7th Canadian Conference on Earthquake Engineering / Montreal / 1995
7ième Conférence canadienne sur le génie paraséismique / Montréal / 1995

Implications of Preliminary Seismic Hazard Spectral Ordinates for Design Values in the National Building Code of Canada

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ABSTRACT

The Geological Survey of Canada, at the request of the Canadian National Committee on Earthquake Engineering (CANCEE), has recalculated seismic hazard in Canada using state-of-the-art data and methodology. This paper presents an engineering evaluation of trial seismic hazard spectral ordinates determined for representative locations in western and eastern Canada. In addition to evaluating acceleration hazard spectra at selected locations, the paper presents a proposed code format for determining elastic base shear coefficients directly from spectral ordinates. Comparisons are made with base shear coefficients determined from the seismic loading provisions of the 1990 edition of the National Building Code of Canada (NBCC).

INTRODUCTION

A brief historical account of earthquake hazard determination in Canada is given by Heidebrecht, Basham and Finn (1995). Maps developed in the early 1980's (Basham et al. 1985) were first introduced in the 1985 edition of the National Building Code of Canada (NBCC) . These maps, which are still used in the current edition of NBCC, represented peak ground acceleration "a" and velocity "v" at a probability of exceedance of 10% in 50 years. The Canadian National Committee on Earthquake Engineering (CANCEE), which has the responsibility for preparing and recommending the seismic loading provisions of the NBCC, requested the Geological Survey of Canada (GSC) to prepare new maps using state-of-the-art seismic hazard methodology incorporating additional seismicity data which has been gained since the preparation of the 1985 maps. The methodology leading to preliminary seismic hazard spectral ordinates and example maps are given by Adams et al. (1995b); detailed results are given in a GSC Open File Report (Adams et al. 1995a).

The purpose of this paper is to present and discuss some of the implications of using the preliminary seismic hazard spectral ordinates as the basis for the determination of seismic lateral loads in the NBCC. Spectral accelerations are presented for a number of western and eastern Canadian cities. Also, a format for code design spectra using these ordinates is presented; results using this format are compared with actual hazard values and with the equivalent elastic base shear coefficients in the 1990 edition of NBCC.

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EVALUATION OF ACCELERATION SPECTRA

Diagrams of uniform hazard spectra, UHS, (spectral acceleration ordinates for 5% damped systems at a uniform probability of exceedance of 10% in 50 years) obtained directly from the seismic hazard evaluation are shown as the curves marked "UHS - MDOF" in Figures 1 and 2 for selected western (Vancouver, Victoria, Kamloops and Prince George) and eastern (Quebec, La Malbaie, Montreal and Toronto) locations respectively. These are subsets of a total of 22 Canadian locations studied. Seismic hazard calculations for western Canada were done at periods ranging from 0.1 to 2.0 s. However, calculations for eastern Canada were only done for periods of 1.0 s and shorter, primarily because the ground motion relations used for eastern Canada were not available for longer periods. However, this is not a significant limitation since low period motions are dominant in eastern Canada.

While spectral ordinates are normally presented for single-degree-of-freedom (SDOF) systems, those presented in this paper have been modified so that they can be used directly as the base shear coefficients for actual structures, which are typically multi-degree-of-freedom (MDOF) systems. Heidebrecht et al. (1994) have shown that the spectra for the fundamental period of MDOF systems are approximately 85% of the corresponding SDOF values; consequently, the SDOF values obtained from the seismic hazard analysis have been multiplied by 0.85 to obtain the MDOF values shown in these figures.

The hazard spectra presented in these figures are at the 84 percentile level, i.e. median plus one standard deviation. Both aleatoric uncertainty (i.e. randomness) and epistemic (modelling) uncertainty are included in the seismic hazard calculations with the standard deviation being dominated by modelling uncertainties, e.g. in ground motions, seismic source zone properties and earthquake recurrence rates. The implication is that any (future) reduction in the degree of uncertainty would reduce the standard deviation while the median would remain more or less the same. However, for the determination of seismic loads, it is important that all of the present uncertainties be incorporated and that the estimate of loads used for design purposes be such that there is little likelihood that the design load will be exceeded. Consequently, it is recommended that seismic loading be determined from the 84 percentile acceleration hazard spectra. While the methodology is completely different, this is somewhat analogous to the current practice of using amplification factors at the mean plus one standard deviation level to obtain design spectra from peak ground motion values.

Hazard spectra are presented for firm or stiff ground conditions (including soft to firm rocks, shale deposits, stiff cohesive soils and dense granular soils such as gravel; shear wave velocities range from 360 to 750 m/s). While the ground motion relations in western Canada represent those conditions directly, those in eastern Canada, originally developed for very hard rock (shear velocities in excess of 2000 m/s), have been modified by period-dependent factors to represent firm ground conditions, as described by Adams et al. (1995a).

It is important to distinguish between UHS such as those discussed in this paper and acceleration response spectra (ARS) . UHS are lines connecting spectral ordinates at given periods, each of which has been determined by a distinct process involving the ground motion relations at those periods and using several seismic source zone models. The ordinates at different periods are often dominated by earthquakes of different magnitudes and at different distances from the particular location. Consequently, a UHS at a particular location is <u>not</u> the same as an ARS, which is defined as a set of responses of SDOF systems with different periods subjected to one specific earthquake motion. It is easy to confuse the two kinds of spectra because, in most instances, their shapes are quite similar.

The shapes of UHS (Figure 1) are typically characterized by a peak value occurring at a period of 0.2 s with a rapid reduction in value with increasing period. The rate of decrease, with increasing period, from the peak value is significantly higher in western Canada than in eastern Canada, although there are also some variations between locations in each region.

It is useful to compare the UHS values for eastern Canada with actual ARS ordinates measured during the 1988 Saguenay earthquake. The envelope of largest Saguenay ARS values (derived from records at distances from 43 to 93 km from the epicentre, amplified to place them on firm ground conditions and multiplied by 0.85 to place on same MDOF basis as the UHS) is shown in the Figure 2 diagram for Montreal. It can be seen that the Montreal UHS values exceed the Saguenay ARS envelope for periods larger than 0.4 s but the Saguenay ARS envelope is somewhat higher than the Montreal UHS for very short periods. Consequently, it can be concluded that a similar event located within 100 km of Montreal could produce short period ground motions which are somewhat in excess of the computed Montreal UHS.

Seismic hazard near the Pacific coast is affected by the potential for a major subduction earthquake, identified as the so-called Cascadia thrust earthquake. As discussed by Adams et al. (1995b), it was deemed appropriate to consider this event on a deterministic basis rather than incorporate it into the probabilistic seismic hazard methodology. The deterministic ARS for a magnitude 8.2 Cascadia thrust earthquake at both the mean and mean plus one standard deviation levels are included in the Figure 1 diagrams. Epicentral distances for these locations range from 120 km (Victoria) to 600 km (Prince George). The mean Cascadia ARS ordinates are enveloped by the UHS ordinates in all four locations. However, the mean plus standard deviation ARS ordinates exceed the UHS ordinates in the medium to long period region in Victoria, Kamloops and Prince George, but both are nearly the same in Vancouver. It should be noted that such a thrust earthquake would have a much longer duration than other earthquakes which contribute to the seismic hazard, which would certainly have an influence on the appropriate reduction factor to allow for inelastic energy dissipation.

ELASTIC BASE SHEAR COEFFICIENTS FROM SPECTRAL ORDINATES

While the ordinates of a UHS for any location can be determined for a number of periods, it is impractical to develop code loading provisions in terms of a different spectral shape for all locations in the country. Rather, it is preferable to specify the seismic load using no more than two parameters to envelope the UHS. For example, NBCC 1990 uses peak horizontal ground velocity "v" and, implicitly, peak horizontal ground acceleration "a" by specifying the low period seismic response factor S on the basis of the relationship of the acceleration-related seismic zone Z_a to the velocity-related zone Z_v. The parameter "v" governs the medium to long-period range of the seismic response factor while "a" governs the short-period plateau.

It is proposed here that the elastic base shear coefficient (V_e / W) be specified as follows:

$$V_e / W = [0.5/T]\,UHS(0.5) \le UHS_m \qquad \text{for } T \le 0.5s \qquad (1)$$

$$= [0.707/\sqrt{T}]\,UHS(0.5) \qquad \text{for } T > 0.5s \qquad (2)$$

in which UHS_m and UHS(0.5) are respectively the maximum UHS ordinate and the ordinate at 0.5 s. The shape of the elastic base shear coefficient is the same as the NBCC 1990 seismic response factor S for periods of 0.5 s and longer. The short period region is also a plateau, in this case equal to the value of UHS_m. While NBCC 1990 uses a straight line transition region (between the short period plateau and the value at T = 0.5s), the proposal here is to use a curve which is proportional to 1/T.

Elastic base shear coefficients using Eqs. 1 and 2 are also included on the diagrams in Figures 1 and 2; these curves are marked "Prop. Code". A close examination of these figures shows that the proposed code formulation using two spectral ordinates only, provides a very good fit of the entire UHS in each location. The degree of conservatism relative to the UHS curves in various period ranges varies considerably from location to location. However, such variation can be expected because of using the same formulation throughout the country.

It is worth commenting on the long period (i.e. T > 1.0 s) conservatism in western Canada. The proposed code coefficients are as much as 30% higher than the UHS values at T = 1 s, increasing to as much as 100% at T = 2 s. In this long period region the NBCC 1990 elastic base shear coefficient is also proportional to $1/\sqrt{T}$. The use of that form of proportionality has traditionally been based on a view that code design forces should be more conservative for long period structures, which are typically high rise buildings. Of course, the degree of conservatism is relative, since the coefficients at T = 1 s are always much smaller than the UHS_m, typically being less than 25% of that value. Since data above 1 s is unavailable for eastern locations, comparisons between UHS and proposed code coefficients in the long period region are not possible; however, proposed code values are as much as 50% higher than UHS values at T = 1 s.

These figures also include the elastic base shear coefficients determined using the NBCC 1990 zoning maps. Comparison of the proposed code values with the NBCC 1990 values shows considerable variation in the degree of change of design forces. Consider first the implications for Vancouver and Montreal, the two largest Canadian urban areas which have significant levels of seismic hazard. In Vancouver, the proposed code coefficient is about 70% higher than the NBCC 1990 coefficient in the short period region but almost the same in the medium to long period region. By contrast, in Montreal the short period coefficient is very nearly the same as in NBCC 1990 but the medium to long period value is about 35% higher than in NBCC 1990.

In terms of the other western locations included in Figure 1, the proposed base shear coefficient in Victoria is about 10% higher than that in NBCC 1990 for very short periods (below about 0.2 s), and approximately 10% lower than NBCC 1990 for all other periods. On the other hand, the proposed base shear coefficients in Kamloops and Prince George are significantly below the NBCC 1990 values throughout the spectrum.

In eastern Canada (Figure 2), base shear coefficients would increase by about 20% throughout the spectrum for La Malbaie while in Toronto they would increase by about 13% in the short period region and remain essentially the same in the medium to long period region. However, values for Quebec would drop throughout the spectrum, only slightly (14%) in the medium to long period region but nearly 50% in the short period region; these significant changes are due to modifications in both the source zone model and ground motion relations used in eastern Canada.

One of the key concerns when evaluating new seismic hazard results is the implication for the overall level of protection provided by the code seismic loading provisions, which is represented by the level of base shear. While there are studies now underway (see Heidebrecht, Basham and Finn 1995) to evaluate the suitability of the level of protection provided by current code provisions, it can be assumed, initially at least, that it is a desirable objective to maintain that level of protection at current levels for major centres in the country. Given that there are slight differences in how the seismic hazard methodology has been applied in eastern and western Canada, it would be necessary to identify at least one such centre in each of those two regions and scale the hazard in each region to maintain the current level of protection in those two centres. Vancouver and Montreal are good candidates both on the basis of population and seismicity.

Given that the proposed code formulation uses UHS ordinates in both the short and intermediate period regions as independent variables, it is not possible to maintain the same base shear coefficient throughout the period range; one has to decide to determine the appropriate scale factor using either the low or intermediate period UHS ordinate. It is preferable to use the intermediate period ordinate, i.e. UHS(0.5), since most engineered buildings have intermediate to long periods and because the determination of resistance (which certainly affects the level of protection) is more reliable at intermediate periods than at short periods.

Given the fact that the new seismic hazard results presented in this paper would result in little change in base shear in the intermediate to long period range in Vancouver, it appears that this objective can be realized in western Canada without having to scale or calibrate the results. However, the new hazard results indicate a medium to long period increase of about 35% in Montreal; maintenance of the same level of protection on the basis outlined above would require that all eastern Canadian values be reduced by 35% at all periods.

It is also clear that the new seismic hazard results show a significant difference in the distribution of hazard throughout the country. As noted in the earlier discussion, there are locations in which the base shear coefficient will increase and other locations in which it will decrease. However, such changes are to be expected given new information on the sources of seismicity and as well as new ground motion relations.

It should be emphasized that the comparisons made in this paper are between proposed base shear coefficients determined from "site specific" seismic hazard ordinates and those in NBCC 1990 which have been detetermined from zonal values of peak ground motions. Site specific values of the UHS ordinates used for determining code base shear will need to be zoned. A suitable zoning scheme should involve no more than 7 non-zero zones and preferably fewer; also, the zoning scheme should ensure that locations with similar seismic hazard are in the same zones and that zone boundaries do not pass through urban regions.

DISCUSSION AND CONCLUSIONS

The preliminary seismic hazard results calculated by the Geological Survey of Canada have been presented and discussed in terms of UHS and proposed code elastic base shear coefficients. The proposed formulation for elastic base shear coefficients using two UHS ordinates directly is both simple to use and also ensures that the UHS is enveloped throughout the spectrum. Diagrams presented for selected western and eastern Canadian cities allow comparisons to be made between the proposed elastic base shear coefficients and those determined using NBCC 1990. The results indicate that changes in base shear coefficients , in the order of +/- 50% , and in some cases greater, can occur in locations throughout the country. Consideration of the desired level of protection will be required in order to determine whether or not the results should be scaled. Further work is also needed to develop a suitable zoning scheme for the UHS ordinates to be used in determining code base shear coefficients.

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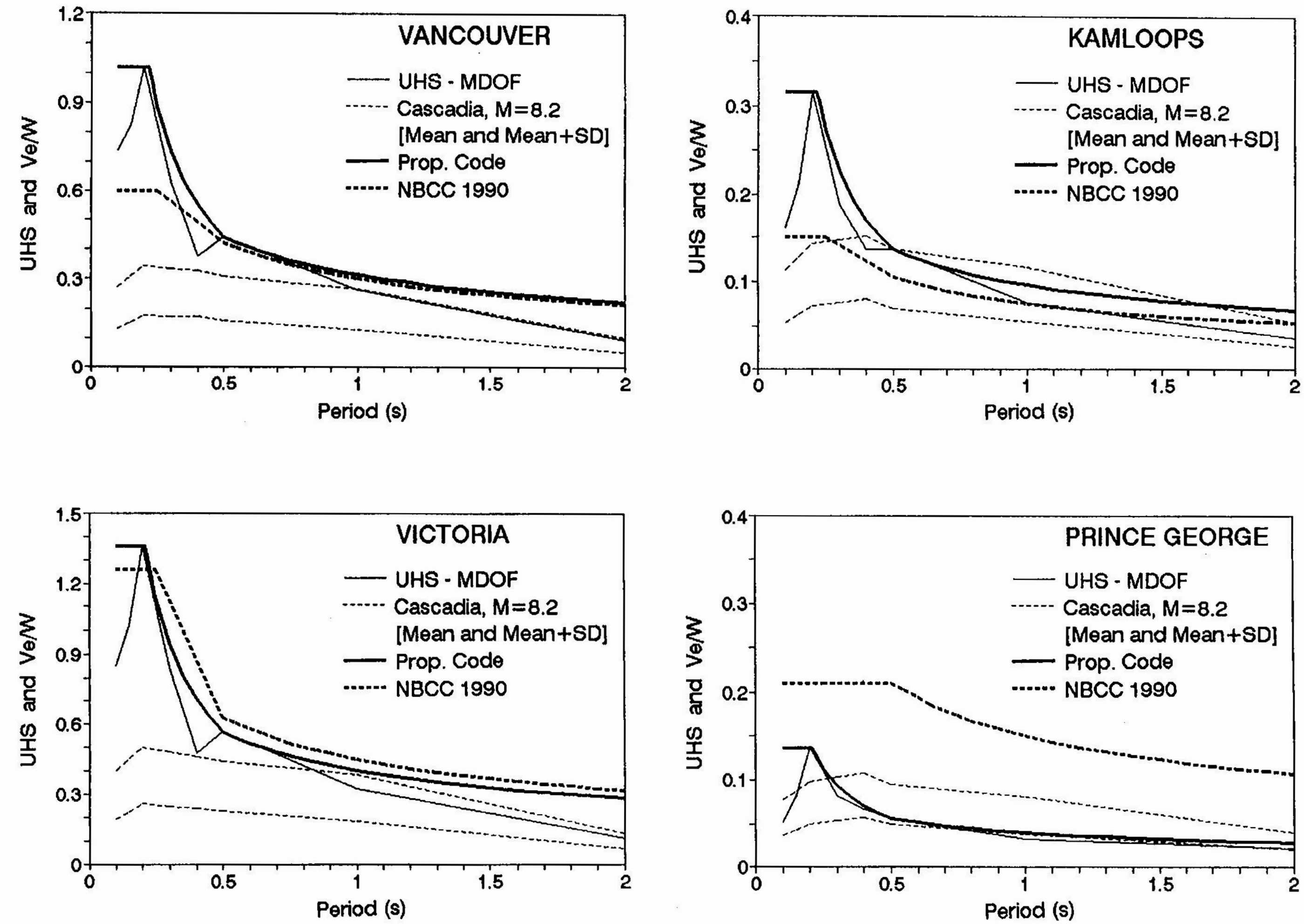

Figure 1. Acceleration spectra (from seismic hazard and from Cascadia thrust earthquake) and base shear coefficients (proposed and NBCC 1990) for Vancouver, Victoria, Kamloops and Prince George.

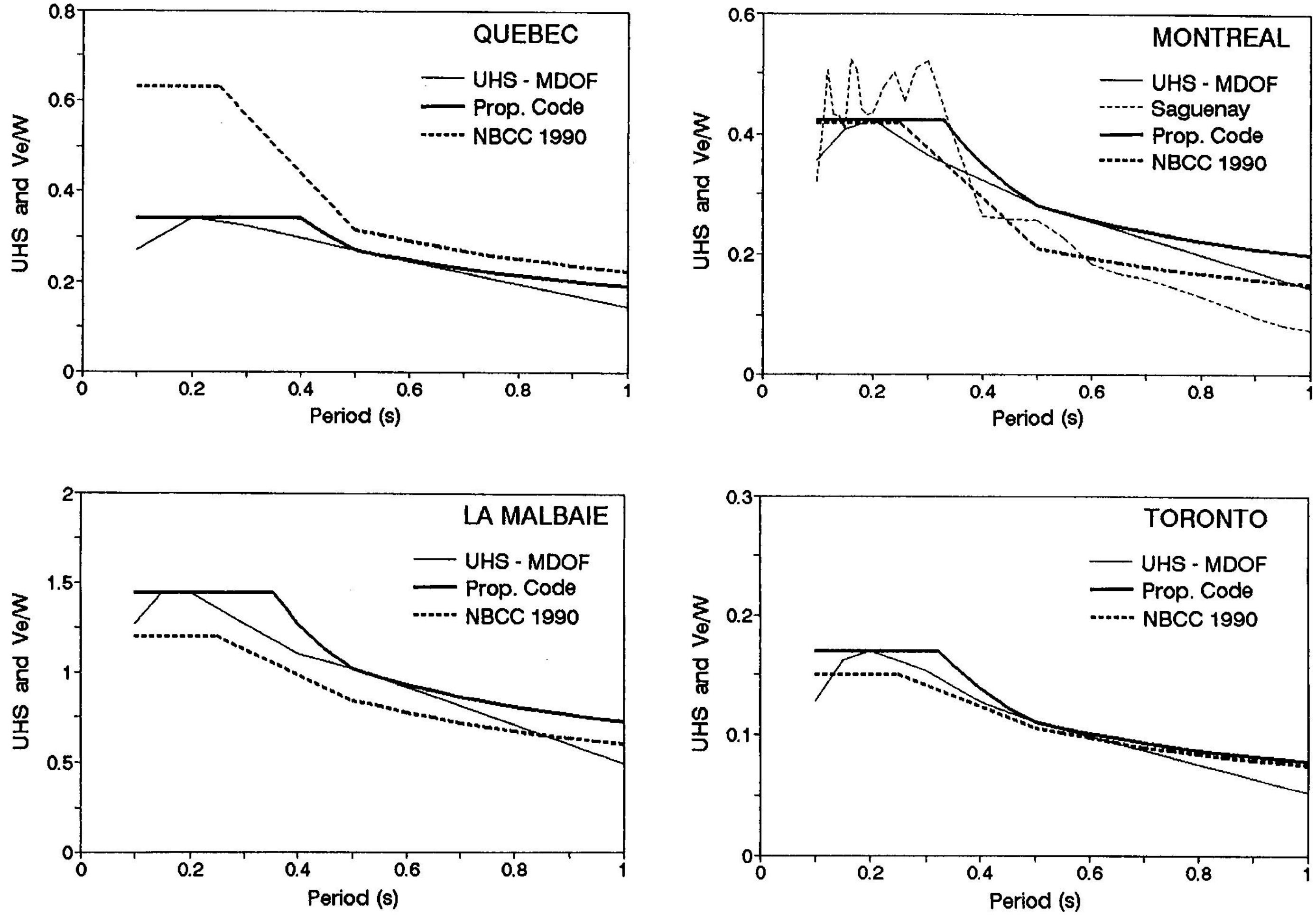

Figure 2. Uniform hazard spectra and base shear coefficients (proposed and NBCC 1990) for Quebec, La Malbaie, Montreal and Toronto.