The 11th Canadian Conference on Earthquake Engineering

Canadian Association for Earthquake Engineering

COMPARISON OF 1995 AND 2005/2010 NBCC SEISMIC PROVISIONS FOR OPERATIONAL AND FUNCTIONAL COMPONENTS IN BUILDINGS

Assi Rola
Professor, École de Technologie Supérieure, Canada
Rola.Assi@etsmtl.ca

ABSTRACT: This paper summarizes the seismic force and displacement requirements for common operational and functional components (OFCs) in buildings according the recent editions of the National Building Code of Canada (1995 and 2005/2010). Force requirements in terms of location, soil conditions and elevation within the building for both architectural and mechanical/electrical components are discussed in order to assess the impact of changes in the recent NBCC editions on the seismic design force levels. Numerical examples illustrate the seismic design force levels for typical architectural and mechanical/electrical components as stipulated in the 1995 and 2005/2010 editions of the NBCC. The components are supposed to be attached at different elevations in a typical building of normal importance category. The building is supposed to be located in different seismic zones of Canada (Vancouver and Montreal) with different soil conditions

1. Introduction

A building comprises various components that can be divided into two groups: structural components and non-structural components known as operational and functional components (OFCs) in Canada. The OFCs are those systems and elements housed or attached to floors, roofs, and walls of a building or industrial facility. Although they are not part of the main or intended load-bearing structural system, OFCs may still contribute to the structural integrity of the building, depending on their location, type of construction, and method of fastening. OFCs can generally be divided into three categories of sub-components according to CSA S832-14 (2014) and Villaverde (1997): architectural (internal like interior partition walls, ceilings and lights and external like cladding and parapets), building or operational services including: plumbing systems (like piping and sprinklers), mechanical systems (like heating, ventilation, and elevators), and electrical systems (like electric generators, transformers, and battery racks), information technology and telecommunications (like telephone system, communication system, and cable trays), and building contents (common like supplies, computer systems, record storage, and specialized like fine arts, medical equipment and hazardous materials). From a structural perspective, OFCs can be classified into either deformation sensitive (drift ratio) or acceleration sensitive (force), and many components are both deformation and acceleration sensitive (FEMA, 2009).

OFCs account for most of the initial investment in a typical building; for example, they constitute 82%, 87% and 92% of the original construction cost in office, hospitals and commercial buildings (Miranda and Taghavi , 2003). A review of typical damage occurred in recent moderate earthquakes such as the M_w = 6.8 February 28, 2001 Nisqually, Seattle earthquake (Filiatrault et al., 2001), the M_w = 6.7 October 15, 2006 Kona, Hawaii earthquake (Chock et al., 2006), the M_w = 6.7 April 6, 2009 L'Aquila, Italy earthquake (Braga et al., 2011), and the M_w = 6.7 September 4, 2010 Darfield, Canterbury earthquake (Dhakal , 2010) highlights the fact that the dysfunction/failure of OFCs is the greatest contributor to damage, losses and business interruption in most facilities. Therefore, the failure of OFCs in an earthquake can not only result in important direct financial losses, but also can significantly disrupt the function of the building and pose a safety risk to building occupants and passersby, so OFCs are far from being secondary in importance when it comes to seismic risk analysis.

In recent years, engineers, researchers, and building code committees have paid increasing attention to the seismic performance of OFCs attached to building structures. As a result, the requirements of the 2005 and 2010 editions of the NBCC are more detailed than previous editions and include explicit provisions for more items in facilities that require post-earthquake functionality.

Good seismic design of OFCs requires consideration of both the accelerations and deformations that arise during an earthquake and that are imposed on such components. This paper compares the NBCC seismic provisions for OFCs in terms of force and displacement requirements as reflected in the 1995 and 2005/2010 editions.

2. Seismic provisions for OFCs in the 1995 edition of NBCC

The 1995 edition of NBCC (NRCC, 1995) uses the same seismic zoning maps as the 1985 edition (NRCC, 1985). The zoning maps divided the country into seven acceleration and velocity related zones and were based on a probability of exceedance of 10% in 50 years (i.e. 0.0021 per annum compared to 0.01 in previous editions).

2.1. Seismic force requirements

The provisions for building parts and portions are similar to those of the 1985 edition of NBCC, which introduced a distinction in the force requirements for architectural components and for mechanical and electrical components. The minimum lateral force, V_p, for which buildings parts and their anchorage shall be designed is given by:

$$V_p = vIS_pW_p \tag{1}$$

Where $S_p = C_pA_rA_x$ for mechanical/electrical components (2)

ν is the zonal velocity ratio expressed as a ratio of the specified zonal horizontal ground velocity to 1m/s. S_p is the horizontal force factor for part or portion of a structure and its anchorage; values of S_p for architectural components are specified and vary between 0.7 (floors and roofs acting as diaphragms) and 15.0 (non-ductile attachments/connections). The importance factor I is introduced again, to establish compatibility of design risks with the structural system of post-disaster buildings (I=1.5) and schools (I=1.3). C_p is the element or component factor, it is specified for few mechanical components and tanks; it varies from 0.7 to 1.5. A_r is the response amplification factor to account for the type of attachment of mechanical/electrical component; it is equal to 1.0 for components that are both rigid and rigidly connected and for non-brittle pipes and ducts, 1.5 for components located on the ground that are flexible or flexibly connected except for non-brittle pipes and ducts and 3.0 for all other cases. A_x is the amplification factor at level x to account for the variation of response of mechanical/electrical components with height; it is equal to $(1+ h_x/h_n)$, where h_x is the height above the base of the structure at level x and h_n is the total height of the structure; the maximum value of A_x at the roof level is equal to 2.0. In this edition, the provisions for mechanical/electrical components were more elaborate and rational than those for architectural components.

It should be noted that no upper or lower limits were specified for the calculated S_p values for mechanical/electrical components. In addition, the effect of soil conditions at the building site is not considered.

2.2. Seismic displacement requirements

The seismic displacement requirements in the 1995 edition of NBCC are the same as the 1990 edition (NRCC, 1990). A major change was introduced for the so-called post-disaster buildings such as hospitals, police and fire stations, and other buildings related to public safety that must remain functional during and immediately after an earthquake with a $0.01h_s$ limit on the interstory drift at any level, based on the lateral deflections obtained from linear elastic analysis. The value of $0.02\ h_s$ remained unchanged for all other buildings. Instead of specifying a fixed value of 3.0 to multiply the lateral deflections obtained from elastic analysis, a factor R was introduced to give more realistic values of anticipated deflections. R reflects the capacity of the structure to dissipate energy through inelastic behavior; suggested values of R varied from 1.0 to 4.0.

3. Provisions of the 2005/2010 editions of the NBCC

The formulation of the 2005 and 2010 provisions of NBCC (NRCC, 2005; NRCC, 2010) for elements of structures, non-structural components and equipment is based on the uniform hazard spectrum approach used for the design of structures (Adams and Halchuck, 2003; Adams and Atkinson, 2003). The uniform hazard spectrum model and resulting maps account for soil type and near-fault effects since they incorporate a significant amount of new earthquake data, recent research on source zones and earthquake occurrence, together with complementary research on strong ground motion relations. The seismic hazard at the site of the structure is included in the design force equation through the spectral value Sa(0.2), which is taken from the uniform hazard spectrum at a period of 0.2s. It is assumed that most components in buildings are stiff or rigid since research from past earthquakes has shown that the forces on the components correlate most closely with this acceleration ordinate (FEMA, 2009).

The 2005 and 2010 provisions use site values for design instead of zone values as used in previous editions of NBCC. Site values are based on a probability of exceedance of 2% in 50 years (instead of 10% in 50 years in previous editions), corresponding to a return period of approximately 2500 years. Site class C (very dense soil or soft rock) was adopted as a reference for reasons summarized in Adams and Halchuck (2003). The values for the UHS of the 2010 edition of NBCC were recalculated using an improved fit to the ground motions used in 2005 (Mitchell et al., 2010).

3.1. Seismic force requirements

The provisions currently in effect use the same equation to describe the lateral force requirements for architectural, mechanical and electrical components. The minimum lateral force, V_p, for which buildings parts and their anchorage shall be designed is given by:

$$V_p = 0.3 F_a S_a(0.2) I_E S_p W_p \tag{3}$$

Where F_a is the acceleration-based site coefficient, it varies from 0.7 to 1.4 and is function of site class and $S_a(0.2)$; $S_a(0.2)$ is the spectral response acceleration value at 0.2s and it varies from 0.12 (Inuvik) to 1.2 (Victoria). I_E is the importance factor for the building (it can take values of 1, 1.3 or 1.5).

$$S_p = \frac{C_p A_r A_x}{R_p} \tag{4}$$

The maximum value of S_p shall be taken as 4.0 and its minimum value shall be taken as 0.7. C_p is the element or component factor specified for different types of components. It considers the risk to life safety associated with the failure of the component and release of contents. It varies from 0.7 for low risk component failure to 1.5 for high-risk components. R_p is the element or component response modification factor that is introduced for the first time to account for the energy-absorption capacity of the element and its attachment; it varies from 1.25 to 5. A_r is the element or component force amplification factor to account for possible tuning between the building and the component, it is function of the ratio of the natural frequencies of the component and the structure and it varies from 1.0 to 2.5. A_x is the height factor; it considers the linear amplification of acceleration through the height of the building and it is equal to $1+ 2h_x/h_n$. It should be noted that the maximum value of A_x at the rooftop level is equal to 3.0 compared to 2.0 in the 1995 edition of NBCC and the height factor is considered for the first time for architectural components.

The NBCC 2005/2010 provisions allow the use of more accurate values of the amplification factor A_r when the fundamental periods of vibration of both the structure (T) and the OFC (T_p) are known. Values of A_r as shown in Figure 1 can be obtained from the National earthquake hazard reduction program (NEHRP) seismic provisions (FEMA, 2009).

In addition, situations where dynamic analysis is needed as a substitute for the simplified static method of analysis are identified more precisely in the 2005/2010 editions of the NBCC.

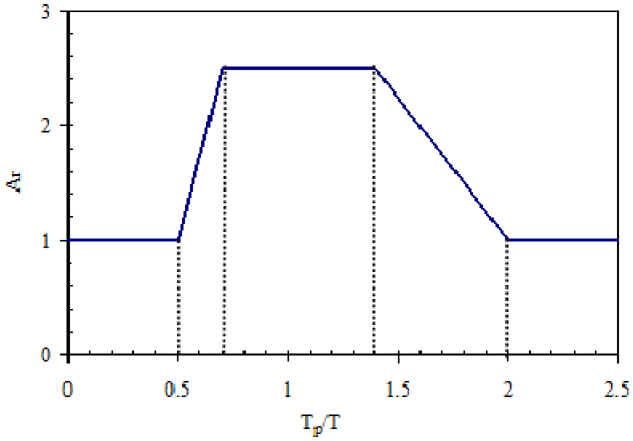

Figure 1 – Component force amplification factor A_r (FEMA, 2009)

3.2. Seismic displacement requirements

Some refinements were introduced compared to the requirements of the 1995 edition. While the largest interstory drift at any level based on the lateral deflections obtained from linear elastic analysis is still limited to $0.01h_s$ for post-disaster buildings ($I_E = 1.5$), the revised provisions indicate new limits of 0.02 h_s for schools ($I_E = 1.3$) and more relaxed limits of 0.025 h_s for all other buildings of normal importance ($I_E = 1$). The lateral deflections obtained from an elastic analysis are to be multiplied by R_dR_o/I_E to give realistic values of anticipated deflections, where R_o is the force overstrength factor (varying between 1.0 and 1.7 depending on the lateral load resisting system) and R_d represents the energy dissipation capacity of the element or its connections (varying between 1.0 and 5.0 depending on the lateral load resisting system).

4. Numerical comparison of the seismic force requirements for the 1995 and the 2005/2010 editions of the NBCC

In the following, seismic design forces for architectural and mechanical/electrical components in a normal importance category building ($I_E = 1$) located in Vancouver (high seismic zone with $\nu = 0.21$, Sa(0.2) = 0.94) and Montreal (moderate seismic zone with $\nu = 0.1$, Sa(0.2) = 0.64/0.69 (2010/2005)) are presented. Forces are computed according to the 1995, 2005 and 2010 editions of the NBCC. The impact of code changes on the seismic design force levels at specific locations in the building is assessed through the ratio of the lateral seismic force, V_p, to the component weight, W_p. Values of V_p/W_p are computed at ground and rooftop levels for architectural components and at ground, middle and rooftop levels for mechanical/electrical components of a regular four-storey building. In order to assess the effect of soil condition on the seismic design forces, two soil conditions are considered: I) very dense soil or soft rock ($F_a = 1.0$ for both Vancouver and Montreal) II) soft soil ($F_a = 1.23$ for Montreal and 0.95 for Vancouver). Tables 1 and 2 summarize the component factors C_p, the dynamic amplification factors A_r, and the response modification factors R_p for the different components used in the study.

Table 1 - Values of C_p, A_r and R_p for architectural components

Year / Component	1995	2005/2010		
	S_p	C_p	A_r	R
Exterior walls	1,5	1	1	2,5
Suspended ceilings	2	1	1	2,5
Cantilever walls	6,5	1	2,5	2,5
Interior walls	1,5	1	1	2,5
Balconies	4,5	1	1	2,5

Table 2 - Values of C_p, A_r and R_p for mechanical/electrical components

Year / Component	1995		2005/2010		
	C_p	A_r	C_p	A_r	R_p
Flexible equipment	1	1.5 (ground) 3 (rooftop)	1	2,5	2,5
Cable tray	1	1	1	2,5	5
Tank	0,7	1	0,7	1	2,5
Rigid equipment	1	1	1	1	1,25
Ductile pipes	1	1	1	1	3
Non-ductile pipes	1	1.5 (ground) 3 (rooftop)	1	1	1

4.1. Case I: Buildings located on very dense soil or soft rock

4.1.1. Architectural components

Figure 2 gives a comparison of the ratio V_p/W_p for different architectural components at the ground and rooftop of a four-storey building located on very dense soil in Vancouver and Montreal.

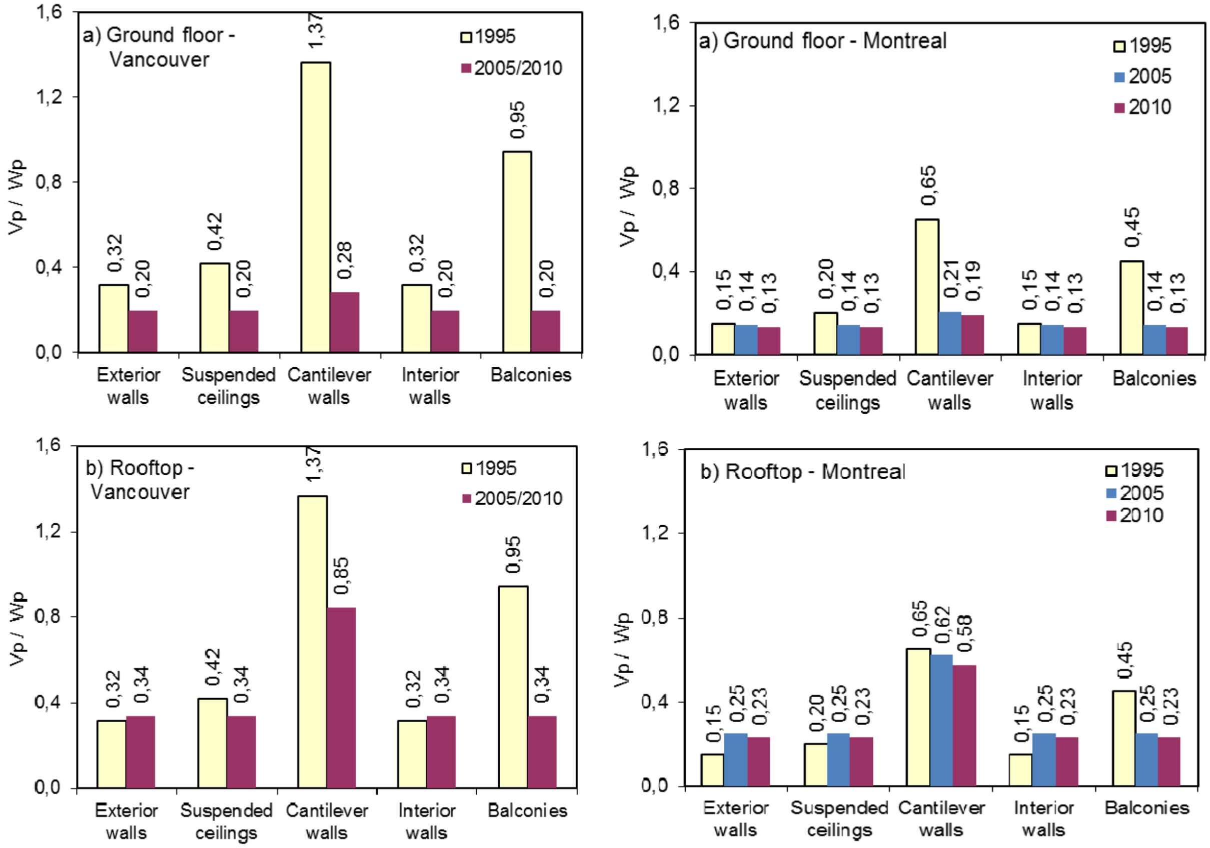

Figure 2 – Comparison of V_p/W_p for architectural components in Vancouver and Montreal, case I

The 1995 NBCC seismic force levels are higher than the 2005/2010 provisions at ground level for all components in both seismic zones. The difference in forces level is less noticeable at the rooftop level, especially in Montreal, except for cantilevered components where the 1995 NBCC provisions yield higher force levels than the 2005/2010 NBCC editions in both seismic zones, namely in Vancouver. We can consider that the 1995 NBCC provisions yield conservative force levels for architectural components at ground level, especially in high seismic zones, this conservatism is less considerable at the upper levels and not systematic, specifically in moderate seismic zones. Therefore, the degree of conservatism in the 1995 NBCC seismic forces levels is proportional to the seismic risk associated with the area studied.

4.1.2. Mechanical/electrical components

Figure 3 gives a comparison of the ratio V_p/W_p for different mechanical/electrical components at the ground, middle and rooftop of a four-storey building located on very dense soil in Vancouver and Montreal.

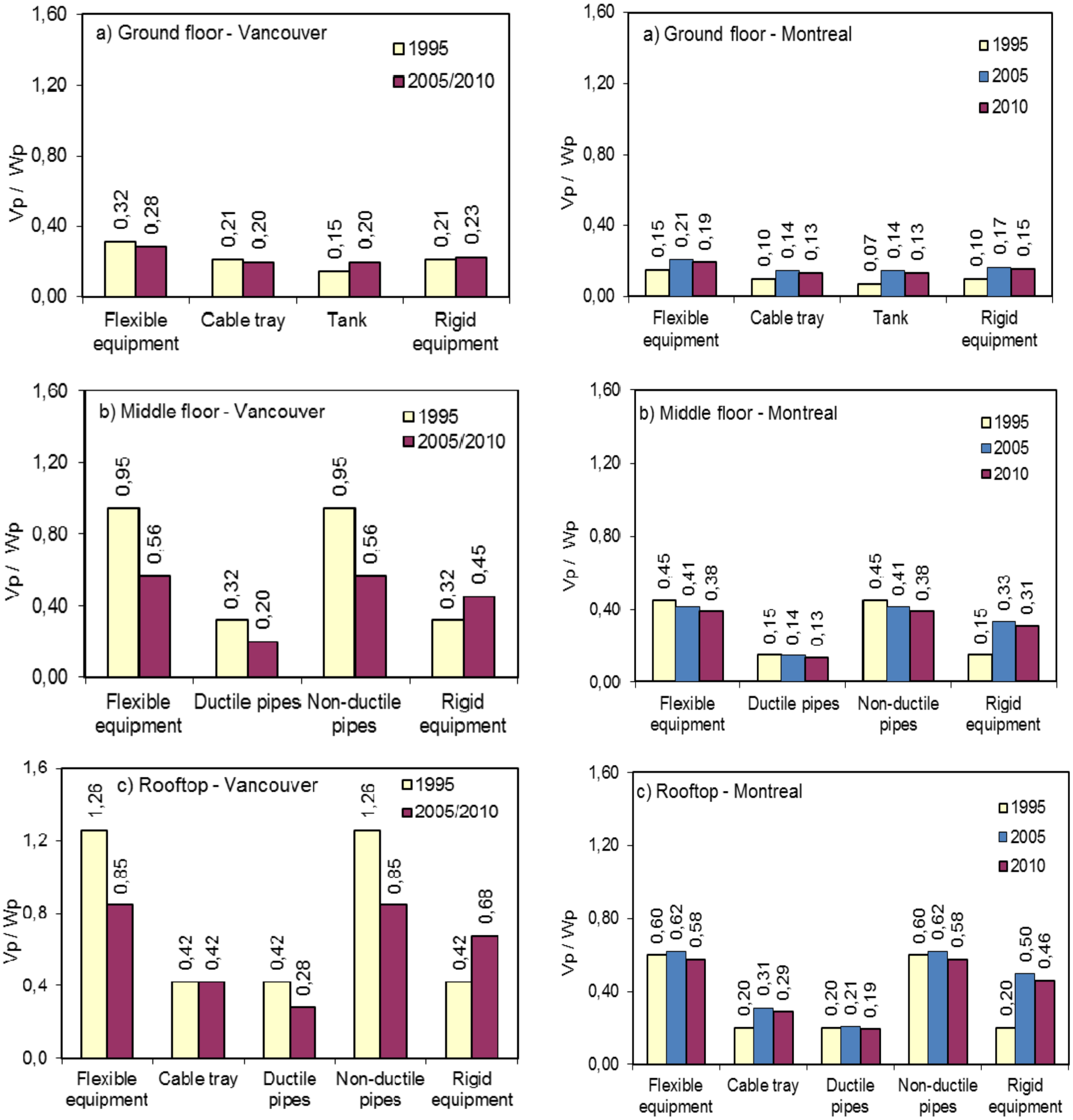

Figure 3 – Comparison of V_p/W_p for mechanical/electrical components in Vancouver and Montreal, case I

At the ground level, the 2005/2010 NBCC provisions give V_p/W_p ratios for mechanical/electrical components that are close to the 1995 provisions in Vancouver, and conservative values in Montreal. At the upper levels, the 1995 design force levels are higher than the 2005/2010 editions for most components, specifically in Vancouver, except for rigid/rigidly attached equipment. In Montreal, the force levels are close at the middle and rooftop of the building, except for rigid/rigidly attached equipment.

4.2. Case II: Buildings located on soft soil

4.2.1. Architectural components

Figure 4 gives a comparison of the ratio V_p/W_p for different architectural components at the ground and rooftop of a four-storey building located on soft soil in Vancouver and Montreal.

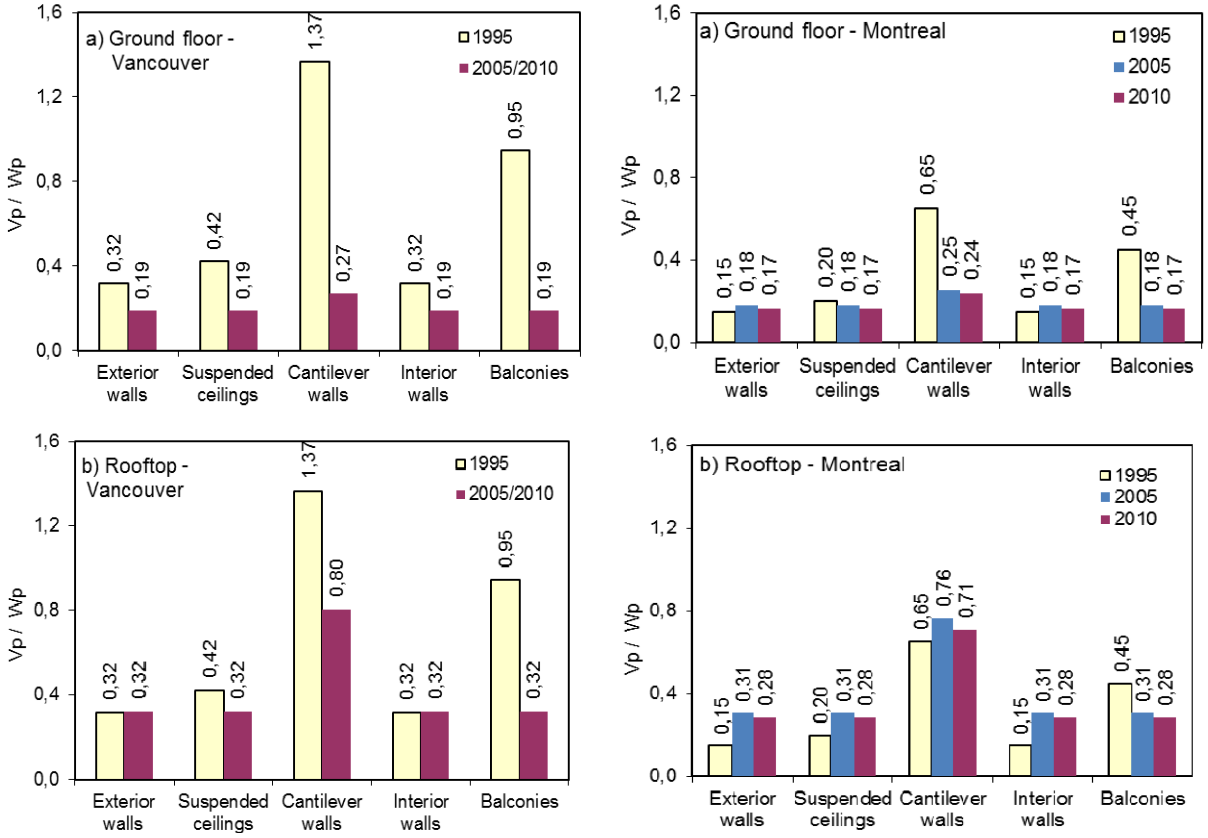

Figure 4 – Comparison of V_p/W_p for architectural components in Vancouver and Montreal, case II

The 1995 NBCC seismic force levels are higher than the 2005/2010 forces at ground and rooftop levels for all components in Vancouver, especially for cantilevered components. In Montreal, the difference in force levels calculated according to different NBCC editions is negligible at ground level except for cantilevered components, while the rooftop forces according to NBCC 2005/2010 are greater than 1995, except for balconies.

We can consider that the 1995 NBCC provisions yield conservative force levels for architectural components at ground level, especially in high seismic zones, this conservatism is less considerable and not systematic in moderate seismic zones at the upper levels. We can also note that neglecting the soil effect in NBCC 1995 is more detrimental in case of moderate seismic zones.

4.2.2. Mechanical/electrical components

Figure 5 gives a comparison of the ratio V_p/W_p for different mechanical/electrical components at the ground, middle and rooftop of a four-storey building located on soft soil in Vancouver and Montreal.

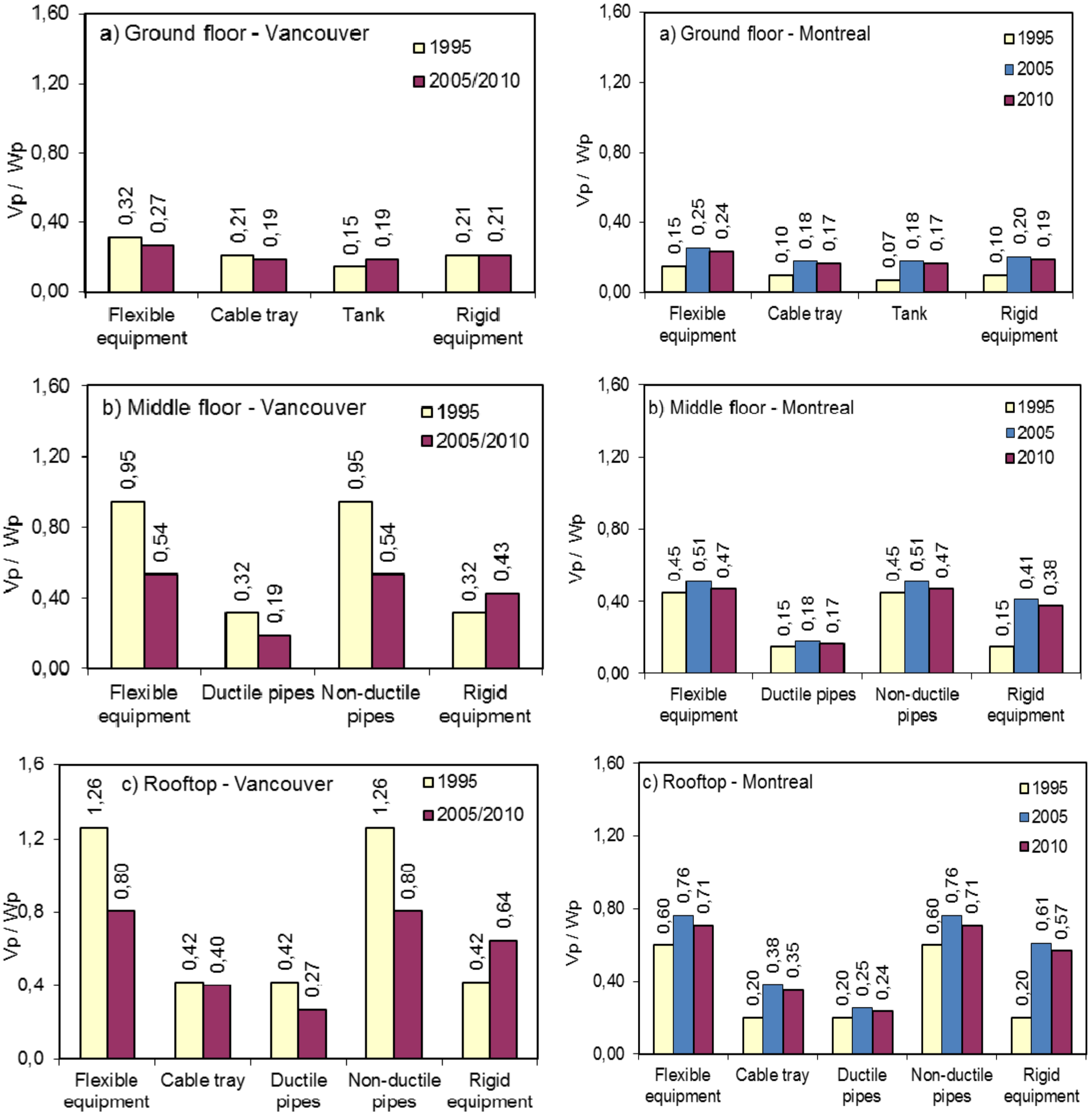

Figure 5 – Comparison of V_p/W_p for mechanical/electrical components in Vancouver and Montreal, case II

The 1995 NBCC provisions yield higher values for V_p/W_p ratios at the upper levels and close values to NBCC 2005/2010 at ground level for mechanical/electrical components located in Vancouver, except for rigid/rigidly attached equipment where calculations done according to NBCC 2005/2010 yield higher V_p/W_p ratios than those according to NBCC 1995.

In Montreal, calculations according to NBCC 2005/2010 yield higher V_p/W_p ratios than NBCC 1995 for all components at all levels.

5. Conclusion

There are a number of differences in the seismic design provisions for OFCs in the NBCC 1995 and 2005/2010 editions. Among others, the NBCC 1995 did not account for the soil type, the near-fault effect, the amplification of horizontal accelerations along the building height for the architectural components and the component response modification factor R was only implicitly accounted for.

In contrast to the 1995 NBCC requirements, the current NBCC provisions provide a unified consistent approach for all OFCs. The force requirements according the 2005/2010 NBCC editions are generally lower than those calculated according to NBCC 1995 provisions, especially for architectural components at ground level. This can be can be explained by the introduction of the R factor, the specification of more realistic values for A_r and C_p and the introduction of upper limit values of S_p.

For mechanical/electrical components, the 1995 NBCC requirements are higher than 2005/2010 requirements in Vancouver while this is not always the case in Montreal, especially at the upper levels and in case of soft soil. We can conclude that the 1995 NBCC seismic provisions for OFCs are conservative in general, specifically for high seismic zones with good soil conditions, while they are not conservative in moderate seismic zones with bad soil conditions, especially above the ground level.

None of the NBCC editions specified the amplification of vertical accelerations.

6. References

Adams, J. and Halchuck, S., "Fourth generation seismic hazard maps of Canada: Values for over 650 Canadian localities intended for the 2005 National Bulding Code of Canada", Ottawa, Geological Survey of Canada Open File 4459, 2003, pp.155.

Adams J. and Atkinson G., "Developments in Seismic Hazard Maps for Building Code Applications in Canada", *Canadian Journal of Civil Engineering*, Vol. 30, No. 2, April 2003, pp. 255-271.

Braga, F., Manfredi, V., Masi, A., Salvatori, A., and Vona, M., "Performance of non-structural elements in RC buildings during the L'Aquila, 2009 earthquake", *Bulletin of Earthquake Engineering*, Vol. 9, No.1, February 2011, pp. 307-324.

Chock, G., Robertson, I. , Nicholson, P., Brandes, H., Medley, E., Okubo, P., Kindred, T., Iinuma, G., Lau, E. and Sarwar, A., "Compilation of Observations of the October 15, 2006 Kiholo Bay (Mw 6.7) and Mahukona (Mw 6.0) Earthquakes", *Earthquake Engineering Research Institute*, December 2006.

CSA S832-14, "CSA S832-14: Guideline for seimic risk reduction of operational and functional components (OFCs) of buildings", Canadian standards association, June 2014, pp. 134.

Dhakal, R. P., "Damage To non-Structural Components and Contents in 2010 Darfield Earthquake." *Bulletin of the New Zealand Society for Earthquake Engineering*, Vol. 43, No.4, December 2010, pp. 404-411.

FEMA, "NEHRP recommended provisions for seismic regulations for new buildings and other structures - Parts 1&2)", 2009, Washington, D.C., Building Seismic safety Council.

Filiatrault, A., Uang, C.-M. , Folz, B., Christopoulos, C. and Gatto, K., "Reconnaissance report of the february 28, 2001 Nisqually Seattle-Olympia) earthquake", Department of structural engineering, University of California, San Diego, La Jolla, CA, March 2001, pp.67.

Miranda, E. and Taghavi S., "Estimation of seismic demands on acceleration-sensitive nonstructural components in critical facilities", *Proc. of the Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities*, Newport Beach, California, ATC, November 2003, pp. 347–360.

Mitchell, D., Paultre, P., Tinawi, R., Saatcioglu, M., Tremblay, R., Elwood, K., Adams J. and DeVall , R., "Evolution of seismic design provisions in the National building code of Canada", *Canadian Journal of Civil Engineering*, Vol. 37, No.9, August 2010, pp. 1157-1170.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario,1980.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario,1985.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario,1990.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario,1995.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario, 2005.

NRCC, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario, 2010.

Villaverde, R., "Seismic design of secondary structures: State of the art", *ASCE Journal of structural engineering*, Vol. 123, No.8, September 2007, pp. 1011-1019.