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# BUILDING CODE IMPLICATIONS OF NEW CANADIAN SEISMIC HAZARD RESULTS

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## ABSTRACT

For purposes of the seismic provisions of the National Building Code of Canada (NBCC), the Geological Survey of Canada has reevaluated the Canadian seismic hazard using state-of-the-art data and methodology. The new seismic hazard results are expressed in terms of 5% damped spectral accelerations at specified periods, with uniform probability of exceedance of 10% in 50 years (i.e. uniform hazard spectra). The purpose of this paper is to present and discuss the implications of use of the computed uniform hazard spectra as the basis for the determination of seismic lateral loads in NBCC. Uniform hazard spectra are presented for several eastern Canadian locations. Since the original ground motion relations for eastern Canada are on hard rock, the paper also discusses alternative ways of transforming the hazard results to firm ground, which is the proposed reference ground condition throughout the country. Also, a format for using uniform hazard values in the design base shear formulation is presented. Base shear coefficients are proposed using two spectral acceleration ordinates, i.e. the maximum low period ordinate, and the ordinate at period of 0.5 s. The proposed base shear coefficients are compared those in NBCC 1995 values for several locations. The results indicate that the new hazard results have significant implications for the design force levels.

## KEYWORDS

seismic, hazard, spectrum, code, design, loads, shear, coefficient.

## INTRODUCTION

In the present edition of the National Building Code of Canada (NBCC) (Associate Committee on the National Building Code 1995), the seismic design forces are based on the seismic zoning maps developed in 1985 (Basham *et al.* 1985), which give contours of seismic zones having different peak ground accelerations and peak ground velocities for probability of exceedance of 10% in 50 years. Since the preparation of the 1985 zoning maps, additional research and new seismicity data have both led to a better understanding of the seismic potential of different regions of the country. In addition, new attenuation relations have been developed for peak ground motions, as well as for spectral values, for eastern and western Canada. Also, significant improvements have been made in the methodology for seismic hazard computations, in terms of incorporation of various uncertainties involved in the seismic hazard. All these advances form the rationale for reevaluation of the seismic hazard throughout the country and preparing new seismic zoning maps for the NBCC.

The engineering community has a growing interest in making direct use of seismic hazard spectral values for the determination of seismic design forces, in lieu of the classical approach of obtaining design values by applying spectral amplifications to the peak ground motions. This suggests that the seismic zoning maps should be based on spectral values at specified periods, rather than on peak ground motions. As requested by the Canadian National Committee on Earthquake Engineering (CANCEE), which has the responsibility for preparing and recommending the seismic loading provisions of the NBCC, the Geological Survey of Canada (GSC) is preparing new maps using state-of-the-art seismic hazard methodology incorporating additional seismicity data which has been obtained 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.* (1995). The computation of new hazard results for eastern Canada has now been completed and those for western Canada are expected to be finalized by mid-1996.

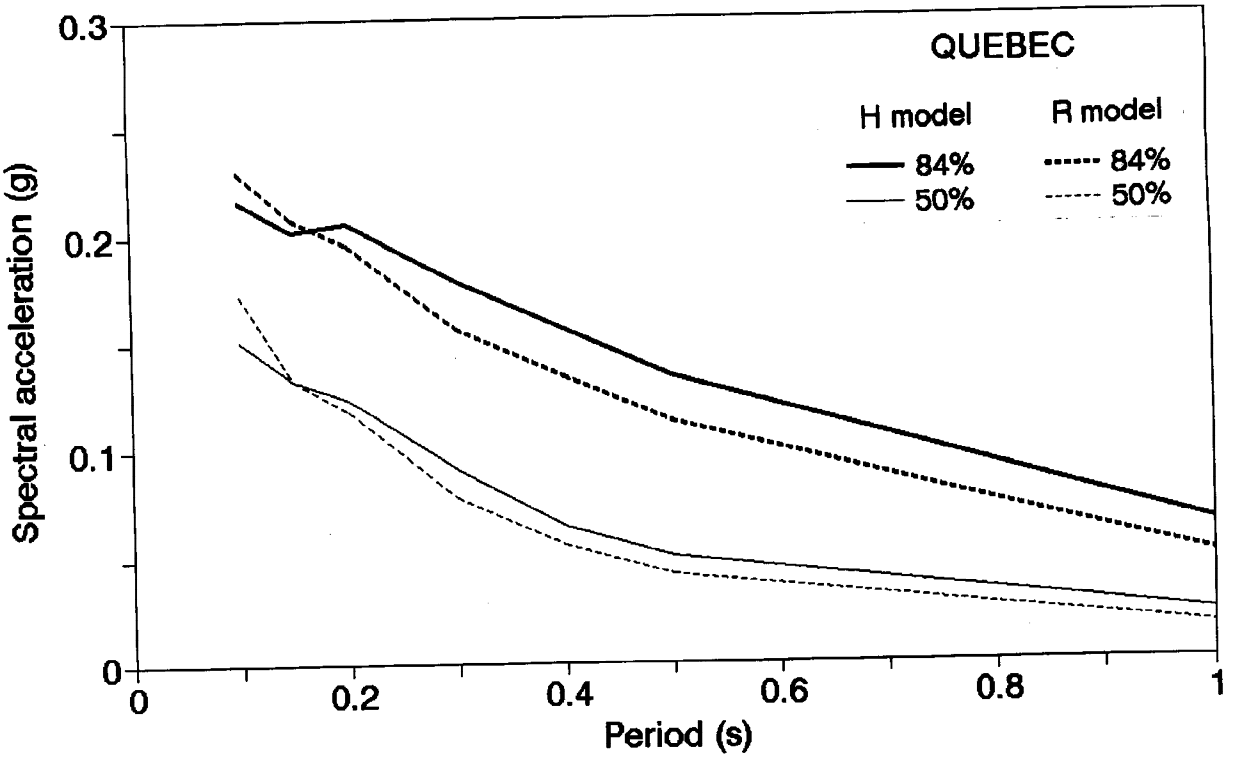
## HARD ROCK UNIFORM HAZARD SPECTRA FOR EASTERN CANADA

The preliminary seismic hazard results are presented in the form of 5% damped uniform hazard spectra (UHS), i.e. spectral acceleration ordinates at a probability of exceedance of 10% in 50 years. These UHS have been computed by the Geological Survey of Canada (Adams *et al.* 1995) for two separate seismic source models, i.e. an H model that in general uses small zones drawn around historical seismicity clusters, and an R model that establishes larger regional zones. The hazard computation was done by incorporating a "logic tree" approach in the well-known Cornell-McGuire method to account for both aleatoric (randomness) and epistemic (modelling) uncertainty (Cornell 1968; McGuire 1993). The aleatoric uncertainty is associated primarily with the scatter of data (i.e. "sigma") in the ground motion relations, and the epistemic uncertainty is associated with the assumptions for the parameters included in the seismic hazard such as focal depth, earthquake recurrence parameters, upper bound magnitude, and ground motion relations. For a given probability of exceedance, the probability distribution for the hazard value can be determined from which the mean and specified fractiles (usually 50th percentile i.e. median and 84th percentile) are computed. These fractiles represent confidence levels that the corresponding hazard values will not be exceeded.

A complete probabilistic hazard analysis was done using each of the H and R seismic source models; for purposes of determining design values, it is proposed that the larger of the two hazard values for each spectral ordinate at any location is then chosen as the specified hazard level. The chief advantage of this so-called "robust" approach is that it preserves protection in areas of high historical seismicity but also provides increased protection in areas which are currently aseismic but have the geological potential to produce large earthquakes.

Figure 1 presents the UHS for two eastern Canadian cities, Montreal and Quebec. For each seismic zone model (H and R), two spectral curves are shown in the figures, which correspond to the 84 percentile and 50 percentile (i.e. median) spectra. The large differences observed between the spectral curves from the H and R models for these two cities are typical of other eastern locations. This figure also shows that the largest spectral values are associated with period of 0.1 s (i.e. the lowest period used in the computation), which is also the case for most of the eastern locations.

For Montreal, the R model results are higher by approximately 20 percent throughout the spectrum, because the H model's emphasis on seismicity in Charlevoix (approximately 300 km from Montreal) has diminished the hazard in Montreal. By contrast, the H model is larger in Quebec City (which is much closer to Charlevoix) except for very short periods. This figure demonstrates the practical utility of the "robust" approach described above in that the use of the maximum value provides a reasonable representation of hazard in each location, without having one or other of the models diminish the hazard at either location.



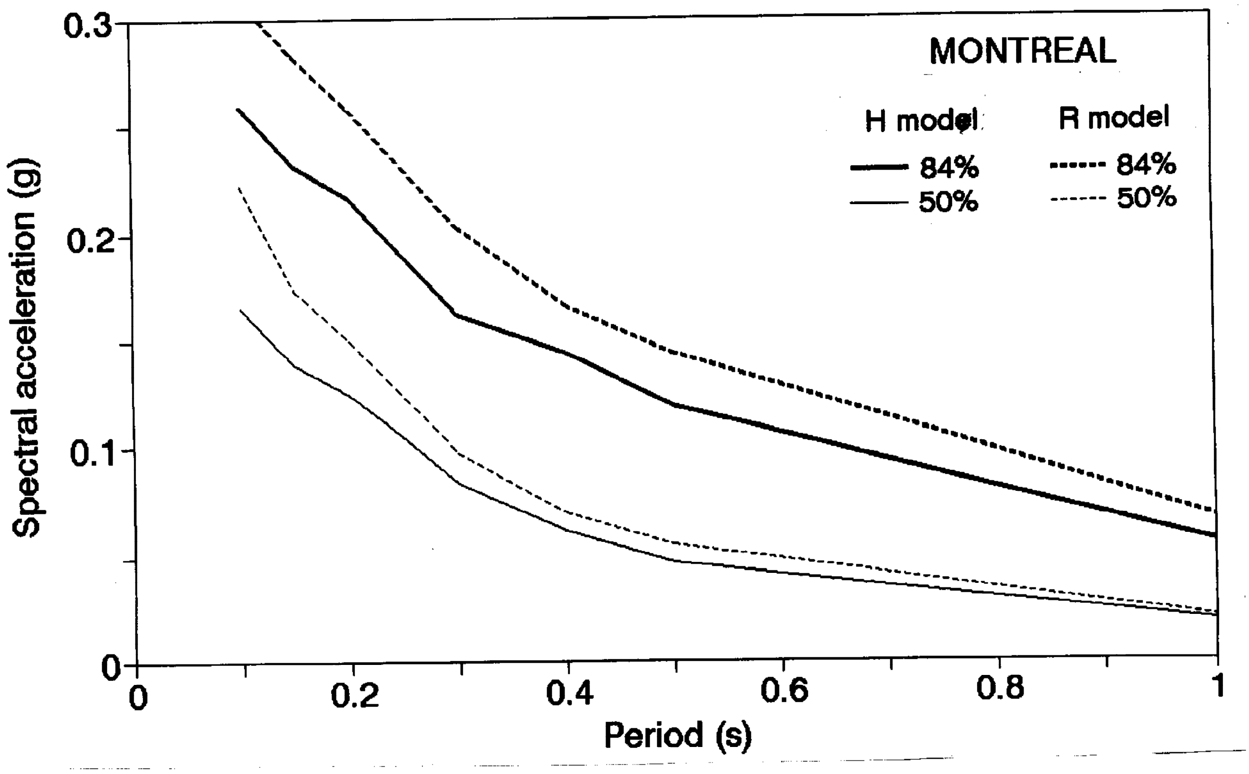




Fig.1 Uniform hazard spectra for Quebec and Montreal (hard rock)

It is also useful to evaluate the extent of epistemic uncertainty in the seismic hazard results by examining the ratio of the 84 percentile ordinates to the median ordinates. This ratio increases as the period increases, ranging from 1.4 to 1.6 at T=0.1s and from 2.7 to 3.8 at T=1.0s. The variation of this ratio with period arises directly from the manner in which "expert opinion" was utilized in determining the alternative ground motion relations used in the logic tree approach (Atkinson, 1995). The importance of this ratio for engineering applications is to demonstrate the very high degree of uncertainty associated with the estimation of seismic hazard due, largely, to the limited amount of earthquake data available for the determination of ground motion relations.

## COMPARISON WITH MOTIONS RECORDED DURING THE 1988 SAGUENAY EARTHQUAKE

The most significant set of recorded earthquake ground motions in eastern North America occurred during the magnitude 5.9 Saguenay earthquake of November 25, 1988. Since that earthquake resulted in significant ground motions and earthquakes resulting in similar motions can be expected in several regions of eastern Canada, it is useful and important to compare the recorded motions with the preliminary seismic hazard results. Among the numerous ground motion records obtained during the Saguenay earthquake, the largest motions were recorded at Les Eboulements and La Malbaie at epicentral distances of 90 and 93 km respectively. The acceleration response spectra from the longitudinal components of these records envelope the spectra from all other records from the Saguenay earthquake.

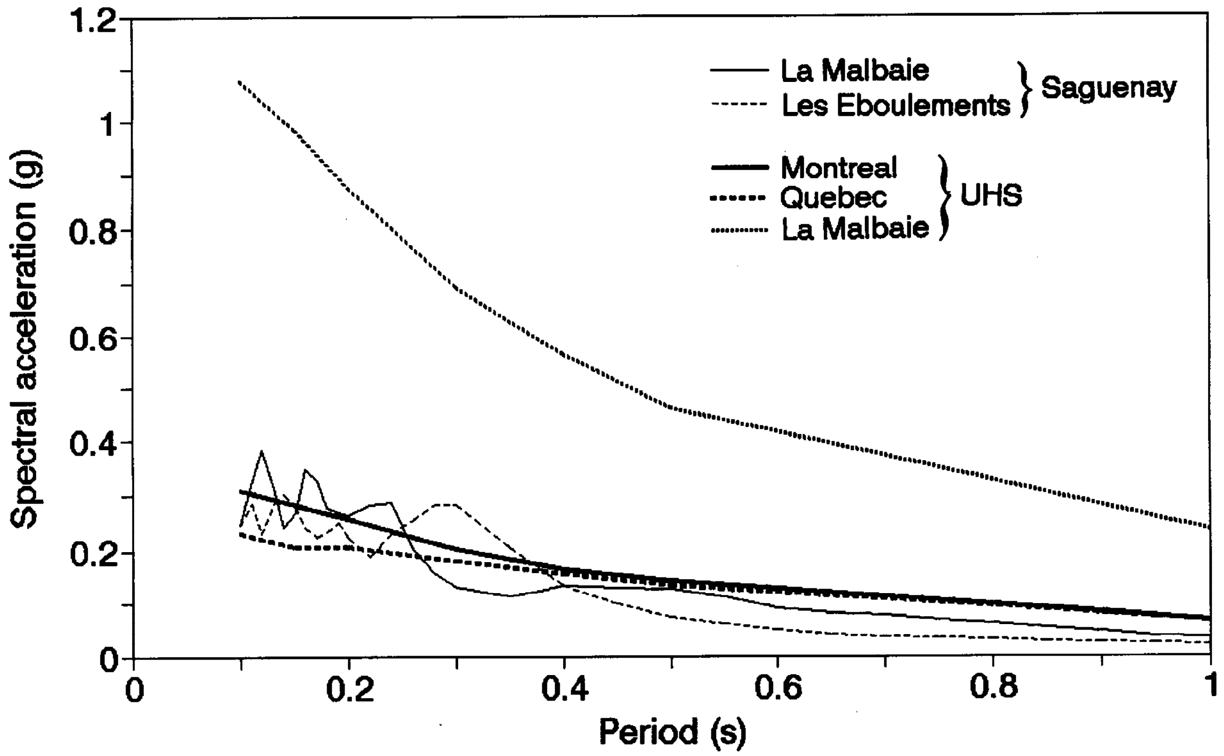



Fig. 2 Comparison of the largest response spectra from the 1988 Saguenay earthquake with the 84% hazard spectra for Montreal, Quebec and La Malbaie

Figure 2 shows the largest acceleration response spectra recorded during the Saguenay earthquake, as described above, and the UHS results (larger of H and R model values) at the 84 percentile level for La Malbaie, Montreal and Quebec. It can be seen from this figure that the UHS for La Malbaie is 3 to 4 times higher than the largest Saguenay spectra within the entire period range. The UHS for Montreal and Quebec envelope the Saguenay spectra for periods larger than 0.4 s. However, for very short periods, the largest ordinates of the Saguenay ARS are somewhat higher than the Montreal and Quebec UHS. These comparisons are problematic, because one would expect that hazard values used in design should exceed those which have been experienced in the same region in recent years. This may indicate that the short period epistemic uncertainty in eastern Canada is too low and/or that a higher weighting should be given to the upper ground motion estimates in the short period range.

## ALTERNATIVES FOR TRANSFORMING EASTERN CANADIAN RESULTS TO FIRM GROUND BASIS

The ground motion relations for eastern Canada are based on very hard rock, i.e. having shear wave velocities in excess of 2000 m/s. It is desirable for practical purposes, e.g. determination of code loading, that the zoning map(s) for the whole country be on the same site basis. While there are a wide range of site conditions, firm ground (shear wave velocities ranging from 350 to 750 m/s) is more prevalent than hard rock and is therefore preferable as the reference site condition. There are a number of possible approaches for transforming the eastern Canadian results from hard rock to firm ground conditions. Among the alternatives described by Heidebrecht and Naumoski (1995), the two most feasible approaches can be summarized as follows:

> Alternative #1: application of period-dependent RGC (Reference Ground Condition) multiplication factors determined from both engineering and seismological considerations (Adams et al. 1995); these factors increase with period and range from 1.39 at T=0.1s to 2.58 at T=1.0s.
>
> Alternative #2: involves application of multiplication factors for two broad regions of the spectrum rather than for each period; these factors are then used in the base shear formulation which is described in the next section. A low period factor $F_a = 1.5$ is applied to the largest UHS ordinate, which usually is at a period of 0.1s. A medium to long period factor $F_v = 2.0$ is applied to the UHS ordinate at a period of 0.5 s. These factors were based on site amplification factors presented by Borcherdt and Glassmoyer (1993) and those in the 1994 NEHRP Provisions (Building Seismic Safety Council, 1994).

These alternatives are considered in terms of their effects on elastic base shear coefficients.

## ELASTIC BASE SHEAR COEFFICIENTS FROM SPECTRAL ORDINATES

The NBCC 1995 seismic provisions define the elastic base shear coefficient by the product v*S, where "v" is the zonal velocity ratio for a given location, and S is the seismic response factor. The S factor is intended to represent an idealized acceleration response spectrum for multi-degree-of-freedom systems for unit value of "v" and unit weight. For periods below 0.25 s, the S factor is defined with three plateaus, each of which corresponds to a different combination of the acceleration- and velocity-related seismic zones ($Z_a > Z_v$, $Z_a = Z_v$, and $Z_a < Z_v$). For periods larger than 0.5 s, the S curve is defined as a function of the fundamental structural period, T, i.e. $1.5/\sqrt{T}$. Each of the plateaus is connected to the intermediate and long period S curve linearly between periods of 0.25 and 0.5 s.

While the ordinates of 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 each different location. Rather, it is preferable to specify the seismic load using no more than two parameters to envelope the UHS. It is proposed here that the elastic base shear coefficient ($V_e$ / W) be based on UHS ordinates, specified as follows:

$$V_e / W = [0.5/T]\,[F_v\,UHS(0.5)] \leq [F_a\,UHS_m] \quad \text{for } T \leq 0.5s \qquad (1)$$
$$= [0.707/\sqrt{T}]\,[F_v\,UHS(0.5)] \quad \text{for } T > 0.5s \qquad (2)$$

in which $UHS_m$ is the maximum value of UHS (between 0.1 s and 0.5 s), UHS(0.5) is the UHS ordinate at T=0.5 s, and $F_a$ and $F_v$ are the multiplication factors required to convert hard rock hazard values to those at the firm ground reference ground condition, which are given explicitly for Alternative #2 in the previous section. For Alternative #1, $F_a$ is at the period at which $UHS_m$ occurs, which is normally T=0.1s in eastern Canada, leading to $F_a$ = 1.39; since $F_v$ is the multiplier at T=0.5s, its value is 2.38. Because of the differences in the amplification factors, medium to long period design forces using alternative #2 are approximately 20% lower than those using alternative #1. However, in the short period region, forces determined using alternative #2 are approximately 10% higher.

The shape of the elastic base shear coefficient is the same as the NBCC 1995 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 product $F_aUHS_m$. While NBCC 1995 uses a straight line transition region (between the short period plateau and the value at T = 0.5 s), the proposal here is to use a curve which is proportional to 1/T.

## NEW ELASTIC BASE SHEAR COEFFICIENTS AND COMPARISONS WITH NBCC 1995

It is first necessary to make a choice concerning which of the computed hazard values are to be used for developing the elastic base shear coefficients. Among the several possible alternative confidence levels (84 percentile, 50 percentile, and mean), the 50 percentile hazard spectra are proposed for the formulation of these coefficients. While the 84 percentile level provides a high confidence that the code loads will not be exceeded, it is the authors' view that the epistemic uncertainty data has not yet been developed to the state such to justify its use in the determination of design forces.

Using the proposed code formulation developed in the previous section, Fig. 3 presents the elastic base shear coefficients $V_e$ /W for Montreal and Quebec using the two alternative approaches for converting hard rock hazard results to the firm ground reference condition. The differences among the two approaches, which are described above, can be seen clearly on both diagrams. This figure also includes the UHS for hard rock in order to demonstrate the significant amplification of spectral values from hard rock to firm ground.

It is also important to compare the proposed code elastic base shear coefficients with those currently specified in NBCC 1995. Since, in determining the final design force, NBCC 1995 applies a calibration factor of 0.6, Fig. 3 includes lines at the 0.6 $V_e$ /W for NBCC 1995. It can be seen that the new results would produce elastic base shear forces in the medium to long period range in Montreal which are comparable to the calibrated NBCC 1995 values, with the values being almost identical for alternative #1. The proposed short period forces in Montreal are 10 to 20 percent higher than the calibrated NBCC 1995 values. It can also be seen that the values in Quebec would be reduced considerably for all periods.. This figure also shows that the shapes of the proposed base shear coefficient curves are more peaked than those in NBCC 1995, i.e. short period values are higher in relation to long period values. These shape changes are directly attributable to the ground motion relations used in developing the new seismic hazard results.

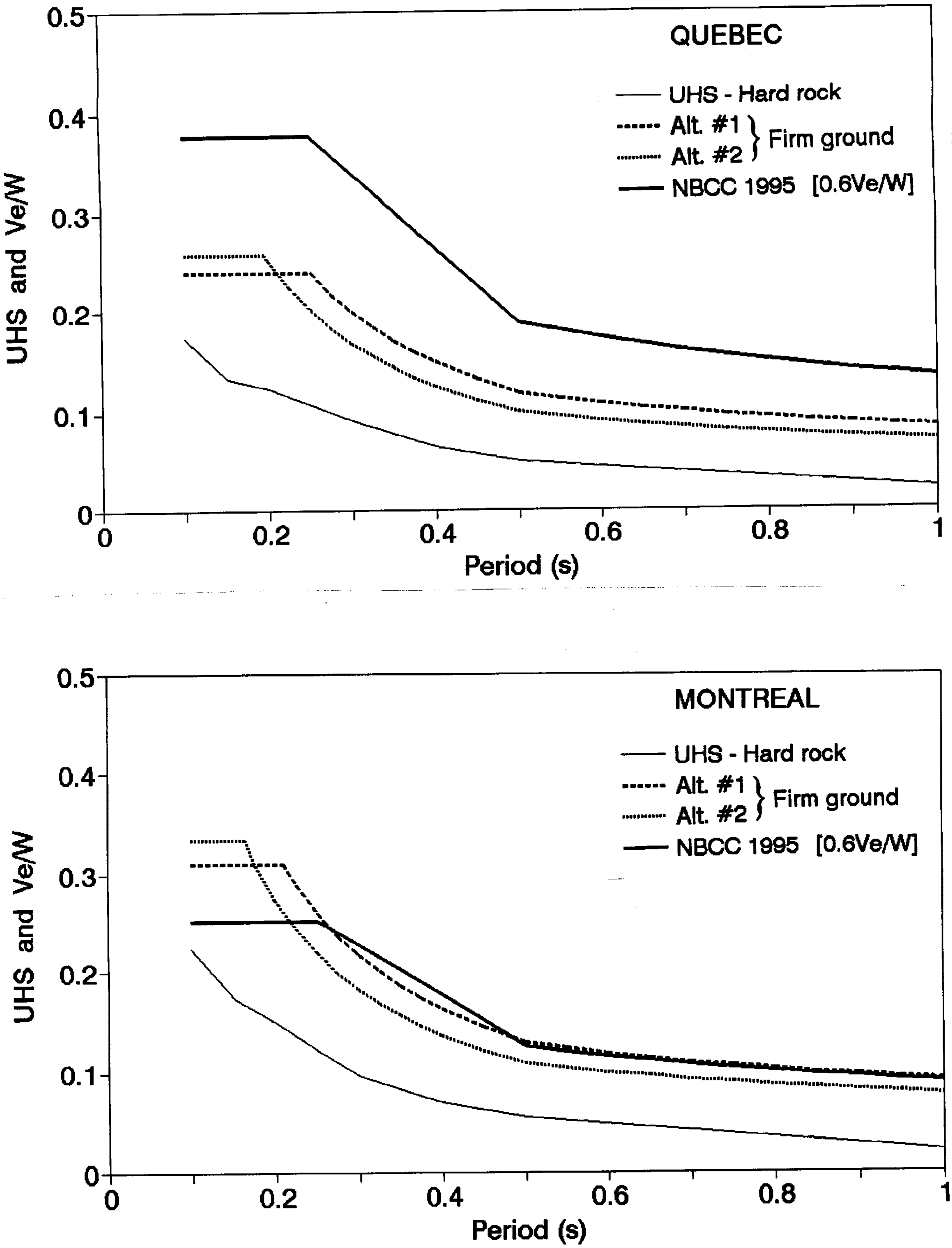



Fig. 3 Comparison of proposed (two alternatives) and NBCC 1995 base shear coefficients for Quebec and Montreal

## CONCLUSIONS

1. The choice of confidence level has a major effect on the estimated value of seismic hazard.

2. Firm ground spectral values vary with period and range from 1.4 to 2.6 times the hard rock values, depending upon the alternative which is used to develop the amplification factors.

3. Using two spectral ordinates in the elastic base shear formulation enables the actual spectral shape to be simulated quite well.

4. New hazard results have significant implications for design force levels.

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