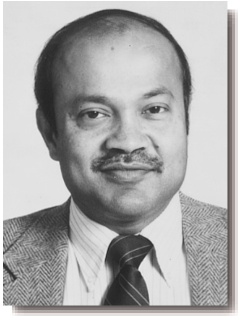
Update on the NEHRP Provisions: The Resource Document for Seismic Design



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This article discusses a number of major changes in the 2003 edition of the NEHRP provisions, which the seismic design provisions of ASCE 7-05 and IBC 2006 will be based on. A brief discussion on the near-term future of the NEHRP Provisions is included.

In 1972, following the San Fernando earthquake of 1971, the National Science Foundation and the National Bureau of Standards (now the National Institute of Standards and Technology) decided to jointly sponsor a Cooperative Program in Building Practices for Disaster Mitigation. Under that program, the Applied Technology Council (ATC) developed a document entitled *Tentative Provisions for the Development of Seismic Regulations for Buildings*.[1]

This document, published in 1978 and commonly referred to as ATC 3-06, underwent a thorough review by the building community in ensuing years. Trial designs were conducted to establish the technical validity of the new provisions and to assess their impact. A new entity, the Building Seismic Safety Council (BSSC), was created under the auspices of the National Institute of Building Sciences (NIBS) to administer and oversee the trial design effort. The trial designs indicated the need for certain modifications to the original ATC 3-06 document. The modifications were made.

The resulting document was the first edition, dated 1985, of the NEHRP (National Earthquake Hazards Reduction Program) *Recommended Provisions for the Development of Seismic Regulations for New Buildings* (starting with the 1997 edition, the title has been "*Recommended Provisions for the Development of Seismic Regulations for New Buildings and Other Structures*").[2]

Under continued federal funding, this document has been updated every three years; the 1988, 1991, 1994, 1997, and 2000 editions of the NEHRP Provisions have been issued by the Building Seismic Safety Council. The 2003 edition of the NEHRP Provisions has been finalized and will be published later this year.

The BOCA/National Building Code (NBC)[3] and the Standard Building Code (SBC),[4] which traditionally adopted the seismic provisions of the ANSI A58.1 (now ASCE 7) Standard,[5] adopted seismic design provisions based on the 1991 NEHRP Provisions in 1993 and 1994, respectively. This is because the 1988 edition of the ASCE/ANSI Standard, published in 1990, still had seismic design provisions based on the 1979 Uniform Building Code (UBC).[6] This code adoption gave the NEHRP Provisions a degree of importance it had not enjoyed until then.

ASCE 7 itself adopted seismic design provisions based on the 1991 NEHRP Provisions in its 1993 edition. Indeed, the sole reason for the publication of a 1993 edition of the ASCE 7 standard was the update of the seismic design provisions. The seismic design provisions of the 1995, 1998 and 2002 editions of ASCE 7 were updated to be based on the 1994, 1997 and 2000 editions of the NEHRP Provisions, respectively. The seismic design provisions of ASCE 7-05 will be based on the 2003 edition of the NEHRP Provisions.

Requirements based on the 1991 NEHRP Provisions were retained in the 1996 edition of the BOCA/NBC and the 1997 edition of the SBC. The 1994 NEHRP Provisions did not become the basis of the seismic design provisions of the 1996 BOCA/NBC or the 1997 SBC. However, both the 1996 edition of the BOCA/NBC and the 1997 edition of the SBC permitted seismic design by ASCE 7-95 (based on the 1994 NEHRP Provisions). The seismic design provisions of the 1999 edition of the BOCA/NBC remained the same as those of the 1996 edition. Similarly, the seismic design provisions of the 1999 edition of the SBC remained the same as those of the 1997 edition.

The seismic design provisions of the International Building Code (IBC)[7] were treated separately from the rest of the structural provisions in the code development process. In 1996, the IBC Code Development Committee agreed in concept for the IBC to be based on the 1997 edition of the NEHRP Provisions. A code Resource Development Committee (CRDC), funded by the Federal Emergency Management Agency (FEMA), was formed under the direction of the Building Seismic Safety Council (BSSC) to generate seismic code provisions based on the 1997 edition of the NEHRP Provisions, for incorporation into the 2000 IBC. The effort was successful and the CRDC submittal was accepted by the IBC Code Development Committee for inclusion in the IBC. The seismic design provisions of the first (2000) edition of the IBC were based on the 1997 NEHRP Provisions, with some of the features of the 1997 UBC also included.

The 2003 IBC permits seismic design to be done entirely by ASCE 7-02. The seismic design provisions of the code itself (Sections 1613 through 1623) make extensive references to ASCE 7-02. As has been noted above, the seismic design provisions of ASCE 7-02 are based on the 2000 NEHRP Provisions. The 2003 edition of the NFPA 5000 Building Construction and Safety Code[8] has adopted ASCE 7-02 by reference for structural design, including seismic design.

2006 IBC, as well as the 2006 edition of NFPA 5000, will adopt ASCE 7-05 for seismic design. The latter document, in its turn, will be based on the 2003 NEHRP Provisions. Thus, changes from the 2000 to the 2003 editions of the NEHRP Provisions will be reflected in changes in seismic design provisions from ASCE 7-02 to ASCE 7-05 and from IBC 2003 or NFPA 5000-2003 to IBC 2006 or NFPA 5000-2006.

This article is devoted to a discussion of the changes that are judged to be the most significant.

ORGANIZATION

The 2003 NEHRP Provisions and Commentary were developed in two parts. First, the 2000 edition was thoroughly edited and reformatted to increase the usability of the documents and eliminate inconsistencies that had crept in over the years. The reformatted version was approved by the member organizations of the Building Seismic Safety Council, although never formally published, and was used as the base document for the remainder of the update process.

A marked-up version of the Table of Contents of the 2000 NEHRP Provisions has been provided at the end of Appendix A to the 2003 NEHRP Provisions. Without this table, it would be virtually impossible to compare the 2003 edition of the NEHRP Provisions with the 2000 edition.

The 2003 Provisions Update Committee also worked closely with those developing the seismic requirements of ASCE 7. The goal was to begin to reduce the redundancy between the NEHRP Provisions and ASCE 7.

GROUND MOTION

The spectral acceleration maps distributed in a separate package with past editions of the NEHRP Provisions now are reduced in number and size and will appear in the 2003 NEHRP Provisions volume. The maps are based on the latest version of the U.S. Geological Survey's hazard maps.

The design spectrum, which gives the seismic design force or base shear (proportional to spectral response acceleration, S_a) as a function of the elastic fundamental period, T, has so far consisted of two branches in the NEHRP Provisions and in all U.S. Codes and Standards (see Fig. 1).

First is the "flat-top" or constant acceleration part of the spectrum, ranging up to the transition period, T_s, which governs the seismic response and design of short, stiff structures having short periods of vibration.

Second is the "descending branch" or constant-velocity part of the spectrum, which governs the seismic response and design of taller, more flexible structures having periods longer than T_s.

The "ramp" building up to the flat top is a detail that need not be discussed here.

In the 2003 NEHRP Provisions, the descending branch terminates at the new long-period transition period, T_L, where a new third branch to the design spectrum, proportional to $1/T^2$ starts. This is the constant-displacement part of the design spectrum that will govern the seismic response of structures with periods in the range beyond T_L. The period T_L is given on new contour maps for all fifty states. A designer must locate the appropriate site on this contour map to determine T_L, which ranges between 4 and 16 seconds, depending upon the location.

While the above is an interesting and an important change, it would affect the design of buildings in the 40-story height range and beyond. Thus, it is not of a high degree of interest to those involved in precast concrete construction.

STRUCTURAL DESIGN CRITERIA

Redundancy

The concept of a penalty factor for a lack of redundancy of load paths to transmit seismic forces from the floor

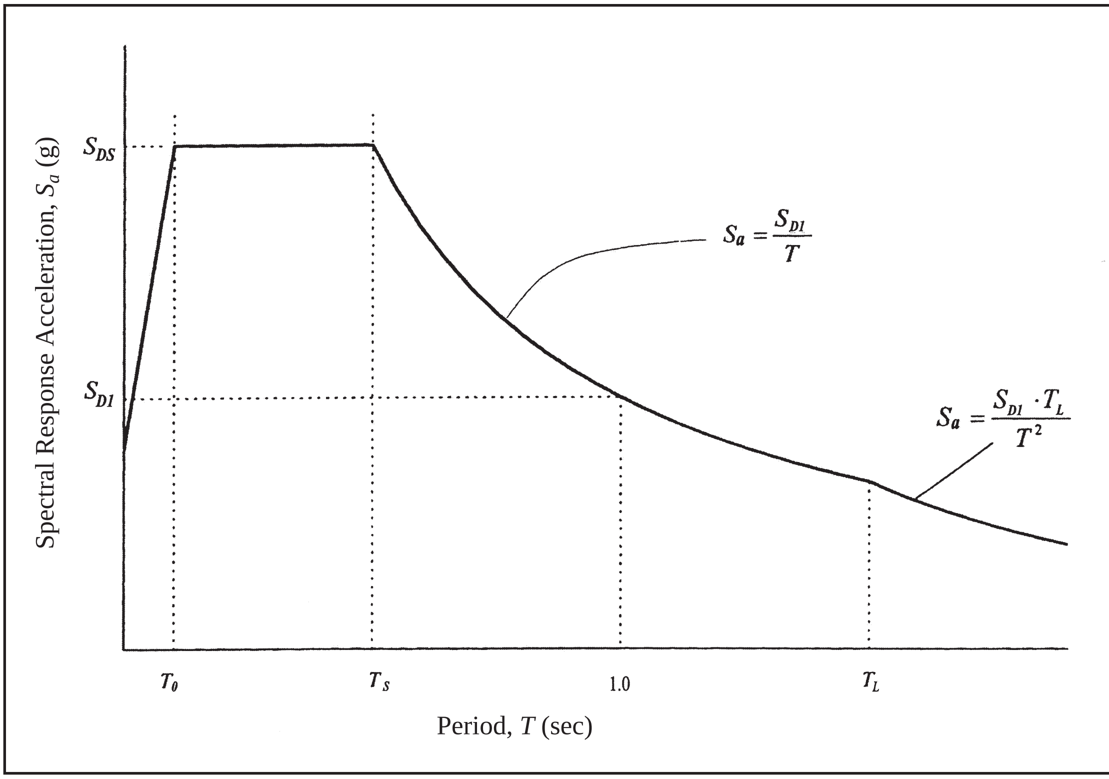

Fig. 1. The spectral response acceleration, S_a, as a function of the elastic fundamental period, T.

and roof diaphragms where they originate down to the ground underlying the foundation originated with the Seismology Committee of the Structural Engineers Association of California (SEAOC). While SEAOC Seismology Committee was working on their formulation of a redundancy factor for inclusion in the 1997 UBC, a separate project was underway, involving other structural engineers.

This project, Applied Technology Council's ATC 19, *Structural Response Modification Factors*, recognized redundancy as one of the three elements of the response modification factor, *R*, and assigned a penalty of about 40 percent for non-redundant structures. Their measure of redundancy was simply the "number of lines" of lateral force resistance of the structure.

The SEAOC Seismology Committee chose not to use the number of lines of resistance as the measure of redundancy. Instead, they formulated a penalty factor ρ for non-redundancy in terms of (1) the number of lateral-force-resisting elements, (2) the distribution of lateral forces to the lateral-force-resisting elements, and (3) the plan area of the building. The redundancy factor had an upper-bound value of 1.5 and a lower-bound value of 1.0. The formulation was adopted into the 1997 UBC and with just three modifications into the 1997 NEHRP Provisions and the 2000 IBC. The 2000 NEHRP Provisions made a number of further modifications, which are reflected in the 2003 IBC.

The SEAOC formula works reasonably well for many structures, but there are situations where it has been shown to lead the designer in the wrong direction. Also, because it is a strictly arbitrary function, it is difficult to extrapolate it to conditions that were not considered by the original developers.

For the 2003 NEHRP cycle, BSSC Technical Subcommittee (TS) 2 on Design took it upon themselves to revisit the effect of redundancy in buildings. If the lack of redundancy is "... when the failure of a component is equivalent to the failure of the entire system," as stated by Bertero,[10] the most logical way to determine such lack of redundancy would be to check whether a component's failure results in an unacceptable amount of story strength loss or in the development of extreme torsional irregularity. This is the basic premise of the new redundancy provisions of the 2003 NEHRP Provisions.

In the 2003 NEHRP Provisions, ρ is equal to either 1.0 or 1.3, depending on whether or not an individual element can be removed (deemed to have failed or lost its moment-resisting capabilities) from the lateral-force-resisting system without causing the remaining structure to suffer a reduction in story strength of more than 33 percent or creating an extreme torsional irregularity (plan irregularity Type 1b).

Braced frame, moment frame and shear wall systems have to conform to redundancy requirements. Dual systems are also included, but in most cases are inherently redundant. Shear walls with a height-to-length ratio greater than 1.0 have been included, even though the issue of redundancy has essentially been solved by requiring collector elements and their connections to be designed for overstrength factor Ω_0 times the design force. This usually results in having to use a reasonable number of shear walls in concrete structures to reduce the force in collector elements to a manageable number. Regardless, shear wall systems were added to the requirements to help ensure that an adequate number of wall elements are included or that the proper redundancy factor is applied.

Design Base Shear

A base shear equation for long-period structures ($T > T_L$) has been added in the equivalent lateral force procedure to be consistent with the new design spectrum discussed above. Base shear by the new equation is inversely proportional to the square of the fundamental period, which is consistent with the constant-displacement part of the design spectrum.

Nonlinear Static Analysis Procedure

The Nonlinear Static Analysis procedure of the Appendix to Chapter 5 of the 2000 NEHRP Provisions required detailed comparisons of member deformation demands and capacities, required peer review, and did not impose restrictions such as a minimum required lateral strength or a maximum system ductility limit. The most significant modification in the 2003 NEHRP Provisions is to allow detailed evaluations of member deformation demands to be omitted provided that the effective yield strength equals or exceeds the Equivalent Lateral Force design base shear multiplied by Ω_0. For this case, peer review is limited to the determination of the effective yield strength and target displacement, along with the development of site-specific spectra where applicable.

For lesser values of resistance, the current requirements for deformation capacity checks and peer review are maintained, and these are supplemented with a check on strength demands, which is needed for force-controlled behavior.

Simplified Design

In a significant development, a simplified design procedure has been developed and added as Alternate Chapter 4. The procedure applies to structures in Seismic Design Categories B, C, D and E, but is not permitted for structures, the design of which is typically drift-controlled. It was felt that the approach should be limited to certain structural systems, so as to avoid problems that may arise from omitting the drift check for drift-controlled systems (steel moment frames for example).

The simplified procedure is allowed for Bearing Wall and Building Frame Systems, provided that several prescriptive requirements are followed, which result in a torsion-resistant regular layout of lateral-force-resisting elements. The following features of the new simplified design procedure are notable:

1. Given the prescriptive restrictions on system configuration, the definitions, tables, and design provisions for structural irregularities become unnecessary.
2. The list of Basic Seismic Force Resisting Systems has been shortened to include only the permitted systems; deflection amplification factors are not used and have been eliminated from the table of design coefficients.
3. Design and detailing requirements have been consolidated into a single set of provisions that do not vary with the Seismic Design Category, largely because whole sections have been rendered unnecessary with the prohibition of system irregularities.
4. The redundancy factor, ρ, is not used.
5. The procedure is not applicable to structures founded on Site Classes E or F. The short-period site coefficient, F_a, may be taken as 1.0 for rock sites and 1.4 for soil sites. For the purposes of the simplified procedure, sites may be considered to be rock if there is no more than 10 ft (3 m) of soil between the rock surface and the bottom of spread footing or mat foundation. In calculating S_{DS}, the value of S_s need not be taken larger than 1.5.
6. Vertical distribution of base shear is based on tributary weight. The special formula for calculation of diaphragm forces is removed, and the calculation of diaphragm forces is greatly simplified. The base shear corresponds to the short-period plateau and does not require calculation of the period. This value is increased by a penalty factor, which varies with the number of stories in a building, to compensate for simplification in the vertical distribution of base shear and other simplifications.
7. Simple rigidity analysis is required for rigid diaphragm systems, but analysis of accidental torsion and dynamic amplification of torsion is not required. Untopped metal deck, wood panel, or plywood-sheathed diaphragms may be considered flexible, providing another simplification in calculations.
8. Calculations for drift or P-Δ (load-deformation) effects need not be performed. A 1 percent drift may be assumed when needed by requirements not covered in the simplified provisions (such as deformation compatibility).

Seismic Design Category

An important change in the procedure for Seismic Design Category determination, which is already a part of the 2003 IBC, and which was the subject of a PCI JOURNAL paper,[11] has now been included in the 2003 NEHRP Provisions in a modified form. The Seismic Design Category is permitted to be determined on the basis of short-period ground motion (S_{DS}) alone when all of the following apply:

1. The approximate fundamental period of the structure, T_a, in each of two orthogonal directions, is less than $0.8T_S$, where T_S is the period at which the “flat-top” part of the design spectrum transitions into the descending branch.
2. The fundamental period of the structure, T, in each of two orthogonal directions used to calculate the story drift is less than or equal to T_s, and
3. The upper-bound design base shear, corresponding to the short-period plateau, is used in the design of the structure.

It should be noted that Condition 2 above is not included in the 2003 IBC. On the other hand, the 2003 IBC requires that for SDC determination to be based on S_{DS} alone, the diaphragms of a structure must not be flexible.

R-Values

Relatively minor modifications were

made to certain R-values in the table of design coefficients, to provide more consistency with respect to nonductile systems and dual systems.

FOUNDATION DESIGN REQUIREMENTS

In a development of major significance, strength design for the sizing of foundations has been introduced for the first time as an alternative to allowable stress design. The provisions and commentary appear in an Appendix to Chapter 7, to provide for trial use and evaluation prior to expected incorporation in the main body of the NEHRP Provisions.

Also, newly introduced are provisions and commentary concerning modeling of the load-deformation characteristics of the foundation-soil system using soil springs. Linear springs are addressed in the main body, while nonlinear springs are treated in an Appendix.

Additional provisions and commentary have been provided concerning: (1) minimum longitudinal reinforcement requirements for uncased concrete piles, (2) piles in a group containing both batter and vertical piles, (3) steel H-piles.

The provisions mandating assessments of seismically induced geohazards in Seismic Design Categories C, D, E, and F have been modified to waive these requirements when the building official determines that sufficient information is available from nearby sites to evaluate the hazard for the proposed construction. The commentary describing methods for geohazards assessment has been updated, and guidance added on hazard screening and determination of earthquake magnitude.

STEEL STRUCTURE DESIGN REQUIREMENTS

Space would normally not have been devoted to changes in the steel chapter. However, there are significant changes in the steel chapter of the NEHRP provisions, which should be of interest to the readers of the PCI JOURNAL.

Changes to the steel chapter of the 2003 NEHRP Provisions include reference to the 2002 edition of the AISC Seismic Provisions and other updated standards. The 2002 AISC Seismic Provisions[12] incorporate recommendations from multi-million dollar federally funded FEMA (Federal Emergency Management Agency) – SAC (a consortium of SEAOC, Structural Engineers Association of California; ATC, Applied Technology Council; and CUREE, California Universities for Research in Earthquake Engineering) research, that was carried out following problems with special steel moment frame joints in the Northridge earthquake of 1994.

New provisions and commentary have been added to address bucking restrained braced frames (BRBF). This system, initially developed in Japan and now gaining widespread use in areas of high seismicity in the United States, provides for highly ductile bracing elements in concentrically braced frames.

Also introduced in the 2003 NEHRP Provisions are new provisions and commentary to address special steel plate shear walls. This system, which has been included in the National Building Code of Canada for a number of years based on research conducted both in the United States and Canada, is gaining some limited use in areas of high seismicity in the United States. The system provides for ductile thin steel plate wall elements.

CONCRETE STRUCTURE DESIGN REQUIREMENTS

Adoption of ACI 318-02

ACI 318-02 has been adopted into the 2003 NEHRP Provisions, while ACI 318-99 was the reference standard in the 2000 NEHRP Provisions. This update has permitted the elimination of many of the definitions and notations that were included in the 2000 NEHRP Provisions as well as the deletion of provisions related to precast gravity systems (structural members not part of the lateral-force-resisting system), emulative design of seismic-force-resisting precast frame and wall systems, non-emulative design of special moment frames constructed using precast concrete, precast concrete connections, anchor bolts embedded at the top of columns, and most of the provisions related to anchoring to concrete. All these items are now addressed in ACI 318-02.

Precast Wall Systems

ACI 318-02 recognizes three categories of structural walls (referred to as shear walls in all codes and standards other than ACI 318). There are: (1) ordinary structural walls, which can be cast-in-place or precast, (2) intermediate structural walls, which can only be precast, and (3) special structural walls, which can be cast-in-place or precast.

While codes and standards have had design coefficients (R, Ω_0, and C_d values) for Bearing Wall Systems and Building Frame Systems consisting of ordinary and special shear walls, there have been no design coefficients for such systems with intermediate shear walls, because such walls did not exist until ACI 318 introduced them in the 2002 edition. Design coefficients did not exist in any model code including the 2000 IBC, in ASCE 7 through its 1998 edition, and in the NEHRP Provisions through its 2000 edition.

IBC 2003 was the first model code to assign R-values to precast wall systems, including systems with intermediate walls. In the 2003 IBC, design coefficients for Bearing Wall Systems and Building Frame Systems depend only on whether ordinary or special walls are used. It does not matter whether the ordinary or the special walls are cast in place or precast. Intermediate precast walls are grouped together with ordinary walls, with the additional requirement that if structural systems including such walls are to be used in Seismic Design Category C, the walls must conform to the requirements of ACI 318 Section 21.13.

The 2003 NEHRP Provisions has created additional rows in the table of design coefficients under Bearing Wall Systems and Building Frame Systems for ordinary precast shear walls and intermediate precast shear walls. Only in the case of special walls are cast-in-place and precast walls grouped together (have the same design coefficients assigned to them). Systems with intermediate precast walls have been assigned the same design coefficients as the same systems with ordinary reinforced walls; systems with ordinary precast walls have been assigned inferior design coefficients.

In another interesting twist of events, intermediate precast walls are permitted to be used as part of seismic-force-resisting systems in SDC D, E, and F, provided the building height does not exceed 40 ft (12.2 m). This is an indirect way of permitting lateral-force resisting tilt-up walls in SDC D, E, and F, which typically would not conform to the special detailing requirements of ACI 318 Section 21.8.

Provisions have been introduced for wall piers (which is a defined term in the NEHRP Provisions) and segments of intermediate precast structural walls that parallel those of the 2000 NEHRP Provisions for wall piers and segments of special structural walls. Wall piers in both special and intermediate walls are required to be designed as columns if their horizontal length to the other plan dimension ratio is less than 2.5.

Non-Emulative Design of Special Precast Structural Walls

In a development of much significance to the precast concrete industry, the 2003 NEHRP Provisions is the first code-like document to include provisions for the non-emulative design of special precast structural or shear wall systems. The provisions are based on acceptance criteria and the validation testing of special precast structural walls that parallel those of ACI T1.1, *Acceptance Criteria for Moment Frames Based on Structural Testing*.[13] While the latter document is applicable to both monolithic and precast frame construction, the new provisions are restricted to precast wall construction only.

The acceptance criteria for special precast structural walls based on structural testing, which are incorporated in the 2003 NEHRP Provisions, represent the modified version of a draft acceptance criteria document developed by Neil Hawkins and S. K. Ghosh[14] which was revised in response to comments from four sources in the following order:

(1) A PCI Fast Team that met at PCI Headquarters to discuss the draft criteria on January 31, 2003.

(2) BSSC Technical Subcommittee 4 on Concrete.

(3) The Provisions Update Committee of BSSC.

(4) BSSC member organizations, approval by whom is the last step in the finalization of a new edition of the NEHRP Provisions.

The final BSSC/NEHRP version of the acceptance criteria document is now being processed through Innovative Task Group (ITG) 5 of the American Concrete Institute. Further modifications have already been made to the final BSSC version as a result of ITG 5 deliberations. Additional modifications are fully expected. Once the ITG 5 document is approved as an ACI Provisional Standard, it will hopefully be referenced in ACI 318, which will then permit the non-emulative design of special precast concrete shear walls.

NON-BUILDING STRUCTURE DESIGN REQUIREMENTS

A new definition for non-building structures similar to buildings has been included in the 2003 NEHRP Provisions and the design coefficients table has been split into two tables – one for structures similar to buildings, and the other for structures not similar to buildings. Also, references to the applicable design and detailing requirements in the other chapters and in Chapter 14 on non-building structures have been added to the two tables.

The design coefficients table for non-building structures of the 2000 NEHRP Provisions prescribed design coefficients for non-building structures similar to buildings that were the same as those for corresponding structural systems in the design coefficients table for building structures, except that less restrictive height limitations were prescribed in the case of non-building structures. This inconsistency has been corrected in the 2003 NEHRP Provisions. In addition, some structural systems may be used in non-building structures similar to buildings with less restrictive height limitations if lower *R*-values are used. This last item represents an interesting and a potentially significant development.

NEAR-TERM FUTURE OF THE NEHRP PROVISIONS

For the first time since the issuance of the first edition of the NEHRP Provisions in 1985, far-reaching changes are in the offing.

First, it has been announced that the NEHRP Provisions following the 2003 edition will be dated 2008, breaking the three-year cycle that has been followed since the beginning of the document.

Second, the 2003 NEHRP Provisions will be the last edition to contain complete seismic design provisions. A version of the 2003 NEHRP Provisions will be prepared, removing much of the text, and referring instead to relevant sections and subsections of ASCE 7-05, which is close to being finalized. This version will be submitted to BSSC member organizations for their approval. The approved version will serve as the base document for the 2008 revisions.

The BSSC committee structure that has been in existence in essentially the same form for almost two decades will change. There will continue to be a Provision Update Committee – probably with fewer members. Two or more existing technical subcommittees will be combined in a number of cases. The number of standing technical subcommittees will decrease as a result of this consolidation – but there will continue to be a technical subcommittee on each of the four primary materials of construction: concrete, masonry, steel, and wood.

The number of members whose meeting expenses are paid for by the BSSC will decrease rather drastically on each technical subcommittee. In addition to the standing technical subcommittees, there will be a number of ad hoc subcommittees to work on specific cutting edge issues. A number of such issues will be identified at the beginning of each NEHRP cycle. Development of provisions on such unsettled or emerging issues will restore the

NEHRP Provisions to its original role of a resource document.

CONCLUDING REMARKS

This article discusses changes from the 2000 to the 2003 edition of the NEHRP Provisions, which will be reflected in changes to the seismic design provisions of (1) ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures*, (2) the 2006 edition of the International Building Code, and (3) the 2006 edition of the NFPA 5000 Building Construction and Safety Code.

The near-term future of the NEHRP Provisions is also discussed.

The 2003 edition of the NEHRP Provisions has not been published yet, but should be available in the late summer or early fall of 2004.

ACKNOWLEDGMENT

The author has made extensive use of Appendix A to the 2003 NEHRP Provisions (differences between the 2000 and the 2003 Editions of the NEHRP Recommended Provisions) and of the reasons for change prepared by the various BSSC technical subcommittees, sometimes reproducing text without paraphrasing. These sources are gratefully acknowledged.

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