

# Proposed Canadian code provisions for seismic design of elements of structures, nonstructural components, and equipment<sup>1</sup>

W.E. McKevitt

**Abstract:** Proposed code provisions for the seismic design of elements of structures, nonstructural components, and equipment are presented. In these provisions a new format is introduced which gives a consistent treatment for all elements and components, architectural, mechanical, and electrical. For the first time, soil effects are included in the provisions, which also seek to ensure that designers consider the interrelationship of the nonstructural components and differential displacements within the building structure. The proposed force equation is based on a uniform hazard spectrum approach with force modification factors. Specified force levels are based on data from instrumented buildings recorded during recent earthquakes. Updated requirements for connection design specify forces that are consistent with component design forces. New element and component categories are provided in an expanded table of elements of structures, nonstructural components, and equipment. To assess the impact of the proposed provisions on component design at various locations across the country, calculations are presented for typical multistorey buildings in a number of Canadian cities.

*Key words:* seismic design, elements of structures, nonstructural mechanical electrical architectural components.

**Résumé :** De nouvelles clauses portant sur la conception parasismique d'éléments de structures, de composants et d'équipements non-structuraux sont proposées et présentées. Pour ces clauses, un nouveau format est introduit, lequel permet un traitement cohérent de tous les éléments et composants : architecturaux, mécaniques et électriques. Pour la première fois, les effets du sol sont pris en compte par les clauses qui cherchent aussi à faire en sorte que les concepteurs considèrent l'interrelation entre les composants non-structuraux et les déplacements différentiels au sein du bâtiment. L'équation de force proposée est basée sur une approche de spectre de risque uniforme avec des facteurs de modification de forces. Les niveaux de force spécifiés sont basés sur des données obtenues sur des bâtiments instrumentés et qui ont été enregistrées au cours de tremblements de terre récents. Les exigences en matière de conception des connexions ont été mises à jour pour indiquer des forces qui sont cohérentes avec les forces de conception des composants. De nouvelles catégories d'éléments et de composants sont fournies dans une table agrandie dite table des éléments de structures, de composants et équipements non-structuraux. Afin d'évaluer l'impact des clauses proposées sur la conception de composants à différents endroits repartis sur tout le pays, des calculs sont appliqués à des bâtiments à étages multiples typiques, ce pour un certain nombre de villes canadiennes.

*Mots clés :* conception parasismique, éléments de structures, composants mécaniques électriques architecturaux non-structuraux.

[Traduit par la Rédaction]

## Introduction

This paper discusses the proposed provisions for design of elements of structures, nonstructural components, and equipment as part of the updated (2005 edition) National Building Code of Canada (NBCC) provisions for earthquake loads and effects.

The aim of the proposed provisions is to establish minimum design criteria for architectural, mechanical, electrical, and other nonstructural components in buildings. The formulation of the proposed provisions is based on the uniform hazard spectrum approach used for the design of structures.

These provisions should ensure that the installation of unattached mechanical and electrical equipment be virtually

Received 22 January 2002. Revision accepted 8 August 2002. Published on the NRC Research Press Web site at <http://cjce.nrc.ca> on 28 April 2003.

W.E. McKevitt. McKevitt Engineering Ltd., Suite 301, 1847 West Broadway, Vancouver, BC V6J 1Y6, Canada (e-mail: [wmckevitt@attglobal.net](mailto:wmckevitt@attglobal.net)).

Written discussion of this article is welcomed and will be received by the Editor until 31 August 2003.

<sup>1</sup>This article is one of a selection of papers published in this Special Issue on the Proposed Earthquake Design Requirements of the National Building Code of Canada, 2005 edition.

**Table 1.** Elements of structures, nonstructural components, and equipment.

Category	Description	$C_p$	$A_r$	$R_p$
1	All exterior and interior walls except those of categories 2 and 3	1.00	1.00	2.50
2	Cantilever parapet and other cantilever walls except retaining walls	1.00	2.50	2.50
3	Exterior and interior ornamentations and appendages	1.00	2.50	2.50
4	Floors and roofs acting as diaphragms	—	—	—
5	Towers, chimneys, smokestacks, and penthouses when connected to or forming part of a building	1.00	2.50	2.50
6	Horizontally cantilevered floors, balconies, beams, etc.	1.00	1.00	2.50
7	Suspended ceilings, light fixtures, and other attachments to ceilings with independent vertical support	1.00	1.00	2.50
8	Masonry veneer connections	1.00	1.00	1.50
9	Access floors	1.00	1.00	2.50
10	Masonry or concrete fences over 1.8 m tall	1.00	1.00	2.50
11	Machinery, fixtures, equipment, ducts, and tanks (including contents) that are rigid and rigidly connected	1.00	1.00	1.25
	that are flexible or flexibly connected	1.00	2.50	2.50
12	Machinery, fixtures, equipment, ducts, and tanks (including contents) containing toxic or explosive materials, materials having a flashpoint below 38°C, or firefighting fluids that are rigid and rigidly connected	1.50	1.00	1.25
	that are flexible or flexibly connected	1.50	2.50	2.50
13	Flat-bottom tanks (including contents) attached directly to a floor at or below grade within a building	0.70	1.00	2.50
14	Flat-bottom tanks (including contents) attached directly to a floor at or below grade within a building containing toxic or explosive materials, materials having a flashpoint below 38°C, or firefighting fluids	1.00	1.00	2.50
15	Pipes, ducts, cable trays (including contents)	1.00	1.00	3.00
16	Pipes, ducts (including contents) containing toxic or explosive materials	1.50	1.00	3.00
17	Electrical cable trays, bus ducts, conduit	1.00	2.50	5.00
18	Rigid components with ductile material and connections	1.00	1.00	2.50
19	Rigid components with nonductile material or connections	1.00	1.00	1.00
20	Flexible components with ductile material and connections	1.00	2.50	2.50
21	Flexible components with nonductile material or connections	1.00	2.50	1.00

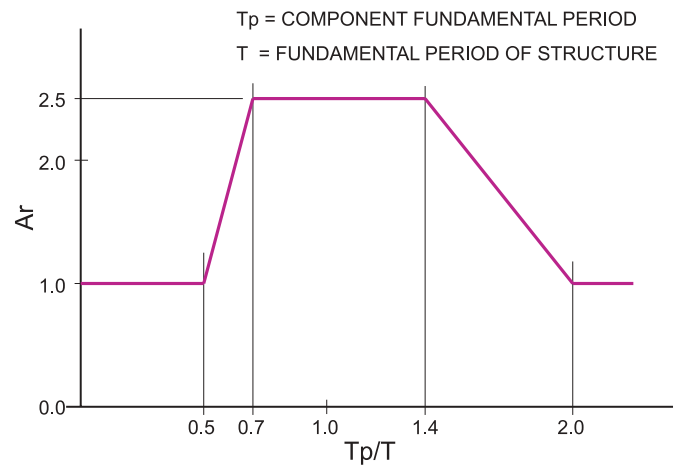
eliminated for buildings in areas of moderate and high seismicity.

The seismic design force equations included in the provisions are based on data and experience obtained from past earthquakes. The design force equations, used in the proposed provisions, originated with a study and workshop sponsored by the National Center for Earthquake Engineering Research (NCEER) in the U.S. The objective of that study was to develop a supportable force equation that is consistent with recorded earthquake data (Bachman et al. 1993).

**Proposed force equation for elements and components**

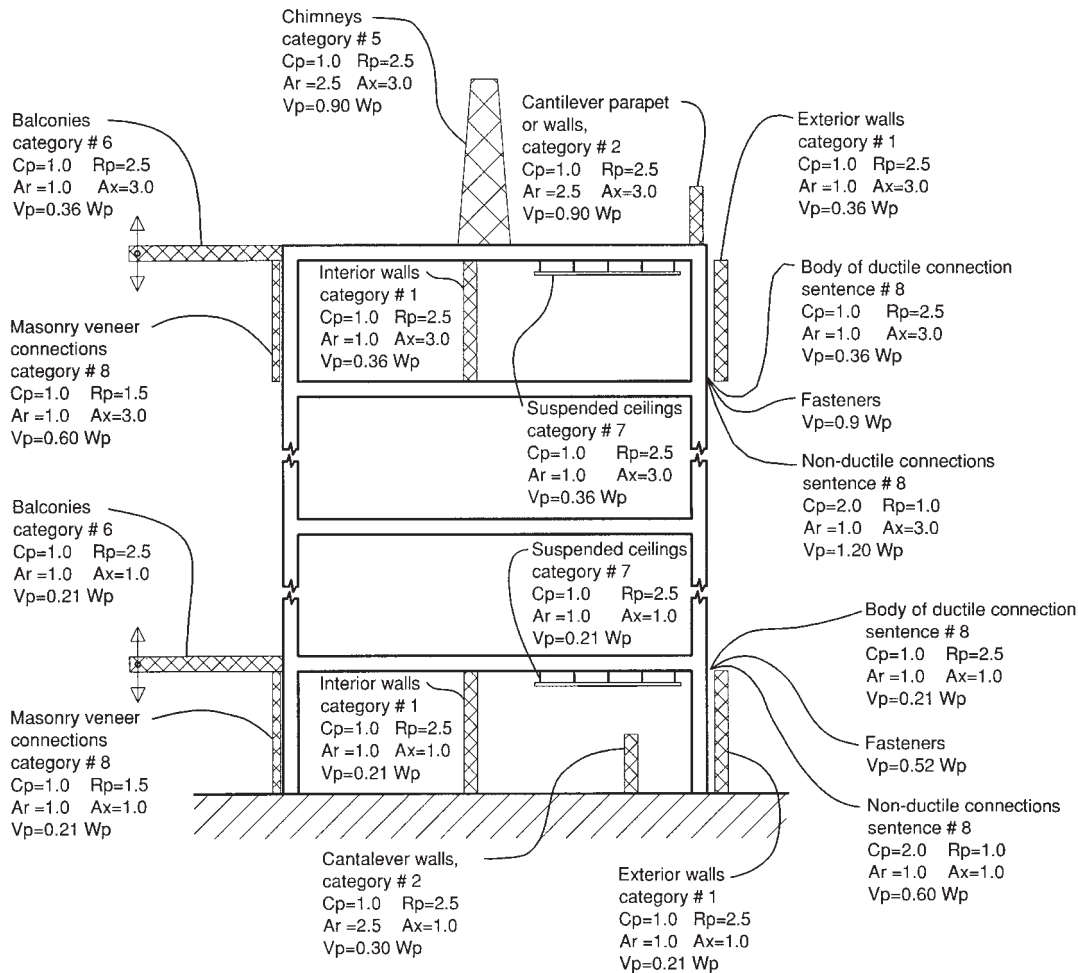
The proposed requirements for earthquake loads and effects include new element and component categories in an expanded table of elements of structures and nonstructural components and equipment. More realistic force factors are specified in the proposed provisions based on data from instrumented buildings during recent earthquakes. The proposed code provisions use force modification factors similar to those of the provisions for seismic design of structures.

**Fig. 1.** Component amplification factor  $A_r$  versus period ratio  $T_p/T$ .



A consistent approach for all elements, components, and connections, architectural, mechanical, and electrical, is introduced. In past code provisions there has been a different set of force requirements for architectural components than for the mechanical and electrical equipment. This has been

**Fig. 2.** Values of the element or component factor  $C_p$ , the element or component response modification factor  $R_p$ , the dynamic amplification factor of the component  $A_r$ , the height factor  $A_x$ , and the seismic force  $V_p$  for architectural components in a typical building in Vancouver.  $W_p$ , weight of the component.



largely because of the historic development of the codes and a sense that the architectural cladding components required a more conservative design force level to avoid large components falling off the sides and roofs of buildings onto sidewalks during an earthquake. The use of large force factors alone, however, does not ensure that the architectural components will not fall from buildings during earthquakes. Experience in seismic events during the last 20 years has shown that the details of the components and their attachment to the structure are also critical aspects of design. In this regard, the proposed code provisions expand the requirements for component detailing to accommodate the seismic displacements of the component and the structure along with the design and detailing requirements for the connections of the components to the structure. With this specific attention paid to the architectural components in the proposed provisions, it is prudent to apply the same formulation as used for the mechanical and electrical components. Hence a height factor is included in the force level calculation for the architectural components.

In the proposed definition, eq. [1], the design force  $V_p$  for elements of structures, nonstructural components, and equipment and their attachments is given as

$$[1] \quad V_p = 0.3 F_a S_a(0.2) I_E S_p W_p$$

where  $F_a$  is the acceleration-based site coefficient,  $S_a(0.2)$  is the spectral response acceleration value for a period of 0.2 s,  $I_E$  is the earthquake importance factor,  $S_p$  is the force factor for the element or nonstructural component, and  $W_p$  is the weight of the component. The new formulation of  $V_p$  includes  $S_a(0.2)$  and  $R_p$ , the element or component response modification factor as part of eq. [2] defining  $S_p$ . This is consistent with the uniform hazard spectrum approach and the general formulation used for the proposed seismic force provisions for structures.

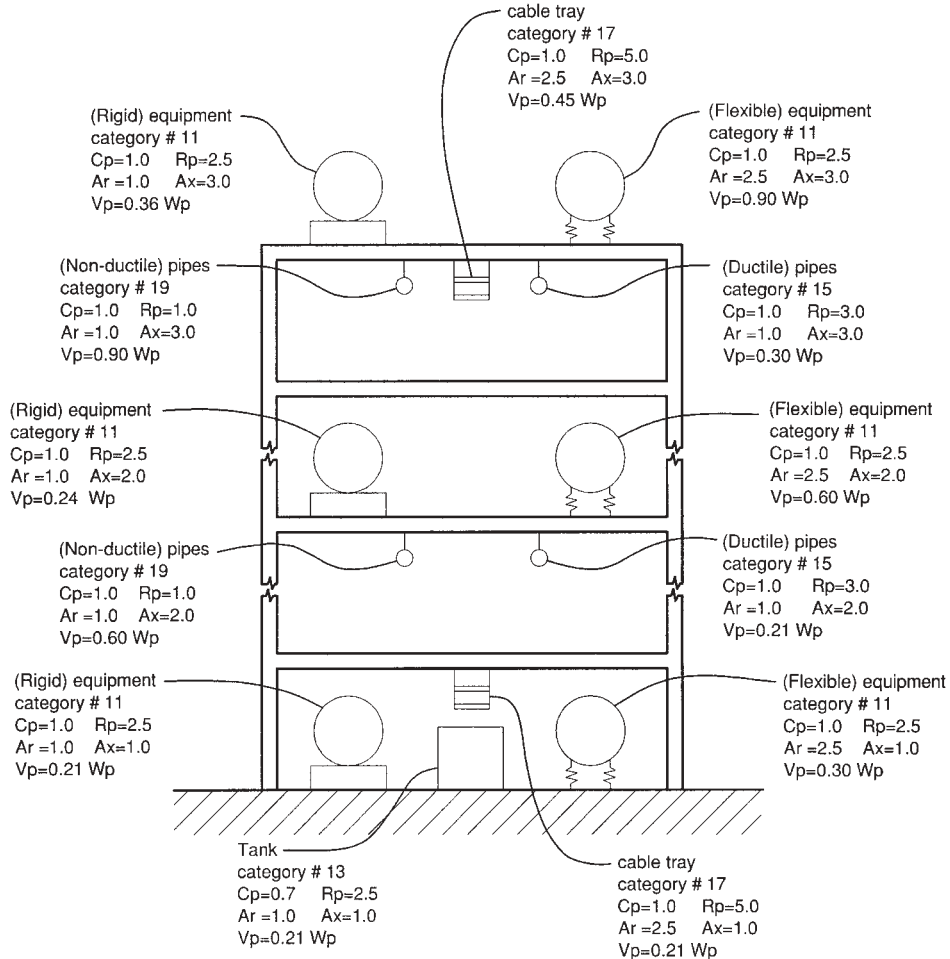
Soil effects are included in the proposed equation by the factor  $F_a$ . In past codes the force factors for components and elements did not take into account soil conditions at the site. In general, the force levels used by past codes were intended to provide upper bound forces for all building and soil types. This led to conservatism in the design force value and inconsistencies between the levels of protection provided by the code provisions for the structure and the nonstructural components in the same building. A comparison of the force levels in two similar buildings, one on rock and one on deep soft soils, highlights this point. The structure of the building

**Table 2.** Exemptions in the provisions for seismic design of structures at locations in areas of low seismic risk.

Location	1995 NBCC			Proposed 2005 NBCC					$S_a$	Proposed 2005 NBCC				
	$Z_a$	$Z_v$	$\nu$	Ordinary building	School	Soft site	Post-disaster	Ordinary building		School	Soft $F_a$	Soil site	Post-disaster	
St. John's	1	1	0.05	n	n	y	y	0.18	n	n	2.1	y	y	
Halifax	1	1	0.05	n	n	y	y	0.22	n	n	2.1	y	y	
Moncton	2	1	0.05	y	y	y	y	0.3	n	y	1.96	y	y	
Fredericton	2	1	0.05	y	y	y	y	0.39	y	y	1.7	y	y	
Toronto	1	0	0.05	n	n	y	y	0.28	n	y	2	y	y	
Windsor	0	0	0	n	n	n	n	0.17	n	n	2.1	y	y	
Calgary	0	1	0.05	n	n	y	y	0.15	n	n	2.1	n	y	
Kelowna	1	1	0.05	n	n	y	y	0.27	n	y	2	y	y	
Kamloops	1	1	0.05	n	n	y	y	0.28	n	y	2	y	y	
Prince George	0	2	0.1	y	y	y	y	0.13	n	n	2.1	n	y	
Prince Rupert	3	5	0.3	y	y	y	y	0.36	y	y	1.8	y	y	
Inuvik	1	2	0.1	y	y	y	y	0.1	n	n	2.1	n	y	

Note: n, seismic restraint not required; y, seismic restraint required.

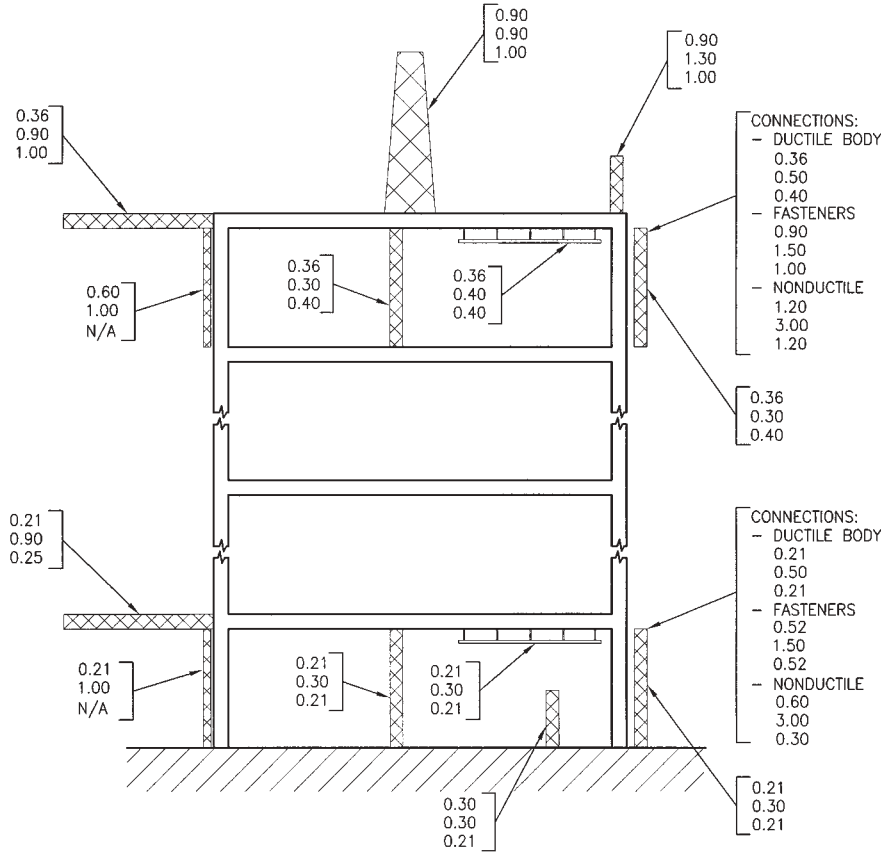
**Fig. 3.** Values of  $C_p$ ,  $R_p$ ,  $A_r$ ,  $A_x$ , and  $V_p$  for mechanical and electrical components in a typical building in Vancouver.



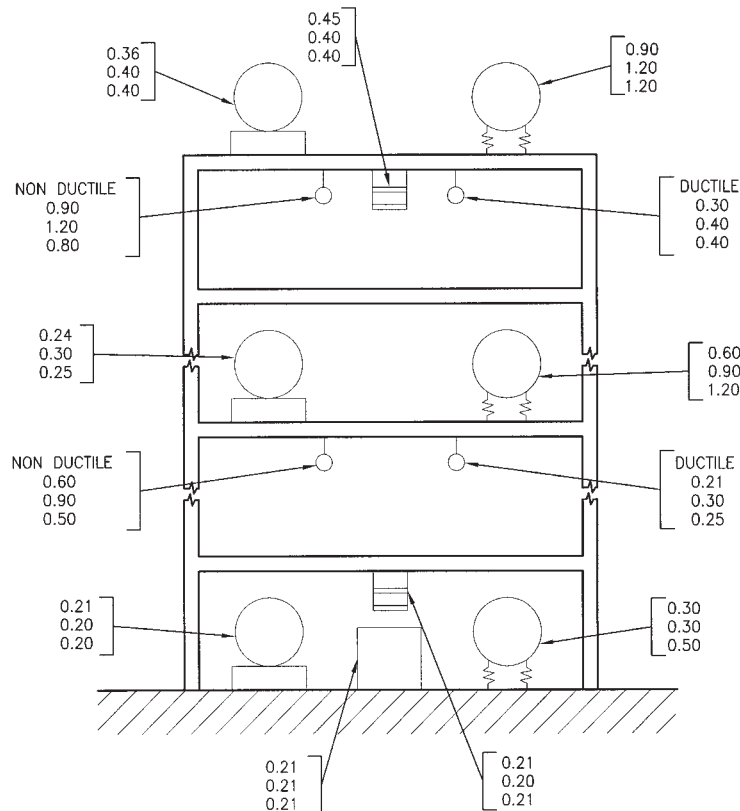
on soft soils could be designed for a higher force level than an identical structure on rock, but the components in both buildings would be designed for the same force level. Inclusion of the soil factor in the proposed formulation of the element and component force levels removes this inconsistency.

The seismic hazard at the site of the structure is included in the design force formula with the spectral response acceleration value  $S_a(0.2)$ , which is the uniform hazard spectrum ordinate at 0.2 s period. Most components and elements in a building are stiff or rigid, and research from past earthquakes has shown that the forces on the components corre-

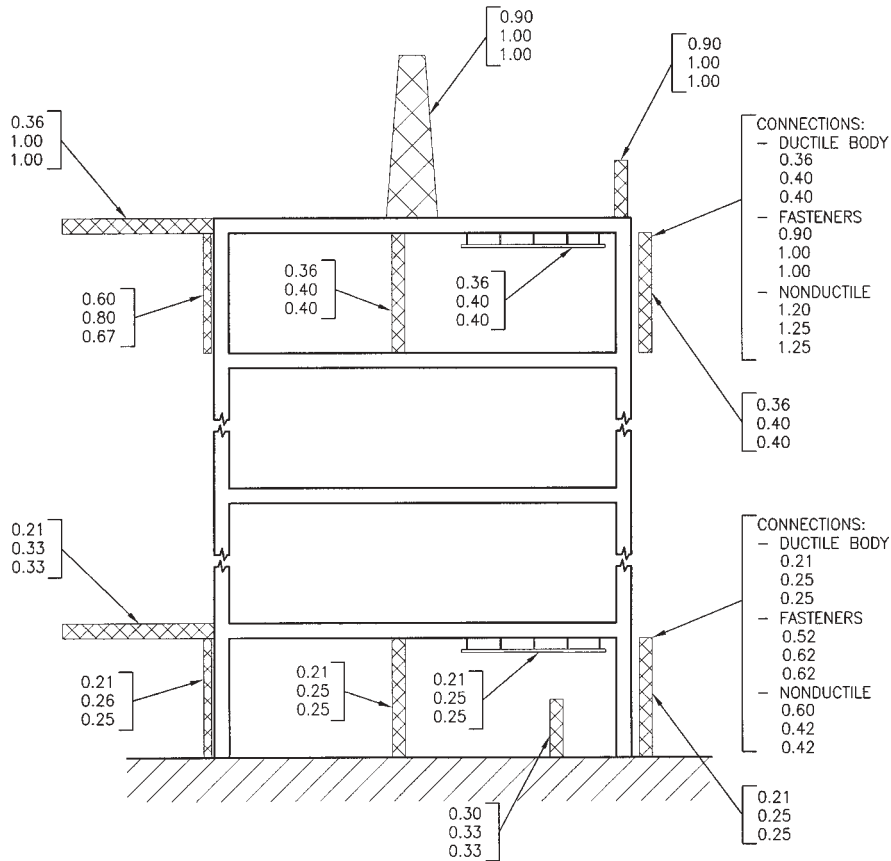
**Fig. 4.** Comparison of proposed force levels (upper value in each grouping of three values) with those from the 1995 NBCC (middle value) and the 1997 UBC (lower value) for architectural components in a typical building in Vancouver.



**Fig. 5.** Comparison of proposed force levels (upper value in each grouping of three values) with those from the 1995 NBCC (middle value) and the 1997 UBC (lower value) for mechanical and electrical equipment in a typical building in Vancouver.



**Fig. 6.** Comparison of proposed force levels (upper value in each grouping of three values) with those from the 1997 NEHRP and 2000 IBC (middle value) and the 2000+ NEHRP (lower value) for architectural components in a typical building in Vancouver.



late most closely with this acceleration ordinate (NEHRP 2000).

The importance factor  $I_E$  is taken as the same importance factor used for the building in which the component is located.

The force factor  $S_p$  for the element or nonstructural component is defined as

$$[2] \quad S_p = C_p A_r A_x / R_p$$

where  $C_p$  is the element or component factor,  $A_r$  is the dynamic amplification factor of the component, and  $A_x$  is a height factor. A lower limit for  $S_p$  for the component and connections was set to be 0.7. This is equivalent to the minimum values used in current standards. A conservative maximum value of  $S_p = 4.0$  is also set in the provisions.

The element or component factor,  $C_p$ , from Table 1 (Table 4.1.8.17 of the proposed provisions) considers the risk to life safety associated with failure of the component and release of contents. Components that contain toxic or explosive materials are given a higher  $C_p$  value to reflect the increased risk to life safety associated with failure of these components.

The factor  $A_r$  is a function of the ratio of the natural frequency of the component and the fundamental period of the structure to which it is attached. When this ratio is close to unity, the dynamic amplification is 2.5. In other cases the dynamic amplification factor is 1.0. Values of the dynamic amplification factor are given in Table 1. These values represent the typical amplification factors for the various compo-

nent categories. More accurate values of  $A_r$  can be used when both the structural and component fundamental frequencies are known. In such cases, values of  $A_r$  can be obtained from Fig. 1, which is taken from the National Earthquake Hazard Reduction Program study (NEHRP 2000).

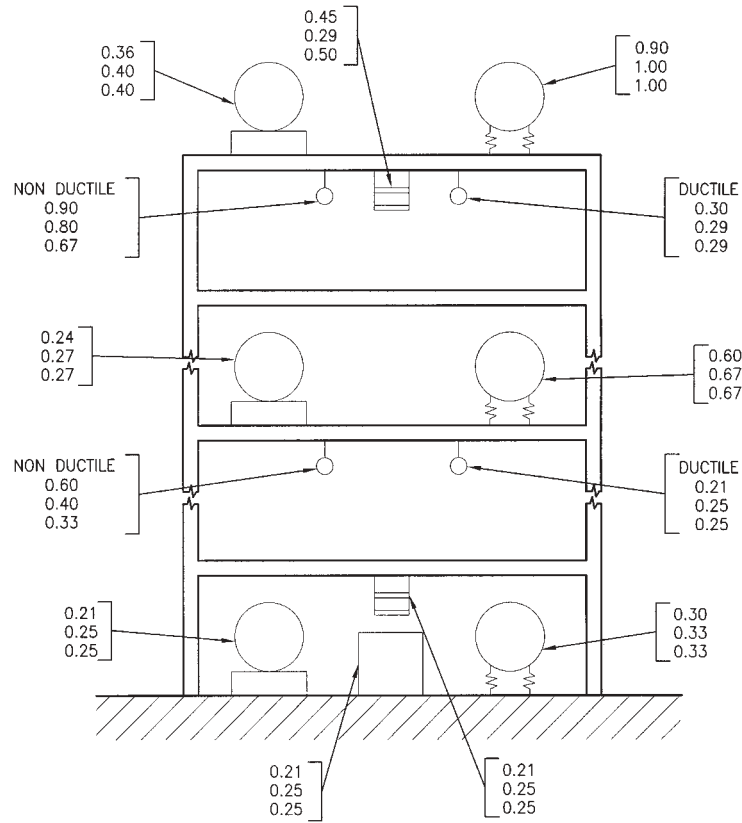
The new height factor,  $A_x = 1 + 2h_x/h_n$ , where  $h_x$  is the height above the base of the structure to level  $x$  and  $h_n$  is the total height of the structure, is a factor that considers the distribution of floor acceleration through the height of the structure. The minimum value of  $A_x$  is 1.0 at foundation level and 3.0 at roof level. This distribution of acceleration with the height of the building is based on recorded in-structure acceleration data obtained from instrumented multistorey buildings in past earthquakes with peak ground accelerations greater than  $0.1g$  (NEHRP 2000).

The factor  $R_p$  is the element or component response modification factor and represents the energy-absorption capacity of the component and its attachments. The values of  $R_p$  given in Table 1 are based on experience from past earthquakes and the judgement of engineers experienced in this aspect of seismic design. From this, a reasonable assessment of the ductility inherent within the components and their connections, based on observation of performance during earthquake events, has been included.

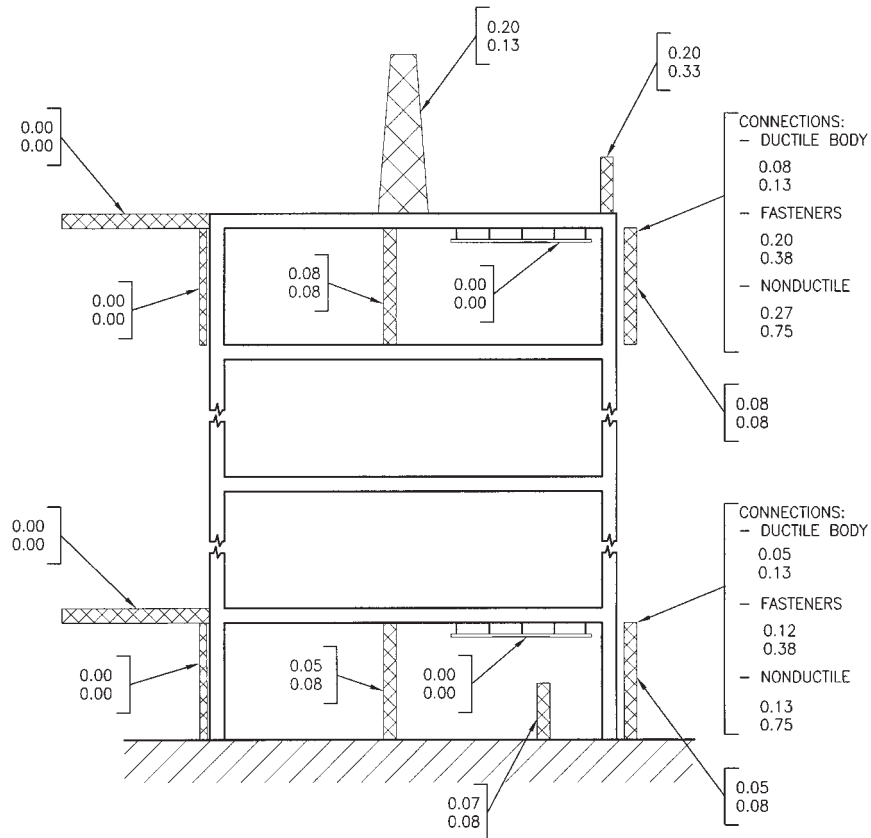
### Connections

Connections for elements and components are to be designed for gravity and seismic forces. The provisions for the

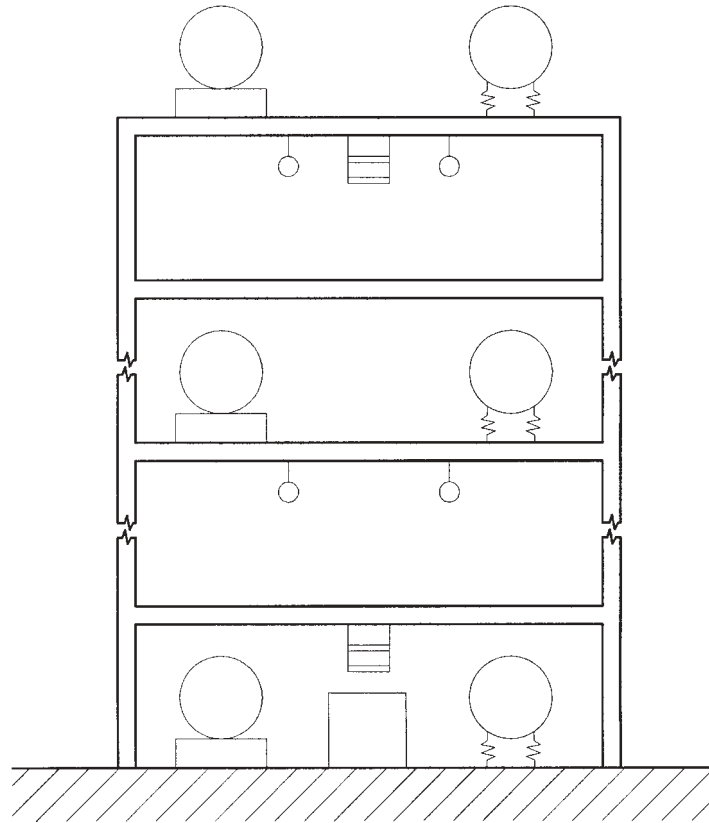
**Fig. 7.** Comparison of proposed force levels (upper value in each grouping of three values) with those from the 1997 NEHRP and 2000 IBC (middle value) and the 2000+ NEHRP (lower value) for mechanical and electrical equipment in a typical building in Vancouver.



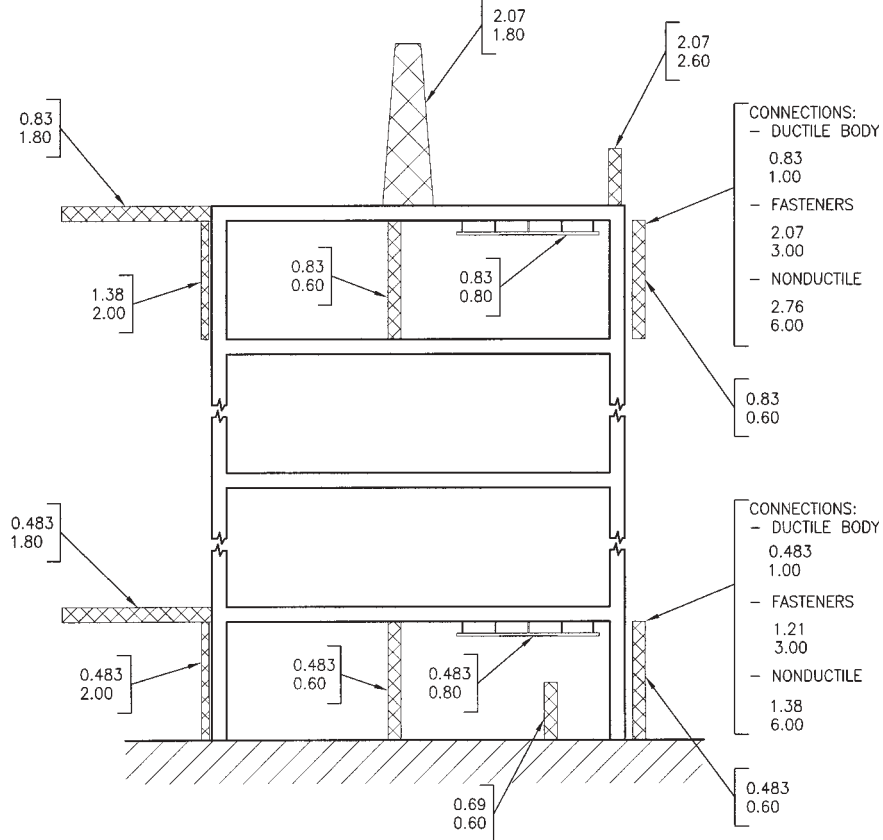
**Fig. 8.** Comparison of proposed force levels (upper value in each grouping of two values) with those from the 1995 NBCC (lower value) for architectural components in a typical building in Toronto.



**Fig. 9.** Comparison of proposed force levels with those from 1995 NBCC for mechanical and electrical equipment in a typical building in Toronto (both sets of forces are 0.00).

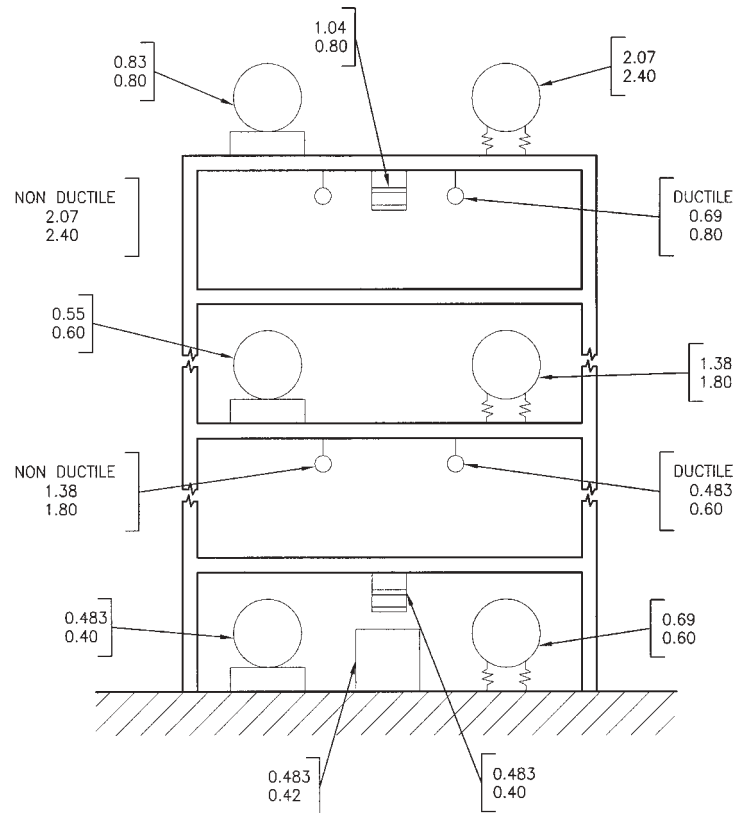


**Fig. 10.** Comparison of proposed force levels (upper value in each grouping of two values) with those from the 1995 NBCC (lower value) for architectural components in a typical building in La Malbaie.





**Fig. 11.** Comparison of proposed force levels (upper value in each grouping of two values) with those from the 1995 NBCC (lower value) for mechanical and electrical equipment in a typical building in La Malbaie.



design of connections are intended to ensure that anchorage and connections will yield in a controlled manner. To achieve this, the provisions require that the body of the connection be designed for smaller forces than those designed for the connecting bolts, welds, or anchors. This is intended to produce a ductile connection that can deform beyond the yield load of the connection and provide a deformable link in the load path. Prying action should be considered in connection design where appropriate. Lower force reduction factors are specified for connection methods that use low-ductility attachments which result in higher design forces.

Forces for connections of architectural components are now consistent with design forces in mechanical and electrical components. Also, in past code provisions there has been an anomaly between the design force required for an architectural component and the force that its connections were designed for. Historically, this came about because of concern that objects might fall off the roof or sides of buildings. This concern is still of paramount importance for designers, but instead of assigning arbitrarily high force levels for the connection design of these components, the proposed provisions go to some length to ensure that the designer will develop ductile connections that can be relied upon to be stable well into inelastic deformation cycles. In this way the force levels for connections are consistent with the force levels used for the design of the components. See, for example, the forces for exterior walls and their connections in Fig. 2.

Frictional resistance of components and attachments cannot be relied upon during seismic events. The dynamic loading of the seismic forces, rocking effects, and vertical

accelerations have caused unattached components to move or “walk” considerable distances in past earthquakes.

## Exemptions

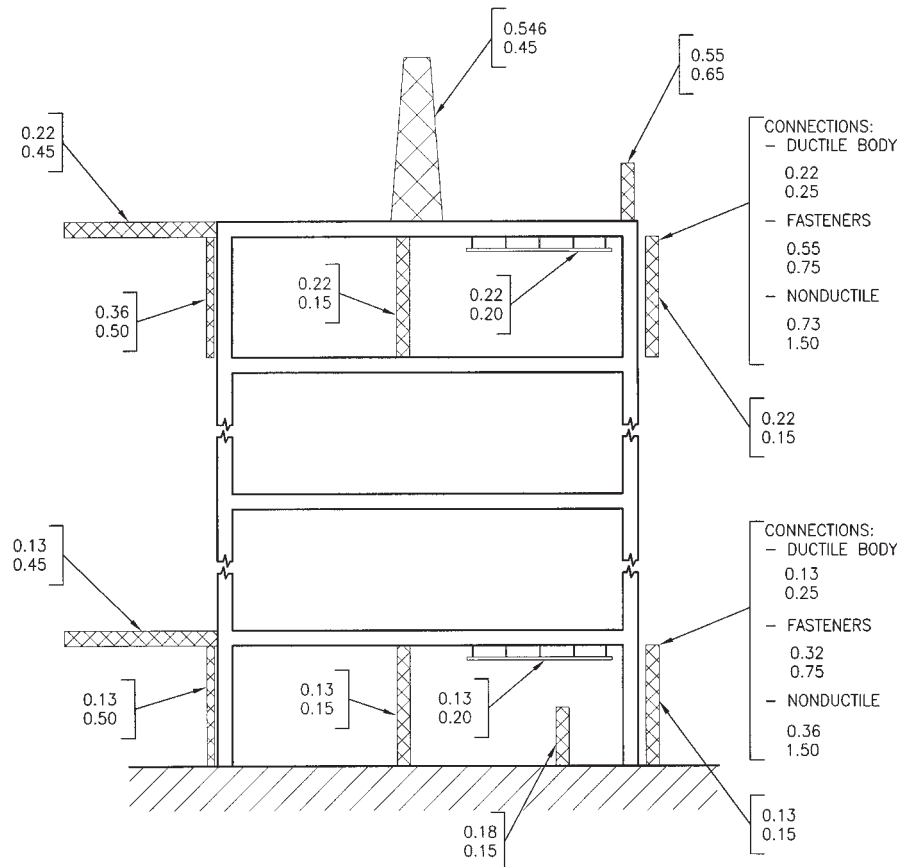
A number of exemptions are made in the provisions for areas of low and moderate seismic acceleration. This reflects the low risk of personal injury and damage associated with local failures of these components in areas of lower seismicity. The trigger that activates these exemptions is effective where, for non-post-disaster buildings,  $I_e F_a S_a(0.2)$  is less than 0.35, where  $I_e$  is the importance factor. There are a number of regions where the application of this exemption differs from those in the 1995 National Building Code of Canada (NBCC 1995). Table 2 summarizes these differences for selected locations.

## Displacements

The proposed provisions also seek to ensure that the designer considers the interrelationship of the nonstructural components with the building structure. In the design of the components, their support structures and attachments, the flexibility of the complete system should be considered. Components that are subjected to relative displacements during a seismic event should be designed to accommodate the relative displacements.

For example, where nonstructural wall components can stiffen the structural system, care must be exercised in selecting the wall materials and in designing the connecting

**Fig. 12.** Comparison of proposed force levels (upper value in each grouping of two values) with those from the 1995 NBCC (lower value) for architectural components in a typical building in Ottawa or Montréal.



details and joints to ensure that the desired performance of each component is achieved. Glazing, partitions, stairs, and veneers are examples of other components that should also be designed to accommodate relative seismic displacements.

The requirements emphasize the need for strength and ductility in the attachment of the component to the building structure and the need to accommodate the differential displacements that can occur.

### Architectural components

The primary focus of the provisions for architectural components and their attachments is to reduce the threat to life safety caused when these components fail or become detached from the structure. Falling objects can pose threats to building occupants and people outside the building on sidewalks and can block egress routes.

Property loss due to failures of architectural components is not addressed specifically by the provisions; however, the failure of architectural components or their attachments can cause serious effects on the function and operation of a facility. In general, improvement in life safety provisions also reduces property loss and improves building function.

Wall panels, nonstructural walls, and partitions are subjected to out-of-plane bending during an earthquake. These elements and any finishing veneers have to be designed for the bending and shear forces induced. The provisions now include a category for veneer connections.

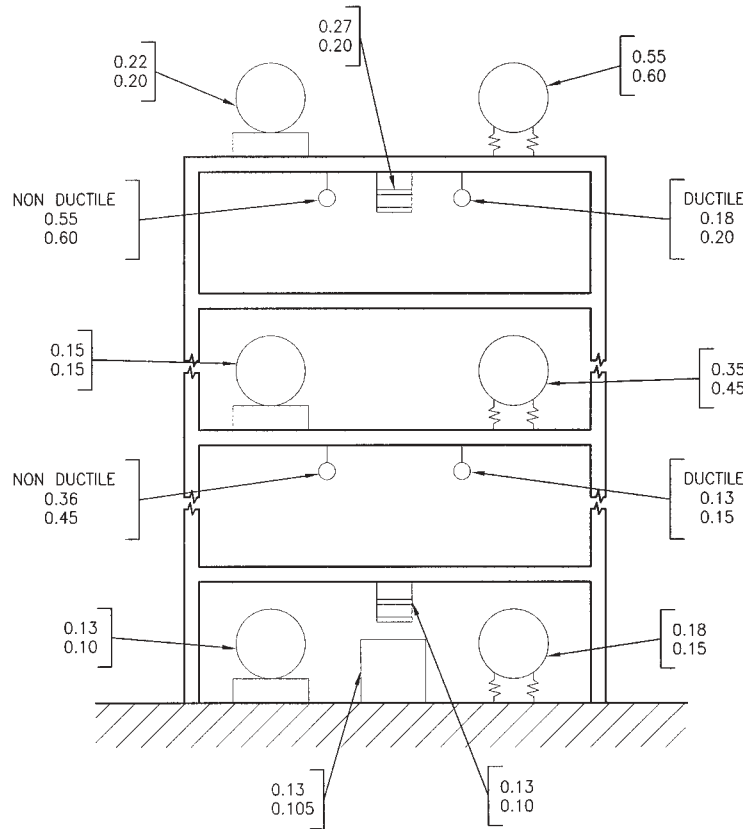
Partitions should be laterally restrained directly to the building structure. Suspended ceilings do not provide adequate lateral support for partitions. Past failures of suspended ceilings have been due primarily to loss of support for individual panels and interaction with sprinkler systems. The use of diagonal wires and compression struts improves the seismic performance of suspended ceilings and reduces displacements. The designer also must consider the effect of components that penetrate the ceiling such as lighting fixtures and sprinkler piping.

Design forces are specified for access floors such as those commonly used in computer rooms and control rooms. Seismic restraint can be provided by cantilever action of the support pedestals or by diagonal bracing from the floor to the supporting slab. The provisions require that design forces for access floors be based on the dead weight of the floor plus 25% of the floor live load plus 0.5 kN/m<sup>2</sup> partition allowance.

### Mechanical and electrical components

The proposed requirements for seismic design of mechanical and electrical equipment are intended to reduce the hazard to life safety posed by the failure of these components. Experience in past earthquakes has shown that, in general, mechanical and electrical equipment is inherently rugged and the majority of equipment built to current industry standards performs well with little damage. Many components can be accepted as meeting the requirements of these provi-

**Fig. 13.** Comparison of proposed force levels (upper value in each grouping of two values) with those from the 1995 NBCC (lower value) for mechanical and electrical equipment in a typical building in Ottawa or Montréal.



sions on the basis of past seismic performance or from shake-table test data. Where required, structural analysis of the components can be made using the forces specified in the provisions. The provisions also seek to ensure that the supports and attachments of the components be designed to accommodate the force and displacements specified.

The primary intent of the provisions is to provide minimum requirements for life safety. Functionality of equipment during or after seismic events is not directly addressed. This aspect of design can be critical for special situations such as emergency-response facilities, hospitals, fire halls, and other post-disaster facilities. Assessment of function can usually only be achieved by full-scale shake-table testing of equipment and is outside the scope of the present provisions.

Experience in past earthquakes has shown that systems of ductile piping, ductwork, and electrical cable tray systems perform well in strong-motion shaking. This is recognized in the provisions, and new categories are included for the design of this equipment. See Table 1 for the proposed new table of elements and components.

### Changes in design force levels

To assess the impact of the proposed provisions on design force levels at specific locations, calculations are presented for typical multistorey buildings in a number of Canadian cities. Note that in Figs. 2–13 data are given for the ground floor, a mid-height floor, and the roof of a multistorey high-rise building. These figures also show the effect of the upper and lower limits of the factor  $S_p$  on the design forces. In some cases the factor  $A_x$  increases by 3, but the changes to

the force levels are less because of the upper and lower limits on  $S_p$ .

Figures 2 and 3 show the appropriate values of the factors  $C_p$ ,  $R_p$ ,  $A_r$ , and  $A_x$  and the design force  $V_p$  to be used in calculations for components and connections in a typical building in Vancouver. Figure 2 shows the factors for architectural components, and Fig. 3 the factors for mechanical and electrical equipment.

In Figs. 4–7, comparisons are given for design forces for various building components in an ordinary building in Vancouver. Force levels obtained from the proposed code provisions can be compared with forces obtained using the 1995 NBCC provisions and the provisions in the Uniform Building Code (UBC 1997), the International Building Code (2000), and the National Earthquake Hazard Reduction Program (NEHRP 1997, 2000). The most significant difference between the proposed provisions and the 1995 NBCC provisions is in the design forces for the architectural components; this difference is a result of the inclusion of the height factor for the architectural components. There is also a general reduction in the connection forces required for architectural components.

Figures 8 and 9 show the difference between the proposed and current NBCC force levels for elements and components in a typical ordinary building in Toronto. This is typical of the effects of the proposed provisions on component forces in low seismic areas. Again, the change in force level for the architectural components can be seen.

Comparison of design forces for a building in the highest seismic area of the country are shown for La Malbaie in

Figs. 10 and 11. The most significant differences in force levels are again for the architectural components.

A comparison of the force levels for components in an ordinary building in Ottawa or Montréal is given in Figs. 12 and 13 to illustrate the effect of the proposed provisions in areas of moderate seismic risk. The effect of the inclusion of the height factor in the force calculation for the architectural components can be seen.

### Summary and conclusions

Proposed new code provisions for the seismic design of elements of structures, nonstructural components, and equipment in buildings are presented. Background data and development of the proposed provisions are given. The effect of the proposed provisions on design for selected locations within Canada is assessed and comparisons are made with previous code provisions.

The proposed provisions, which are based on data from past earthquakes and experience gained from these events, provide a consistent and comprehensive approach to the design of components and their attachment to structures.

### References

- Bachman, R.E., Drake, R.M., and Richter, P.J. 1993. 1994 Update to 1991 NEHRP provisions for architectural, mechanical and electrical components and systems. Letter report to the National Center for Earthquake Engineering Research, Building Seismic Safety Council, Washington, D.C.
- IBC. 2000. International Building Code 2000. International Code Council, Falls Church, Va.
- NBCC. 1995. National Building Code of Canada. Institute for Research in Construction, National Research Council of Canada, Ottawa, Ont.
- NEHRP. 1997. NEHRP recommended provisions for seismic regulations for new buildings and other structures. 1997 Edition. National Earthquake Hazard Reduction Program, Building Seismic Safety Council, Washington, D.C.
- NEHRP. 2000. NEHRP recommended provisions for seismic regulations for new buildings and other structures. 2000+ Edition. National Earthquake Hazard Reduction Program, Building Seismic Safety Council, Washington, D.C.
- UBC. 1997. Uniform Building Code. Vol. 2. Structural engineering design provisions. International Conference of Building Officials, Whittier, Calif.

