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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8294

Third generation seismic hazard model for Canada: grid values of hazard used with the 1985, 1990, and 1995 National Building Codes of Canada

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ABSTRACT

Canada's 3rd Generation seismic hazard model was the basis for the seismic design provisions in the 1985, 1990, and 1995 National Building Codes of Canada. These codes use best-estimate ground motion on firm soil sites for a probability of exceedance of 10% in 50 years. The ground motion was quantified by seismic hazard values for two parameters: peak acceleration and peak velocity. For consistency with our later products, we tabulate code values of the two parameters for more than 200,000 grid points over Canadian territory and surrounding areas. Values at four probability levels ranging from 1 in 100 to 1 in 1000 years are also provided which allows for the construction of 3rd Generation hazard curves for every locality in Canada. The information retroactively comprehensively documents the basis for earthquake-resistant design for buildings constructed according to the requirements of the 1985 to 1995 codes, and may prove useful in structural retrofit decisions.

INTRODUCTION

The Earth Physics Branch of the Federal Department of Energy, Mines and Resources Canada produced a seismic hazard model (Basham et al., 1982; Basham et al., 1985) to provide seismic hazard values for the 1985 National Building Code of Canada. This 3rd Generation model (previous generations were created for the 1953 and 1970 editions of the code) formed the basis for the Canadian National Committee on Earthquake Engineering's (CANCEE) final recommendations for the seismic design provisions in the 1985, 1990, and 1995 edition of the National Building Code of Canada (NBCC).

The present Open File is being issued to place on record and make available seismic hazard values for a grid of more than 200,000 grid points over the Canadian territory and surrounding areas, computed using the final methods and model used for the 1985 National Building Code of Canada. The grid values supplement the published values, which were given just for the localities listed in Table J-1 "Design Data for Selected Locations in Canada" of the Supplement to the National Building Code of Canada 1985. For other places it replaces the printed instruction to contact our precedent organization to obtain values for other Canadian localities (see the sample calculation that was supplied in Appendix A), as we foresee that it may become difficult to continue to run the computer code on future computer operating systems.

The primary values given in this report represent best-estimate[1] ground motion on firm soil sites (V_{S30} = 450 m/s) for a probability of exceedance of 10% in 50 years (0.0021 per annum), for the two ground motion parameters, Peak horizontal Ground Acceleration (PGA) and Peak horizontal Ground Velocity (PGV) used by NBCC1985. The parameters will allow for the review of buildings designed during the period when the 1985, 1990, and 1995 codes were in effect for every place in Canada (approximately those designed in 1986 to 2007[2]).

This Open File follows the equivalent NBCC2005 work presented in GSC Open File 5813 (Halchuk and Adams, 2008), which should be referred to for the prior history of the methodology and parameters of the grid. Sample solution lines are given in Table 1, together with a detailed explanation of the format.

METHOD

The method for calculating seismic hazard built upon the work of Milne and Davenport, (1969) which established the second generation of seismic hazard map for Canada based on extreme-value statistics applied to the catalog of known Canadian earthquakes. For the 3rd Generation

[1] Unlike the 4th Generation model which has a full treatment of uncertainty, the 3rd Generation model is a "best-estimate" model that only includes the sigma uncertainty in the ground motion relations. For a best-estimate model the mean value equals the median value which also equals the best-estimate value. In general, seismic hazard models that include uncertainty give a higher value for mean hazard than those that do not.

[2] The implementation of the model National Building Code across Canada is a Provincial/Territorial responsibility, so the applicable dates in each jurisdiction lag the issuance of the code.

model, Basham, Weichert, Anglin and Berry applied the method developed by Cornell (1968) and adapted the computer program of McGuire (1976).

Ground Motion Models

The different physical properties of the crust in eastern and western Canada require the use of separate ground motion models, also termed Ground Motion Prediction Equations (GMPEs). The GMPEs (known as "attenuation relations" at the time of their development) of Hasegawa et al. (1981) were adopted for the 3rd Generation model.

Reference Ground Condition for Canada in 1985-2005

For the comparison of national hazard maps it is essential to present seismic hazard levels on the same ground condition. NBCC2005 chose Site Class "C" as the reference ground condition, and NBCC2015 further specified it as having a 450 m/s time-averaged shear wave velocity in the uppermost 30 m (V_{S30}). By contrast, NBCC1985 considered just "rock or dense soil" with a foundation factor of 1.0 plus two categories of softer soil with foundation factors greater than 1. Therefore no allowance was made prior to 2005 that a site on rock would be shaken less strongly than one on stiff soil. That conservative choice was a consideration in the adoption of Site Class C as the reference condition in 2005. The reference ground condition for Canada in the 1985-2005 codes is therefore considered to be Site Class C, and so directly comparable to subsequent Site Class C values.

Computational aspects

A version of the McGuire (1976) hazard modelling computer program modified by Mr. Frank Anglin was employed. A listing of the program and discussion of the modifications and features of the program specific to the 3rd Generation model are provided in Basham et al. (1982). For posterity we provide a digital copy of the program and its input files as electronic supplements.

Grid chosen

A grid of points with 10-km spacing was constructed to generate the seismic hazard values for NBCC2005 (Halchuk and Adams, 2008). The same grid was used for this Open File and has a total of 200,694 points.

Accuracy and precision in this report

The main data file represents the direct output from the computer model, and is definitive. In our view seismic hazard values should be reported to two significant figures (an appropriate level of precision). However we have retained three places after the decimal in Table 1 for three reasons: (i) this conforms to the originally-supplied locality-specific calculations, (ii) the reported precision confirms these values as direct numerical output, and (iii) for interpolation of values for localities between grid points it is advisable that no imprecision be introduced through rounding errors.

Cautions

Distal grid points, i.e. those beyond Canadian territory, are likely to be inaccurate because they extend towards regions where the 3rd Generation source zones represent an incomplete account of the seismicity that is contributing ground motions. Thus these distal grid values should be used with extreme caution. The accompanying file canada_2015grid_released.txt contains the latitude and longitude coordinates of boundary of the region for which hazard values were calculated, while canada_2015grid_border.txt contains the coordinates of the Canadian border (the region for which seismic hazard values are currently considered valid).

Values for grid points in United States of America territory should never have been used for seismic hazard design. Values from the US building codes should have been used instead.

RESULTS

Tabulated Values

For each parameter [PGA and PGV], we tabulate the best-estimate firm ground NBCC hazard values at four different probabilities ranging from 40% in 50 to 5% in 50 years[3]. A sample part of this ASCII flatfile is provided in Table 1. The top of each column in the grid file is labelled with the parameter and annual probability (equivalent probabilities in 50 years and return periods are listed in Table 2). Hazard curves can be generated for the two parameters at each grid point (e.g. Figure 1). The region gridded extends beyond the borders of Canada, mainly to ensure smooth contouring at the border (for validity refer to Cautions section above).

Maps

Figures 2 and 3 are coloured maps of each of the peak values for Canada. The maps show the level of seismic hazard and an indication of the direction and steepness of the hazard gradient, important insights that are hard to gain from the tabulated values. Note that solid colours are used to map the seven zones (labelled 0 to 6 on the scales, see also Table 3) used in the building code. It is not intended that values be read off these maps (hence their small scale). Instead, values in the electronic table file should be used. Hazard depicted on these maps has been extended into the offshore but is limited to Canadian onshore and offshore territory. Grid values for regions outside of Canadian territory are given in the electronic tables to ensure smooth contouring near the border, but the caveats noted in the Caution section apply.

In examining these maps we note that the contoured maps generated for this report do not exactly match the original published maps (published as figures J-1 (PGA) and J-2 (PGV) in the various editions of the code, reproduced in Appendix B) in the following ways:

- Contours on the published maps were smoothed by the graphic arts department. This is most easily seen by the jitter in the 0.04 m/s contour on Figure 2.

[3] While the supplement to the NBCC1985 (Table J-1) did not include the 5% in 50 year values, the computer code was set up to generate them and the locality reports (Appendix A) did provide them.

- The northern tip of Ellesmere Island (of lower hazard than the southern part; the PGA 0.04g contour is just visible on the published map) was cut off on the published maps.
- Although generally replicated by Figure 2, the drafting on the published 1985 and 1995 maps did not show the small region of Zone 2 PGA in the Niagara peninsula region. In contrast, the 1990 PGA map (Figure J-1) shows a contour that encompasses almost all of the Niagara peninsula. This extension of the contour to cover a larger region may have been artistic license to draw attention to the higher hazard in the immediate vicinity of Niagara Falls. Designers who consulted the localities in the Design Data for Selected Locations in Canada table would have obtained the correct PGA zonal values.
- The published PGV map (Figure J-2) lacks an area of Zone 1 in the Labrador Sea. As can be seen from Figure 3, the Labrador Sea straddles a model boundary leading to an artifact in the contours, and because of this the entire zone appears to have been dropped (also because grid values, of which the maximum was 0.046 g, only just exceeded the contour value of 0.04 m/s).

DISCUSSION

Seismic hazard values for all points in Canada can be obtained from the definitive grid values in this report by interpolation. Halchuk and Adams (2008) contains details on the interpolation method used in the online hazard calculator. The interpolated values will generally be close to the actual hazard values, especially in regions of low hazard gradient. The gradient can be found by inspection of neighboring data points, or in a more general way from Figures 2 and 3. Tests in Halchuk and Adams, 2008 indicated that interpolated NBCC2005 results differ from the directly calculated results by less than 2%, 19 times out of 20. We would expect the 1985/1995 interpolation to be much better than this, because its underlying model is fully probabilistic[4].

SUMMARY

This Open File gives the 10% in 50 year seismic hazard results used by the 1985, 1990, and 1995 editions of the National Building Code of Canada. Values for three additional probabilities are also tabulated to provide locality-specific hazard curves to be constructed for each location in Canada.

ACKNOWLEDGEMENTS

This document summarizes the result of the extensive work of the team who created the 3rd Generation model: Peter Basham, Dieter Weichert, Frank Anglin and Michael Berry.

[4] The interpolations in the 2005 model are not as precise because the larger deviations arose when the values of adjacent grid points came from different seismicity models within the 2005 "Robust" model, with a consequent abrupt change in seismic hazard gradient.

Most of the figures were generated using the freely available GMT (Generic Mapping Tools) software package, developed by P. Wessel and W.H.F Smith (1991). Our sincere thanks for their development and maintenance of this versatile product.

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Wessel, P., and W. H. F. Smith, 1991. Free software helps map and display data, Eos Trans, AGU, v. 72, p. 441.

TABLES AND FIGURES

Table 1 – Sample format of the electronic supplement file containing seismic hazard values for the 10-km grid across Canada. An explanation of the columns is given in the Results section. Line 1 identifies the hazard data set and the units. Line 2 contains the column labels for latitude, longitude, probabilities and hazard parameters. Line 3 and subsequent lines give the latitude and longitude values, followed by the four sets of probabilities (expressed in terms of *per annum* values) and best-estimate, firm-ground seismic hazard values. The values are in units of g (9.81 m/s^2) for PGA, and in units of m/s for PGV. Grid points should be in the same order as the 4^{th} Generation grid (Halchuk and Adams, 2008).

```
1985/1990/1995 National Building Code of Canada Hazard values. PGA expressed in terms of g (9.81 m/s^2), PGV in m/s

Lat N   Long W  Prob  PGA   PGV  Prob  PGA   PGV   Prob   PGA   PGV   Prob   PGA   PGV

 60.000 -140.000 0.01 0.331 0.398 0.005 0.516 0.638 0.0021 0.824 1.076 0.001 1.223 1.628

 59.999 -139.821 0.01 0.322 0.386 0.005 0.502 0.622 0.0021 0.807 1.049 0.001 1.198 1.598

 59.997 -139.642 0.01 0.318 0.377 0.005 0.497 0.610 0.0021 0.802 1.035 0.001 1.195 1.588

 59.995 -139.462 0.01 0.308 0.364 0.005 0.481 0.591 0.0021 0.782 1.003 0.001 1.168 1.554…

…

…
```

Table 2 – Equivalent probabilities. Seismic hazard values are provided for the following annual probabilities in the electronic supplement files. Equivalent probabilities in 50 years and return periods are given.

Annual probability (p.a.)	Probability (%) in 50 years	Return period (years)
0.01	40	100
0.005	22	200
0.0021	10	475
0.001	5	1000

Table 3 – 1985/1995 NBCC Seismic zones. Zone boundaries and zonal values defined based on 10% in 50 year (0.0021 annual probability) calculated hazard values. So, for example, a 10% in 50 year PGA value of 0.13g lies between 0.11g and 0.16g, would be assigned to NBCC seismic zone 3 and would have a zonal value of 0.15g.

PGA (g) or PGV (m/s)	0.00	0.04	0.08	0.11	0.16	0.23	0.32
Zone	0	1	2	3	4	5	6*
Zonal value	0.0	0.05	0.10	0.15	0.20	0.30	0.40

* Zone 6 has a nominal value of 0.40; site specific studies are suggested for important projects.

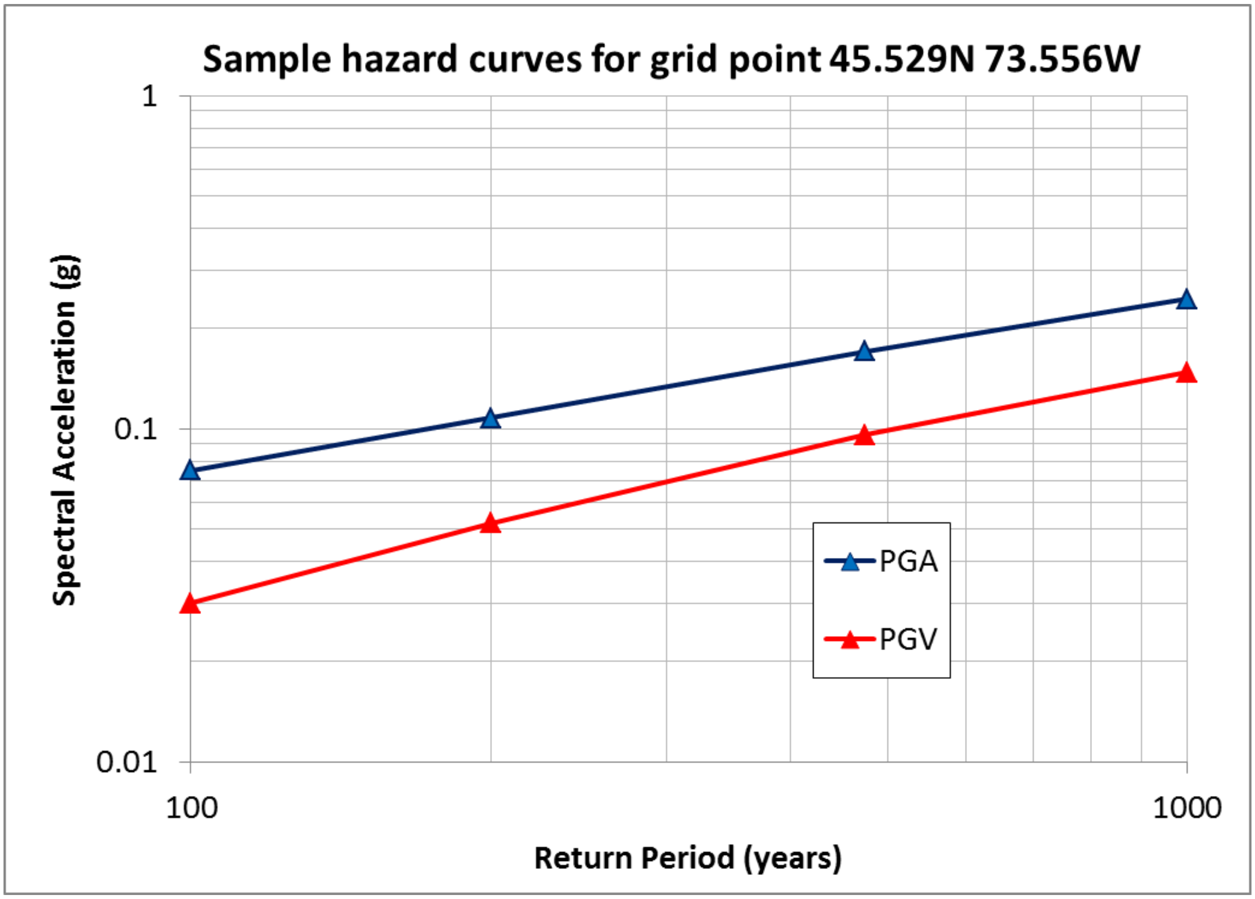

Figure 1. Sample hazard curves of PGA and PGV for a grid point near Montreal.

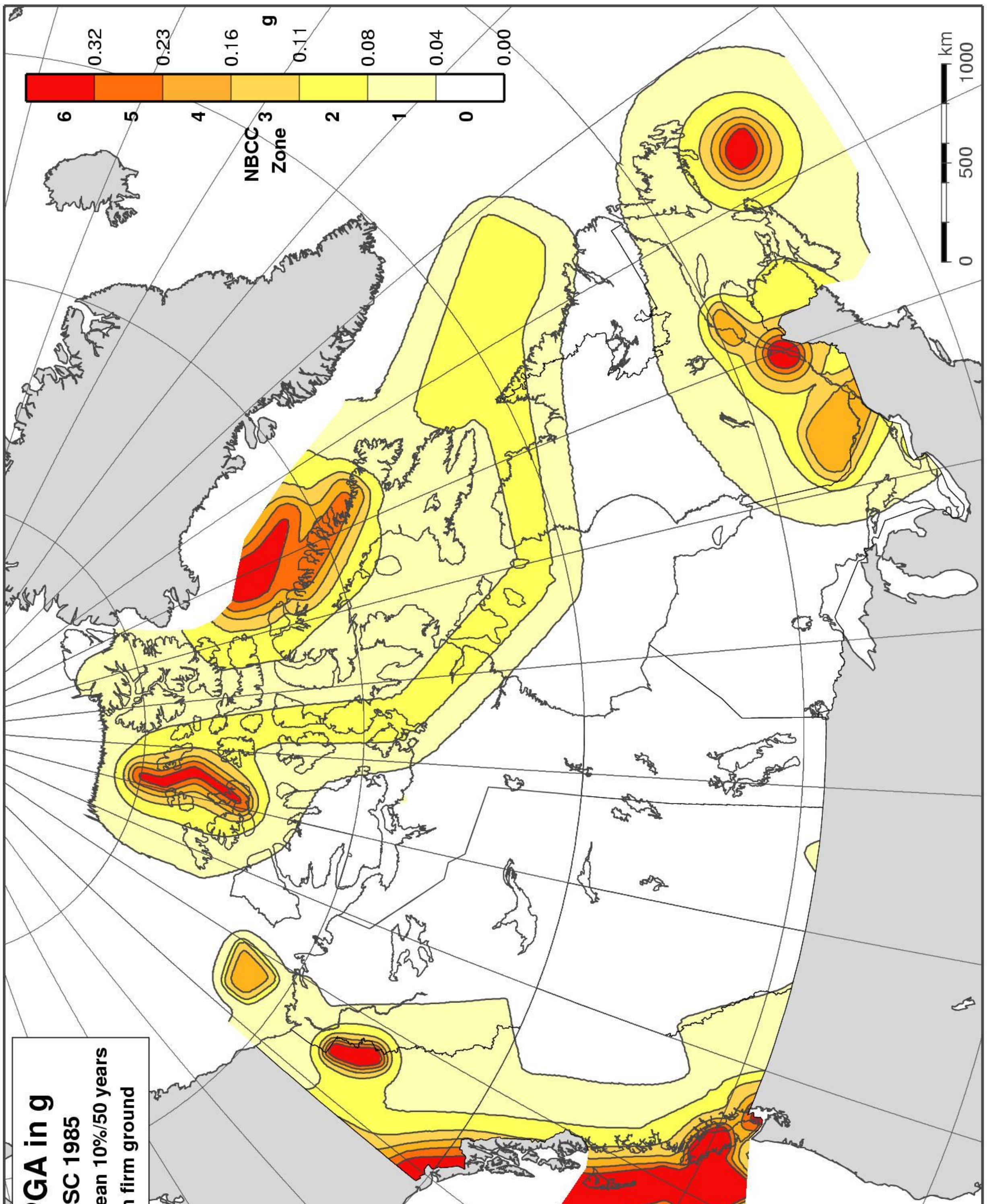

Figure 2. Peak acceleration (PGA) map for Canada. Mean values for firm ground and a probability of 10%/50 years, in g.

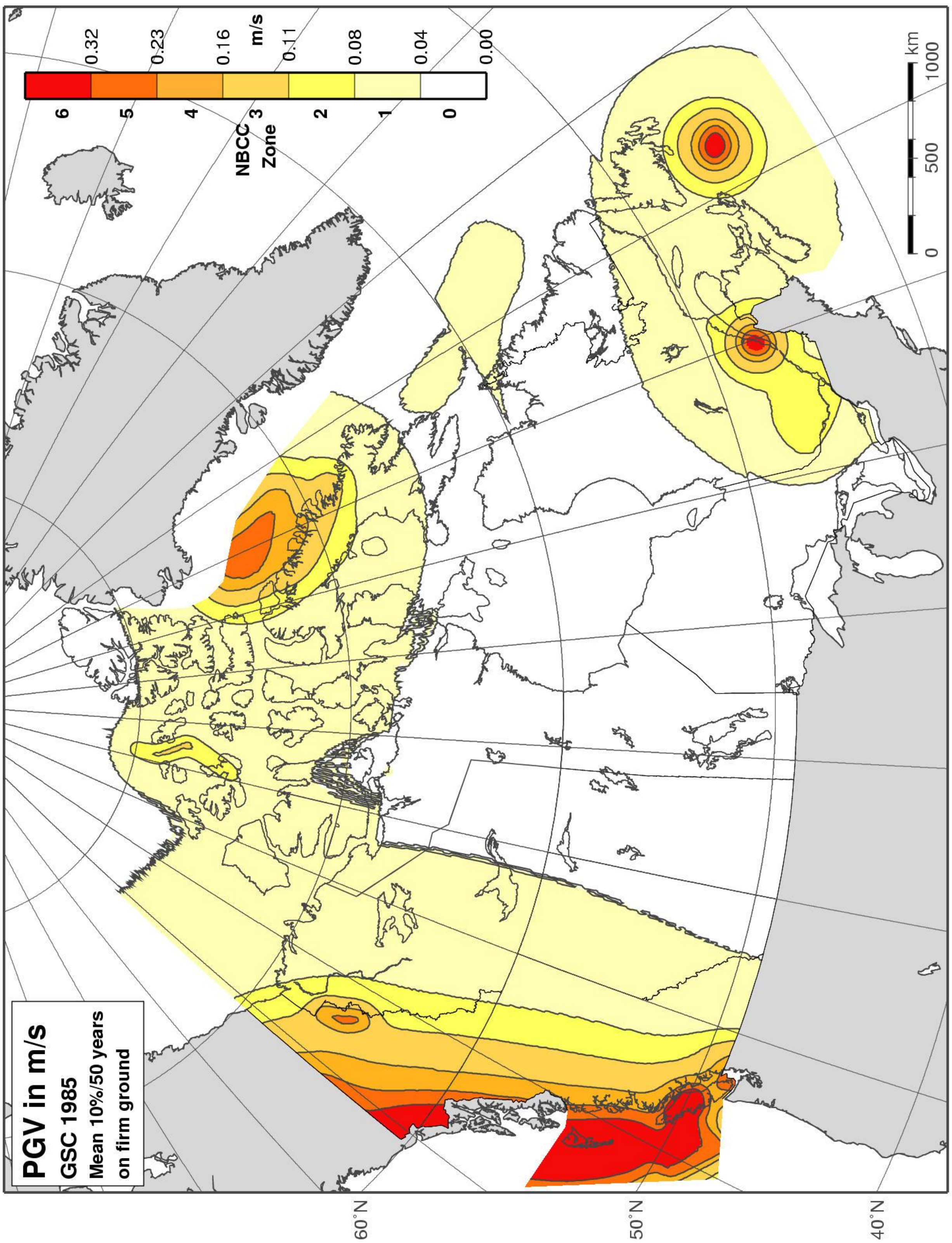

Figure 3. Peak velocity (PGV) map for Canada. Mean values for firm ground and a probability of 10%/50 years, in m/s.

APPENDIX A

Sample 3rd Generation hazard values used to be provided on payment of a $60 fee per site.

SEISMIC HAZARD CALCULATION

Geological Survey of Canada		Commission géologique du Canada

INFORMATION...(613)995-5548 [English] (613)995-0600 [français]

FAX:(613)992-8836 EMAIL: info@seismo.nrcan.gc.ca WEB:www.seismo.nrcan.gc.ca

Requested by	**Natural Resources Canada**	**15/06/2017**
Site	**Ottawa, ON**	
Located at	**45.42 North 75.69 West**	

Zoning for above site

Acceleration zone	$Z_a = 4$	**Zonal acceleration**	**0.20 g**
Velocity zone	$Z_v = 2$	**Zonal velocity**	**0.10 m/s**

Ground motions for selected probability levels for above site

Probability of exceedence per annum	0.010	0.005	0.0021	0.001
Probability of exceedence in 50 years	40%	22%	10%	5%
Peak horizontal ground acceleration (g)	0.084	0.124	0.200	0.283
Peak horizontal ground velocity (m/s)	0.031	0.054	0.098	0.153

1995 NBCC seismic zones

probability level: 10% in 50 years

g or m/s	0.00	0.04	0.08	0.11	0.16	0.23	0.32	
zone		0	1	2	3	4	5	6*
zonal value		0.00	0.05	0.10	0.15	0.20	0.30	0.40

* zone 6: nominal value 0.40;
site-specific studies suggested for important projects

REFERENCES

National Building Code of Canada 1995 NRCC no. 38726; section 4.1.9.1 sentence 5 and **Appendix C:** Climatic Information for Building Design in Canada

User's Guide - NBC 1995, Structural Commentaries (Part 4) NRCC no. 38826
Commentary J: Effects of Earthquakes

See also the WEB site "www.seismo.nrcan.gc.ca"

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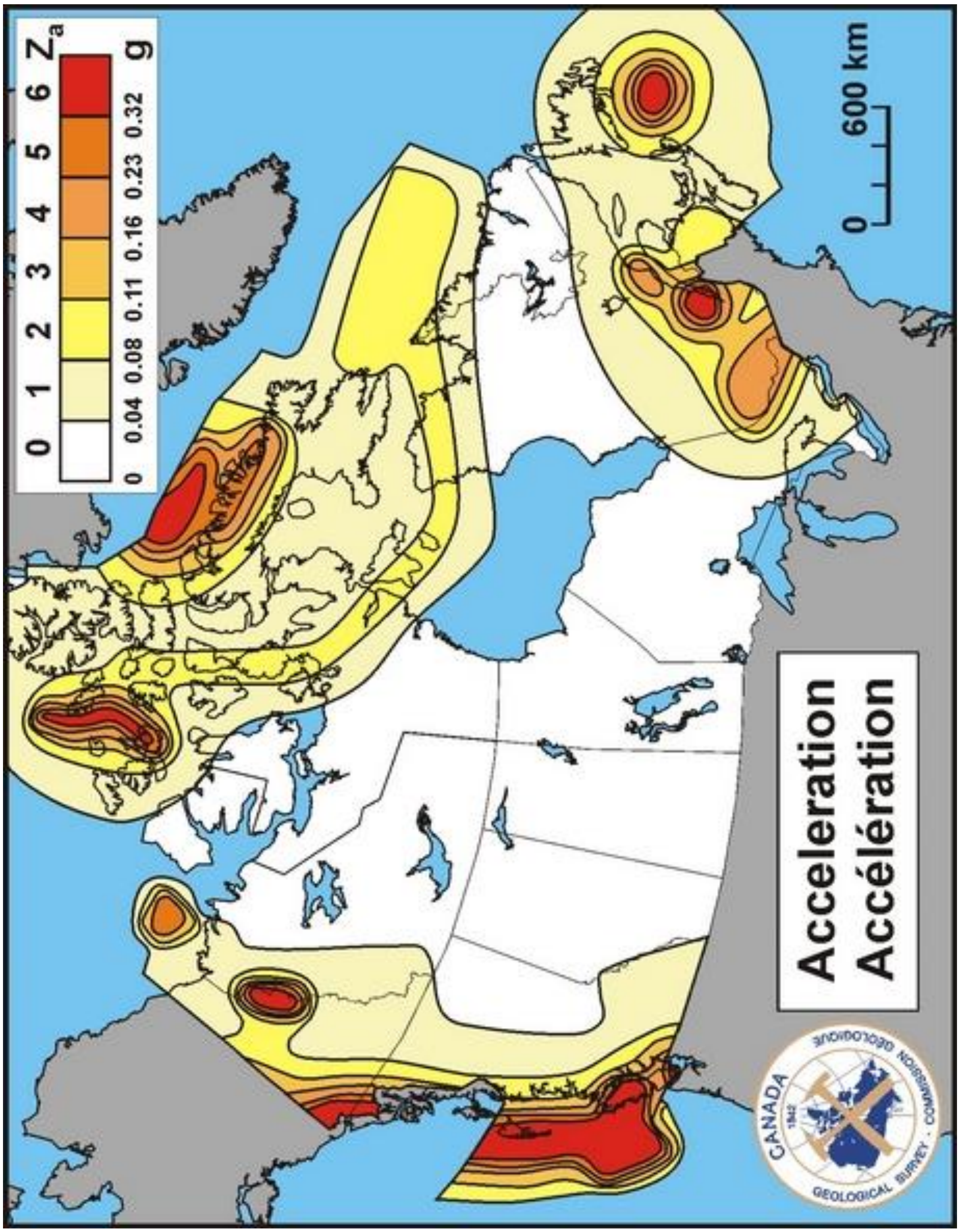
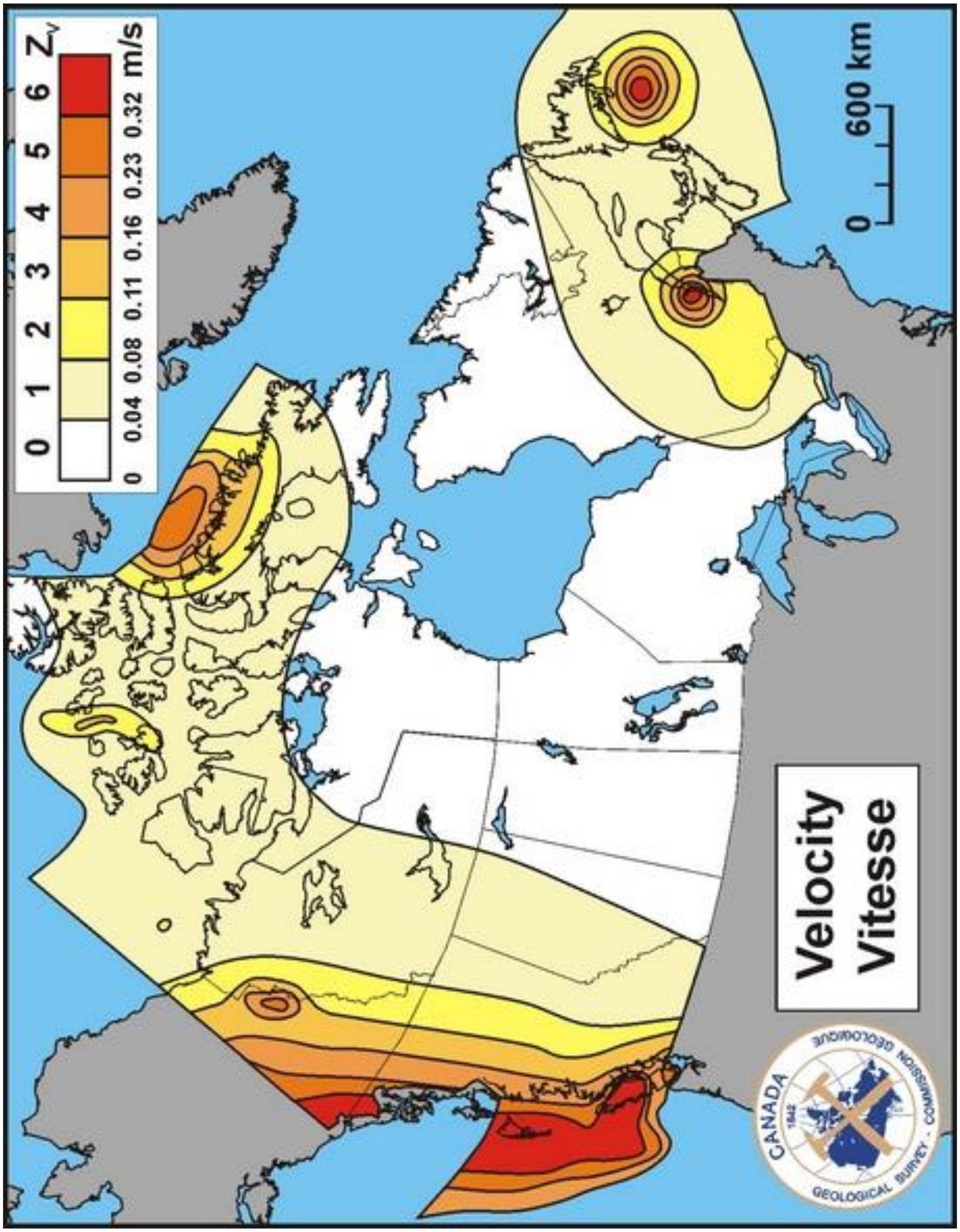
APPENDIX B

Peak acceleration (PGA) and velocity (PGV) maps for Canada, published as figures J-1 and J-2 respectively in the NBCC1985 and NBCC1990 supplements and the NBCC1995 structural commentaries. Note that the original figures were published in black and white. Compare these maps to Figures 2 and 3 in the main text of this Open File.




0 1 2 3 4 5 6 Zv
0 0.04 0.08 0.11 0.16 0.23 0.32 m/s
0 600 km
Velocity
Vitesse
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