Seismic Design Provisions in U.S. Codes and Standards: A Look Back and Ahead

The seismic code development process that was in place in the United States for many decades is undergoing dramatic changes. These changes and their possible impact on seismic design provisions for precast concrete structures in the U.S. model codes are discussed.

S. K. Ghosh, Ph.D.
President
S. K. Ghosh Associates, Inc.
Northbrook, Illinois

Almost every building or structure in the United States must be designed and constructed in accordance with the building code of the local jurisdiction (city, county or state), which is a legal document. A local jurisdiction will typically make sure that the design documents are in compliance with its building code before issuing a construction permit (see Fig. 1a).

A local jurisdiction will also typically make sure that all inspection requirements of its building code have been complied with in the construction of a building before issuing a certificate of occupancy (see Fig. 1b). The only exceptions to these regulations might be military installations and structures located in remote parts of the country.

MODEL BUILDING CODES

The legal building codes of most jurisdictions within the United States have in the recent past been based on one of three model building codes:

- The BOCA National Building Code (BOCA/NBC), published by the Building Officials and Code Administrators International, Country Club Hills, Illinois.[1]
- The Standard Building Code (SBC), published by the Southern Building Code Congress International, Birmingham, Alabama.[2]
- The Uniform Building Code (UBC), published by the International Conference of Building Officials, Whittier, California.[3]

The BOCA/NBC is typically adopted in the northeastern quarter, the SBC in the southeastern quarter, and the UBC in the western half of the United States. This division is obviously imprecise, and is meant solely to convey an overall picture; there are exceptions to the normal patterns.

In the mid-1990s, there was a concerted attempt at developing a single unifying model building code for the entire country, to replace the three regional model building codes mentioned above. This resulted in the International Building Code (IBC),[4] developed by the three model code groups under the auspices of the International Code Council which they had together formed. Unfortunately, before the first edition of the IBC could even come out in April 2000, the unification process came unraveled. Recently, the National Fire Protection

Association (NFPA), Quincy, Massachusetts, has decided to bring out a competing model building code of its own, NFPA 5000,[5] the first edition of which is expected to be published in the fall of 2002, ahead of the publication of the second edition (2003) of the International Building Code.

Right now, the building code of a local jurisdiction somewhere in the United States is likely to be based on one of the following:

(1) The 1993, 1996 or 1999 edition of the BOCA/NBC.

(2) The 1994, 1997 or 1999 edition of the SBC.

(3) The 1991, 1994 or 1997 edition of the UBC.

(4) The 2000 edition of the IBC.

Soon to be added to the list are the 2003 edition of the IBC and the 2002 edition of the NFPA 5000. In the short run, obviously, the confusion in the codes arena has increased, rather than decreased. In the long run, the three model codes of the recent past will be replaced by the IBC and/or NFPA 5000, because the model code groups have announced that the 1999 BOCA/NBC, the 1999 SBC and the 1997 UBC are the last editions of these model codes.

How long the transition will take; whether it will eventually be one or two model codes; if it is going to be one, which one it is going to be; if it is going to be two, which jurisdiction will opt to adopt which model code – these are all questions for the future.

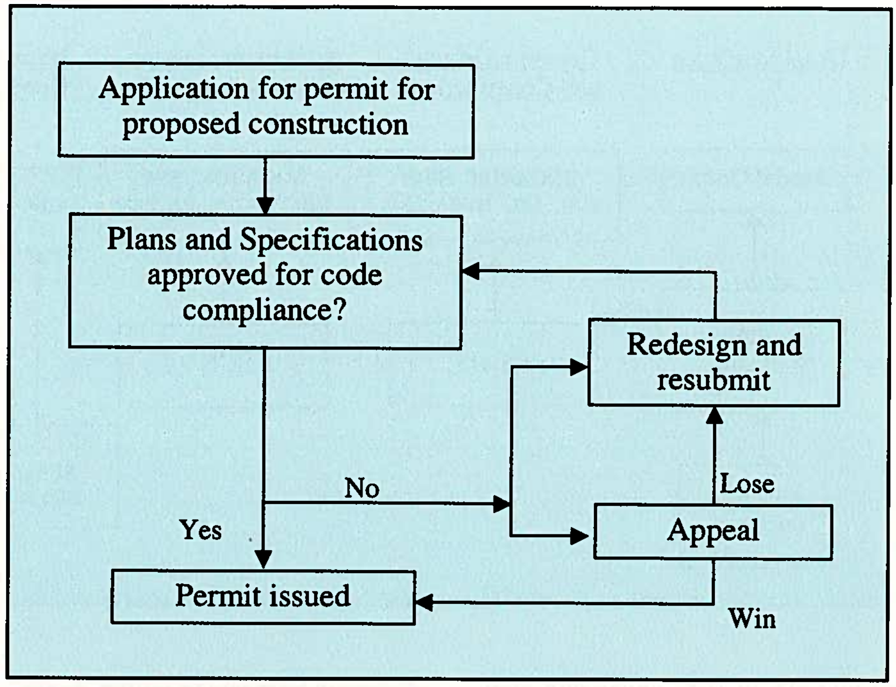

Fig. 1a. Issuance of construction permit.

STANDARDS

The model code organizations do not have resources to develop code provisions on every aspect of design and construction covered by the building code. Thus, it is common for the model codes to adopt standards. The ASCE 7 "Minimum Design Loads for Buildings and Other Structures"[6] and the ACI 318 "Building Code Requirements for Structural Concrete"[7] are two important standards that are adopted by all model codes for design loads on structures and for concrete design and construction provisions, respectively.

The latter document is a standard and not a code, even though the word "code" appears in its title. The various standards published by the American Society for Testing and Materials (ASTM) are also widely adopted by all the model codes as well as by many other standards such as ACI 318.

The model codes are typically reluctant to adopt a standard that is not developed by a consensus process approved by the American National Standards Institute (ANSI). In the absence of a consensus standard, a code or a standard would sometimes adopt a non-consensus document, and then replace it with a consensus standard as soon as one becomes available.

RESOURCE DOCUMENTS

Besides codes and standards, there is an important class of documents, probably best called Resource Documents, that is quite important, particularly when it comes to seismic design

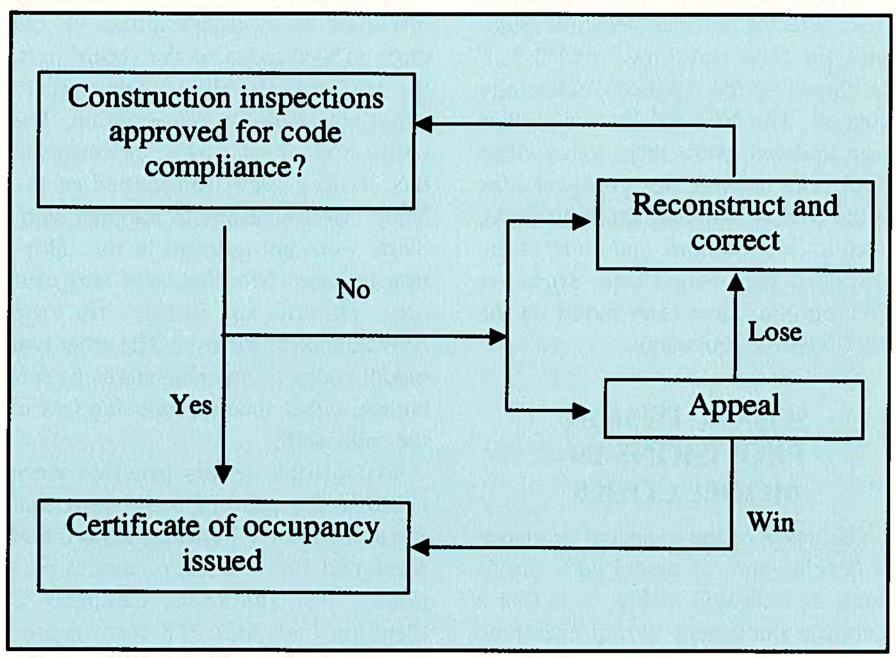

Fig. 1b. Issuance of certificate of occupancy.

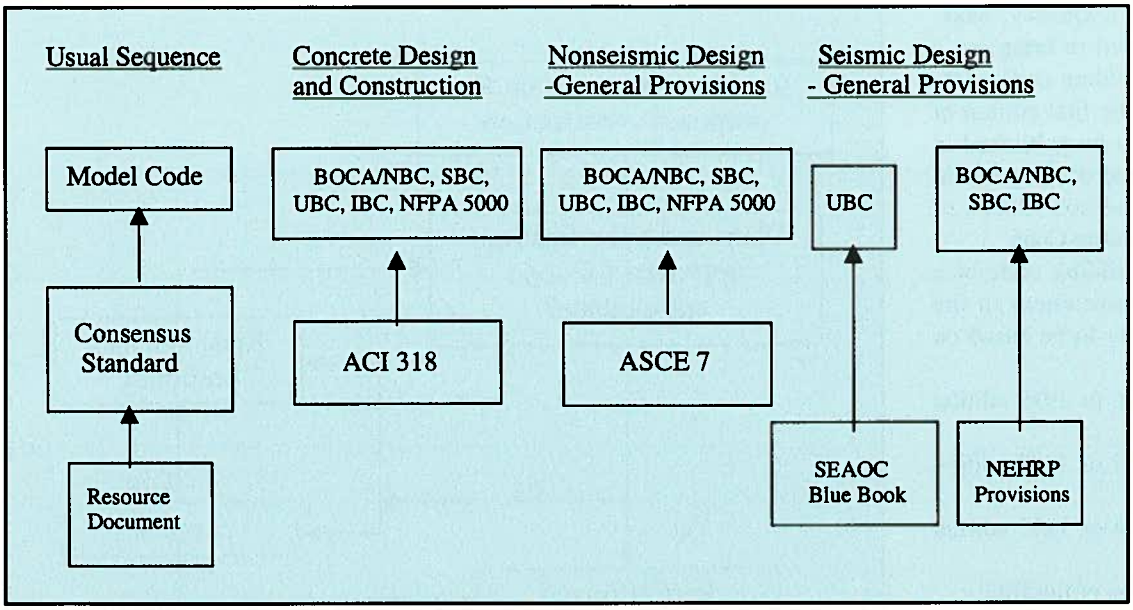

Fig. 2. Seismic design provisions and concrete design and construction provisions in various codes and standards.

provisions in U.S. codes and standards. The seismic design provisions of the Uniform Building Code, since its 1962 edition, have been based on the "Recommended Lateral Force Requirements and Commentary" developed by the Seismology Committee of the Structural Engineers Association of California (SEAOC).[8] This so-called SEAOC Blue Book is an important resource document.

Another very important resource document in the seismic arena is the National Earthquake Hazards Reduction Program (NEHRP) Provisions,[9] the first edition (1985) of which was a modified version of the "Tentative Provisions for Seismic Design Regulations for New Buildings" (ATC 3),[10] developed by the Applied Technology Council. The NEHRP Provisions has been updated every three years since 1985. The seismic design provisions of the BOCA National Building Code, since its 1993 edition, and those of the Standard Building Code, since its 1994 edition, have been based on the 1991 NEHRP Provisions.

SEISMIC DESIGN PROVISIONS IN MODEL CODES

The usual or the expected sequence of development of model code provisions, as indicated in Fig. 2, is that a resource document would either be standardized or would form the basis of certain provisions within a standard. For instance, the very significant FEMA 273 resource document has now been processed into a pre-standard (FEMA 356),[11] on its way to becoming an ASCE standard.

For another example, the design load combinations of the current ASCE 7 standard are based on a major statistical study commissioned by the National Bureau of Standards (now the National Institute of Standards and Technology, or NIST) and reported in Reference 12.

The standard (typically based on several resource documents) is then adopted into a model code either by reference or by transcription. Of the three model codes of the recent past, the Uniform Building Code used to adopt standards by transcription. The entire text of ACI 318, for instance, has always been transcribed in the UBC. Modifications to adopted standards were not unusual in this adoption process. Modified text was usually shown in italics for the convenience of the user. The other two model codes adopted standards by reference, rather than reproducing text in the code itself.

Exceptions to this practice were made in the case of provisions that were needed by building department personnel for code enforcement purposes. For instance, Chapters 2 through 7 of ACI 318 were reproduced in both the BOCA/NBC and the SBC. The IBC is very similar to the BOCA/NBC and SBC as to how standards are adopted. Only portions of Chapters 2 through 7 of ACI 318 are reproduced in the code. The rest of the standard is adopted by reference. Reproduced text is expected to become rarer as time goes on. NFPA 5000 has decided to adopt standards almost entirely by reference.

As also shown in Fig. 2, in the case of seismic design provisions of model codes, an exception to the normal sequence of adoption has been made in the past. As indicated earlier, the seismic design provisions of the Uniform Building Code, since its 1962 edition, have been based directly on the SEAOC Blue Book, which is a resource document, not a consensus standard. Through its 1988 edition, the national loading standard, ASCE 7 (previously ANSI A58.1), had its seismic design provisions based on those of the Uniform Building Code. Thus, the normal sequence was, in fact, reversed.

Instead of a model code adopting standards, a standard was adopting model code provisions. Or one could think in terms of ASCE 7/ANSI A58.1 adopting seismic design provisions out of the Blue Book, a resource document, via the UBC. The BOCA/NBC through its 1990 edition and the SBC through its 1991 edition used to adopt general design provisions for all loads, including seismic, from ASCE 7/ANSI A58.1. So that part of the process followed the expected sequence of a model code adopting provisions out of a standard.

Table 1 shows that the BOCA/NBC since its 1993 edition and the SBC since its 1994 edition have, like the UBC before them, adopted seismic design provisions directly out of a resource document, namely, the 1991 edition of the NEHRP Provisions, rather than from a standard. The IBC has done the same, adopting in its 2000 edition seismic design provisions out of the 1997 NEHRP Provisions.

The above pattern is now about to be changed. ASCE 7, in its 1993 edition, broke the tradition of adopting seismic design provisions based on the UBC, choosing instead to adopt seismic design requirements out of the 1991 NEHRP Provisions. The seismic design requirements of the 1995 and 1998 editions of ASCE 7 were based on the 1994 and the 1997 NEHRP Provisions, respectively; those of the 2002 edition of ASCE 7 will be based on the 2000 NEHRP Provisions.

NFPA 5000 will contain hardly any structural design provisions in the code. ASCE 7-02 will be adopted by reference for all general design provisions, including seismic design. It looks very likely at this point (January 2002) that IBC 2003, unlike IBC 2000 and the model codes preceding it, will cease to have complete seismic design provisions in the code.

Several segments of the seismic design provisions will be deleted in favor of references to the corresponding provisions in ASCE 7-02. It is further expected that IBC 2005 will adopt seismic design provisions out of ASCE 7-05 (which in turn will be based on the 2003 NEHRP Provisions), almost entirely by reference.

Two important observations may be made from the above. First, the ASCE 7 (previously ANSI A58.1) standard is becoming important in the seismic design arena for the first time since its inception. Second, although the United States, in all probability, will not end up with a single model building code, the structural design provisions in the two competing model codes will be virtually identical, because they will be making references to the same standards.

Table 1. Seismic design provisions and concrete design and construction provisions of various codes and standards.

Code or Standard		Seismic Design Provisions Based on	Concrete Standard
BOCA/NBC	1993	NEHRP 1991	ACI 318-89 (Revised 1992)
	1996	NEHRP 1991	ACI 318-95
	1999	NEHRP 1991	ACI 318-95
SBC	1994	NEHRP 1991	ACI 318-89 (Revised 1992)
	1994	NEHRP 1991	ACI 318-95
	1999	NEHRP 1991	ACI 318-95
UBC	1991	Blue Book 1988	ACI 318-95
	1994	Blue Book 1990	ACI 318-89 (Revised 1992)
	1997	Blue Book 1996, Appendix C	ACI 318-89
IBC	2000	NEHRP 1997	ACI 318-99
	2003	NEHRP 2000/ASCE 7-02	ACI 318-02
NFPA 5000	2002	ASCE 7-02	ACI 318-02
ASCE 7-02	1993	NEHRP 1991	ACI 318-89†
	1995*	NEHRP 1994	ACI 318-89 (Revised 1992)†
	1998	NEHRP 1997	ACI 318-95†
	2002	NEHRP 2000	ACI 318-02†

* Allowed to be used for seismic design by BOCA/NBC 1996, 1999 as well as SBC 1997, 1999.
† Referenced by the seismic design provisions only.

It may also be worth noting that the 2003 edition of the NEHRP Provisions will very likely be the last edition to contain complete seismic design provisions. It also appears likely that starting with its 2006 edition, the NEHRP provisions will delete significant portions of the current text, making reference instead to the corresponding provisions of ASCE 7.

SEISMIC DESIGN PROVISIONS FOR PRECAST CONCRETE IN MODEL CODES

The ACI 318 standard, through its 1999 edition, did not contain seismic design provisions for precast concrete structures in regions of moderate or high seismic risk, although it did contain a vague, general requirement that would permit a precast structure as long as it was equivalent to a monolithic concrete structure in terms of strength and toughness. Toughness is a general term for inelastic deformability, or the ability of a structure to continue to support gravity loads as it deforms laterally under seismic excitation beyond the stage of elastic response, up to which all deformations are recoverable. Seismic design provisions for precast concrete structures in model codes thus could not come from the concrete design and construction standard (ACI 318).

Seismic design provisions for precast concrete structures were first developed for and introduced into the 1994 NEHRP Provisions, which, as has been noted, is a resource document. The provisions were for emulative design of precast concrete frames using strong connections (that would remain elastic as inelastic deformations took place at locations remote from the connections). Emulative design using ductile connections was permitted for frame- as well as wall-type structures, although prescriptive provisions were not developed.

With regard to ductile connections, it had to be demonstrated through test results that ductile connections would have adequate energy dissipation capacity, and that the deformed shape of a precast concrete structure would emulate that of a comparable monolithic concrete structure. The provisions were in the form of amendments to the 1989 edition (revised 1992) of ACI 318. Non-emulative design provisions (for jointed precast) were included in an appendix to the concrete chapter of the 1994 NEHRP Provisions for trial design only.

The first model code to adopt seismic design provisions for precast concrete structures was the 1997 UBC. The provisions were essentially the same as those of the 1994 NEHRP Provisions, except that they were restricted to emulative design of frame-type structures, using strong connec-

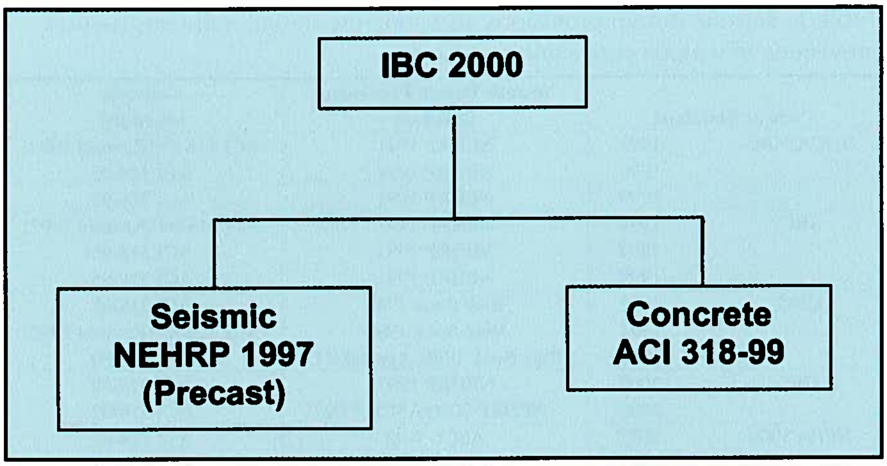

Fig. 3. Seismic design provisions for precast concrete structures in the 2000 IBC.

tions only. Safeguards were added for precast gravity frames, that were not part of the 1994 NEHRP Provisions. The provisions were in the form of amendments to ACI 318-95.

The 1997 NEHRP Provisions incorporated virtually all the modifications made by the 1997 UBC to the seismic design requirements for precast concrete structures of the 1994 NEHRP Provisions. The ductile connection option of emulative design was dropped. Safeguards for precast gravity systems were added.

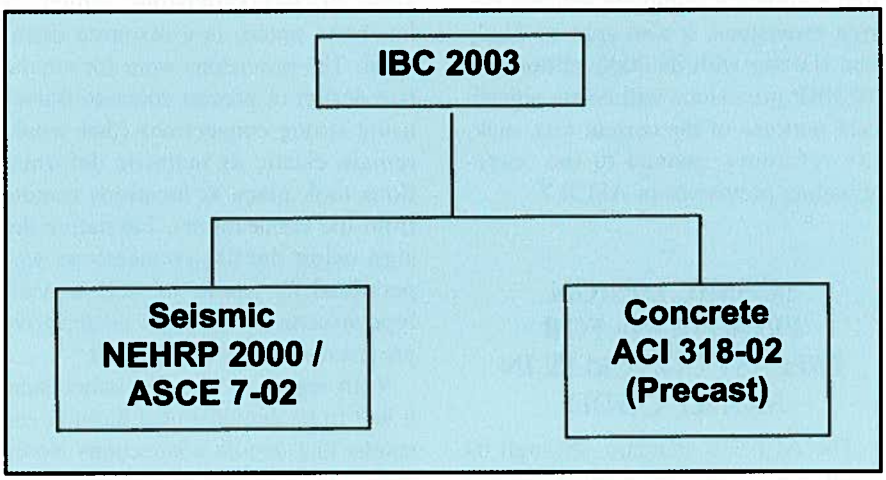

Fig. 4. Seismic design provisions for precast concrete structures in the 2003 IBC.

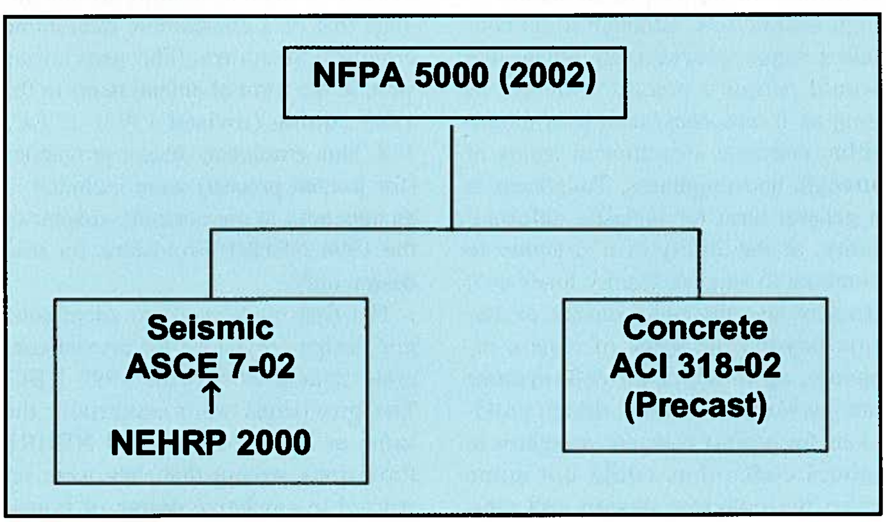

Fig. 5. Seismic design provisions for precast concrete structures in NFPA 5000 (2002).

The 2000 IBC adopted seismic design provisions for precast concrete structures out of the 1997 NEHRP Provisions (see Fig. 3). These are in the form of amendments to ACI 318-99.

The 2000 NEHRP Provisions has significantly expanded seismic design provisions for precast concrete structures. The ductile connection option is now included under monolithic emulation for frame- as well as wall-type structures. More importantly, included for the first time now are non-emulative design provisions for frame- and wall-type structures.

ACI 318-02 has also, for the first time, added seismic design provisions for precast concrete structures. These are largely based on and are similar to, but not the same as, those of the 2000 NEHRP Provisions. The ACI 318 provisions are somewhat more limited in scope. Notably, non-emulative design provisions for wall-type structures are not included.

In view of the above development, the 2000 IBC modifications to ACI 318-99 incorporating precast seismic design provisions have now been removed from the 2003 IBC. Seismic design provisions for precast concrete structures in the 2003 IBC will be adopted by reference from ACI 318-02 (see Fig. 4). NFPA 5000 has also chosen to adopt precast seismic design provisions by reference from ACI 318-02 (see Fig. 5).

ASCE 7 has moved in the same direction. ASCE 7-98 contained the 1997 NEHRP modifications to ACI 318-95, incorporating seismic design provisions for precast concrete structures. These are going to be removed from ASCE 7-02 in favor of adoption by reference of the ACI 318-02 precast seismic design provisions.

Current plans are for the 2003 NEHRP Provisions to significantly enhance the precast seismic design provisions of the 2000 NEHRP Provisions by including specific requirements for some of the PRESSS non-emulative structural systems. Whether this will be done in time for incorporation into ACI 318-05 is unknown. IBC 2006 will adopt ACI 318-05 by reference, which will include the precast seismic design provisions of ACI 318-02, probably with certain modifications and enhancements.

If seismic design provisions for the PRESSS structural systems are available by then in the 2003 NEHRP Provisions, but not in ACI 318-05, it may be possible to include these in the 2006 IBC via ASCE 7-05, the seismic design provisions of which will be based on the 2003 NEHRP Provisions (see Fig. 6). The second edition of NFPA 5000 will be very similar to the 2006 IBC in this regard (see Fig. 7).

CONCLUDING REMARKS

The manner in which seismic design provisions end up being included in the model codes of the United States is changing. In the near-term future, these provisions will be adopted by reference from the ASCE 7 Standard, thereby making this standard more important than it has been in the past. Seismic design provisions for precast concrete structures in U.S. model codes will be enhanced, and will be largely unaffected by changes in the code development process.

The important point is that codes are in a state of continual transition. Structural engineers must stay vigilant as to future changes. Future articles will endeavor to bring some semblance of order to this state of confusion.

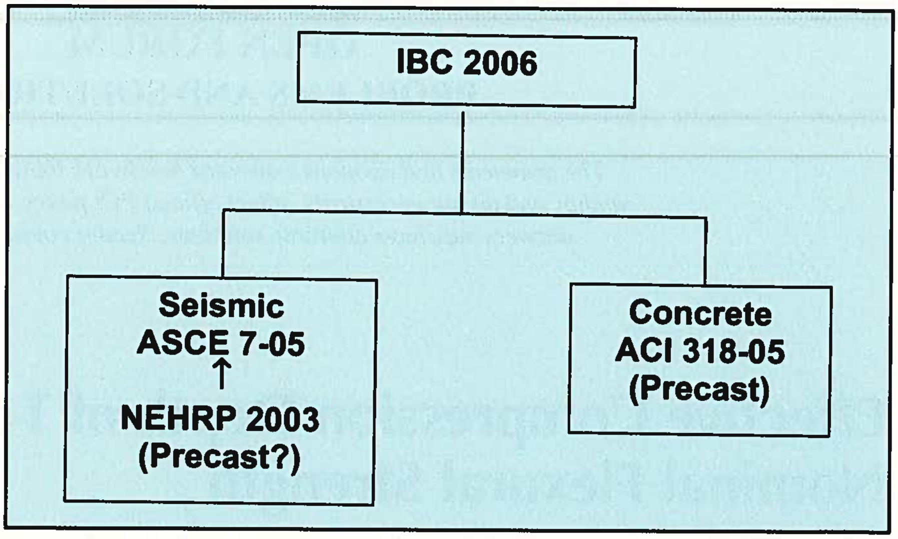

Fig. 6. Seismic design provisions for precast concrete structures in the 2006 IBC.

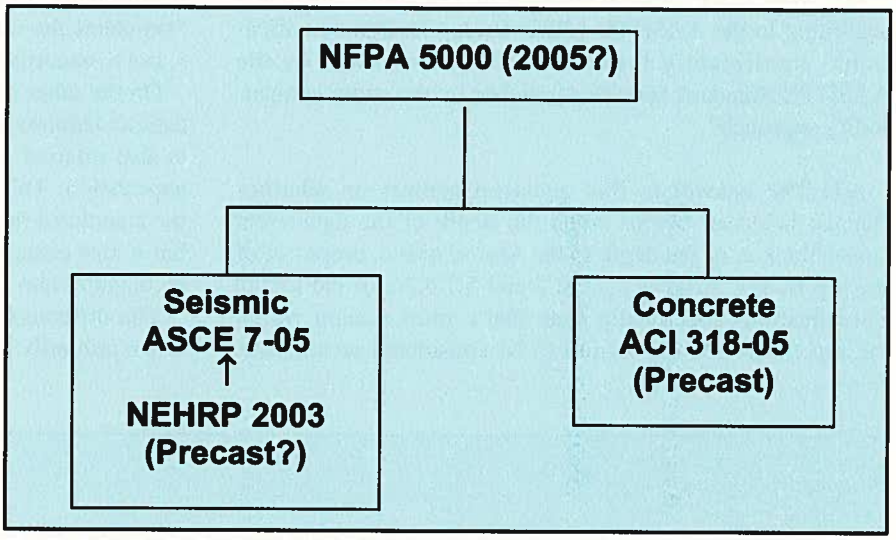

Fig. 7. Seismic design provisions for precast concrete structures in NFPA 5000 (2005).

REFERENCES

1. BOCA, *The BOCA National Building Code*, Building Officials and Code Administrators International, Country Club Hills, IL, 1993, 1996, 1999.
2. SBCCI, *Standard Building Code*, Southern Building Code Congress International, Birmingham, AL, 1994, 1997, 2000.
3. ICBO, *Uniform Building Code*, International Conference of Building Officials,Whittier, CA, 1991, 1994, 1997.
4. ICC, *International Building Code*, International Code Council, Falls Church, VA, 2000.
5. NFPA, *NFPA 5000 Building Code*, National Fire Protection Association, Quincy, MA, to be published in 2002.
6. ASCE, *ASCE Minimum Design Loads for Buildings and Other Structures*, ASCE 7-88, ASCE 7-93, ASCE 7-95, ASCE 7-98 (also ANSI A58-55, ANSI A58.1-72, ANSI A58.1-82), American Society of Civil Engineers, Washington, DC, 1990, 1993, 1995, and 2000, respectively.
7. ACI Committee 318, "Building Code Requirements for Structural Concrete, (ACI 318-99)," American Concrete Institute, Farmington Hills, MI, 1999.
8. Seismology Committee, SEAOC, *Recommended Lateral Force Requirements and Commentary*, Structural Engineers Association of California, San Francisco (later Sacramento), CA, 1988, 1996, 1999.
9. Building Seismic Safety Council, NEHRP, *Recommended Provisions for the Development of Seismic Regulations for New Buildings (and Other Structures)*, National Earthquake Hazards Reduction Program,Washington, DC, 1985, 1988, 1991, 1994 (1997, 2000).
10. ATC, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, ATC Publication ATC 3-06, NBS Special Publication 510, NSF Publication 78-8, Applied Technology Council, U.S. Government Printing Office, Washington, DC, 1978.
11. FEMA, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, FEMA 273, Federal Emergency Management Agency, Washington, DC, October 1997, and *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, FEMA 356, Washington, DC, November 2000.
12. Ellingwood, B., Galambos, T. V., MacGregor, J. G., and Cornell, C. A., *Development of a Probability-Based Load Criterion for American National Standard A58*, NBS SP 577, U.S. Department of Commerce, National Bureau of Standards, Washington, DC, 1980.