13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 512

PROBLEMS ASSOCIATED WITH CURRENT OVERLY PRESCRIPTIVE SEISMIC CODES

Roberto VILLAVERDE[1] and Manuel PORTILLO[2]

SUMMARY

It is postulated that current seismic codes are overly prescriptive and that this over-prescription is prone to hinder the safety of structures instead of increasing it, as it is the original intention. Consequences of this over-prescription are (a) the production of complex and obscure documents that are difficult to interpret and to follow; (b) many empirical or oversimplified procedures; (c) an obstruction to the application of advanced concepts and innovative techniques; (d) an increase in the number of undereducated engineers that design complex structures without an adequate understanding of structural behavior; and (e) more importantly, a decline in the importance of the structural engineering profession and the associated fee structure. It is argued that codes should not prescribe the procedures by which to perform a structural design and should be limited to general safety and performance requirements. Furthermore, it is contended that how these safety and performance requirements are fulfilled should be left to the knowledge and experience of the designer, who in many cases is in better position to make decisions in accordance to the particular characteristics of the design project at hand. Examples are provided of current seismic code provisions that are considered to be too prescriptive, unnecessary, and may not necessarily increase the safety of structures. Finally, recommendations are given as to what should be the trend of future seismic codes in order to avoid the unintended consequences of current codes.

INTRODUCTION

The basic purpose of a seismic code is to regulate the design and construction of structural systems through the specification of minimum standards to safeguard public welfare during a major earthquake. Another purpose is to synthesize and disseminate past experience and current knowledge about structural performance and design issues. Codes also help remind the designer of some important aspects of the design process that he or she might otherwise overlook. As such, seismic codes are an essential tool for the seismic design of structures. As the codes have evolved, however, they have become increasingly difficult to understand and use. In fact, there seems to be a general agreement among structural engineers that current building codes are just too complex (see, for example, Tawresey [1]). Moreover, it is contended that the complexity of building codes is due to the fact that they are unnecessarily over-prescriptive and that this over-prescription is prone to hinder the safety of structures instead of increasing it, as it is the original

[1] Civil Eng. Dept., University of California, Irvine, California, U.S.A. Email: rvl@eng.uci.edu
[2] Portillo and Young, Consulting Engineers, Chihuahua, Chih., Mexico. Email: mportillo@pyysc.com

intention. More importantly, it is argued that over-prescriptive building codes have contributed to the decline in the importance of the structural engineering profession and the associated fee structure.

This paper presents a critical evaluation of current seismic codes that gives support to the points just made. This evaluation includes an overview of the provisions contained in earlier and current seismic codes, contrasting the simplicity of the earlier codes against the complexity of the current ones. It also identifies and discusses what is believed to be some of the consequences of over-prescriptive codes, providing examples of current seismic code provisions that are considered to be too prescriptive, unnecessary, and may not necessarily increase the safety of structures. Finally, recommendations are given in regard to what should be the trend of future seismic codes in order to avoid the unintended consequences of the format adopted by current codes.

The paper has been written in response to the shared frustration felt by the authors, an academician and a practitioner, in dealing with modern building codes. The frustration of the first author arose from the deciphering he had to endure during the writing of a book chapter describing the seismic provisions in modern building codes. The frustration of the second author evolved from the loss of many clients because of the extremely low fees that engineers, many times under-educated and under-trained, charge for structural designs performed, not by them, but by computer programs. The paper is thus written from the perspective of the academic and the designer's worlds.

EARLIER SEISMIC CODES

The Uniform Building Code, for many years used as a "model code" in the United States, was first published by the International Conference of Building Officials in 1927 and revised at approximate three-years intervals afterward. The first seismic provisions in this model code appeared in its 1930 edition. These seismic provisions basically stipulated the consideration of lateral forces at each building level equal to a fraction of the building's total dead load and part of the design live load. The first set of rational seismic design requirements were based on the 1959 report *Recommended Lateral Force Requirements* prepared by the Seismological Committee of the Structural Engineers Association of California [2]. This document was 7-pages long in a 6"x 9" format. It included five definitions and provisions for (1) calculation of base shear, (2) vertical distribution of base shear, (3) distribution of horizontal shear, (4) lateral forces on parts of buildings, (5) torsion, (6) overturning, (7) setbacks, (8) drifts, (9) foundations, and (10) miscellaneous design requirements, such as building separations. In particular, the base shear was determined in accordance with the following formula:

$$V = KCW \tag{1}$$

where

K = horizontal force factor, ranging from 1.0 to 1.5 for the State of California, selected from a given table according to building type,

W = total dead load,

C = seismic coefficient, given by

$$C = \frac{0.05}{\sqrt[3]{T}} \tag{2}$$

in which

T = fundamental period of vibration of the structure in the direction considered determined either by properly substantiated analysis or some stipulated empirical formulas.

The formula for the distribution of the base shear over the height of the building was

$$F_x = \frac{w_x h_x}{\sum wh} V \tag{3}$$

where

w_x = the portion of W located at the level designated as x,

h_x = height above the base to the level designated as x.

The provision to account for torsional moments was stated as follows:

> *Provisions shall be made for the increase in shear resulting from the horizontal torsion due to an eccentricity between the center of mass and the center of rigidity. Negative torsion shall be neglected. In addition, where the vertical resisting elements depend on diaphragm action for shear distribution at any level, the shear resisting elements shall be capable of resisting a torsional moment assumed to be equivalent to the story shear acting with an eccentricity of no less than five per cent of the maximum building dimension at that level.*

Similarly, the provision regarding story drifts was stipulated as follows:

> *Lateral deflections or drift of a story relative to its adjacent stories shall be considered in accordance with accepted engineering practice.*

It may be seen, thus, that the earlier seismic provisions were very simple and easy to understand by most structural engineers. In particular, it may be noted that by specifying the effect of eccentricities in a single paragraph, the code did not pretend to neglect the effect of torsional moments. Instead, it assumed engineers knew how to compute the associated torsional moments. The same can be said about the consideration of story drift limits. The code reminded the designer that it was important to consider story drift limits, but it left to the experience of the designer the selection of such limits.

MODERN SEISMIC CODES

Representative of modern seismic provisions are those contained in the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* [3], issued by the Building Seismic Safety Council under the sponsorship of the Federal Emergency Management Agency (FEMA); the International Building Code [4], issued by the International Building Council; and ASCE Standard 7-02 (*Minimum Design Loads for Buildings and Other Structures*) [5], published by the American Society of Civil Engineers. The International Building Code, first published in 2000, is the successor of the Uniform Building Code and other U.S. codes. The latest edition of the International Building Code (2003 edition) makes extensive references to ASCE Standard 7-02, which in turn is based on the 2000 edition of the NEHRP provisions. For simplicity, reference will be made here to the seismic provisions in ASCE Standard 7-02, which may be considered typical of what is contained in current codes. Henceforth, these provisions will be referred to simply as “the code.”

The Earthquake Loads section of ASCE Standard 7-02 is 111-pages long in an 8 ½” x 11” format. It includes 126 definitions and provisions to: (1) select a design response spectrum; (2) classify the site soil; (3) classify the seismic-force resisting system; (4) classify the structural configuration; (5) select the seismic design category; (6) select the allowable analysis procedure; (7) specify design and detailing requirements; (8) combine load effects; (9) specify story drift limits and building separations; (10) determine the seismic base shear; (11) determine the structural natural period; (12) distribute vertically the base shear; (13) account for torsional effects and distribute horizontally the seismic forces; (14) determine the overturning moments; (15) determine the story drifts; (16) account for P-delta effects; (17) specify the way to perform a modal analysis; (18) specify the way to perform a linear response-history analysis; (19) specify the way to perform a nonlinear response-history analysis; and (20) account for soil-structure interaction effects. Provisions are also furnished for the seismic design of nonstructural components, foundations, and base-isolated structures. In particular, it is noted that the seismic hazard in the United States is defined by means of 18 pages of seismicity maps. This is in contrast to the seismicity map used in the 1997 edition of the Uniform Building Code whose size was half a page. It is also noted that the seismic hazard is now defined in terms of maps that contain contour lines of equal spectral acceleration as opposed to a seismic zone map.

Clearly, modern seismic codes have gone overboard. They are too long and overly prescriptive. Unnecessarily, they prescribe in too much detail how to carry out a seismic analysis and how to account for special effects such as P-delta, torsional, and soil-structure interaction effects. They also specify items that are well known to any competent structural engineer. Consider, for example, the following specification:

> *The structure shall include complete lateral and vertical force-resisting systems capable of providing adequate strength, stiffness, and energy dissipation capacity to withstand the design ground motions within the prescribed limits of deformation and strength demand. The design ground motions shall be assumed to occur along any horizontal direction of a structure. The adequacy of the structural system shall be demonstrated through the construction of a mathematical model and evaluation of this model for the effects of design ground motions.*

Obviously, this is a superfluous specification since well-educated and experienced structural engineers are fully aware of what constitutes and how to carry out a good seismic design. A similar problem is the provided hazard contour maps. These maps are so refined that in some areas the design spectral accelerations may be substantially different at two locations that are only a few kilometers apart. It is understood that the intention in the development of these maps was to account for near-field effects, but such a refinement implies that all future earthquakes will occur at previously know faults. One wonders, therefore, if the code seismicity maps are giving owners and designers a false sense of safety.

CONSEQUENCES OF OVER-PRESCRIPTIVE CODES

As it may be seen from the brief reviews presented in the foregoing sections, seismic codes have evolved from documents that basically specify design loads to documents that prescribe in detail not only the design loads but also the structural systems and the procedures that in the judgment of code writers lead to satisfactory seismic designs. Inevitably, the question arises as to whether or not such a prescriptive approach indeed safeguards the public safety, or hinders instead this safety. The main argument often given in support of prescriptive provisions is that they are easy to enforce since plan checkers know exactly what to look for. Another argument is that by requiring designers follow proven procedures safety is guaranteed. It is contended, however, that over-prescriptive codes are prone to hinder instead the safety of structures by (a) producing complex and obscure documents that are difficult to interpret and follow; (b) incorporating many empirical or oversimplified procedures; (c) obstructing the application of advanced concepts and innovative techniques; (d) facilitating the practice of engineers who lack an adequate understanding of structural behavior; and (e) fostering low professional fees and consequently rushed designs. Furthermore, the authors believe that another consequence of overly prescriptive codes is a decline in the importance of the structural engineering profession. In what follows, examples will be given and arguments will be presented in support of these assertions.

Obscure Documents

As pointed out, one of the consequences of over-prescriptive codes is complex and obscure documents that are difficult to interpret and follow. Consider, for example, the code provisions to account for soil-structure interaction effects. The code allows a reduction in the base shear used for the design of a building in accordance with the following provision:

*A soil-structure interaction reduction (*in base shear*) shall not be used unless Section 9.5.9 or another generally accepted procedure approved by the authority having jurisdiction is used.*

According to the provisions in Section 9.5.9, one can then reduce the design base shear using the formula

$$\overline{V} = V - \Delta V \tag{4}$$

where

$$\Delta V = \left[C_s - \tilde{C}_s \left(\frac{0.05}{\tilde{\beta}} \right)^{0.4} \right] \overline{W} \le 0.3V \tag{5}$$

in which

C_s = seismic response coefficient computed considering the fundamental natural period T of the fixed-base structure,

$\tilde{C}_s$ = seismic response coefficient computed considering the fundamental natural period $\tilde{T}$ of the structure supported on flexible soil,

$\tilde{\beta}$ = effective damping ratio of the structure of the structure supported on flexible soil,

$\overline{W}$ = effective gravity load of the structure, taken as $0.7W$ for multi-level buildings and equal to W for single-level buildings,

V = base shear for fixed-base structure,

W = total gravity load.

For the computation of the effective building period, the code specifies the formula

$$\tilde{T} = T \sqrt{1 + \frac{\overline{k}}{K_y} \left(1 + \frac{K_y \overline{h}^2}{K_\theta} \right)} \tag{6}$$

where

T = fundamental natural period of the fixed-base structure,

$\overline{k} = 4\pi^2 \left(\dfrac{\overline{W}}{gT^2} \right)$

$\overline{h}$ = effective structure height, taken as $0.7h_n$ for multi-level buildings and as h_n for single-level buildings, h_n being the building height,

K_y = lateral stiffness of foundation soil defined as the horizontal force at the level of the foundation necessary to produce a unit displacement at that level, applying the force and measuring the displacement in the direction of analysis,

K_θ = rocking stiffness of foundation soil defined as the moment necessary to produce a unit average rotation of the foundation, applying the moment and measuring the rotation in the direction of analysis,

g = acceleration due to gravity.

Table 1. Values of G/G_0 and v_s/v_{s0} as a function of spectral acceleration level

Spectral acceleration, S_{D1}	G/G_0	v_s/v_{s0}
≤ 0.10	0.81	0.90
0.15	0.64	0.80
0.20	0.49	0.70
≥0.30	0.42	0.65

In the application of Equation 6, the code requires that the soil stiffnesses K_y and K_θ be computed using established principles of foundation mechanics and soil properties that are compatible with the soil strain associated with the design ground motion. To this end, it specifies that the average shear modulus at large strains, G, and the associated shear wave velocity, v_s, for the soils beneath the foundation be determined using the G/G_0 and v_s/v_{s0} ratios given in Table 1, where

v_{s0} = average shear wave velocity for soils beneath the foundation at small strain levels (10^{-3} percent or less),

$G_0 = \gamma v_{s0}^2 / g$ = average shear modulus of soils beneath the foundation at small strain levels,

γ = average unit weight of the soils beneath the foundation.

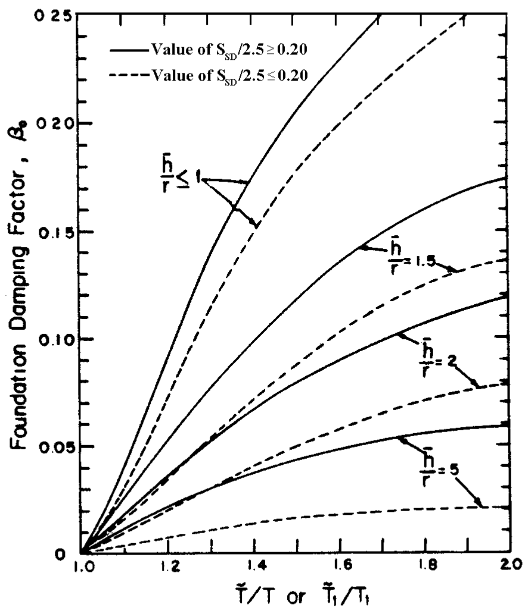

Figure 1. Code-specified foundation damping factor

Similarly, for the computation of the effective damping ratio, the code provides the formula

$$\tilde{\beta} = \beta_0 + \frac{0.05}{(\tilde{T}/T)^3} \tag{7}$$

noting that in no case $\tilde{\beta}$ should be taken as less than 5 percent or greater than 20 percent. For the determination of β_0, the code provides the graph shown in Figure 1, where r is computed according to

$$r = r_a \quad \text{if} \quad \bar{h}/L_0 \le 0.5 \tag{8}$$

$$r = r_m \quad \text{if} \quad \bar{h}/L_0 \ge 1.0 \tag{9}$$

and obtained by linear interpolation for intermediate values of $\bar{h}/L_0$. In Equations 8 and 9,

L_0 = overall length of the foundation in the direction of analysis, and

$$r_a = \sqrt{\frac{A_0}{\pi}} \tag{10}$$

$$r_m = \sqrt[4]{\frac{4I_0}{\pi}} \tag{11}$$

where

A_0 = foundation area in contact with the soil,

I_0 = moment of inertia of foundation in contact with the soil about a horizontal centroidal axis normal to the direction of analysis.

The following may be noted about these provisions:

(1) They are long, convoluted, and difficult to understand by someone with a limited background in soil dynamics. Consider, for example, the definitions of the lateral and rocking stiffness of the foundation soil. Many questions arise in the interpretation of these definitions. For instance, what is the depth below the foundation and what is the lateral extent from the center of the foundation that should be considered in these definitions? Another question is in regard to pile foundations. Shall the influence of piles be considered in the calculation of the soil stiffnesses?

(2) No formulas are given to compute the soil stiffnesses K_y and K_θ. Hence, the consideration of soil-structure interaction effects requires elaborate and expensive field studies that involves shear-wave velocity or shear modulus measurements for the different materials that comprise the foundation soil. Furthermore, it requires the participation of a soil dynamics expert.

(3) The consideration of soil-structure interaction effects is not a requirement. Therefore, it is easier for a designer to ignore soil-structure interaction effects rather than retain the services of a soil dynamics expert and request the field studies that would be necessary to take them into account.

(4) Given that the consideration of soil-structure interaction effects is not a safety issue (otherwise, it would be required), it is believed that it would be better—for simplicity sake—to eliminate the reviewed provisions from the code and simply add a statement that would read like: "A reduction in base shear due to soil-structure interaction effects is permitted, provided these effects are accounted for using a generally accepted procedure."

Empirical or Oversimplified Procedures

Another consequence of overly prescriptive codes is the inclusion of empirical or oversimplified procedures whose only justification is that they can be codified. An example of such empirical and oversimplified procedures contained in the code is the formula specified for the design of nonstructural components permanently attached to structures. The code requires that nonstructural components be designed to resist a minimum equivalent static force given by

$$F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right) \tag{12}$$

except that F_p need not be greater than

$$(F_p)_{\max} = 1.6 S_{DS} I_p W_p \tag{13}$$

and must not be less than

$$(F_p)_{\min} = 0.3 S_{DS} I_p W_p \tag{14}$$

In the foregoing equations,

F_p = seismic design force considered acting at the component's center of mass and distributed according to the component's mass distribution,

S_{DS} = design spectral acceleration for short-periods specified for the design of the supporting structure,

I_p = component importance factor selected from a given table according to component importance,

a_p = component amplification factor selected from a given table according to type and flexibility of component,

R_p = component response modification factor selected from a given table according to type and deformability of component,

z = height above grade of highest point of component attachment (for items at or below structure base, z = 0),

h = average height of structure's roof relative to grade elevation,

W_p = component weight.

Equation 12 is an empirical formula that accounts for the amplification of the ground motion at the level where the nonstructural component is attached (represented by the factor 1 +2z/h), the amplification of the motion at the base of the nonstructural component owing to the component's own flexibility (represented by the factor a_p), and the reduction in response that is possible as a result of the component's ductility (represented by the factor R_p). The specified factors, however, do not have a theoretical basis. For example, it is assumed, arbitrarily, that the ground motion amplification factor varies linearly between the values of 1.0 at the base and 3.0 at the top of a building. In other words, it is assumed that the peak floor acceleration varies linearly from the peak ground acceleration at the base of the building to three times the peak ground acceleration at roof level. Some studies, however, have shown that there exist significant differences between theoretically calculated peak floor accelerations and those determined using the assumption made in the derivation of Equation 12. Miranda and Taghavi [6], for example, find the differences shown in Figure 2. This figure shows a comparison between the recorded peak floor accelerations against those determined theoretically and those obtained using the linear distribution assumed in the derivation of the code formula introduced above. It may be seen from this figure that there is indeed significant differences between the calculated and recorded peak floor accelerations and those obtained on the basis of the linear distribution assumed in the derivation of the code formula.

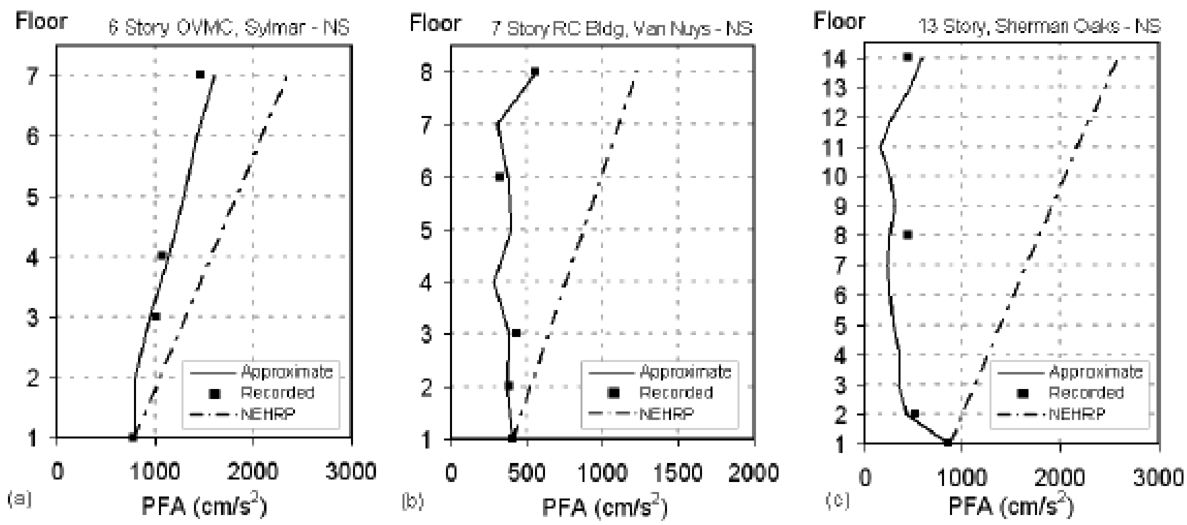

Figure 2. Comparison of recorded, calculated, and code-recommended (NEHRP label) peak floor accelerations (PFA) in three instrumented buildings (after Miranda and Taghavi [6])

The following observations may be thus made about these provisions:

(1) The formula specified by the code for the design of nonstructural components is simple but lacks a theoretical justification and may not lead to accurate results in all cases. Furthermore, the safety margin inherent in this formula is not known.

(2) There is no need to specify an empirical formula for the design of nonstructural components since there are nowadays tools and techniques that can be used to determine in a relatively simple way the forces that may affect nonstructural components when the supporting building is excited by the design earthquake.

(3) The specification of a formula for the analysis of nonstructural component implies either that alternative methods are too complicated and costly (which may not be true), or designers are not competent enough to determine these forces without the help of a code-specified formula (which may also not be true).

(4) Specification of simplified procedures of this type may give the designer a false sense of safety (i.e., the feeling that safety is assured just because the design complies with the code) and obligates a structural engineer to reduce his or her consulting fee (is the purpose of building codes to provide inexpensive design tools?).

(5) By specifying a simple formula for the design of nonstructural components when there are more rigorous alternatives, code writers are downgrading the importance of an engineering analysis, promoting the practice of structural engineering by individuals who lack an adequate understanding of structural behavior, and compromising the safety of nonstructural components.

(6) Safety would be enhanced if the selection of the design procedure were left to the judgment and experience of the designer. It is believed, thus, that it would be better to reduce the provisions concerning nonstructural components to a simple statement that would read like: "Nonstructural components and their anchorage shall be designed to resist the maximum lateral and vertical forces they may be subjected to under the design earthquake as determined from a rational analysis."

Obstruction to Application of Innovative Techniques

As indicated before, it is believed that over-prescriptive codes also become an obstruction to the application of advanced concepts and innovative techniques. Consider, for example, the code provisions for base-isolated structures. These provisions are, first of all, long and complicated. The length of the section in the code for the design and construction of base-isolated buildings is eleven 8" x 11" pages. Secondly, they require a dynamic analysis in most cases for which base isolation is an attractive solution. They also require a site-specific design spectrum when the structure is located on a site for which the spectral acceleration S_{D1} in the code-provided hazard maps exceeds 0.60g. This is in contrast with the simple static analysis that could be used based on the fact that in an isolated structure the displacements are concentrated at the isolation level and the structure above the isolation interface virtually moves as a rigid body. What is more, the provisions require that the total design displacement and the design lateral force on the isolation system be not less than 90% of the designed displacement and design lateral force determined with the specified equivalent lateral force procedure. This means that for all practical purposes the code requires that both static and dynamic analyses be carried out for the design of base-isolated structures. More importantly, the requirements are overly conservative. As pointed out by Naeim and Kelly [7], this fact may be verified by comparing the formulas specified by the code to calculate the base shear in base-isolated and fixed-base structures. To this end, consider that the code formula for the calculation of the base shear in the case of a base-isolated structure is given by

$$V_s = \frac{k_{D\max} D_D}{R_i} \tag{15}$$

where

$k_{D\max}$ = maximum effective stiffness of the isolation system at the design displacement in the horizontal direction under consideration,

D_D = design displacement at the center of rigidity of the isolation system in the direction under consideration,

R_i = factor selected on the basis of the type of lateral-force resisting system used for the structure above the isolation system, equal to 3/8 of the corresponding response modification factor used for the design of fixed-based structures.

Similarly, the code formula for the calculation of the design displacement is

$$D_D = \frac{g S_{D1} T_D}{4\pi^2 B_D} \tag{16}$$

where

S_{D1} = design 5%-damping spectral acceleration at 1-sec period determined from the code-provided hazard maps,

B_D = numerical coefficient related to the effective damping of the isolation system at the design displacement,

g = gravitational acceleration,

T_D = effective period of seismically isolated structure at the design displacement under consideration, computed according to

$$T_D = 2\pi\sqrt{\frac{W}{k_{D\min} g}} \tag{17}$$

in which

W = total seismic dead load weight of the structure above the isolation interface,

k_{Dmin} = minimum effective stiffness of the isolation system a the design displacement in the horizontal direction under consideration.

Thus, if k_{Dmin} is solved from Equation 17 and substituted into Equation 15, after considering that $k_{Dmin} \approx k_{Dmax}$ one obtains,

$$V_s = \frac{4\pi^2 W D_D}{T_D^2 g R_i} \tag{18}$$

which by virtue of Equation 16 may also be written as

$$V_s = \frac{S_{D1} W}{T_D B_D R_i} \tag{19}$$

On the other hand, the formula specified by the code for the calculation of the base shear in a fixed-base structure with a long period and an occupancy importance factor, I, equal to1.0 is of the form

$$V = \frac{S_{D1} W}{TR} \tag{20}$$

where

R = response modification factor selected on the basis of the type of lateral-force resisting system used,

T = fundamental natural period of the structure,

and all other symbols are as defined before.

Thus, for a base-isolated structure with an effective natural period of 2.0 seconds, an effective damping ratio of 10% (which, from the table given in the code, corresponds to $B_D = 1.2$), and a response modification factor of 8.0 for the structure above the isolation system, the base shear mandated by the code (without the allowed reduction if a dynamic analysis is performed) would be

$$V_s = \frac{S_{D1} W}{(2.0)(1.2)(3/8)(8.0)} = 0.139 S_{D1} W \tag{22}$$

In contrast, the base shear for a fixed-base structure with a fundamental natural period of 2.0 seconds and a lateral resisting system for which the response modification factor is also 8.0 would be

$$V = \frac{S_{D1} W}{TR} = \frac{S_{D1} W}{(2.0)(8.0)} = 0.063 S_{D1} W \tag{23}$$

These results indicate that two structures with the same fundamental natural period, same lateral force resisting system, same total weight, and located at exactly the same site would be designed to resist different base shears if one follows the code. Moreover, they indicate that the code requires that the base isolated structure be designed for a base shear that is more than double the base shear it requires for the fixed-base structure. Obviously, the difference is mainly due to the use of a response modification factor of 8.0 for the fixed-base structure but only 3.0 for the isolated structure. A reduced response modification factor is used in the case of base-isolated structures because it is considered that in these structures the part above the isolation interface is not subjected to significant forces and hence it is kept in its linear range of behavior. As such, base isolated structures cannot rely on the hysteretic behavior of that part of the structure to reduce the magnitude of the forces acting on it.

Another feature of the code provisions that makes base isolated structures be in many cases more expensive than equivalent fixed-base structures is the mandate to conduct peer reviews of the design and construction of the isolation system, tests of the isolators to determine their deformation and damping characteristics, and periodic inspections of the isolation system. The following are the pertinent specifications in this regard:

1. *A design review of the isolation system and related test programs shall be performed by an independent engineering team including persons licensed in the appropriate disciplines and experienced in seismic analysis methods and the theory and application of seismic isolation.*
2. *The deformation characteristics and damping values of the isolation system used in the design and analysis of seismically isolated structures shall be based on tests of a selected sample of the components prior to construction as describe in this section.*
3. *Seismically isolated structures shall have a periodic monitoring, inspection, and maintenance program for the isolation system established by the registered design professional responsible for the design of the system.*

The following observations may be made regarding the provisions for base isolated structures:

(1) The provisions are unnecessarily long and complicated. It is evident that they have been written by engineers who are overly cautious with new technologies. They may be simplified by leaving the details of the design to the judgment and experience of the designer or his or her consultants, who may be in better position to decide what method of analysis to use and when a test program is justified.

(2) The response modification factor specified by the code for base isolated structures is unnecessarily too small since it is possible to design for much lower forces. The result would imply inelastic deformations in the structure above the isolation interface, which does not necessarily means its failure if this incursion is accounted for in the design. Prescribing design forces that keep the superstructure into its linear range of behavior prevents an owner from selecting the optimum performance objective for his or her particular project and may discourage him or her from adopting a base isolation solution.

(3) The requirement of a design and construction review team and a test program complicates the design of base isolated buildings and substantially increase the initial cost of these buildings.

(4) The test requirements may discourage a designer from considering base isolation as a design alternative since in many cases the required tests cannot be performed due to the lack of adequate testing facilities.

(5) As currently written, the code provisions virtually eliminate the economic benefits of isolating a structure and hinders thus a wide use of this technology.

Facilitating Practice of Undereducated Engineers

It may also be argued that building codes that practically spell out the entire design process facilitate the development of computer programs that can carry out an entire design and the practice with the help of these computer programs of inexperienced designers. To accept this assertion, one only has to take a close look at modern computer programs. Modern computer programs allow designers the use of equivalent static, response spectrum, or time-history analysis procedures; consider different materials like steel, concrete or wood; proportion structural elements on the basis of ASD or LRFD criteria; comply with different codes such as IBC, UBC, ASCE 7, and NBCC; and produce structural drawings that need only minor modifications to become construction documents. And all this can be performed with just the touch of a button, without much participation from the designer. In many cases, the role of the designer is reduced to define the geometric and material properties of the structure and specify the code that needs to be used. It is true that good computer programs in the hands of well-trained and competent structural engineers are invaluable to produce excellent designs. But it is also true that the same program in the hands of undereducated or inexperienced engineers may produce not only unreasonable but also unsafe designs. Many examples of this situation may be found in the literature. For example, in his book *To Engineer is Human* [8], Henry Petroski describes an incident in which an incorrect sign in a structural engineering program led the computer to subtract stresses instead of adding them. During the seismic analysis of several nuclear power plants, the program gave thus stress values that were lower than they should have been. In consequence, the plants had to be re-analyzed at a great cost in terms of both time and money. Another example is the case of a distressed structure the second author was asked to investigate. The case involved a reinforced concrete flat-plate structure that presented severe cracks and large deflections. When confronted, the designer of the structure denied any design error arguing that his design was correct because the structure was analyzed by a very good computer program that used finite elements. The investigation revealed, however, that the problem was caused simply because the depth considered for the flat plates was inadequate for the long spans of the structure. The first author also has first-hand evidence that designs are being carried out by undereducated engineers who rely on powerful computer programs to overcome their limited understanding of structural behavior. He has heard some of his part-time students, engineers working in local engineering firms, saying after taking some of his graduate courses: "I finally understand why I am doing what I am doing at the office." There is no doubt, thus, that the development of do-it-all computer programs and the consequent practice of undereducated or inexperienced engineers are all promoted by overly prescriptive building codes.

Fostering Low Professional Fees and Rushed Designs

Another equally important consequence of the automatization of the design process made possible by overly prescriptive codes is that now designs can be produced with less effort and shorter turnarounds. While this has certainly increased the productivity of engineering firms, it has also allowed under-trained engineers, many times working on their home kitchens, to charge only a fraction of the fees charged by engineering firms that are well established, have a strong infrastructure and a vast experience. The end result is that established firms have been gradually forced to reduce their consulting fees in order to remain competitive. Reversing this tendency is not an easy task because architects and investors feel, often without realizing that they are taking unacceptable risks, that paying low engineering fees is a sign of good negotiating skills. Less effort and shorter turnarounds have also increased the pressure on structural engineers to finish projects in increasingly shorter times. Typically, an investor takes months or even years studying the feasibility of a new project, but once a decision is made, he or she wants to begin construction immediately. Consequently, he or she expects that the structural design be finished in the shortest, and in many occasions absurd, amount of time. Under these circumstances, a structural engineer has two options: refuse the job unless an adequate amount of time is given to achieve a sound design; or, carry out the design with the help of a commercial computer program that includes the applicable codes to speed up the design procedure, even though he or she does not have a clear understanding of the principles behind the code specifications. An experienced engineer may go for the first option, even though he or she risks losing the job, because he understands that a sound design requires a minimum amount of time that can not be reduced further by the use of powerful computer programs. On the other hand, the second option will most probably be the choice of under-educated and under-trained engineers, who are not capable of identifying all the important aspects of the project but who may be easily tempted to trust a computer program that automatically applies the code regulations. It may be seen, thus, that while the intention of modern building codes is to increase public safety, as a result of lower fees and shorter design times the net effect could be pretty much the opposite.

Decline in Importance of Structural Engineering Profession

As mentioned earlier, the authors also believe that another consequence of overly prescriptive codes is a decline in the importance of the structural engineering profession, as reflected by the low fees paid for structural engineering work and the inability to attract the best young minds to this profession. As discussed above, prescriptive codes have been partly responsible for the low fees currently paid for structural engineering work. Prescriptive codes have also taken the "engineering" out of structural designs, making the practice of the profession less challenging and less exciting. With a prescriptive code, the task of an engineer becomes one of meeting code requirements as opposed to using his or her knowledge and ingenuity to produce the best designs at the lowest cost. The end result is underpaid professionals doing unexciting work, conditions that can transform any profession into an unattractive one.

ARE PRESCRIPTIVE CODES NECESSARY?

Are prescriptive codes really necessary to ensure public safety? The authors believe that the answer to this question is “no.” The proof is that the largest and most important projects are successfully designed and built without the benefit of code guidelines. Examples abound: tall buildings, tall chimneys; large suspension and cable-stayed bridges; large earth and arch dams; and transnational pipelines and tunnels. Important projects are designed by teams of competent engineers using basic engineering principles and techniques and the results from laboratory or field tests whenever the needed information is not available. The designers of these large projects do not rely on code provisions to select the best structural system, or analysis procedure, or to decide what tests should be performed to define the design loads or soil or structural characteristics. Instead, they rely on their knowledge, experience, and professional judgment. It may be argued that not all projects have the large budgets allocated to large projects for their designs and consequently prescriptive code provisions are needed to achieve the safe designs of ordinary projects at a low cost. The counterargument is that this is not necessarily so because competent engineers are equally capable of safe designs for ordinary projects at a cost commensurate with the importance of the projects. After all, they are supposed to be familiar with the simplified procedures recommended in prescriptive codes. It may be seen, therefore, that the only justification for over-prescriptive codes is to ensure the designs performed by under-educated or inexperienced engineers are, nominally at least, safe.

RECOMMENDED CODE FORMAT

In the light of the concepts discussed above and before suggesting what should be the format of future seismic codes, it is appropriate to make the following comments in regard to what the authors believe a code must include or not include:

(1) It is clearly accepted by the engineering profession that the main objective of a building code is to protect and safeguard public safety. In this sense, one has to ask oneself if modern building codes are really fulfilling this objective. It is the authors’ belief that the over-prescription in these codes does not contribute to this objective.

(2) It must be emphasized that a code is not a textbook. A code must establish what items must be taken into account by a designer, but in no way “teach” him or her how to account for those items. It must be accepted by code writers and the society at large that competent structural engineers are capable of designing safe structures even in the absence of a building code; he or she is not supposed to learn structural design by studying a building code.

(3) Codes should not specify what methods of analysis should or may be used. The designer should be able to select the most appropriate method according to the characteristics of the structure being analyzed.

(4) A code should limit its recommendations to general principles and not analysis or design details. It is believed that these details should be left to the structural designer and the code must only specify them as items that must be taken into account according to the importance and characteristic of the project.

(5) A code must, above all, be understandable, especially by practicing engineers who have been out of school for many years, so that designers can understand exactly what the code requirements are.

(6) Finally, a code must be written in a way that discourages the practice of inexperienced or under-educated designers. This may be done by eliminating the level of detail found in many sections of the latest codes.

In summary, it is believed that seismic codes should be limited to general safety and performance requirements. That is, items that cannot be determined using basic engineering principles and techniques. Codes should also specify, in general terms, the aspects of structural behavior that need to be addressed in a design. They should not prescribe the criteria and procedures with which designers should perform a seismic design. These criteria and procedures should be left to the knowledge and experience of the designer, who in any case is in better position to make decisions in accordance to the particular characteristics of the design project at hand. Specifically, seismic codes should include:

(1) General provisions, such as what is expected from a safe design and when design reviews are required.
(2) The specification of the minimum seismic hazard for which structures should be designed according to geographical location.
(3) Specification of load combinations.
(4) Specification of safety factors according to occupancy category.
(5) The requirement that soil amplification, torsional, P-delta, and soil-structure interaction effects be accounted for using generally accepted procedures whenever these effects are deemed important by the designer.
(6) The requirement that nonstructural components be included in the overall seismic design of buildings.

The adequacy of designs carried out with this type of code could be verified by a careful review by plan checkers for ordinary projects (which means that plan checkers would also have to be well-educated and experienced engineers) and by requiring peer reviews in the case of large and special projects. Past experience, methods of analysis, and design details may be communicated to designers (for information purposes only) through supplementary publications.

One of the advantages of the suggested code format is that it gives designers the flexibility to select the best structural system and best design procedure for each particular project. This flexibility would foster creativity and innovation. It would also foster an extra amount of care—and hence safer structures, as designers would have to rely on their experience and judgment for the safety of their designs instead of blindly relying on required code procedures they do not fully understand and may not work for all cases. Another advantage is that by leaving the responsibility for the selection of the best design criteria and procedures to them, designers would be performing real engineering work as opposed to following a set of instructions or, worse, feeding computer programs. This would certainly enhance the stature of structural engineers and the compensation they would receive for their services. In short, it would enhance the importance of the structural engineering profession.

REFERENCES

1. J. Tawresey, "Simplify the building codes," Editorial in *Structure Magazine*, Nov. 2003, p. 7.
2. Seismological Committee, Structural Engineers Association of California, *Recommended Lateral Force Requirements*, San Francisco, Calif., July 1959.
3. Building Seismic Safety Council, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures,* 2000 Ed., Part I: Provisions (FEMA 368), Washington, D.C., 2001.
4. International Code Council, Inc., *International Building Code*, 2002.
5. American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, SEI/ASCE 7-02, Reston, Virginia, 2003.
6. E. Miranda and S. Taghavi, "Estimation of seismic demands on acceleration-sensitive nonstructural components in critical facilities," *Proc. ATC-29-2 Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities*, Newport Beach, Calif., Oct. 23-24, 2003.
7. F. Naeim and J. M. Kelly, *Design of Seismic Isolated Structures: From Theory to Practice*, John Wiley & Sons, Inc., 1999.
8. H. Petroski, *To Engineer Is Human: The Role of Failure in Successful Design*, St. Martin's Press, New York, N.Y., 1985