.3(1)], provided:

- $T_a \leq 0.8T_s$, where T_a is the approximate fundamental period of the structure and $T_s = S_{D1}/S_{DS}$.
- Upper-bound design base shear is used in design [that is, $S_{DS}/(R/I_E)$].
- The diaphragm is not flexible.

S_{DS} is the 5 percent damped design spectral response acceleration at short periods (Section 1615.1.3).

S_{D1} is the 5 percent damped design spectral response acceleration at a 1-second period (Section 1615.1.3).

R is the response modification factor (Table 1617.6).

I_E is the seismic importance factor (Table 1604.5).

A flexible diaphragm is defined in the 2003 IBC Section 1602.

ASCE 7-02 allows $0.2S_{DS}D$ to be taken equal to zero in determining the earthquake effect, E, or special earthquake effect, E_m, as long as $S_{DS} \leq 0.125g$. This is not permitted by IBC 2003 when the simplified analysis procedure of Section 1617.5 is used.

IBC 2003 Section 1617.2.1 references ASCE 7-02 Section 9.5.2.4 for redundancy provisions and then makes the following significant modifications not adopted by NFPA 5000 (2003):

- Calculation of $r_{max\ x}$ need not consider the effects of accidental torsion and need not consider any dynamic amplification of torsion. Note that $r_{max\ x}$ is the maximum element-to-story shear ratio in story level x.
- For a story with a flexible diaphragm immediately above, $r_{max\ x}$ may be calculated from an analysis that assumes rigid diaphragm behavior and ρ_x (redundancy factor for story level x) need not exceed 1.25.
- The calculated value of ρ (redundancy factor for the entire building along one principal plan axis) may exceed the limits of 1.25 for SDC D and 1.10 for SDC E, F when the design story drift Δ does not exceed Δ_a/ρ for any story, where Δ_a is the allowable story drift.
- The value of ρ is permitted to be taken equal to 1.0 in the following circumstances:
  - When calculating displacements for dynamic amplification of torsion in ASCE 7-02 Section 9.5.5.5.2 (Torsion).
  - When calculating deflections, drifts, and seismic shear forces related to ASCE 7-02 Sections 9.5.5.7.1 (Story Drift Determination) and 9.5.5.7.2 (P-Delta Effects).
  - For design calculations required by ASCE 7-02 Sections 9.5.2.6 (Design and Detailing Requirements), 9.6 (Architectural, Mechanical, and Electrical Components and Systems) or 9.14 (Nonbuilding Structures).

The 2003 IBC Section 1620.1, Structural Component Design and Detailing, refers the code user to ASCE 7-02 Section 9.5.2.6 for the requirements, but makes three modifications, which are detailed in the 2003 IBC Sections 1620.1.1, 1620.1.2 and 1620.1.3.

The 2003 IBC Section 1621.1 (Architectural, Mechanical and Electrical) Component Design, refers the code user to ASCE 7-02 Section 9.6 for the requirements, but makes three amendments detailed in the 2003 IBC Sections 1621.1.1, 1621.1.2 and 1621.1.3.

The 2003 IBC Section 1622.1, Non-Building Structures, references ASCE 7-02 Section 9-14, but makes three amendments described in the 2003 IBC Sections 1622.1.1, 1622.1.2, and 1622.1.3.

The 2003 IBC Section 1623.1, (Seismically Isolated Structures) Design Requirements, references ASCE 7-02 Section 9.13, and makes just one modification detailed in the 2003 IBC Section 1623.1.1.

STRUCTURAL TESTS AND SPECIAL INSPECTIONS

The primary emphasis in NFPA 5000 Chapter 40 is on a quality assurance program, which includes inspections and testing, that is typically to be prepared by the responsible registered design professional. The primary emphasis in IBC Chapter 17 is on special inspection and testing, which is required for most construction. In the IBC, the only time a quality assurance plan is required is for moderate- and high-seismic and high-wind applications.

The quality assurance provisions in NFPA 5000 were based on proposals submitted by the Boston Area Structural Engineers (BASE). IBC Chapter 17 is based on provisions in the latest editions of the BOCA National Building Code,[5] the Standard Building Code,[6] the Uniform Building Code,[7] and the 2000 NEHRP Recommended Provisions.[8]

SOILS AND FOUNDATIONS

Soil Classification and Investigation

With respect to soil investigation, the 2003 IBC is more comprehensive. The 2003 IBC has an exception, not included in NFPA 5000 (2003), that allows the building official to waive the soils investigation if there are satisfactory data from adjacent areas. NFPA 5000 requires a soils investigation when the authority having jurisdiction explicitly requires it. Under the IBC, a soils investigation is required unless the building official waives this requirement.

The following is a list of soil investigation provisions in the 2003 IBC, which are not included in NFPA 5000 (2003):

- Requirement for subsurface soil investigation to determine location of groundwater table.
- Requirement to investigate rock strata to a depth of 10 ft (3.05 m).
- Submittal of a written report, including code-specified information, when required by the building official.

Expansive Soils

Both codes rely on the plasticity index determined in accordance with ASTM D 4318[9] to evaluate if soil is expansive. The 2003 IBC requires additional specific test results to be determined in order for the soil to be classified as expansive. NFPA 5000 (2003) simply states that the soil "shall be subjected to additional approved tests and evaluation to determine if the soil will adversely affect the structural integrity and serviceability of the structure."

With respect to design, the 2003 IBC addresses soil volume changes, deflection, racking, and uplift of the supported structure; these issues are not explicitly addressed in NFPA 5000 (2003). Both codes reference WRI/CRSI's Design of Slab-on-Ground Foundations[10] and PTI's Design and Construction of Post-Tensioned Slabs-on-Ground.[11] The 2003 IBC, but not the NFPA 5000, exempts compliance with these documents if slab-on-ground systems have performed adequately in soil conditions similar to those encountered at the building site, if approved by the building official.

Excavation, Grading and Fill

The excavation provisions of the two codes are quite different. The 2003 IBC only addresses protection of the footing or the foundation from excavation, whereas NFPA 5000 addresses this type of protection, as well as extent of excavations, drainage and retaining walls for permanent excavations.

NFPA 5000 (2003) requires that the site be graded away from the foundation for a distance of 10 ft (3.05 m) at a 1:12 slope. The 2003 IBC requires the same, except that the slope needs to be only 1:20.

The fill provisions of the two codes are quite similar, except that NFPA 5000 explicitly requires that the report that specifies the fill material and how it is to be placed, compacted and tested must be completed by a registered design professional.

Allowable Vertical and Lateral Soil Pressures

Comparable tables listing allowable soil pressures are different in the two codes with respect to the class of materials listed, format as well as content. NFPA 5000 lists allowable vertical soil pressures as a function of depth and width; the IBC does not. The IBC lists a coefficient of friction for lateral sliding; the NFPA 5000 does not. The 2003 IBC addresses mud, organic silt, organic clays, peat and unprepared fill; NFPA does not.

Depth of Embedment to Resist Lateral Loads

The design formulas to determine the depth of embedment in the ground of cantilever posts or columns required to resist lateral loads are the same in the two codes. NFPA 5000 (2003) requires that the annular space around the post or column be filled with concrete, while the IBC permits clean sand to be used.

Footing Requirements

NFPA 5000 requires that excavations be made to firm, clear bearing soil, to the frost line or 12 in. (305 mm) below grade, whichever is the largest. The 2003 IBC has more comprehensive frost protection requirements.

IBC 2003, but not NFPA 5000 (2003), requires the minimum width of footings to be 12 in. (305 mm).

The 2003 IBC includes an exception to the edge thickness requirement for plain concrete footings, which is not included in NFPA 5000 (2003).

NFPA 5000 limits the maximum rise and the minimum run of steps in a stepped footing; the IBC does not contain these requirements. The 2003 IBC permits the bottom surface of a footing to have as much as a 10 percent slope, which NFPA 5000 does not.

The 2003 IBC addresses the placement of buildings and structures on or adjacent to slopes steeper than 1:3. Comparable provisions are not included in NFPA 5000 (2003).

Waterproofing and Dampproofing

The NFPA 5000 waterproofing and dampproofing provisions are much more general in nature than the prescriptive provisions in IBC 2003. NFPA 5000 indicates that waterproofing and dampproofing must be completed using approved materials and methods, whereas the IBC specifies exactly what needs to be done.

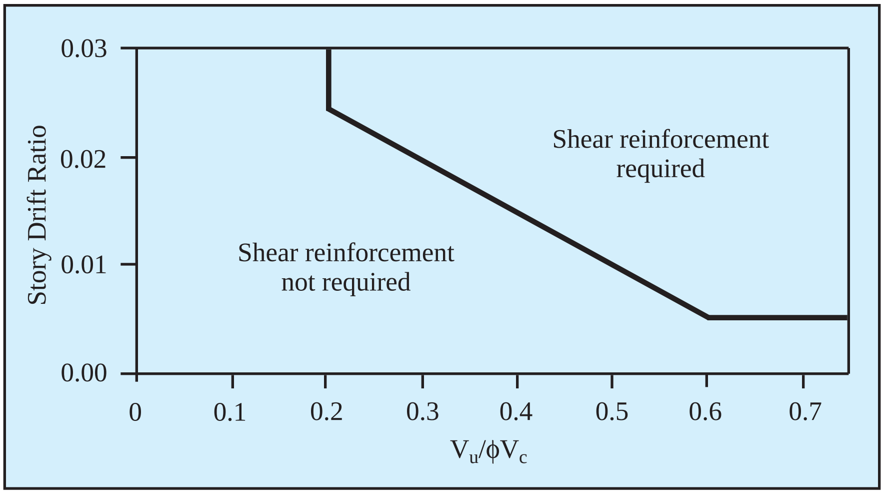

Fig. 3. Punching shear reinforcement requirements at flat plate-column joints.

Pile and Pier Foundations

The pile and pier foundation requirements of the two codes are set up quite differently. The IBC takes a more comprehensive approach, giving definitions first, then general requirements, followed by seismic design requirements that are organized by the Seismic Design Category.

CONCRETE

ACI 318-02 is adopted as the referenced standard for concrete design and construction by both codes.

IBC Chapter 19 has made an exception to ACI 318-02 requiring that in buildings less than four stories in height that house residential occupancies, normal-weight concrete subject to weathering (freezing and thawing), as determined from Fig. 1904.2.2, or deicer chemicals, must comply with the requirements of Table 1904.2.2(2). Neither Fig. 1904.2.2 nor Table 1904.2.2(2) is part of ACI 318-02, ASCE 7-02, or NFPA 5000 (2003). The exception, the table, and the figure are adopted into the IBC from the International Residential Code,[12] which in turn adopted these from the BOCA/NBC[5] and the CABO One- and Two-Family Dwelling Code.[13]

IBC Chapter 19, in another exception to ACI 318-02, allows the use of prestressing tendons in structural members, resisting earthquake-induced forces, of buildings assigned to Seismic Design Category D and above, subject to certain safeguards. ACI 318-02 requires reinforcement in such members to be ASTM A706 bars or ASTM A615 Grade 40 or 60 bars that meet the supplementary requirements of ACI 318.

IBC Chapter 19, in a third exception to ACI 318-02, gives detailing requirements for wall piers. A wall pier is defined as a wall segment with a horizontal length-to-thickness ratio of at least 2.5, but not exceeding six, whose clear height is at least two times the horizontal length.

The fourth IBC Chapter 19 exception to ACI 318-02 applies to columns that are not part of the lateral-force-resisting system of a building assigned to Seismic Design Category D or above. The exception applies when such a column is going to remain elastic under the combined effects of factored gravity and imposed design displacements of the lateral-force-resisting system. Design displacements are displacements elastically computed under code-prescribed seismic forces, amplified by the deflection amplification factor, C_d. Under the exception, lap splices of longitudinal reinforcement in such a column need not be confined to the middle half of the column height in structures where the seismic-force-resisting system does not include special moment frames.

A new, very important modification to ACI 318-02 involves slab (flat plate)-to-column connections in frames that are not part of the lateral-force-resisting system of a building assigned to Seismic Design Category D or above. Such gravity frames would normally need to satisfy the deformation compatibility requirement of the code, which would require checking that the frames would continue to support full, factored gravity loads, as they deform together with the lateral-force-resisting system all the way up to the design displacements.

Such a check is onerous; also, the punching shear stress at slab-column joints under the combined effects of factored gravity and imposed design displacements of the lateral-force-resisting system often turn out to be excessive, except when a building is short or the lateral-force-resisting system is very stiff. Under the exception in question, the deformation compatibility requirement can be deemed to be satisfied if a prescriptive amount of shear reinforcement is provided around a slab-column joint that satisfies the criterion illustrated in Fig. 3. Along with the provision of the prescribed punching shear reinforcement, the structural integrity reinforcement requirements (involving column-strip bottom bars) are strengthened somewhat.

In a final exception to ACI 318-02, yielding in intermediate as well as special precast concrete shear walls is restricted to reinforcement only, whereas ACI 318 permits yielding in reinforcement as well as other steel elements.

Basement, foundation and above-grade walls of one- and two-family dwellings using insulating concrete forms as well as conventional forms with flat surfaces are permitted in NFPA 5000 to be designed and constructed in accordance with the provisions of PCA Publication EB118, Prescriptive Method for Insulating Concrete Forms for Residential Construction.[12] A similar provision does not exist in IBC 2003, because the IBC defers to the IRC when it comes to the construction of one- and two-family dwellings.

The 2003 IBC contains provisions for concrete-filled pipe columns and working stress design of anchors that are not found in NFPA 5000.

CONCLUDING REMARKS

Only the structural provisions of the 2003 IBC and the 2003 NFPA 5000 Building Construction and Safety Code have been compared in this article. The very important fire and life-safety provisions are beyond the scope of the paper. Also beyond the scope are structural provisions concerning masonry, steel and wood. The limited comparison presented here should be of interest to a wide audience, and shows that while the differences between the two model codes are not drastic, they are far from insignificant in some areas – most notably, structural tests and special inspection.

ACKNOWLEDGMENTS

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