Appendix 5-F

Seismicity Assessment

Knight Piésold
CONSULTING

MEMORANDUM

To:	Mr. Ken Brouwer	Date:	March 8, 2012
Copy To:		File No.:	VA101-458/4-A.01
From:	Graham Greenaway	Cont. No.:	VA12-00565
Re:	Harper Creek Project – Seismicity Assessment		

A seismicity assessment has been carried out for the Harper Creek Project, including a review of the regional seismicity and a seismic hazard analysis. The results of the seismic hazard analysis are required to provide seismic design parameters for the design of the Tailings Management Facility and for other geotechnical structures at the project site.

This memo presents the findings of the seismicity review and the methodology and results of the seismic hazard analysis. Design ground motion parameters provided by the seismic hazard analysis include peak ground acceleration, spectral acceleration (defining the uniform hazard spectrum) and design-earthquake magnitude.

1.0 REGIONAL TECTONICS AND SEISMICITY

The Harper Creek project is situated within south-eastern B.C., where the level of historical seismic activity has been low. Figure 1 shows the regional tectonics and historical seismicity of southern B.C. and the location of the Harper Creek project.

The level of seismicity in the interior of B.C. and the Rocky Mountains region drops off rapidly with distance from the west coast and to the north. The largest earthquake recorded in the southern Cordillera region was an event of about Magnitude 6.0 in 1918, located in the Valemount area of the Rocky Mountain trench. More recently, a Magnitude 5.4 earthquake occurred near Prince George in 1986 causing minor damage, and a Magnitude 5.3 earthquake occurred in 2001 east of Dawson Creek. The maximum earthquake magnitude for the region of south-eastern B.C. is estimated to be about Magnitude 7.0, with an upper bound estimate of Magnitude 7.3, based on historical earthquake data and the regional tectonics (Adams and Halchuk, 2003).

The seismic hazard along the west coast of B.C. is significant due to subduction zone earthquakes along offshore faults and within the subducting oceanic tectonic plate. There is potential for very large earthquakes of Magnitude 8.0 to 9.0+ along this Cascadia subduction zone. Geological evidence indicates that these great subduction earthquakes occur on average approximately every 500 years, but this interval varies from about 300 to 800 years. The last great Cascadia earthquake occurred over 300 years ago, in 1700. However, such an event would be located over 450 km southwest of the project site, and therefore the amplitude of ground motions experienced at the site would be very low due to attenuation over such a large distance. Peak ground accelerations on rock at the project site from a great subduction earthquake would likely be less than 0.05g. There is also potential for intraslab (inslab) earthquakes, occurring deep within the subducted Juan de Fuca plate that extends eastwards beneath the North American plate. These events, which have potential to be as large as about Magnitude 7.5, would likely occur over 300 km to the southwest, at a depth of over 40 km. Ground motions on rock experienced at the project site for this type of subduction earthquake are likely to be less than 0.1g. The seismic hazard at the Harper Creek project is predominantly from potential shallow crustal earthquakes occurring closer to the site.

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2.0 SEISMIC HAZARD ANALYSIS

The seismic hazard for the Harper Creek project has been defined using probabilistic methods of analysis. This method requires an examination of historical earthquake data and the regional tectonics to identify potential seismic sources and to determine the maximum earthquake magnitude for each seismic source. Appropriate relationships defining the attenuation of earthquake ground motion with distance are also required.

Design ground motion parameters have been determined for the Harper Creek project site using information provided by the probabilistic seismic hazard database of Natural Resources Canada (NRC) (http://earthquakescanada.nrcan.gc.ca/hazard-alea/zoning/haz-eng.php). The results are summarized in Table 1 in terms of earthquake return period, probability of exceedance (for a 23 year design operating life) and the corresponding peak ground acceleration (median and mean hazard values). However, the NRC database only provides ground motion parameters up to a return period of approximately 2500 years (corresponding to a 2% probability of exceedance in 50 years). Higher return periods will need to be considered for dam design if the classification is defined as Very High or Extreme (based on the requirements of the Canadian Dam Safety Guidelines). Therefore, a probabilistic seismic hazard analysis has been conducted to provide ground motion parameters beyond 2500 years, specifically for return periods of 5000 and 10,000 years.

The methodology used to complete the site-specific probabilistic seismic hazard analysis and the results of the analysis are described in the following sections.

2.1 Ground Motion Attenuation

Appropriate attenuation models defining the relationship between earthquake magnitude, source to site distance and peak ground motion (acceleration) are required to carry out a probabilistic seismic hazard analysis. The ground motions experienced at the project site are dependent on the regional ground motion attenuation characteristics and the earthquake source mechanism.

For shallow crustal earthquakes a set of four ground motion attenuation models, known as the New Generation Attenuation (NGA) relations was used (Earthquake Spectra, 2008). These include the ground motion relationships of Abrahamson and Silva, Boore and Atkinson, Campbell and Bozorgnia and Chiou and Youngs. These ground motion attenuation relationships are applicable to shallow crustal earthquakes in western North American and similar tectonic regions of the world. The predicted peak ground accelerations for shallow crustal earthquakes are average values calculated using the four attenuation relationships (equal weighting).

The peak ground accelerations and spectral accelerations predicted using the attenuation relationships are for soft rock/very dense soil site conditions, assuming an average shear wave velocity in the upper 30 meters (defined as the Vs30 value) of 560 m/sec (range of 360 to 760 m/sec). This corresponds to Site Class C, as defined by the National Building Code of Canada (NBCC 2010).

Attenuation relationships provided by Youngs (1997) were used for interface subduction and intraslab subduction earthquake source zones. These relationships were developed specifically for oceanic subduction zone earthquakes. These relationships are also used in the seismic hazard model developed for the NRC probabilistic seismic hazard database.

2.2 Probabilistic Analysis

A probabilistic seismic hazard analysis is carried out to define a unique probability of occurrence for each possible level of ground acceleration experienced at a site. The methodology used for the probabilistic analysis is based on that presented by Cornell (1968). The likelihood of occurrence of earthquakes within defined seismic source zones is determined by examining seismicity data. Using historical earthquake records for the region, magnitude-frequency recurrence relationships are established for potential earthquake source zones. The magnitude recurrence relationships are of the form derived by Gutenberg-Richter (1944):

$$\log(N) = a - b(M)$$

where, M = Earthquake magnitude
N =Annual frequency of occurrence for earthquakes exceeding magnitude M
(1/N = Return Period)

The computer program EZ-FRISK (Risk Engineering, Inc., 2008) was used to develop a seismic hazard model for southern British Columbia and the surrounding regions. The seismic hazard analysis module available with EZ-FRISK includes a database provided by Risk Engineering Inc. of faults and areal seismic sources for the pertinent regions of western Canada. Seismic sources defined in the hazard model include South-eastern B.C., Puget Sound and the Cascadia Subduction Zone. The project site is located within an areal seismic source that defines the seismicity in south-eastern B.C. A maximum earthquake of Magnitude 7.3 was assigned to this source zone, which is characterized by shallow crustal earthquakes.

Magnitude-frequency recurrence relationships and the corresponding maximum earthquake magnitude for each seismic source are prepared by Risk Engineering from consideration of historical seismicity, fault characteristics and the regional tectonics, using information obtained from the Geological Survey of Canada and proprietary studies. For calculation of peak ground accelerations a minimum magnitude of 5.0 was used in the analysis for all seismic source zones. Earthquakes of lower magnitude are not considered to be a risk to engineered facilities. Appropriate ground motion attenuation relationships were assigned to each seismic source, as discussed in Section 2.1 above.

The seismic hazard model developed using EZ-FRISK was used to determine the relationship between peak ground acceleration and annual frequency of occurrence for the project site. Median hazard values of peak ground acceleration have been determined for return periods up to 10,000 years. Predicted values for the project site are included in Table 1 for return periods of 5000 and 10,000 years. Predicted values for lower return periods were very similar to those provided by the NRC seismic hazard database.

The probabilistic seismic hazard analysis has also been used to calculate spectral acceleration values (5% damping). These have been used to develop site-specific uniform hazard spectra corresponding to return periods of 5000 and 10,000 years. The uniform hazard spectra are shown on Figure 2. Tabulated values of these uniform hazard spectra are provided in Table 2.

Deaggregation of the probabilistic seismic hazard results has been carried out to provide the relative contributions of all potential seismic sources, and to more accurately define the characteristics of potential earthquakes contributing to the seismic hazard. The findings indicate that the seismic hazard for the project site is predominantly from shallow crustal earthquakes in the region of south-eastern B.C.

Conservative design earthquake magnitudes of 7.0 and 7.3 have been selected for earthquake return periods of 5000 years and 10,000 years respectively, based on the review of regional tectonics and historical seismicity, and the findings of deaggregation off the probabilistic seismic hazard.

3.0 REFERENCES

Adams, J. and Halchuk, S., (2003), Fourth generation seismic hazard maps of Canada: Values for over 650 Canadian localities intended for the 2005 National Building Code of Canada, Geological Survey of Canada, Open File 4459.

Cornell, C.A., (1968), "Engineering Seismic Risk Analysis", Bulletin of the Seismological Society of America, Vol. 58, p.1583-1606.

Earthquake Spectra (2008), "Special Issue on the Next Generation Attenuation Project", Vol. 24, No. 1.

EZ-FRISK (2008), Software for Earthquake Ground Motion Estimation, Version 7.32, Risk Engineering, Inc., Boulder, Colorado, USA.

Gutenberg, B. and Richter, C.F., (1944), "Frequency of Earthquakes in California", Bulletin of the Seismological Society of America, Vol. 34, p.185-188.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R. (1997) "Strong Ground Motion Attenuation Relationships for Subduction Zone Earthquakes", Seismological Society of America, Seismological Research Letters, Vol. 68, No.1, p.58-73.

Signed: G.R. Green

Graham Greenaway, P.Eng. – Specialist Engineer/Project Manager

Approved:

Ken Brouwer, P.Eng. – Managing Director

Attachments:

Table 1 Rev 0	Summary of Probabilistic Seismic Hazard Analysis
Table 2 Rev 0	Uniform Hazard Spectra for 1/5000 and 1/10,000 Year Earthquakes
Figure 1 Rev 1	Regional Tectonics and Historical Seismicity
Figure 2 Rev 0	Uniform Hazard Spectra for 1/5000 and 1/10,000 Year Earthquakes

/grg

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TABLE 1

YELLOWHEAD MINING INC.
HARPER CREEK PROJECT

FEASIBILITY DESIGN STUDIES
SUMMARY OF PROBABILISTIC SEISMIC HAZARD ANALYSIS

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Return Period (Years)	Probability of Exceedance[1] (%)	Peak Ground Acceleration (PGA)[2]	
		Median PGA[3,4] (g)	Estimate Mean PGA[5] (g)
100	21	0.03	0.04
500	4	0.07	0.08
1,000	2	0.10	0.11
2,500	1	0.14	0.16
5,000	0.5	0.16	0.19
10,000	0.2	0.23	0.26

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Rev 0

NOTES:

1. PROBABILITY OF EXCEEDANCE CALCULATED FOR A DESIGN LIFE OF 23 YEARS.

$q = 1^{-(-L/T)}$

WHERE: q = PROBABILITY OF EXCEEDANCE
L = DESIGN LIFE IN YEARS
T = RETURN PERIOD IN YEARS

2. PEAK GROUND ACCELERATIONS ARE FOR SOFT ROCK/VERY DENSE SOIL (Vs30 = 560 M/SEC)
3. MEDIAN PEAK GROUND ACCELERATIONS FOR RETURN PERIOD UPTO 2,500 YEARS OBTAINED FROM THE SEISM
4. MEDIAN PEAK GROUND ACCELERATIONS FOR RETURN PERIODS OF 5,000 AND 10,000 YEARS OBTAINED FROM :
5. MEAN PGA VALUES ESTIMATED AS 1.15 X MEDIAN VALUES.

0	7MAR'12	ISSUED WITH MEMO VA12-00565	GRG	DDF	KJB
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

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TABLE 2

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HARPER CREEK PROJECT

UNIFORM HAZARD SPECTRA FOR 1/5000 AND 1/10,000 YEAR EARTHQUAKES

Spectral Period (seconds)	Spectral Accelerations for 1/5,000 Year Earthquake Median (g)	Spectral Accelerations for 1/5,000 Year Earthquake Estimated Mean (g)	Spectral Accelerations for 1/10,000 Year Earthquake Median (g)	Spectral Accelerations for 1/10,000 Year Earthquake Estimated Mean (g)
PGA	0.16	0.19	0.23	0.26
0.02	0.17	0.19	0.23	0.26
0.03	0.18	0.21	0.25	0.29
0.05	0.22	0.25	0.30	0.35
0.1	0.33	0.38	0.46	0.53
0.2	0.40	0.46	0.55	0.63
0.3	0.35	0.40	0.47	0.55
0.4	0.29	0.34	0.40	0.45
0.5	0.25	0.29	0.33	0.38
0.75	0.22	0.26	0.28	0.32
1.0	0.17	0.20	0.22	0.25
2.0	0.09	0.11	0.12	0.14
3.0	0.05	0.06	0.06	0.07
4.0	0.03	0.04	0.04	0.05

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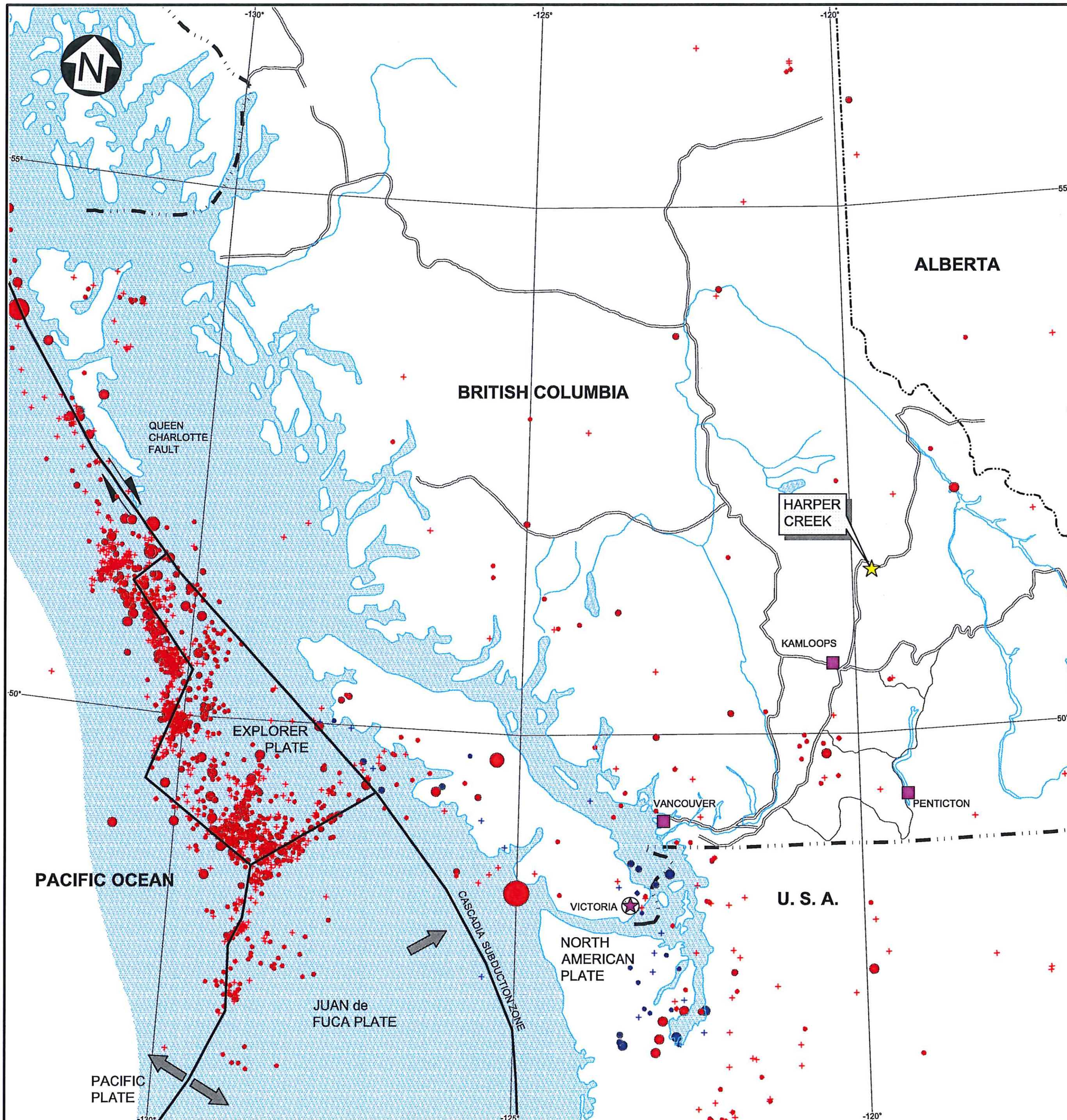
NOTES:

1. SPECTRAL ACCELERATIONS ARE MEAN HAZARD VALUES FOR SOFT ROCK/ VERY DENSE SOIL SITE CONDITIONS (Vs30 = 560 m/sec).
2. ESTIMATED MEAN VALUES ESTIMATED AS 1.15 X MEDIAN VALUES.

0	7MAR'12	ISSUED WITH MEMO VA12-00565	GRG	DDF	KJB
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTES:

1. GLOBAL COORDINATE SYSTEM IS UTM WITH NAD83 DATUM, ZONE 10 m, CENTRAL MERIDIAN.
2. HISTORICAL EARTHQUAKE DATA FROM NRCAN, USGS, AND NGDC DATABASES.
3. INCLUDES RECORDED EARTHQUAKES FROM 1600 TO 1973 (MAGNITUDE > 6.0) AND FROM 1973 TO 2009 (MAGNITUDE > 3.5).

SCALE A: 50 0 100 200 300 km

SYMBOL SIZE PROPORTIONAL TO MAGNITUDE

- 3.5 - 3.9
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.0 - 8.9
- 9.0 +

EARTHQUAKE FOCAL DEPTH

- 35 or LESS km
- > 35 km
- DIRECTION OF TECTONIC PLATE MOVEMENT

YELLOWHEAD MINING INC.

HARPER CREEK PROJECT

REGIONAL TECTONICS AND HISTORICAL SEISMICITY

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P/A NO.	REF NO.
VA101-458/4	VA12-00565

FIGURE 1 REV 0

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	CHK'D	APP'D
0	07MAR'12	ISSUED WITH MEMO	GRG	NSD	DDF	KJB

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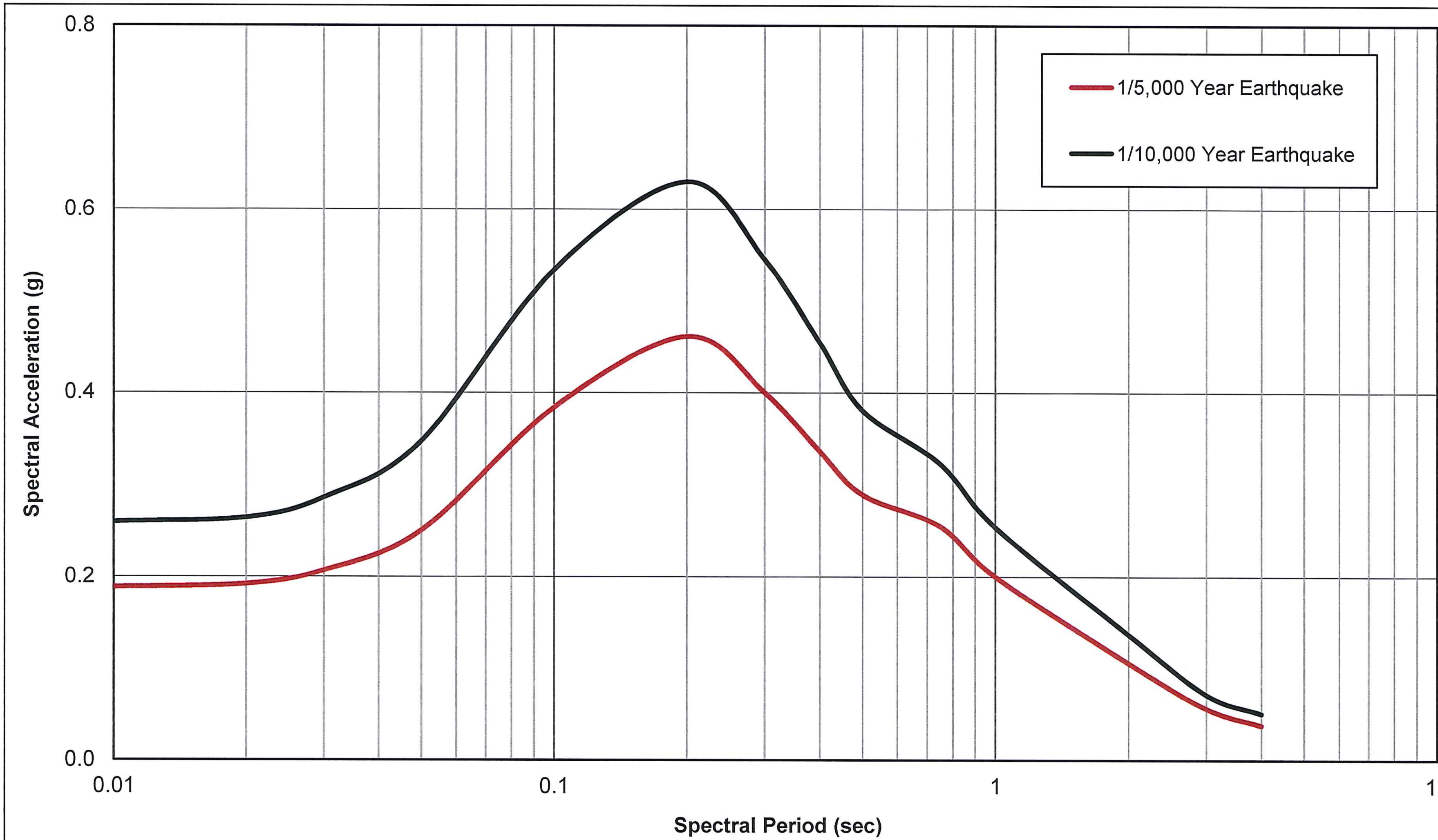

NOTES:

1. SPECTRAL ACCELERATIONS ARE MEAN HAZARD VALUES FOR SOFT ROCK/ VERY DENSE SOIL SITE CONDITIONS (Vs30 = 560 m/sec).

0	7MAR'12	ISSUED WITH MEMO	GRG	DDF	KJB
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

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HARPER CREEK PROJECT

UNIFORM HAZARD SPECTRA FOR 1/5,000 AND 1/10,000 YEAR EARTHQUAKES

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FIGURE 2

REV 0