Site Specific Seismic Hazard Assessment to Determine Low Probability Ground Motions for a Site in Northwestern British Columbia

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ABSTRACT
A site specific seismic hazard assessment was performed for a site in northwestern, BC to derive the ground motion parameters corresponding to 10,000 year return period earthquake. Three alternative source zone models were developed and the epistemic uncertainties in the model, model parameters and ground motion prediction equations were treated following a logic tree approach in the probabilistic assessment. A deterministic seismic hazard assessment was also performed to verify that the motions predicted by the probabilistic approach are appropriate for the site. This paper describes the details of the assessment and presents the results of the seismic hazard analyses.

RÉSUMÉ
Une évaluation du risque seismique spécifique a été exécutée pour un site du nord-ouest de la Colombie Britanique afin d’évaluer les paramètres de déformation du sol relatifs à une période de retour séismique de 10,000 ans. Trois modèles de zones source différentes ont été développés et les incertitudes épistemiques du modèle, ses paramètres, ainsi que les équations de déplacement du sol anticipées ont été traités en suivant un modèle d’arborescence logique basé sur une évaluation probabiliste. Une évaluation déterministe des risques sismiques a aussi été réalisées pour vérifier que les mouvements prédits par l’approche probabiliste étaient appropriés pour le site en question. Cette publication décrit les détails de cette évaluation et présente les résultats.

1 INTRODUCTION
Seismic hazard assessment is a rapidly evolving field with emerging new technologies to characterize sources, advances in ground motion prediction equations (GMPEs) and methods to address uncertainties in probabilistic seismic hazard methods (PSHA). These advances together with new earthquake and geological data have prompted many countries to update their seismic hazard maps regularly. The regulatory bodies also emphasize the need for a site specific seismic hazard assessment for critical structures such as dams and they often call for a detailed PSHA. The Canadian Dam Association (CDA, 2007) guidelines states that it is essential to conduct a site specific seismic hazard assessment to derive low probability ground motions for design and the hazard values obtained using the 2005 NBCC (Adams and Halchuck, 2003) may not be appropriate.

Uncertainties in the seismic hazard assessment should be considered and addressed quantitatively to obtain reliable estimate of ground motions. Recent seismic codes emphasize the need for treatment of uncertainties in the estimation of seismic hazard. Two types of uncertainties are normally considered in PSHA, namely the aleatory uncertainty and the epistemic uncertainty. The epistemic uncertainty is usually treated following a logic or event tree approach. The logic tree approach allows the determination of ground motions at the desired confidence level, i.e. mean, median (50th) or 84th percentiles.

Deterministic seismic hazard assessments are typically conducted to derive maximum credible earthquake (MCE) ground motion parameters. Deterministic concept is suitable for sites that are located near well defined or well studied active faults such as many areas in California. However, in Western Canada, away from the coast and the subduction zone, the seismicity is distributed over diffuse network of buried faults whose locations and activity rates are not known. For sites located in these areas, a probabilistic approach is more applicable than the deterministic approach. Thus, a site specific seismic hazard assessment was conducted to derive the low probability ground motions for a site located in northwestern BC.

2 2005 NBCC AND GSC MODEL
The 2005NBCC was based on a countrywide seismic hazard model developed by the Geological Survey of Canada (GSC). The GSC model incorporated some of the recent advances in the understanding of seismicity and reflected the current state of practice for seismic hazard assessment. However, the model is regional and was intended to provide ground motions for the 2005 NBCC, which uses a probability level of 2% in 50 years (or 2,475 year return period). Extrapolation of ground motions to lower probability levels, such as for a 10,000 year return period, is not recommended by the GSC as their model is not intended to provide motions at such lower return period level. The GSC cautions against using its model to establish low probability ground motion parameters (i.e. annual exceedance of 0.0001 or 10,000 year return period) for critical structures such as dams. Therefore, a site specific seismic hazard assessment to derive low probability motions will require development of source zone models and parameters that reflect the tectonic setting surrounding the site and captures the seismicity activity around the site within the region of interest.
3. TECTONICS, GEOLOGY AND EARTHQUAKES

Figure 1 shows the tectonic setting and major faults in the region around the site. Active tectonics in the offshore region to the west of the site are dominated by the northwestward motion of the Pacific Plate relative to the North America Plate. Along the west coast, this motion is largely accommodated by dextral transcurrent motion along the Queen Charlotte and Fairweather faults. In Alaska, this motion is accommodated by subduction of the Pacific Plate beneath the North America Plate. In southeast Alaska, the transition from strike slip to subduction is denoted by oblique collision of the Yakutat block. There is a series of coastal fault zones close to the plate boundaries, of which the most significant is the Denali fault zone. The extension of Denali fault further southwest is the Chatham Straight fault. To the east of these coastal fault zones is a series of accreted terranes. Away from the coast and on land, Tintina fault is a dominant feature that extends across the northern Cordillera and has been interpreted as a major continental transform fault. The continuation of Tintina fault further south is the North Rocky Mountain Trench.

Local regional faults in the area are considered to be inactive (Jurassic to Eocene age) and include east-west faults such as the Pitman and Iskut Faults antithetic to the coastal and Rocky Mountain trench faults. North-south regional faults include Forrest Kerr and Harry Mel Faults to the west of the area. The local area was subject to Cretaceous age shortening, detachment and thrusting that resulted in the formation of the Skeena fold belt.

3. SEISMICITY

The historical seismicity around the site was studied using data from earthquake catalogs. The catalogue for Western Canada, containing data from January 27, 1700 to December 31, 2007, was obtained from Pacific Geoscience Centre (PGC) (Cassidy, 2008). Earthquake data from January 1, 2008 to November 30, 2009 were downloaded from the online database maintained by Natural Resources Canada and added to the PGC earthquake catalogue. The original magnitude type in PGC catalogue was generally M_L, especially in the interior of British Columbia, sometimes mb for offshore events, and often Ms for the older larger events. For more recent events (since about 1995), Mw has been computed directly for earthquakes larger than about M4. PGC has used conversions, which are same as those used by USGS in their development of seismic hazard maps for the United States (Petersen et al., 2008), to convert mb, Ms and M_L magnitudes into Mw (Cassidy, 2008). The recent earthquake data downloaded from online database maintained by NRC Canada were either in Mw or M_L. The M_L were converted to Mw.

Figure 2 shows historical earthquakes with magnitude M ≥ 2 within approximately 600 km of the site and the major active faults in the region. The largest earthquakes that occurred within 100 km, 200 km and 300 km are M3.9, M4.5 and M5.0, respectively, and they occurred approximately 90 km, 186 km and 230 km from the site, respectively, in 2004, 1965 and 1949, respectively. The seismic activity within 200 km of the site in the last century was low.

An unusual series of low magnitude seismic events have been observed near Mt Ogden on the Alaska-British Columbia Border. Figure 3 shows these swarm of earthquakes that occurred between January 1, 1985 and November 30, 2009. Except for three events with magnitude M3.6, M3.7 and M3.8, all other events shown in Figure 3 had magnitude between M1.6 and M3.5. The low magnitude events are concentrated in a cluster located near Mt. Ogden about 50 km southeast of Juneau. These events have a seasonal cycle of occurrence. Wolf et al. (1997), who studied the events that occurred between 1975 and 1991, and noted that the annual cycle has two pulses of earthquake occurrence, one beginning in May and increasing into June and July, and the second beginning in late August and increasing into October. Events were largely absent during the winter months. Figure 4 shows the events up to 2009 which shows that the two pulses noted by Wolf et al. (1997) appear to continue. The same periodic seismicity was also noted by Cassidy et al. (2005).

Wolf et al. (1997) considered four possible mechanisms for the swarm of low magnitude earthquake activity: (1) Mine blasts or explosions; (2) Glacier or ice related dynamics; (3) Volcano related processes; and (4) Induced or triggered failure resulting from loading or transient modifications to a pre-existing stress regime. Wolf et al. (1997) discounted the first three and argued for the fourth
Figure 2. Earthquakes with magnitude greater than 2 and regional faults

Figure 3. Swarm of earthquakes near Mt. Ogden between 1985-1999

one as a possible causal mechanism. They concluded that the earthquakes are hydrologically triggered either by transient changes in pore pressure due to influx of meteoric water within faulted rock or by increased pore pressures due to surface loading of glaciated areas.

4 PROBABILISTIC SEISMIC HAZARD ASSESSMENT

The quantification of the probabilistic seismic hazard at the site is estimated using the well-known Cornell-McGuire approach. The steps in a probabilistic seismic hazard assessment (PSHA) consist of defining seismic sources, either areal or linear faults; definition of the earthquake frequency within each source zone; definition of the attenuation of ground shaking relationship for earthquakes in the area, and, finally, numerical summation of the contributions of all earthquake magnitudes at all distances from the site from each source. The computer program EZ-Frisk (Risk Engineering Inc., 2009) is used to perform the calculations in the last step.

4.1 Uncertainties and Treatment of Uncertainty

Two types of uncertainties associated with the seismic hazard were considered in the analyses, namely the aleatory uncertainty and the epistemic uncertainty. The aleatory uncertainty or the random uncertainty is due to the physical variability of the earthquake processes such as the randomness of the location of the earthquakes and the scatter in the earthquake ground motions. This uncertainty is readily incorporated within the Cornell-McGuire analysis framework by integrating over the statistical distribution in the ground motion relations and by considering the randomness in earthquake location.
The epistemic uncertainty or the professional uncertainty is due to incomplete understanding the physical models governing the earthquake occurrence and ground motion generation. The epistemic uncertainty was considered in the analyses following a logic tree approach.

Uncertainties in the source zone models and model parameters are key parameters that can significantly affect the seismic hazard estimates. Three alternative source zone models were developed for the site based on the tectonic setting, geological structures and the historical seismicity. Figures 5, 6 and 7 show the three alternative source zone models. In the development of the models, the factors described below were considered.

The site is located in an area with low seismic activity, just east of the Coast Range-Coast Shear Zone, which is considered inactive. The seismic activity east of the site was comparatively much lower than the seismic activity west of the site. Significant seismic activity in the region is associated with the following known active faults: Queen Charlotte Fault to the west and Eastern Denali, Fairweather and Transition Fault to the north west. Distinct lack of activity was noted for the Chatham Straight fault located west of the project site. Some activity was noted for the Tintina Fault and Rocky Mountain Trench located northeast and east of the site. Concentration of seismic activity was also noted in the Glacier Bay region located northwest of the site and in the Hecate straight region located southwest of the site.

Note that, except for the Chatham Straight Fault, the active faults and areas of concentrated seismic activity are located more than 200 km from the site.

Figure 5 shows Alternative Model 1, in which the entire coastal shear zone is captured in a zone called CSZ. The CSZ zone includes the relatively inactive Chatham Straight fault. However, it excludes other active known faults and seismically active zones in the region, namely the Queen Charlotte fault, Eastern Denali fault, Fairweather fault, Glacier Bay and Hecate Straight. The region east of CSZ and west of the Tintina and Northern Rocky Mountain Trench, which is considered seismically less active than the CSZ zone, is captured in Model 1 in NEBC zone. Apart from CSZ and NEBC zones, the remaining zones in Model 1 are the same as those used by the GSC in their H model with slight modifications to their DEN (Denali) and SYT (Southern Yukon Territory) zones.

Model 1 assumes that the pocket of seismic activity observed within the CSZ zone is possible anywhere within the zone, and this model has the effect of spreading the pockets of activity over a much broader area. Thus, the overall activity for the CSZ zone is considered a better predictor for future activity at the site. This model also assumes that the moderate to strong seismic activity on the well-known active faults in the region, which are located far away from the site, and relatively low activity observed east of the site, will not unduly alter the activity rate at the site.
4.3 Magnitude Recurrence Relationships

The earthquake recurrence within each source zone was assumed to follow the well-known Gutenberg-Richter relationship. The Gutenberg–Richter parameters for each source zone are determined by plotting the logarithm of the number of events per year against earthquake magnitude. These relationships are dependent on the reliability of the earthquake records in an area. The magnitude completeness of earthquake records varies significantly with time. Prior to calculating the magnitude-recurrence relationships for each of the source zones, earthquake data were removed from the database for periods where the data were incomplete within a given magnitude range. This prevents bias in the computation of per annum activity rates at each magnitude level. Exponential curve fitting was generally used for the source zones to develop the M-R relationships, and they were truncated at the maximum magnitude values selected for the zones.

Figure 8 shows the data and the M-R relationships for source zones CSZ, NCCSZ and NCSZ, which contain the induced seasonal seismic activity observed near Mt. Ogden. As can be seen from the figure, the unusually intense induced seismic activity, with magnitude less than M3.5, unduly exaggerates the rate of activity in the low magnitude range. As shown, the rate of activity at the low end of magnitude was even greater than the activity rate observed on the Queen Charlotte Fault. Thus, in the development of M-R for these source zones, which contained the swarm of earthquakes, earthquakes with M < 3.5 were not taken into account. Table 1 lists the magnitude recurrence parameters used for the source zones. The b value for the source zones varies between 0.7 and 1.1. in the analyses, the rate of activity per unit area in the NEBC zone was conservatively assumed as one half the activity rate for the CSZ zone due to lack of historical earthquakes with M > 3 and satisfying completeness criteria for this zone.

Table 1. Magnitude Recurrence Relationship Parameters Used in the Analyses.

<table>
<thead>
<tr>
<th>Models</th>
<th>Source Zone</th>
<th>b</th>
<th>N5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>CSZ</td>
<td>0.80</td>
<td>0.0596</td>
</tr>
<tr>
<td>Models 1, 2 and 3</td>
<td>NEBC</td>
<td>0.80</td>
<td>0.0172</td>
</tr>
<tr>
<td>Models 2 and 3</td>
<td>CSF</td>
<td>0.67</td>
<td>0.0360</td>
</tr>
<tr>
<td>Model 2</td>
<td>NCCSZ</td>
<td>1.10</td>
<td>0.0122</td>
</tr>
<tr>
<td>Models 2 and 3</td>
<td>SCSZ</td>
<td>0.67</td>
<td>0.0194</td>
</tr>
<tr>
<td>Model 3</td>
<td>NCSZ</td>
<td>1.10</td>
<td>0.0090</td>
</tr>
<tr>
<td>Model 3</td>
<td>CCSZ</td>
<td>1.10</td>
<td>0.0048</td>
</tr>
<tr>
<td>Models 1, 2 and 3</td>
<td>DENHM</td>
<td>0.75</td>
<td>0.1114</td>
</tr>
<tr>
<td>Models 1, 2 and 3</td>
<td>SYTM</td>
<td>0.77</td>
<td>0.0419</td>
</tr>
</tbody>
</table>
4.4 Maximum and Minimum Magnitudes

It is generally accepted that the low magnitude earthquakes below a certain threshold value are incapable of causing damage to engineered structures, and thus should not be considered in the seismic hazard assessment. This threshold magnitude is typically taken to be in the range of M4.5 to M5.0. In the analyses presented in this paper, a minimum magnitude of M5.0 was used. For the maximum magnitude, three possible values called the best, upperbound and lowerbound estimates were considered. The best estimate values ranged between M7.0 and M7.5 while the lowerbound and upperbound ranged between M6.8-M7.0 and M7.5-M8.0, respectively.

Note that studies by Johnston et al. (1994) and Fenton et al. (2006) concluded that M7.0 is the approximate maximum magnitude that occurs in unrifted stable continental cratons throughout the world, and would therefore be the lowest maximum magnitude that would be appropriate to include in seismic hazard models for any continental source zone. Adams and Atkinson (2003) noted that the current best estimates of maximum moment magnitude are M7.0 for the stable continental shield, and M7.0 - M7.8 for zones of weakness within the continent. Ebel and Kafka (1991) noted that because earthquake activity in the region cannot be identified with specific faults and geologic features, geologic arguments cannot be used to further constrain the maximum magnitude that can be expected in a region.

5 GROUND MOTION PREDICTION EQUATIONS

The seismic hazard at the site comes from relatively shallow crustal earthquakes. For these earthquakes, the following four Ground Motion Prediction Equations (GMPEs) were used:

- Abrahamson and Silva (2008);
- Boore and Atkinson (2008);
- Chiou and Youngs (2008); and
- Campbell and Bozorgnia (2008).

The epistemic uncertainties in the Ground Motion Prediction Equations (GMPEs) are one of the significant contributors to overall uncertainty in a seismic hazard analysis and are assessed by considering alternative GMPEs. The above four GMPEs were developed by a group of leading experts as part of the New Generation Attenuation (NGA) Model Project sponsored by Earthquake Engineering Research Institute (EERI). The NGA equations are based on strong motion database containing strong motion records from 173 worldwide shallow crustal earthquakes with magnitudes M4.2 to M7.9.

In probabilistic seismic hazard analyses, the ground motion variability, which is usually described by a lognormal distribution, has significant impact on the computed hazard. The standard deviation of the lognormal distribution is typically used to characterize the aleatory uncertainty or the random uncertainty in the ground motions. This random uncertainty is directly incorporated into hazard calculations by integrating over the entire distribution of the ground motion about the mean values. However, sometimes, the lognormal distribution is truncated at a specified number of standard deviations. The value of the standard deviation and the number of standard deviations at which the distribution is truncated have significant control on the ground motions at lower probability level, such as the 10,000 year return period (Abrahamson, 2000, Bommer et al., 2004). Larger values of standard deviation and untruncated distribution result in larger computed ground motion, especially at low probabilities. In this study, the standard deviation values recommended by the respective authors of the GMPEs were used and the ground motion distributions were not truncated. Note that Abrahamson (2006), who studied the truncation of lognormal distribution of ground motion relations, concluded that using an untruncated lognormal distribution in probabilistic seismic hazard analyses is appropriate for ground motion values that are below the physical limits of the underlying rock or soils.

The reference site condition for the analyses was taken as NEHRP Site Class B (Rock) and Site Class C (Soft Rock and Very dense Soil) boundary (NEHRP, 2003).

6 LOGIC TREE

Figure 9 shows the logic tree used in the analyses to handle the epistemic uncertainty and the corresponding weightings. The uncertainties, which can affect the seismic hazard estimate at the site, namely the uncertainties in the source zone models, maximum magnitude and the Ground Motion Prediction Equations (GMPEs), were considered in the analysis.

The reference site condition for the analyses was taken as NEHRP Site Class B (Rock) and Site Class C (Soft Rock and Very dense Soil) boundary (NEHRP, 2003).

7 ANALYSES AND RESULTS

Seismic hazard analyses were conducted for each combination of parameters shown in the logic tree using the computer program EZ-Frisk (Risk Engineering Inc., 2009), and the results were processed to obtain the mean, median, 16<sup>th</sup> and 84<sup>th</sup> percentile PGAs and spectral accelerations. Source zones within 600 km radius from the site were included in the analyses.
Figure 10 shows the probability of annual exceedance versus PGA for the site for the three alternative source models, each with the best estimate magnitude and for the four ground motion prediction equations. Figure 11 shows the mean, median, 16th and 84th percentile Uniform Hazard Response Spectra (UHRS) (with 5% damping) for the 10,000 year return period for the site.

As evident from Figure 10, despite the scatter due to GMPEs, the 10,000 year return period PGAs predicted by Models 1, 2 and 3 were in decreasing order. The range of PGAs predicted by Models 1, 2 and 3 ranged approximately between 0.14 g - 0.17 g, 0.09 g - 0.12 g, and 0.07 g - 0.10 g, respectively. The 10,000 year return period PGA at the site was dominated by contribution from the CSZ zone in Model 1 as shown in Figure 12 and to a much lesser extent by Queen Charlotte Fault. In Model 2, the source contribution from the NCCSZ dominated the low probability PGA hazard, while in Model 3 as shown in Figure 13, the hazard contributions from Queen Charlotte Fault and the CCSZ dominated. Analyses showed that the effect of maximum magnitude on the PGA was not significant.

Figure 10. Probability of annual exceedance versus PGA for the three source zone models

7.1 Comparision with GSC Model Results

The “robust” median spectral values for 5% damped Uniform Hazard Response Spectra (UHRS) for return periods ranging between 100 and 2,475 year return periods based on the 2005 NBC hazard model (Adams and Halchuck, 2003) were obtained for the site from the webroutine provided by Natural Resources Canada. The “robust” values are the greater of the spectral ordinates predicted by the GSC’s H and R models and they are for NEHRP Site Class C conditions. The median 10,000 year UHRS for the site was estimated using log-log extrapolation on the annual probability of exceedance and spectral acceleration. Figure 14 shows the comparison of mean and median 10,000 year UHRS obtained from the site specific seismic hazard assessment described in this paper and the median UHRS obtained by extrapolation from 2005NBC hazard model values. Although the source zone models, model parameters and ground motion prediction equations and logic tree used in our study are different from those used in the 2005NBC hazard model, the median UHRS from our study compared well with the 10,000 year extrapolated spectra based on the 2005NBC hazard model.

Figure 11. 10,000 year Return period Uniform Hazard Response Spectra (UHRS)

Figure 12. Source zone contributions for Model 1

Figure 13. Source zone contributions for Model 3
Consideration of earthquake size and distance is less straightforward in a probabilistic seismic hazard analysis than in a deterministic analysis. This is because in probabilistic analysis, the total hazard at a particular site is the result of possible occurrences of many different earthquakes of varying sizes and distances from the site. The hazard analysis results must be examined to identify the major contributors to the hazard at the ground motion level of interest. This is achieved through de-aggregation of the probabilistic seismic hazard. The representative earthquake scenario defined by dominant magnitude-distance may vary, depending not only on the probability level under consideration, but also on the period. For example, the dominant earthquake scenario for PGA is not necessarily the same as that for a one second period motion. A rigid and a flexible structure may be controlled by different earthquakes. Thus, there are different magnitude-distance combinations applicable to different ground motions. Selection of ground motion time histories for dynamic deformation analyses and liquefaction assessment also requires a design earthquake be defined in terms of earthquake magnitude and distance. Results from de-aggregation analysis can be used to define such design earthquake scenarios.

Figure 15 shows the de-aggregation analysis results for PGA for the site. The mean magnitude and mean distance corresponding to a 10,000 year PGA of 0.14 g are approximately M6.1 and 28 km. Note that selection of the appropriate magnitude for the design earthquake will depend on several factors, including: (1) whether the magnitude is to be used in liquefaction assessment following a deterministic approach or probabilistic approach or in the estimate of seismic displacements or deformation; (2) the natural period or dominant modal periods of the structures during the design earthquake; and (3) whether the dominant source contributions to the hazard is unimodal or bi-modal.

8 DETERMINISTIC SEISMIC HAZARD ASSESSMENT

A deterministic seismic hazard assessment was conducted to assess the PGAs due to earthquakes associated with the rupture of known and unknown or blind faults in the vicinity of the project site. A deterministic seismic hazard assessment typically involves the following four steps: identification and characterization of earthquakes sources capable of producing significant ground motion at the site. (Earthquakes at these sources are called the scenario earthquakes); determination of source-to-site distances.; selection of controlling earthquake usually expressed in terms of earthquake magnitude and distance; and estimation of ground motion due to the controlling earthquake using GMPE appropriate for the source and site.

8.1 Scenario Earthquakes

All the known local faults in the vicinity of the site are considered as inactive. Thus, in the deterministic seismic hazard assessment, shallow crustal earthquakes at unknown or uncharacterized faults were considered.

Historical earthquake records show that the maximum magnitudes of earthquakes, which occurred within 100 km and 200 km, from the site are M3.9 and M4.5, respectively. The site is located in the CSZ zone in Model 1 described above and the maximum magnitude assigned for the CSZ zone is M7.5. Thus, in the deterministic seismic hazard assessment, random events with magnitude M5.0 and M7.5 and return period of 10,000 years were considered.

The epicentral distances for the two events were determined using a methodology similar to that introduced by Wood and Ostenaa (1984). The magnitude recurrence
parameter for the CSZ zone was used in this procedure to estimate the distance. The same suite of four GMPEs that were used in the probabilistic analyses, were used in the deterministic analyses.

Table 2 summarizes the estimated average PGAs from the median and median plus one standard deviation (σ) estimates using the four GMPEs for the two earthquakes, M5.0 and M7.5.

Table 2 Peak Ground Accelerations (PGAs) for the Random Floating Earthquakes.

<table>
<thead>
<tr>
<th>Earthquake Magnitude, Mw</th>
<th>Distance (km)</th>
<th>Average Peak Ground Acceleration, PGA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
</tr>
<tr>
<td>5.0</td>
<td>13</td>
<td>0.06</td>
</tr>
<tr>
<td>7.5</td>
<td>133</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 2: Comparison of 2,475 Year return Period PGAs from GSC Model and the Model Used in this Study.

<table>
<thead>
<tr>
<th>Point</th>
<th>Longitude</th>
<th>GSC Model</th>
<th>Model used in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>129.73W</td>
<td>0.178</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>128.73W</td>
<td>0.165</td>
<td>0.078</td>
</tr>
<tr>
<td>P3</td>
<td>127.73W</td>
<td>0.083</td>
<td>0.073</td>
</tr>
</tbody>
</table>

In addition, in the deterministic seismic hazard assessment, an M7.9 earthquake on the Chatham Straight Fault and an M8.5 earthquake on the Queen Charlotte fault were also considered. These two are the active or potentially active known faults in the region. The assumed magnitudes are the best estimates of the maximum magnitudes possible on these faults.

The estimated average median + σ PGAs using the four GMPEs for the M7.9 and M8.5 earthquakes at the two faults are low, 0.03g and 0.05g, respectively. The deterministic assessment showed that PGAs due to a random earthquake in the vicinity of the project site or on known regional active faults are less than the 10,000 year return period PGA of 0.14g estimated from the probabilistic assessment.

9 EFFECT OF SOURCE ZONE BOUNDARY IN GSC MODEL

In the GSC model, the PGA values appear to change significantly across the boundary between two zones with very different activity rates. In the GSC R model, the rate of M5 earthquakes in the CST zone is approximately 22 times greater than the M5 rate in the adjoining NBC zone. Thus, the PGAs change significantly across the boundary. To demonstrate this effect, the points P1, P2 and P3 were taken along latitude 54.5°N with P2 located on the boundary between the two zones. Table 3 shows the 2,475 year return period PGAs (robust median values for “firm ground” conditions) computed using the GSC model. The PGA at point P3 is reduced to almost half of the PGA at P2: P3 is located approximately 60 km to the east on the boundary between the two zones. For comparison, the median PGAs computed using the modified model described in this paper for points P2 and P3 are listed in Table 2. The reduction in PGA at points P3 compared to P2 is not as significant as that obtained using the GSC model. This example highlights the shortcoming of the GSC model and illustrates the need for the modification of GSC model for site specific seismic hazard assessment for sites that might be located on boundary between two zones with significantly different but uniform rates.

10 SUMMARY AND CONCLUSIONS

A site specific seismic hazard assessment was performed for a site in northwestern, BC to derive ground motion parameters corresponding to a 10,000 year return period earthquake.

The site is located east of the inactive Coast Shear Zone in an area with a low seismic activity and more than 250 km from the known active faults in the region: Queen Charlotte, Eastern Denali, Chatham Straight, Fairweather and Transition Faults. As there is no known active fault in the vicinity of the site, the probabilistic approach was selected as a preferred approach and the analyses were performed using the Cornell-McGuire method. Three alternative source zone models were developed to capture the uncertainties in the earthquake sources surrounding the site. The magnitude recurrence-relationships for the source zones were developed using historical earthquake data and a suite of ground motion prediction equations were used for earthquakes on shallow crustal sources. The epistemic uncertainties in the model, model parameters and attenuation equations were treated following a logic tree approach. Uniform hazard response spectra (UHRS) corresponding to
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This paper also highlights the effect of location of site on
located much further away were considered.
project site and earthquakes on known active faults
deterministic assessment, a random floating earthquake
consequently in the site specific seismic hazard
A deterministic seismic hazard assessment was also
performed to verify that the motions predicted by the
uniform activity rates and the need for the modification of the
in order to derive low probability ground motions.

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