LOWER PROBABILITY HAZARD, BETTER PERFORMANCE? UNDERSTANDING THE SHAPE OF THE HAZARD CURVES FROM CANADA'S FOURTH GENERATION SEISMIC HAZARD RESULTS

John ADAMS[1], Stephen HALCHUK[2] And Dieter WEICHERT[3]

SUMMARY

Canada's fourth generation seismic hazard model was released for public comment in 1996 and will be revised to form the basis for seismic design codes in the year-2003 edition of the National Building Code of Canada (NBCC). The Cornell-McGuire method is used, with two complete earthquake source models together with a deterministic Cascadia subduction earthquake and a floor hazard for the low seismicity regions. A "robust" method is used to combine the model results: the mapped value is the largest of the four values. Spectral-value and peak-acceleration maps and Uniform Hazard Spectra for main cities have been produced for median (50th percentile) ground motions at a 10% and a 2% probability of exceedence in 50 years. Despite different methods and strong ground motion relations, our results generally agree at the border with the 1997 US NEHRP maps. Engineers consider that the current NBCC, formulated with California experience in mind and based on 10%/50 year hazard values, provides adequate seismic safety in Vancouver, and thence proportionately across the country. However, the complexity of seismological inputs is such that no simple engineering factor ("overstrength" or "experience factor" or other) can convert those moderate-probability hazard maps into design values intended to provide uniform protection against low-probability building collapse (even across California). Thus the 2%/50 year hazard results are considered a better basis for achieving a uniform level of building safety across Canada, as they are closer to the acceptable frequency of collapse. Use of the 2%/50 year values increases design levels in the low-moderate seismicity eastern Canada by about 15-30% relative to the moderate-high seismicity western Canada.

METHODS

Three generations of seismic hazard maps for Canada have been produced at roughly 15-year intervals (1953, 1970, 1985), and a fourth generation is now justified because there is sufficient new information available to improve the hazard estimates [Basham et al., 1997]. The GSC applies the traditional Cornell-McGuire [e.g. McGuire, 1993] method of delineating source zones based on historic seismicity and/or regional tectonics [Adams et al., 1999a]. Hazard is calculated with a customized version of the FRISK88 program (a proprietary product of Risk Engineering), which includes epistemic uncertainty. The GSC has adopted four seismicity models [Adams et al., 1999a] - two sets of probabilistic source zones that attempt to capture the spectrum of knowledge for seismicity and tectonics across Canada that are detailed by Adams et al. [1999a], together with, as discussed below, a probabilistic floor level for the "stable" part of Canada, and a deterministic Cascadia model in southwestern Canada.

Seismic Hazard for the "Stable" Part of Canada.

About half of the Canadian landmass has too few earthquakes to define reliable seismic source zones, and on prior maps the hazard computed for these regions came only from distant external sources. However, international examples suggest that large earthquakes might occur *anywhere* in Canada (albeit rarely). To

[1] *National Earthquake Hazards Program, Geological Survey of Canada, Canada, Email : adams@seismo.nrcan.gc.ca*
[2] *National Earthquake Hazards Program, Geological Survey of Canada, 7 Observatory Crescent, Ottawa K1A 0Y3 Canada*
[3] *National Earthquake Hazards Program, Geological Survey of Canada, P. O. Box 6000, Sidney, V8L 4B2 Canada.*

improve the reliability of the estimate of seismic hazard for the stable part of Canada we combine the earthquake activity of those stable continental shields of the globe comparable to the Canadian shield

[Fenton and Adams 1997] and then compute the hazard, using eastern strong ground motion relations, at the centre of a large octagonal source zone with this per-area activity level. As our selection of comparable shield areas was conservative, these values are expected to be the lowest likely for any part of Canada not included in a source zone, and so form an appropriate "floor". This floor is also used for low-hazard sites west of the Rockies, where the activity rates are likely to be higher, but the attenuation is stronger.

Deterministic Subduction Earthquake Ground Motions.

Great earthquakes happen on the Cascadia subduction zone on the average about every 500-600 years, so the median values from our magnitude 8.2 deterministic scenario have an annual probability about the same as for the 10%/50 year probabilistic values. However, those median values are not appropriate for the 2%/50 year hazard, since in circa 2500 years (i.e., equivalent to 0.0004 p.a. or 2%/50 years) we can expect to have 4-5 Cascadia subduction earthquakes with a suite of shaking levels. Hence, for five events, there is an even chance one of the five will exceed the 75-80th percentile ground motions of the suite. This percentile is very close to the 84th, so we have used the "median plus one sigma" ground motions from our 10%/50 year calculations for the 2%/50 year deterministic hazard.

Strong Ground Motion Relations and Reference Ground Condition.

We compute seismic hazard for a "firm ground" site condition equivalent to and average velocity in the top 30 m of 360-750 m/s (=NEHRP class C). For eastern Canada we use the Atkinson and Boore [1995] hard-rock relations, with our refenence ground condition factor to convert them to "firm ground". The factors used are (in brackets): PGV (2.38), PGA (1.39), 0.2 s (1.94), 1.0 s (2.58). While the Atkinson-Boore relations are fairly consistent with the majority consensus in the field, the excellent Saguenay data and contrary opinions [Haddon, 1997] give us strong reservations about the shaking predicted for the larger (magnitude about 62) earthquakes critical for hazard estimation. We would emphasize that no matter how good our source models, the reliability of the final hazard values is highly dependent on the reliability of the extrapolations within the attenuation relations used, as observational data from large eastern earthquakes is sparse. For the western Canadian shallow source zones, including the subcrustal transition zones west of Vancouver Island as well as the Queen Charlotte Fault, we continue to use our adaptation of the ground motion relations of Boore et al. [e.g., 1997]. For subcrustal source zones deeper under Puget Sound and for the Cascadia subduction zone we use the Youngs et al. [1997] relations, adjusted to "firm ground".

Ground Motion Parameters and Choice of Confidence Level.

While the 1985 maps gave PGV and PGA values, we present 5%-damped spectral acceleration values for 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 1.0, and 2.0 second periods (denoted PSA0.1 etc) for both east and west (note epistemic uncertainty is not available for PSA2.0 in the east). We also give PGA values for both east and west, but PGV values for just the east (a PGV ground motion relation is not available for the west). We provide values for two confidence levels, the 50th percentile and the 84th percentile; the former is the median, and the latter includes a measure of epistemic uncertainty arising from the incorporation of uncertainty in the model. Either might be used for engineering design. The median has been chosen for NBCC because it is a robust parameter and can be expected to remain stable as the range of scientific opinion changes.

Combining Hazard Estimates Using the Robust Approach.

We combine the complete probabilistic hazard calculation from each of the two models, together with the probabilistic "floor" level for the "stable" part of Canada and the deterministic Cascadia model, in the fashion we term "robust" [Adams et al., 1995; 1999a,b], i.e. by choosing the highest value of the four sources for each grid point. The chief advantage of the "robust" approach is that it preserves protection in areas of high seismicity but also provides increased protection in low seismicity areas that are geologically likely to have future large earthquakes.

Comparison with USGS methods.

The USGS has recently produced a new generation of seismic hazard maps [Frankel et al., 1996]. At the border, the two agencies have a common recorded earthquake history, share an understanding of the seismotectonics, and agreement on the probability levels and ground motion parameters to be mapped. While there is some similarity in how the seismic hazard model is constructed, the approaches differ in detail. For eastern Canada the GSC applied the Cornell-McGuire method to two new seismic source models, one historical and one geological. In the eastern United States the USGS employed spatially-smoothed representations of historic seismicity (together with direct input for a few large earthquakes and a background source zone) to avoid using subjective source zones to calculate hazard. Hence not all the hazard captured by the GSC's “geological” model (e.g. how often large earthquakes may happen in areas of low historical seismicity) is represented in the USGS results. For western Canada the GSC used two source zone models but combined them with a deterministic estimate for a repeat of the 1700 A.D. Cascadia subduction earthquake. This is very different from the USGS's incorporation of Cascadia subduction earthquakes into its probabilistic model.

RESULTS

Table 1 gives the 2% in 50 year probabilistic hazard values for selected Canadian cities, itemizing separately the values for the two source zone models and their 50th and 84th percentiles, together with the appropriate Cascadia values. Space precludes the presentation of individual uniform hazard spectra, but these are given in Adams et al. [1999a]. The “floor” hazard for the “stable” part of Canada, for firm-ground at the 2% in 50 year probability level, is: PSA0.1=16%g; PSA0.2=16%g; PSA0.3=12%g; PSA0.4=9.2%g; PSA0.5=7.5%g; PSA1.0=2.9%g; PSA2.0=1.0%g; PGA=11%g; PGV=0.045 m/s. Figure 1 shows the Canada-wide distribution of PSA0.2 hazard. Note that the inclusion of the floor value (16%g for this map) eliminates the lowest contours of prior maps. Table 2 compares the 2% and 10% values, and gives the ratio of their medians. As it happens, median values for the 2%/50 year probability level are larger than, or nearly the same as, 84th percentiles for the 10%/50 year level.

Table 1. Selected seismic hazard values at 0.000404 per annum for "Firm Ground"

			PGV (m/s)	PGA (%g)	----- 0.2 second PSA ----- (%g)				----- 1.0 second PSA ----- (%g)				1.0 s PSA (%g)
	Coordinates		50%	50%	50%		84%		50%		84%		84%
City	°North	°West	H	H	H	R	H	R	H	R	H	R	Cascadia
St. John's	47.6	52.7	0.048	*8.4*	*15*	18	27	31	4.5	6.0	13	16	**see**
Halifax	44.6	63.6	0.052	*8.5*	16	23	29	41	5.1	7.0	14	19	**note**
Moncton	46.1	64.8	0.095	21	30	28	52	49	6.8	6.5	22	20	
Fredericton	45.9	66.6	0.11	23	35	39	62	69	8.6	8.1	26	27	
La Malbaie	47.6	70.1	0.62	110	230	65	380	100	59	13	180	41	
Quebec	46.8	71.2	0.14	28	52	59	89	100	14	11	44	37	
Trois-Rivieres	46.3	72.5	0.11	20	35	64	62	110	10	12	29	40	
Montreal	45.5	73.6	0.17	37	58	71	97	110	13	14	38	44	
Ottawa	45.4	75.7	0.13	25	45	67	85	110	10	14	31	42	
Niagara Falls	43.1	79.1	0.13	30	41	21	93	38	7.1	5.5	25	15	
Toronto	43.7	79.4	0.081	20	28	20	55	34	4.9	5.4	17	14	
Windsor	42.3	83.0	*0.038*	*5.9*	*12*	17	21	32	*2.4*	3.9	8.4	11	
Calgary	51.0	114.0	**see**	*8.8*	*15*	*9.7*	29	19	4.1	3.2	8.0	6.4	*1.2*
Kelowna	49.9	119.4	**note**	14	27	19	55	37	8.6	8.9	17	18	4.1
Kamloops	50.7	120.3		14	28	20	55	40	8.5	10	17	20	4.1
Prince George	53.9	122.7		*7.1*	*13*	*9.3*	26	19	4.0	3.8	8.0	7.6	*2.5*
Vancouver	49.2	123.2		48	96	100	190	200	30	34	60	69	14
Victoria	48.5	123.3		62	120	110	250	230	38	38	77	75	26
Tofino	49.1	125.9		16	32	63	65	130	12	24	24	48	37
Prince Rupert	54.3	130.4		*10*	19	36	39	72	13	16	26	32	**see**
Queen Charlotte	53.3	132.0		34	63	65	130	130	45	50	91	100	**note**
Inuvik	68.4	133.6		*6.0*	*10*	*8.7*	20	17	3.7	3.9	7.4	7.8	

Abbreviations: PGV = peak ground velocity; PGA = peak ground acceleration; 0.2 s PSA and 1.0 s PSA = 5% damped pseudo-spectral acceleration at 0.2 and 1.0 seconds. The columns labeled "50%" and "84%" are the medians and 84th percentiles (exceeded 50% and 16% of the time, respectively). Columns labeled ‘H’ and ‘R’ are the hazard values for the probabilistic models discussed in the text; ‘Cascadia’ is the Cascadia scenario event. Median values in *italics* are below the Floor values. Note: PGV values are not available for the west; Cascadia values are given only where relevant.

In Table 3 we group selected Canadian and United States cities we consider to have similar seismic hazard. Where we believe that each country's model adequate, we provide both sets of results for PSA0.2 and PSA1.0 for a direct comparison. Site conditions used for the US calculations are slightly firmer than for Canada (760 m/s vs 560 m/s). Therefore we have increased the USGS PSA0.2 values by 10% and the PSA1.0 values by 15% in order to match their results to ours, factors we based on the NEHRP Fa/Fv ratios. The same factors were applied before we contoured Figure 2.

In eastern Canada, GSC hazard values in the Appalachians are generally higher than USGS values. The GSC's regional model spreads the historical seismicity from northern New York to northern New Brunswick, whereas the USGS method concentrates the hazard in the historically active northern New Brunswick and southern New Hampshire regions. The cities of Fredericton and Portland show generally comparable hazard (Table 1), though for PSA0.2 the GSC has Fredericton higher than Portland, while the USGS has Portland higher than Fredericton. The similarities of the Charlevoix region occur because the USGS specifically adopted the magnitude recurrence slope determined by the GSC (β=1.74, b=0.76). The steeper slope (β=2.20, b=0.95) obtained by the USGS based on the entire eastern US catalogue and applied to the entire region generally results in lower hazard for historically active zones when compared to the GSC, which determines magnitude recurrence relations for most zones directly (compare hazard for northern Ohio (β=2.05), Buffalo-Hamilton (β=1.80), southern New Brunswick/Maine border region (β=1.72), and the lower St. Lawrence (β=1.93); all yielding higher hazard than from the USGS model (β=2.20)).

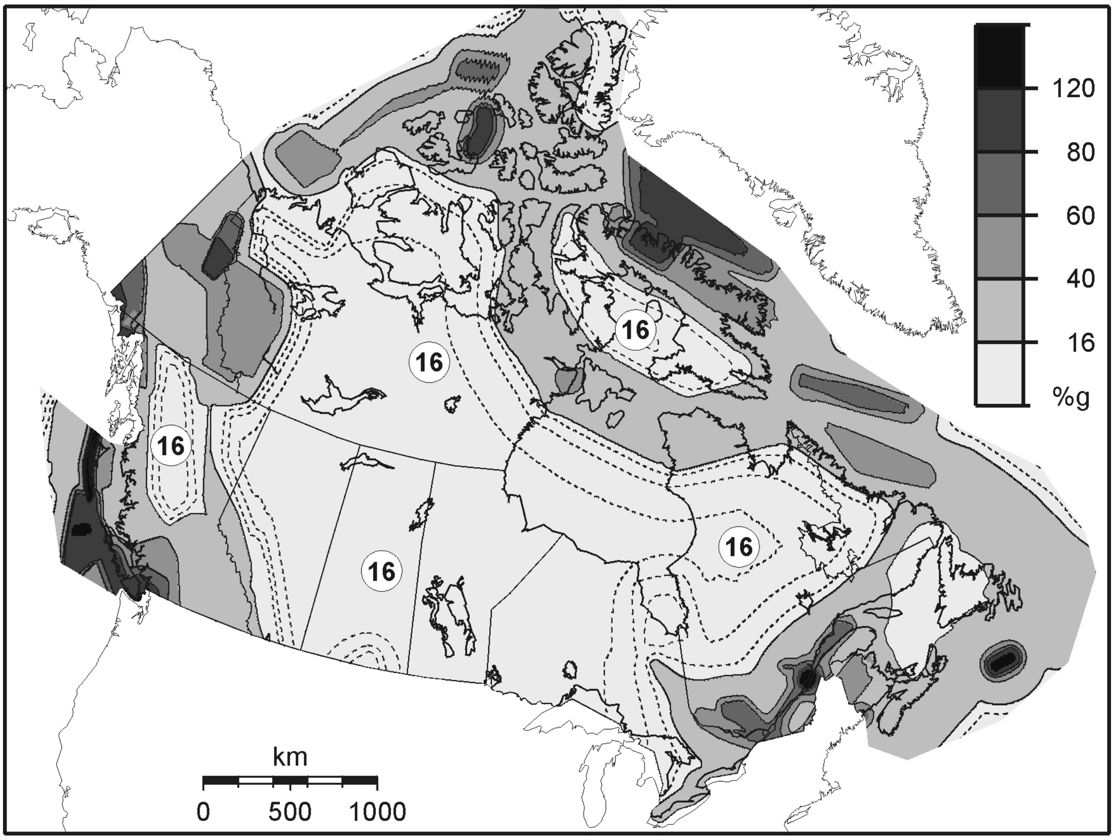

Figure 1. **2%/50 year seismic hazard for 5% damped PSA 0.2 seconds, on firm ground.**

The main difference in the east occurs within Canada where the GSC model attempts to provide protection to regions with few historical earthquakes. The regional zones of the GSC model generate hazard values that are up to twice those from the smoothed-historical USGS approach [e.g., Halchuk and Adams, 1999]. Despite these differences, the overall similarity in contour level and pattern is high. Hazard determined for both Montreal and Ottawa is quite comparable for both long and short periods (Table 3). We group Boston and New York with Montreal and Ottawa, rather than Fredericton and Portland (which have comparable calculated hazard according to the USGS), because of our understanding that New York lies near to the Iapetan passive margin and both New York and Boston lie near rift basins of the present passive margin. Thus we implicitly argue that the USGS's estimates, based on the short historical record, may have underestimated their long-term hazard. Around the southern Great Lakes, the long-period hazard for the three large cities determined by the GSC is slightly lower than that of the USGS, but the PSA0.2 values are slightly higher from the GSC model. When the hazard values from each agency are cut off at the border, the differences are minimal and most contours match well (Figs 2c and 2d).

Though we judge Calgary and Denver to have broadly similar seismotectonic environments and although direct inter-comparison of results is not possible, the GSC places Calgary at a lower hazard level than the USGS places Denver. Kelowna and Spokane are both mid-Cordilleran cities and have comparable hazard levels (Table 3). As was evident in the comparisons of the previous generations of hazard estimates [Basham et al., 1985], the USGS model still has more active earthquake sources contributing to the hazard in the northern Idaho-Montana region than does the GSC's model.

Table 2. Comparison of PSA0.2 hazard values for probabilities of 10% and 2% per 50 years and ratios of the median values. For eastern and western cities the average ratios are 2.34 and 1.91.

City	10%/50 yr		2%/50 yr		Ratio
PSA0.2 (%g)	50%	84%	50%	84%	2%/10%
St. John=s	8.9	15	18	30	1.99
Halifax	9.7	17	20	34	2.10
Moncton	14	23	31	51	2.28
Fredericton	17	28	38	66	2.27
La Malbaie	99	170	230	380	2.28
Quebec	24	40	56	90	2.32
Trois Rivieres	27	48	68	110	2.48
Montreal	29	50	68	110	2.32
Ottawa	27	46	62	99	2.34
Niagara Falls	15	31	40	90	2.57
Toronto	11	21	28	55	2.55
Windsor	6.8	12	18	31	2.64
Calgary	6.7	14	15	30	2.20
Kelowna	14	28	27	50	1.99
Kamloops	13	28	26	48	1.92
Prince George	5.7	12	12	25	2.16
Vancouver	50	110	97	190	1.96
Victoria	64	130	120	240	1.91
Tofino	29	55	49	110	1.66
Prince Rupert	18	35	33	61	1.86
Queen Charlotte	41	82	63	130	1.54
Inuvik	5.4	11	10	20	1.91

Table 3. Comparison of spectral accelerations (5% damped, 0.000404 p.a.) at selected Canadian and US cities for firm ground. USGS values have been corrected to match Canadian site conditions.

City	PSA 0.2 (%g)		PSA 1.0 (%g)	
	GSC	USGS	GSC	USGS
Fredericton	39	30	8.6	10
Portland, Me	32	41	7.2	12
Montreal	69	70	14	17
Ottawa	67	60	14	15
New York	-	47	-	11
Boston	-	34	-	10
Toronto	28	22	5.4	6.7
Buffalo	39	35	6.8	7.9
Cleveland	28	23	5.0	6.7
Calgary	15	-	4.1	-
Denver	-	22	-	6.7
Kelowna	27	31	8.9	11
Spokane	-	35	-	11
Vancouver	100	120	34	46
Victoria	120	132	38	53
Seattle	120	177	37	64
San Francisco	-	264	-	167

A southwestern border comparison is shown in Figure 2a and 2b. Along the western portion of the border, different attenuation relations, the treatment of the Cascadia zone, and the implementation of individual fault models result in the USGS hazard being higher than the GSC values. For the Cascadia subduction zone, the USGS uses two scenarios which they include in their probabilistic model: a floating M8.3 earthquake somewhere in the zone every 110 years, or a M9 earthquake rupturing the entire zone every 500 years. The GSC treats the Cascadia earthquake as a deterministic magnitude 8.2 event, and consider its effects only where they exceed the probabilistic hazard from other earthquakes, chiefly along the west coast of Vancouver Island. The higher magnitude events in the USGS Cascadia scenarios, their shallower depths, and probabilistic treatment provide the larger coastal hazard values in the west.

Although GSC and USGS values are broadly the same for Vancouver and Victoria at high frequency (Table 3), the long period hazard determined by the USGS is higher due to its treatment of the subduction earthquakes. The USGS's Seattle results are 50-80% higher than ours, perhaps because the underlying Seattle fault is included as a separate source by the USGS. The PSA1.0 estimates (Figure 2b) are also similar in the Puget Sound region. In the west, the PSA0.2 (Figure 2a) estimates match very well in the border region of Puget Sound, despite difference in modeling of the shallow and deep (Juan de Fuca Plate) seismicity, and different treatment of the Cascadia subduction earthquake. The San Francisco results, shown for comparison, indicate that even the Canadian cities with the highest seismic hazard are only half to a third as hazardous as this well-known California city.

DISCUSSION AND CONCLUSIONS

While many differences have been featured above, it should be emphasized that the similarity in level and pattern across the Canada-US border is generally good. Despite the use of different methods and attenuation relations, values for cities in similar tectonic environments agree to within 50%. With the different interpretations given the similar (but not identical) earthquake catalog and strong ground motion relations, this level of disagreement is not unexpected.

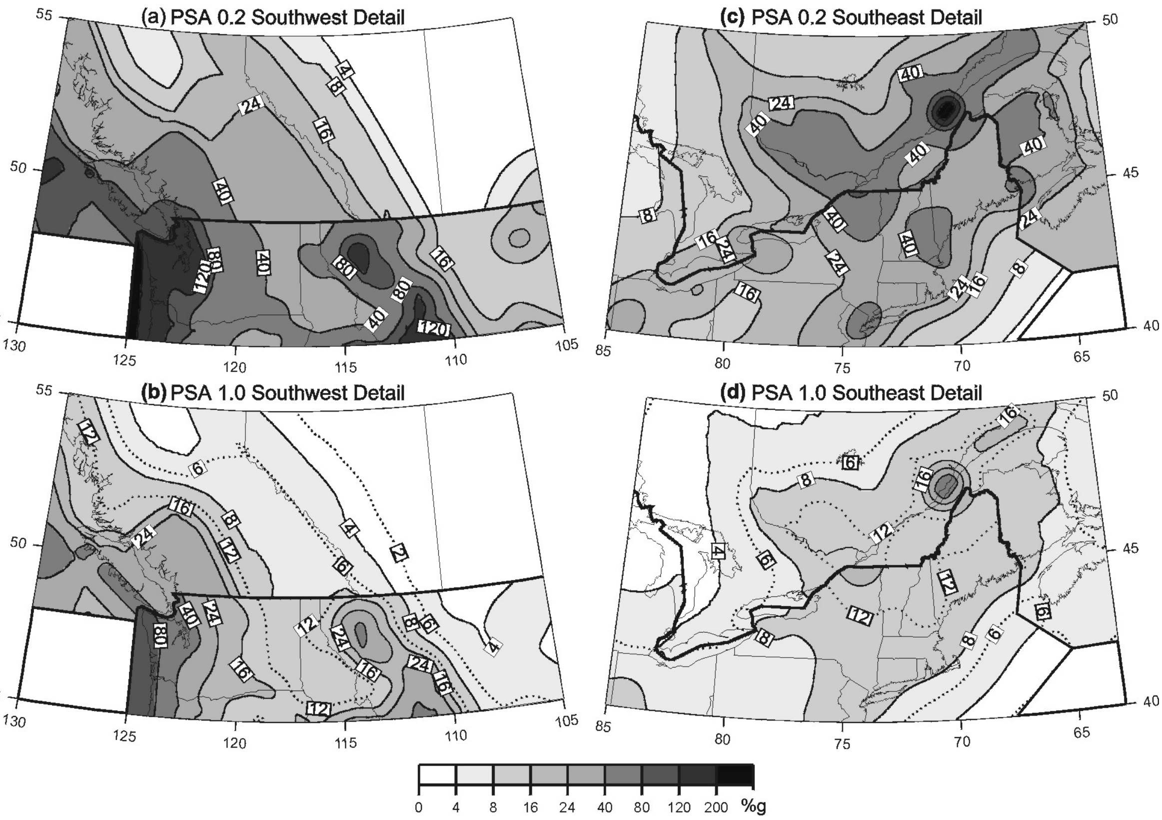

Figure 2. Comparison of PSA0.2 and PSA1.0 (2%/50 year probability) hazard estimates in western and eastern Canada-United States border regions. USGS PSA 0.2 and 1.0 values have been increased by 10% and 15% respectively to match GSC site conditions.

Considering the Canadian 2% and 10% results, the reason for the different ratios in the east and west is illustrated on Figure 3, which shows the complete hazard curves for PSA0.2 for the important (and fairly typical of western and eastern) cities of Vancouver and Montreal. The hazard curve for Montreal is steeper than for Vancouver, with the 2%/10% ratio being 1.94 for Vancouver but 2.35 for Montreal. Thus the different ratios in Table 2 reflect the slopes of each city′s hazard curve. These in turn are a function of the size and distance distribution of earthquakes contributing hazard to each city. In general, where sites are dominated by distant, high-activity zones (in which earthquakes near the upper bound are relatively common), the hazard curve is less steep (= low ratio) than for sites that lie within moderate seismicity zones. While average values for the ratios for east and west cities are approximately 2.34 and 1.91 (Table 2), they vary considerably, as shown also by the spatial variation for southwestern B.C. (Fig. 4).

The variation means that applying a national (e.g. 2.1), or even regional (e.g. 2.34 and 1.91), multiplicative factor to the 10%/50 year values will not reproduce lower probability hazard values reliably. The very different average slopes between east and west have important consequences for safe design. For example, the annotations on Figure 2 show the effect of applying a constant factor of two (say an "experiental factor of safety" term) to both the Vancouver and Montreal 10%/50 values. For Vancouver this would give a design appropriate to 1/2400 year shaking, but for Montreal a design appropriate to 1/1600 year shaking. Clearly the same level of safety has not been achieved. Even if different constants were used for east and west, the geographical variation shown in Figure 4 (and present across all of Canada, as well as in the USGS's results for California) would preclude achieving a constant level of safety.

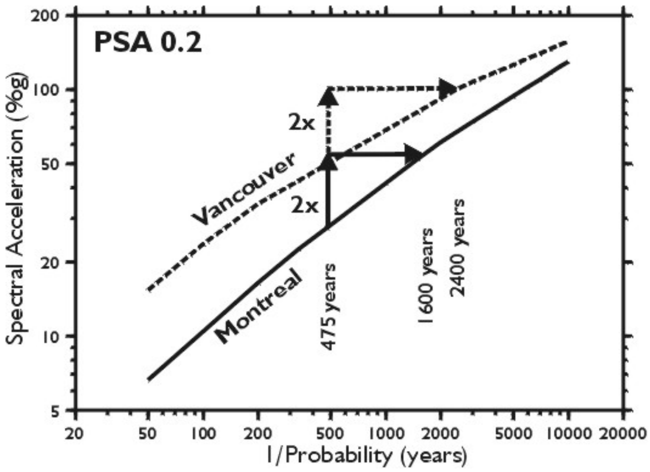

Figure 3. PSA 0.2 hazard curves for Vancouver and Montreal, showing how increasing the 10%/50 year median hazard by a factor of two produces different increases in safety

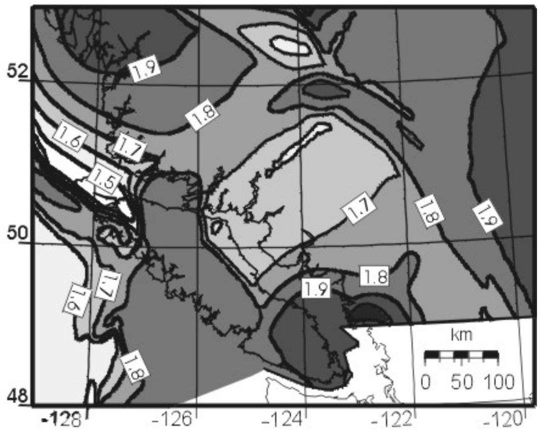

Figure 4. Ratio of 2%/50 year to 10%/50 year PSA 0.2 median hazard for southwestern British Columbia

No recent earthquake has thoroughly tested building design in Canada, but engineers consider that the current NBCC, formulated with California experience in mind and based on 10%/50 year hazard values, provides adequate seismic safety in Vancouver, and thence proportionately across the country. However, the complexity of seismological inputs to the hazard calculation (represented in aggregate by the varied shapes of the hazard curves) is such that no simple engineering factor "overstrength" or "experience factor" or other) can convert such moderate-probability hazard maps into design values intended to provide uniform protection against low-probability building collapse (even across California). Thus the 2%/50 year results are considered a better basis for achieving a uniform level of building safety across Canada as they are closer to the acceptable frequency of collapse and require little or no extrapolation along hazard curves of varied slope. If a normalization factor of 1/2 is used to adjust the 2%/50 year PSA1.0 values for Vancouver, they approximate the 10%/50 year hazard (i.e. consistent with the existing code providing adequate safety for Vancouver). The same normalization factor used with the 2%/50 year values for eastern cities like Montreal increases design levels for the low-moderate seismicity eastern Canada by about 15-30% for short periods and 30-40% for long periods, relative to the moderate-high seismicity western Canada [see e.g. Heidebrecht, 1999].

We conclude that the direct calculation of seismic hazard at the probability level most appropriate for the design goal is necessary. As suggested by Heidebrecht [1999], the 2%/50 year probability level represents the approximate structural failure rate deemed acceptable, and so the 2%/50 year seismic hazard values we present can help to achieve a uniform level of safety. We caution that issues of reliability and seismological model-dependence of the low-probability results are still a concern, especially in the moderate to low seismicity regions.

REFERENCES

Adams, J., Weichert, D.H., Halchuk, S., and Basham, P.W. 1995. "Towards fourth generation seismic hazard maps of Canada". *Proceedings, 7th Canadian Conf. on Earthquake Eng.,* Montreal, p. 1009-1016.

Adams, J., Weichert, D.H., and Halchuk, S. 1999a. "Trial seismic hazard maps of Canada - 1999: 2%/50 year values for selected Canadian cities". *Geological Survey of Canada Open File 3724*, 100 pp. (See also http://www.seismo.nrcan.gc.ca).

Adams, J., Weichert, D.H., and Halchuk, S. 1999b. "Lowering the probability level - Fourth generation seismic hazard results for Canada at the 2% in 50 year probability level". *Proceedings 8th Canadian Conference on Earthquake Engineering*, Vancouver 13-16th June 1999, p. 83-88.

Atkinson, G.M., and Boore, D.M. 1995. "New ground motion relations for eastern North America". *Bull. Seism. Soc. Am.* v. 85, p. 1327-1342.

Basham, P.W., Halchuk, S., Weichert, D. and Adams, J., 1997. "New seismic hazard assessment for Canada". *Seismological Research Letters* v. 68, p. 722-726.

Basham, P.W., Weichert, D.H., Anglin, F.M., and Berry, M.J. 1985. "New probabilistic strong seismic ground motion maps of Canada". *Bull. Seism. Soc. Am.*, v. 75, p. 563-595.

Boore, D.M., Joyner, W.B., and Fumal, T.E. 1997. "Equations for estimating horizontal response spectra and peak acceleration from western North America earthquakes: a summary of recent work". *Seismological Research Letters*, v. 68, p. 128-153.

Fenton, C.H and Adams, J. 1997. "Seismic hazards assessment for radioactive waste disposal sites in regions of low seismic activity". *Proceedings, 3rd European Engineering Geology Conference*, Newcastle, U.K. 10-14 September, 161-180.

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., Hopper, M., 1996. "National Seismic-Hazard Maps. Documentation, June 1996, Open File Report 96-532" available on the WWW, (http://geohazards.cr.usgs.gov/eq/).

Haddon, R.A.W. 1997. "Reply to Comment by G. Atkinson *et al.* on 'Earthquake source spectra in eastern North America' ". *Bull. Seism. Soc. Am.*, v. 87 p. 1703-1708.

Halchuk, S. and Adams, J., 1999b. "Crossing the Border: Assessing the differences between new Canadian and American seismic hazard maps". *Proceedings 8th Canadian Conference on Earthquake Engineering*, Vancouver 13-16th June 1999, p.77-82.

Heidebrecht, A.C. 1999. "Implications of new Canadian uniform hazard spectra for seismic design and the seismic level of protection of building structures". *Proceedings 8th Canadian Conference on Earthquake Engineering.*, Vancouver 13-16th June 1999, p. 213-218.

McGuire, R.K. 1993. "Computations of seismic hazard". In Giardini, D., and Basham, P.W., (Eds.), *Global Seismic Hazard Assessment Program*, Annali di Geofisica, vol. 34, 181-200.

Youngs, R.R., Chiou, S.-J., Silva,W.J., and Humphrey, J.R. 1997. "Strong ground motion relationships for subduction zone earthquakes". *Seismological Research Letters*, v. 68, p. 58-73.