NRC Publications Archive Archives des publications du CNRC

Guidelines for the seismic evaluation of existing buildings

Allen, D. E.; Rainer, J. H.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Canadian Journal of Civil Engineering, 22, 3, pp. 500-505, 1995-06-01

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=6cd9b8b0-caf7-4dd7-812c-52578e6b169b>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=6cd9b8b0-caf7-4dd7-812c-52578e6b169b>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research
Council Canada

Conseil national de
recherches Canada

Canada

Guidelines for the seismic evaluation of existing buildings

D.E. Allen and J.H. Rainer

Abstract: Because of the difficulties in applying current earthquake requirements in the National Building Code of Canada to existing buildings, a document "Guidelines for the seismic evaluation of existing buildings" has been developed to provide alternative criteria. The Guidelines are based primarily on similar U.S. documents with changes to suit Canadian seismicity and practice. The basis of the document is earthquake damage experience as it relates to life safety, and the methodology is based on the identification of deficiencies of the building from a master list known from earthquake experience to result in life-threatening failures. Potential deficiencies are checked against evaluation criteria which are based on the NBC/CSA seismic limit states design using a load reduction factor of 0.6. The paper provides a background on those features which differ substantially from the NBC requirements.

Key words: existing buildings, seismic evaluation, procedure, criteria.

Résumé : En raison des difficultés associées à l'application des exigences du Code national du bâtiment relatives aux séismes aux bâtiments existants, un document intitulé « Lignes directrices pour l'évaluation sismique des bâtiments existants » a été élaboré afin de proposer des critères parallèles. Le document s'inspire principalement de documents américains semblables auxquels des modifications ont été apportées afin de tenir compte de la sismicité et des pratiques au Canada. Le fondement du document est l'expérience relative aux dommages causés par les tremblements de terre en relation avec la sécurité des personnes; la méthodologie repose sur l'identification, à partir d'une liste de base, des lacunes du bâtiment qui sont susceptibles d'entraîner des défaillances constituant un danger de mort. Les lacunes possibles sont ensuite comparées aux critères d'évaluation qui sont basés sur le calcul aux états limites du CNB/CSA utilisant un coefficient d'étalonnage de 0,6. Cet article examine le contexte de ces caractéristiques qui diffèrent de façon substantielle des exigences du CNB.

Mots clés : bâtiments existants, évaluation sismique, procédure, critères.
[Traduit par la rédaction]

Introduction

The National Building Code (NBC) has been written for the design of new buildings. As a consequence, specific code requirements which are economical for the design of new buildings can be very uneconomical and destructive of heritage values if applied to existing buildings. This is especially the case for earthquake requirements, where some code requirements are virtually impossible to satisfy without replacing the existing structure or radically altering it. Code requirements of this nature include two-way reinforcement in masonry, minimum structural ductility for buildings over three storeys, prevention of foundation failure prior to "yielding" of the superstructure, and lateral stiffness requirement to control building damage. The cost associated with strict application of the code can easily put a needed

building renovation on "hold."

As a result of this situation, structural consultants have generally been allowed leeway by building officials in the application of the earthquake code requirements when applied to existing buildings. Opinions, however, vary widely among consultants on the appropriate degree of such relaxation, affected, on the one hand, by pressure from their clients and heritage groups for minimum structural intervention and, on the other, by the threat of litigation to follow the code. This problem becomes greater in medium to low seismic areas (i.e., the major part of Canada outside the West Coast and a small region of the St. Lawrence Valley) because of the low risk perceived by most people combined with the high cost of seismic upgrading.

To address this difficulty, the Institute for Research in Construction, National Research Council Canada (NRC) has, with the help of other experts (see Acknowledgments), developed a document "Guidelines for the seismic evaluation of existing buildings" (NRC 1992a), referred to hereafter as the NRC Guidelines or simply Guidelines. The NRC Guidelines are largely based on the U.S. document "NEHRP Handbook for the seismic evaluation of existing buildings" (FEMA 1992a) which is a revision of an earlier document known as "ATC-22." The NEHRP Handbook was used as the model, since it is the best document of this kind already

Received November 23, 1993.

Revised manuscript accepted September 13, 1994.

D.E. Allen and J.H. Rainer. Institute for Research in Construction, National Research Council Canada, Montreal Road, Ottawa, ON K1A 0R6, Canada.

Written discussion of this paper is welcomed and will be received by the Editor until October 31, 1995 (address inside front cover).

available, and the time and cost involved in developing a new document is very large.

In adopting the NEHRP Handbook, notable changes that were made include the use of basic NBC/CSA limit states criteria, the inclusion of the most recent California criteria for unreinforced masonry (UCBC 1991) which differ substantially from the NBC seismic requirements, and the inclusion of better guidance on foundations and geotechnical site hazards. Also, a reduction factor of 0.6 has been applied to the NBC earthquake loading for the NRC Guidelines as compared to a reduction factor of 0.67 for medium to high buildings and 0.85 for low buildings used in the NEHRP Handbook. The justification for the 0.6 reduction factor is given later.

A companion document, "Manual for screening of buildings for seismic investigation" (NRC 1992b), provides a procedure for rapidly ranking an inventory of buildings for detailed seismic evaluation. Its use therefore precedes the use of the Guidelines.

Scope and basis of the Guidelines

The NRC Guidelines are intended for "ordinary" buildings covered by Part 4 of the NBC. They can also be used for special buildings, such as hospitals, but specific requirements for damage control to maintain operational readiness would have to be introduced. The Guidelines are also intended to be used by well-qualified structural engineers, but not necessarily ones who are experts in earthquake engineering. They therefore provide a procedure to guide the engineer through the evaluation.

The basis of the Guidelines is life safety. In terms of building damage, a threat to life safety occurs when the building or part of it collapses, building components fail and fall, and exit and entry routes are blocked, preventing evacuation and rescue of occupants. Control of property damage is not an objective of the Guidelines. If it is found that seismic upgrading is necessary, however, then control of property damage should be considered in the design of the upgrading, based on economics and the future use of the building.

Evaluation procedure

Evaluation statements

The key to the Guidelines is the identification of structural deficiencies or flaws which earthquake experience has shown lead to failure and falling of building components which threaten life safety. These deficiencies become *potential* deficiencies in any existing building and are therefore expressed in the form of "evaluation statements" written such that a positive or "true" response implies that the building is adequate for that potential deficiency.

The Guidelines contain a master list of evaluation statements for potential deficiencies, grouped in accordance with the following categories:

- building system as a whole,
- vertical structural system,
- horizontal structural systems (diaphragms),
- connections between main structural elements,
- foundations and geological site hazards, and
- nonstructural building components.

Table 1. Typical values of the recommended force modification factor, R , for existing buildings.

Type of construction	R^*
Moment frames	
Concrete	1.5
Steel	3.0
Shear walls	
Concrete	2.0
Unreinforced masonry	1.0
Reinforced masonry	1.5
Wood	3.0
Braced frames	
Steel	2.0
Wood	1.5

*These values are adjusted downwards for evaluation of critical details such as partial penetration welds in steel column splice plates or overdriven nails and staples in wood sheathing. They are adjusted upwards for recent buildings with ductile construction.

Steps in the evaluation procedure

The Guidelines contain a two-phase evaluation procedure for determining the answers to the evaluation statements, consisting of a quick phase, followed if necessary by a detailed phase. The quick phase is based on a site visit and review of the construction documents plus "quick check" calculations. The quick check is a simple estimate of the capability of the building structure to resist lateral earthquake forces. If the quick check is not met or if a construction detail affecting seismic safety is not known, then a more detailed investigation consisting of detailed calculations or site investigations is required.

The steps of the evaluation procedure are the following:

Quick phase:

- Step 1. Visit the site and collect data, including geotechnical information and building construction data (drawings, alterations, etc.).
- Step 2. Determine the type of structure and make an initial review of the evaluation statements using, where necessary, the quick check procedure.

Detailed phase:

- Step 3. Perform follow-up field work. Uncovering of construction details and testing may be required.
- Step 4. Perform the analysis required by the evaluation statement. The analysis closely follows the NBC design criteria, with the exception of unreinforced masonry. Typical values of the force modification factor, R , for older buildings are given in Table 1.

Final evaluation:

- Step 5. Make the final evaluation. This includes ranking the final list of deficiencies based on risk in terms of life safety and property damage and the cost and disruption associated with upgrading each deficiency.

If the evaluation statements are satisfactorily answered during the quick phase (steps 1 and 2), then the detailed

Table 2. Earthquake load factor for building evaluation based on a life safety criterion (Allen 1991).

Risk category	Redundancy		
	Little	Average	High
High	1.0	0.8	0.63
Medium	0.8	0.63	0.5
Low	0.63	0.5	0.4

phase (steps 3 and 4) may not be necessary. Even if steps 3 and 4 are necessary, the quick phase provides a good indication of the potential deficiencies and a focus for the rest of the investigation.

The evaluator is usually also asked to recommend upgrading based on the deficiencies found. The Guidelines do not address upgrading, with the exception of unreinforced masonry. Guidance on upgrading, however, is available in FEMA (1992b), which has been made compatible to the NEHRP Handbook (1992a). An NRC guideline on seismic upgrading is also in preparation.

Base shear for evaluation

The Guidelines use a reduction factor of 0.6 applied to the NBC seismic base shear to arrive at a minimum level of seismic resistance for evaluating the adequacy of existing buildings. This level therefore represents a trigger for seismic upgrading of any building. Where upgrading is triggered, it should be designed for a level of resistance equal to that of the NBC, except in special cases where a lower resistance can be justified in terms of life risk, cost, and damage control.

The reasons for the reduction factor are economic and social. The incorporation of earthquake resistance in a new building is a marginal construction cost which is relatively small compared with the total cost of the building. Seismic upgrading of an existing building, however, is generally expensive and may be very disruptive to the use of the building. For economic and social reasons it is therefore necessary to develop a reduction factor for triggering seismic upgrading that satisfies the minimum life-safety requirements of the NBC. The justification for the reduction factor of 0.6 is based on the following two life-safety assessments:

Life safety versus structural safety

The NBC design criteria are intended to provide a minimum level of structural safety. Life safety, however, is different from structural safety in that the former implies a limitation on the risk of deaths or serious injuries. Structural criteria in the NBC, which are the same for all applications, are based on a worst scenario of deaths or injuries in the event of a structural failure. An exception is an importance factor as low as 0.8 applied to buildings of low human occupancy. The concept of an importance factor related to life safety has been extended to structural evaluation of bridges (Allen 1992), and more recently, to buildings (Allen 1991) to determine load factors as a function of system behaviour and human exposure to the failure. The result is a matrix of load reduc-

tion factors for earthquake shown in Table 2, where it is seen that the reduction factor is 0.63 for average conditions of redundancy and risk category. Although the matrix approach in Table 2 can be considered for the seismic evaluation of all types of structures, for the Guidelines it was decided to adopt a single "average" reduction factor for all buildings. One reason for adopting the single factor in preference to the matrix approach in Table 2 is that the latter is based on the assumption that the NBC/CSA limit states criteria result in consistent structural reliability for various applications; this assumption is reasonable for gravity and wind loads, but less reasonable for earthquake because of the high modelling uncertainty inherent in the seismic code criteria.

Calibration with NEHRP Handbook

How have structures designed and built to past criteria, generally less severe than current criteria, performed in earthquakes? Past U.S. seismic design criteria have been tested in earthquakes in California, Alaska, and other countries where the U.S. criteria were adopted. The most recent U.S. criteria for evaluation of existing buildings can thus be considered to be based on earthquake experience. These criteria, contained in the NEHRP Handbook for Seismic Evaluation of Existing Buildings (FEMA 1992a), represent the consensus of a society whose concepts of safety and whose economic system are comparable to those in Canada, and are therefore used as basis for comparison.

The NEHRP Handbook applies a reduction factor to the seismic design forces of the NEHRP code for new buildings of 0.67 for medium to tall buildings, and 0.85 for low stiff buildings. These values are based on a probabilistic argument of adopting the mean spectral response to various seismic inputs instead of the mean plus one standard deviation. While this argument may make some intuitive sense, it does not provide an adequate justification per se. Nevertheless, since the final results obtained by the NEHRP Handbook are considered appropriate for a region with greater seismic experience, the base shears of the NEHRP Handbook are used as a basis for comparison.

Table 3 contains the results of comparing base shear from the NRC Guidelines with that from the NEHRP Handbook for the same zonal velocity and acceleration (the basis for comparison is given in Appendix A). Table 3 shows that the NRC Guidelines criteria are approximately equivalent to the NEHRP Handbook for low buildings (1–2 storeys) but are more conservative for tall buildings.

These two assessments, based on risk assessment and calibration to earthquake experience, demonstrate that the minimum load reduction factor of 0.6 in the NRC Guidelines satisfies the life safety intent of the NBC.

Foundations

Historically, few foundations on level compact ground conditions have failed during earthquakes. Foundation failures have occurred where the ground consisted of loose saturated sandy soil, or very soft sensitive clays, or where foundations have been located on steep slopes. Earthquake damage can occur to foundations on compact ground condition, but the damage is seldom a life safety hazard. The Guidelines therefore place emphasis on liquefaction of sandy soils and loss

Table 3. Base shear comparison of NRC Guidelines with NEHRP Handbook.

	Typical R factor for older buildings		V_{NRC}/V_{NEHRP}	
	R_{NRC}	R_{NEHRP}	Low buildings (eq. [A12])	Tall buildings (eq. [A10], $T = 1$ s)
Unreinforced masonry	1.0	1.25	0.8–1.5*	—
Reinforced masonry				
Bearing wall	1.5	3.5	1.2	1.6
Frame infill	1.5	4.5	1.5	2.0
Concrete shear walls				
Bearing wall	2.0	4.5	1.1	1.5
Frame infill	2.0	5.5	1.4	1.9
Concrete moment frames	1.5	2.0	0.7	0.9
Steel moment frames	3.0	4.5	0.8	1.0
Steel braced frames	2.0	5.0	1.3	1.7
Wood shear walls	3.0	6.5	1.1	1.5
Range			0.7–1.5	0.9–2.0
Average			1.08	1.43

*Equations [A10] and [A12] are not used for unreinforced masonry. See Appendix A.

of stability of sensitive clays. The Guidelines recommend that such conditions be evaluated by a competent geotechnical engineer. Geological site hazards such as tsunamis, rock falls, or slope failures may need to be evaluated as well.

Earthquake experience also shows that risk of structural failure increases substantially with soft soil conditions and this is reflected in the foundation factor F , which ranges from 1.0 for firm ground to 2.0 for deep soft deposits. This site-specific factor is therefore incorporated in a number of Guidelines criteria as discussed later.

Low seismic zones

The majority of populated areas of Canada are located in medium to low seismic zones, whereas the criteria in the NEHRP Handbook are based to a large extent on high seismic zones. An effort was therefore made to relax the criteria adopted from the NEHRP Handbook in medium to low seismic zones. This was done in two ways: one by restricting the applicability of certain evaluation statements to zones equal to or greater than a specified zone, the other by introducing a zone-dependent parameter into the empirical criteria contained in the evaluation statements. Table 4 shows the first approach for unreinforced masonry, where a number of potential deficiencies need to be checked only in medium or high seismic zones. An example of the second approach is the evaluation statement for adjacent buildings (i.e., pounding damage) which states “A neighbouring structure is considered to be “immediately adjacent” if it is within $100vF$ (in millimetres) times the number of storeys away from the building being evaluated,” where v is the seismic velocity ratio and F is the foundation factor. This compares with a constant 51 mm in the NEHRP Handbook.

There have been many queries concerning the application of the NBC in low seismic zones (e.g., Toronto, Edmonton, Calgary) where it is found that many existing buildings do not satisfy the current NBC. Earthquake experience indicates that for buildings in acceleration- or velocity-related zones 0, 1, or 2 and founded on rock or firm soil, severe damage to

Table 4. Potential deficiencies of unreinforced masonry to be evaluated.

Potential deficiency	Effective seismic zones*
Masonry integrity	2–6
Parapet slenderness	2–6
Anchorage of masonry walls	2–6
Masonry wall slenderness	3–6
Shear in masonry walls and anchors	3–6
Toughness of wood diaphragms and partitions	5–6

*See eq. [1].

the building structure is very unlikely but there is a significant risk of failure of poorly anchored nonstructural components such as parapets. A statement to this effect was introduced in the NRC Guidelines. Whether seismic evaluation and upgrading should be pursued in all such zones, however, needs to be further clarified.

Special procedure for unreinforced masonry

The construction of unreinforced masonry bearing walls is not permitted in medium to high seismic zones by the current NBC, yet many such buildings exist in Canada, and many of them have considerable heritage value. The NBC seismic requirements are clearly not suitable for the evaluation and upgrading of these buildings. A special procedure for unreinforced masonry is therefore provided in Appendix A of the NRC Guidelines, based on the Uniform Code for Building Conservation (UCBC 1991). The only major change made to the UCBC requirements is the incorporation of the foundation factor F in the evaluation criteria.

The special procedure is intended for low-rise buildings with flexible but tough diaphragms (usually wood) and unreinforced masonry walls, typically enclosure walls around the

perimeter. Other unreinforced masonry bearing wall buildings, such as those with concrete diaphragms, are analyzed by a combination of the conventional procedure (contained in Chapter 3 of the NRC Guidelines) and parts of Appendix A.

Appendix A of the NRC Guidelines contains criteria and resistance values for the evaluation of potential deficiencies of unreinforced masonry buildings listed in Table 4. A more detailed discussion of the special procedure and its basis is given by Bruneau (1994).

An important feature of the special procedure is that not all potential deficiencies of masonry buildings need to be checked in medium to low seismic zones, and this makes the special procedure simple to apply in most of Canada. The main potential deficiencies of these buildings (other than a major configurational problem, such as soft storey) are itemized in Table 4, along with the applicable seismic zones. Table 4 shows, for example, that only masonry integrity, parapets, and wall anchorage need be considered in Zone 2. For application of Table 4, an "effective" seismic zone, Z' , has been defined as follows:

$$[1] \quad Z' = Z_v + 1 \text{ (if } Z_a > Z_v) + 1 \text{ (if } F \geq 1.5)$$

where Z_v and Z_a are, respectively, the velocity- and acceleration-related seismic zones given in the 1990 NBC Supplement, and F is the foundation factor given in Table 4.1.9.C of the 1990 NBC. As already discussed, foundation conditions were included in this definition because of the increased risk of structural failure for buildings on soft soil.

In summary, the special procedure for unreinforced masonry bearing wall buildings provides an alternative to the NBC seismic requirements by making maximum use of the materials found in this type of heritage construction.

Status of the Guidelines

The NRC Guidelines are presently being used in projects across Canada as a "state-of-the-art" document. The NRC Guidelines will be recommended as an alternative to the NBC for the seismic evaluation of existing buildings in a new NBC 1995 Commentary N on the application of Part 4 to existing buildings. In the future, it is expected that code writing bodies and enforcement agencies will review, update, and adapt the Guidelines to suit the needs of existing buildings in their jurisdictions.

Summary

The NRC Guidelines on seismic evaluation of existing buildings have been developed to provide an alternative to the NBC for the seismic evaluation of existing buildings. Application of the Guidelines will result in less structural intervention of the building, which translates into less upgrading cost, less disruption to occupants, less waste materials, and more preservation of heritage. The Guidelines contain a procedure to guide qualified structural engineers in the practice of seismic evaluation of existing buildings.

The NRC Guidelines apply a reduction factor of 0.6 to the NBC base shear to trigger seismic upgrading of an existing building. This decision arises from economic and social pressures and is justified by a life-safety assessment based on risk and calibration to earthquake experience.

Specific areas where further improvements of Guidelines

are needed include better criteria for low seismic zones, for thick stone masonry, and for masonry infill.

Acknowledgements

The development of the Guidelines for Seismic Evaluation of Existing Buildings was financially supported by the following agencies: B.C. Housing Management Commission; Canada Mortgage and Housing Corporation; Public Works Canada; Société Immobilière du Québec; City of Vancouver; and National Research Council Canada. The development of the NRC Guidelines was carried out by a team which, in addition to the authors, involved participation of the following individuals: A.M. Jablonski, formerly with the Institute for Research in Construction, NRC, now with Canadian Space Agency, St-Hubert, Que.; J. Blohm of Wayte, Blohm & Associates, Victoria, B.C.; P. Byrne of The University of British Columbia, Vancouver, B.C.; A. Caron of Polytec Groupe-Conseil, Québec, Que.; R. DeVall of Read, Jones, Christoffersen Ltd., Vancouver, B.C.; F. Knoll of Nicolet, Chartrand, Knoll Limitée, Montreal, Que.; W. McKevitt of McKevitt Engineering Ltd., Vancouver, B.C.; and B. Tomecek of RKTG Associates, Vancouver, B.C.

References

- Allen, D.E. 1991. Limit states criteria for structural evaluation of existing buildings. *Canadian Journal of Civil Engineering*, **18**(6): 995–1004.
- Allen, D.E. 1992. Canadian highway bridge evaluation: reliability index. *Canadian Journal of Civil Engineering*, **19**(6): 987–991.
- Bruneau, M. 1994. Seismic evaluation of unreinforced masonry buildings — a state-of-the-art report. *Canadian Journal of Civil Engineering*, **21**(3): 512–539.
- FEMA. 1992a. NEHRP Handbook for the seismic evaluation of existing buildings. Federal Emergency Management Agency, Washington, D.C., Report FEMA-178.
- FEMA. 1992b. NEHRP Handbook of techniques for seismic rehabilitation of existing buildings. Federal Emergency Management Agency, Washington, D.C., Report FEMA-172.
- NRC. 1992a. Guidelines for seismic evaluation of existing buildings. Institute for Research in Construction, National Research Council Canada, Ottawa, Ont., December.
- NRC. 1992b. Manual for screening of buildings for seismic investigation. Institute for Research in Construction, National Research Council Canada, Ottawa, Ont., September.
- UCBC. 1991. Uniform code for building conservation. International Conference of Building Officials, Whittier, Calif.

Appendix A. Comparison of base shear: NRC Guidelines for seismic evaluation versus NEHRP Handbook

For the NRC Guidelines (NRC 1992a), the seismic base shear in a given direction, V_{NRC} , is determined from

$$[A1] \quad V_{NRC} = (V_e/R)U_{NRC}$$

where U_{NRC} is a calibration factor equal to $0.6 \times 0.6 = 0.36$; R is the force modification factor; and V_e , the lateral base shear representing elastic response, is determined from

$$[A2] \quad V_e = \nu SIFW$$

where W is the weight of the building, ν is the zonal velocity ratio for the location, I is the importance factor, F is the foundation factor, and S is the seismic response factor determined as a function of the fundamental period of the building, T .

For medium to tall buildings ($T \geq 0.5$ s), the value of S is given by

$$[A3] \quad S = \frac{1.5}{\sqrt{T}}$$

and therefore

$$[A4] \quad V_{NRC} = \frac{0.54IF\nu W}{R\sqrt{T}}$$

For low stiff buildings ($T \leq 0.25$ s), application of the NBC criteria results in upper limits of the product SF equal to 3.0 for $Z_a = Z_v$, 4.2 for $Z_a > Z_v$, and $2.1F$ for $Z_a < Z_v$. For low stiff buildings, therefore,

$$[A5] \quad V_{NRC} = \frac{C\nu W}{R}$$

where C is equal to 1.08 when $Z_a = Z_v$, 1.51 when $Z_a > Z_v$, and 0.756 F when $Z_a < Z_v$.

For the NEHRP Handbook (FEMA 1992a), the base shear in a given direction, V_{NEHRP} , is determined from

$$[A6] \quad V_{NEHRP} = C_s W$$

where W is the weight of the building and C_s is a seismic design coefficient determined from

$$[A7] \quad C_s = \frac{0.80A_v S}{RT^{2/3}}$$

where S is a site coefficient (essentially equivalent to the NBC foundation factor F), A_v is the peak velocity-related acceleration coefficient (essentially equivalent in definition to the NBC zonal velocity ratio ν), T is the fundamental period of the building, and R is a response modification coefficient similar in definition but not identical to the NBC force modification factor R . For low stiff buildings, the value of C_s has an upper limit determined from

$$[A8] \quad C_s = \frac{2.12A_a}{R}$$

where A_a is the effective peak acceleration coefficient. To aid in distinguishing the symbols from those of the NRC Guidelines, the symbols for the NEHRP provisions have been set in roman.

Although the definitions of the parameters entering into base shear calculations are similar for the two documents, the resulting base shear values can be quite different. The most significant cause for this difference is the respective R factor; the other factors, although not exactly the same, are similar in value. For medium to tall buildings, [A4], [A6], and [A7] apply; and the ratio of base shears is determined by

$$[A9] \quad \frac{V_{NRC}}{V_{NEHRP}} = \frac{0.54IF\nu W/R\sqrt{T}}{0.80SA_v W/RT^{2/3}}$$

For any given location, the values of A_v and ν will not be exactly the same because different procedures are used to determine their value. However, they have the same basic range (0–0.4) and, for practical purposes, they can be assumed equal. Also, the foundation factors are essentially equal, $F \cong S$, as is the building weight $W = W$ and the period $T = T$. The importance factor is assumed the same for both documents, i.e., $I = 1.0$. Consequently,

$$[A10] \quad \frac{V_{NRC}}{V_{NEHRP}} = \frac{0.675}{T^{1/6}} \times \frac{R_{NEHRP}}{R_{NRC}}$$

where now the respective subscripts for the modification factor are used for clarity.

The ratio of base shears for low stiff buildings is obtained from [A5], [A6], and [A8]:

$$[A11] \quad \frac{V_{NRC}}{V_{NEHRP}} = \frac{C\nu W/R_{NRC}}{2.12A_a W/R_{NEHRP}}$$

In this equation, the value of I is taken equal to 1.0 and the term W cancels out. Although the values of ν and A_a are not the same, a comparison can be made when $Z_a = Z_v$, in which case $V = A_a$ and $C = 1.08$; thus

$$[A12] \quad \frac{V_{NRC}}{V_{NEHRP}} = 0.51 \times \frac{R_{NEHRP}}{R_{NRC}}$$

Table 4 summarizes the results of application of [A10] and [A12] using the respective R factors generally used in the two documents. Equations [A10] and [A12], however, are not used for unreinforced masonry, for which both documents use the same equations except that the NRC Guidelines replace ν by ν' , where $\nu' = \nu IF/1.3 \leq 0.4I$, which results in a range of V_{NRC}/V_{NEHRP} from 0.8 to 1.5.