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Notes:

First memorandum is an evaluation of: *Final report on seismic studies for Susitna Hydroelectric Project* / prepared by Woodward-Clyde Consultants. 1982. (APA 1255-1256 and 1434)

Second memorandum consists of excerpts from *Volume 12, Exhibit E, Chapter 6, Geological and soil resources* (APA 3436 and SUS 579) of: *Before the Federal Energy Regulatory Commission, application for license for major project, Susitna Hydroelectric Project draft license application*. 1985.

R&M CONSULTANTS, INC.
GEOTECHNICAL MEMORANDUM

TO:	John Magee, P.E. Project Manager	2 July 2009
FROM:	Bob Scher, P.E. Sr. Geotechnical Engineer	R&M No. 1158.21
RE:	Task 1 - Seismic Setting Review Susitna Hydroelectric Project	

The following summarizes our general opinions regarding the seismic studies performed between 1980 and 1981 for the Susitna Hydroelectric Project (SHP), reported in WCC (1982), relative to: (i) the potential types of seismic hazards that should be considered; (ii) the current understanding of the seismic environment in southcentral Alaska; and (iii) the present state-of-practice for evaluating seismic hazards for FERC hydroelectric projects. These discussions are considered generic to the entire SHP; however, for convenience our comparisons of potential differences between WCC (1982) and the present state-of-practice use the Watana site as the example dam location.

Note that it was beyond the scope of and time available for our review to develop the specific criteria that will be necessary for seismic evaluation and design of the SHP; tasks which will require more substantial studies should the project proceed beyond the conceptual level.

SEISMIC HAZARDS

General categories of seismic hazards that may affect hydroelectric facilities include ground motion (shaking), surface fault rupture, soil failure (e.g. landslides, liquefaction, settlement, lateral spreading, etc), and seiches (Idriss & Archuleta, 2007). The scope of WCC's studies were limited to evaluating the potential ground motions (discussed later), and potential for faults which could rupture the surface within the project area.

Briefly, WCC recognized 13 known (mapped) shallow faults or lineaments within the SHP area; but concluded there was no evidence of "recent displacement"[1] along any of these features; and therefore considered none to be potential seismic sources that could cause surface rupture.

Based on our interpretation of the recent literature, we are not aware of any additional studies of the rupture potential along any of the 13 features WCC recognized within the

[1] Defined by WCC as "faults that have caused rupture of the ground surface within the past 100,000 years".

SHP area. Further, we are not aware of any new faults or lineaments identified within at least 30 to 40 km of the SHP area, with one exception: the possible existence of a northwest-dipping thrust fault through Broad Pass, located about 35-40 km northwest of the SHP area (Haeussler, 2008).

REGIONAL SEISMIC ENVIRONMENT

The interpretation of the regional seismic environment (i.e. active faults and historic earthquakes) described in WCC (1982) is generally consistent with that reported in recent literature, subject to the few changes described below. Based on our conceptual evaluations, these changes are not expected to have much significance on the conclusions presented in WCC (1982), with one possible exception; the assumed northern limit of a rupture during the maximum considered megathrust subduction earthquake (see Discussion & Recommendations, below).

Earthquake Source Model: WCC's evaluation the seismic-induced ground motions that could be expected in the SHP area considered four known earthquake sources, including two distinct regions of the Aleutian (Pacific plate – North American plate) Subduction Zone (the shallow megathrust {inter-plate} zone, and the deep Wadati-Benioff {intra-plate} zone); and two shallow crustal sources[2] (the Denali fault and the Castle Mountain fault). In addition, WCC also considered the maximum potential earthquake that could occur, on an unknown source, without leaving any detectable geologic evidence; which they designated the "detection level earthquake" (DLE).

Table 1 summarizes the index characteristics (i.e. fault mechanism, distance from the Watana site, and maximum characteristic earthquake {MCE}) for each of the earthquake sources considered in WCC (1982), versus the seismic environment as it is understood today. Briefly, the main differences between the WCC (1982) and present seismic source models include:

- Recent earthquakes or studies have identified two new sources known to have produced earthquakes within the past 100 years, and close enough to produce notable ground motions in the SHP area, including the Susitna Glacier fault, along which the 2002 $M_w7.9$ Denali Earthquake originated (Crone et al., 2004); and the Susitna seismic zone[3], a band of historic seismic activity not associated with any known faults (Ruppert et al., 2008).

- WCC (1982) noted that the megathrust subduction zone ruptured during the 1964 $M_w9.2$ Great Alaska Earthquake (considered to be the MCE for that source; Table 1) to within about 142 km of the Watana site; although WCC "assumed" that the megathrust zone could be as close as 64 km. Recent in-depth studies of the

[2] WCC (1982) limited their consideration of potential crustal sources to "faults that have caused rupture of the ground surface within the past 100,000 years".

[3] WCC considered this zone as the boundary of the subtectonic region, but not as a separate seismic source.

seismic hazard in southcentral Alaska have all used the area that was interpreted to have ruptured during the 1964 earthquake as the 'limits' for a maximum characteristic megathrust earthquake (e.g. URS, 2008; Wesson et al., 1999 & 2007).

- WCC (1982) defined the MCEs using surface wave (local) magnitudes (M_s), while the recent literature uses moment magnitude (M_w). And,

- WCC estimated that the DLE would be an M_s6 event. If the DLE is considered synonymous with the largest earthquake that could occur on an unknown local fault, the magnitude determined by WCC may not be conservative. For example, the latest probabilistic studies of the seismic hazard in Alaska considered an $M_w7.3$ earthquake the largest expected in southcentral region and not otherwise associated with either the Denali fault of Castle Mountain fault (Wesson et al., 1999 & 2007).

Historic & Seismographic Earthquakes: In addition to the seismic source model described above, WCC (1982) listed five $\geq M_s6$ historic and seismographic (instrumented) earthquakes interpreted to have occurred between 1904 and 1980, within about 200 km of the SHP; the largest, $M_s7.4$, occurring in 1948 about 200 km southwest of the Watana site. For comparison, we searched the current Alaska Earthquake Information Center (AEIC) database[4], which included at least six additional $\geq M_s6$ events occurring within about 200 km of the SHP; the most recent including an $M_s6.5$ earthquake in 1992 about 150 km west-southwest of the Watana site, and the 2002 $M_w7.9$ Denali Earthquake (which originated on the previously unknown Susitna Glacier fault; Table 1) about 65 km north of the SHP area.

SEISMIC HAZARD ASSESSMENT

In general, WCC evaluated the seismic hazard within the SHP area following the same basic steps and considerations applied today for FERC hydroelectric projects (Idriss & Archuleta, 2007). However, there have been a number of improvements to some of the specific elements of the hazard assessment, in particular: (i) the models presently available to predict how seismic-induced ground motions attenuate with distance, developed from an ever-increasing database of strong motion records, and more sophisticated regression analysis tools; and (ii) advances in the computer modeling of the probabilistic hazard, allowing for consideration of more complex and ranging combinations of variable source mechanisms, earthquake recurrence rates, and attenuation models. Based on our review, it appears that the improvements in the ground motion attenuation models could have the most significant affect on the findings and recommendations presented in WCC (1982).

Attenuation Models: WCC (1982) developed their attenuation models based on works (by WCC and others) published between 1973 and 1980: to our knowledge all of those

[4] http://www.aeic.alaska.edu/html_docs/db2catalog.html

attenuation models are no longer used in seismic hazard assessments. For comparison, we used the attenuation models summarized in Table 2; which were either suggested in the FERC engineering guidelines for hydroelectric projects (Idriss & Archuleta, 2007), and/or used for recent in-depth studies of the seismic hazard in southcentral Alaska (Wesson et al., 2007) and at Anchorage (URS, 2008).

Figure 1 compares the mean horizontal acceleration response spectra provided in WCC (1982) for MCEs generated on both the megathrust subduction zone and Denali fault, with the spectra we predicted using the weighted combination of newer attenuation models listed in Table 2. From inspection, the more recent attenuation models suggest that design ground motions in the SHP area may be lower than considered at the time of the WCC studies; at least for structures with fundamental periods less than about 2 to 3 seconds.

Probabilistic Hazard Assessment: The WCC studies included evaluation of the probabilistic peak horizontal ground acceleration (PHGA) versus return period (as a measure of risk). For comparison, we used the most current USGS on-line seismic hazard programs[5] to determine the probabilistic PHGAs, in order to qualify the potential significance of recent improvements to the ground motion attenuation models and probabilistic hazard assessment software. Figure 2 illustrates the probabilistic PHGAs provided in WCC (1982), and those predicted using the most current USGS on-line seismic hazard programs. The results of this simple comparison suggest that recent improvements to the attenuation and earthquake source models applied to evaluate the probabilistic hazard may predict peak ground motions lower than those presented in WCC (1982) at return periods less than about 1,000 to 2,000 years.

DISCUSSION & RECOMMENDATIONS

WCC recommended that the deterministic design ground-motion criteria for the SHP be based on the maximum characteristic megathrust subduction earthquake (M_w9.2). However, based on the current state-of-practice, our conceptual evaluations indicate that the deterministic design ground motions could be controlled by a different MCE/source, depending upon: (1) the assumed northern limit of the rupture during a maximum characteristic megathrust earthquake; (2) the potential for, and characteristics of the maximum credible earthquake (i.e. magnitude, and distance) which should be considered in the vicinity of the project on an unknown fault (e.g. synonymous with WCC's DLE); and, (3) the selection and weighting scheme of the attenuation models used to predict ground motions.

1. The assumed northern boundary (limits) of the area which ruptures during a maximum characteristic megathrust subduction zone earthquake would have a dramatic affect on the design ground motions.

[5] http://earthquake.usgs.gov/research/hazmaps/).

As stated above, WCC (1982) assumed that the maximum characteristic megathrust earthquake (set as equal to the 1964 $M_w9.2$ Great Alaska Earthquake) could rupture to within about 64 km of the Watana site; while the northern limits of the rupture used for recent in-depth studies of the seismic hazard in southcentral Alaska (Wesson et al., 2007) and at Anchorage (URS, 2008) would increase that distance to about 150 km (Table 1). The significance of the distance factor is illustrated in Table 3 and Figure 3, which compare respectively the PHGA and horizontal acceleration response spectra predicted for the maximum characteristic megathrust earthquake assuming the rupture extends to 64 km and 150 km of the project.

2. The concept and treatment of the seismic hazard associated with the potential for, and characteristics of the maximum credible earthquake (i.e. magnitude, and distance) which should be considered in the vicinity of the project on an unknown fault (e.g. synonymous with WCC's DLE) could have a dramatic effect on the seismic parameters used to design the SHP.

   WCC (1982) concluded that the DLE (M_s6) would produce the strongest (largest) peak and spectral ground motions within the SHP area. However, WCC did not consider that the seismic design parameters should be based on the DLE, as their probabilistic assessment indicated that the DLE accounted from on a minor fraction of the total hazard.

   Based on our evaluations, we concur that a moderate, but very close earthquake could be expected to produce the strongest ground motions at the project site. Table 3 and Figure 4 respectively illustrate the 'range' of PHGA and spectral ground motions we predicted for an M_s6 earthquake, generated from strike-slip or thrust faulting within 5 to 10 km of the project site, using the attenuation models for crustal sources listed in Table 2. However, contrary to WCC (1982), the current USGS on-line programs indicate that a moderate, local earthquake may account for a more significant portion of the total probabilistic hazard (e.g. possibly on the order of roughly 20 to 40% depending upon the return and spectral periods).

3. Determination of the seismic parameters to be used in design will be very dependent upon the attenuation models and weighting scheme selected to predict ground motions. WCC recommended that design ground-motion criteria for the SHP be based on the maximum characteristic megathrust subduction earthquake. However, as a consequence of (i) considering the rupture area from the megathrust earthquake to be 150 km from the project (versus 64 km by WCC, see Table 1), (ii) using the most recent attenuation models (Table 2), and (iii) neglecting at this time consideration of a moderate local earthquake occurring on a yet known fault (as did WCC, see 2, above), our evaluations indicated that the deterministic ground motions would be controlled by the maximum characteristic Wadati-Benioff (deep, intra-plate) subduction earthquake, not the megathrust earthquake.

The significance of this point is illustrated in Table 3 and Figure 5, which compare respectively the PHGA and 84th percentile response spectra predicted at the Watana site for each of the seismic sources described in Table 1, using the attenuation models in Table 2.

In conclusion, while the work reported in WCC (1982) may still be appropriate for conceptual evaluations, we believe that additional studies are warranted to assess and reconcile each of the three facets discussed above, before the specific seismic parameters can be established for further design of the SHP.

REFERENCES:

Atkinson, G.M., and Boore, D.M. 2003. Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions. *Bull. of the Seismological Society of America*, 93(4):1703-1729.

Campbell, K.W., and Bozorgnia, Y. 2008. NGA Ground motion model for the geometric mean horizontal component of PGA, PGV, PGD, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. *Earthquake Spectra*, 24(1):139-172.

Chiou, S.-J., and Youngs, R.R. 2008. An NGA model for the average horizontal component of peak ground motion and response spectra. *Earthquake Spectra*, 24(1):173-215.

Crone, A.J., Personius, S.F., Craw, P.A., Haeussler, P.J., and Staft, L.A. 2004. The Susitna Glacier thrust fault: Characteristics of surface ruptures on the fault that initiated the 2002 Denali fault earthquake. *Bull. of the Seismological Society of America*, 94(6B):S5-S22.

Gregor, N.J., Silva, W.J., Wong, I.G., and Youngs, R.R. 2002. Ground-motion attenuation relationships for Cascadia subduction zone megathrust earthquakes based on a stochastic finite-fault model. *Bull. of the Seismological Society of America*, 9(5):1923-1932.

Haeussler, P.J. 2008. An overview of the neotectonics of interior Alaska: Far-field deformation from the Yakutat microplate collision. *In*: Active Tectonics and Seismic Potential of Alaska (Freymueller, et al. eds). *Geophysical Monograph 179*, American Geophysical Union, Washington, D.C.

Idriss, I.M. 2008. An NGA empirical model for estimating the horizontal spectral values generated by shallow crustal earthquakes. *Earthquake Spectra*, 24(1):217-242.

Idriss, I.M., and Archuleta, R.J. 2007. Evaluation of earthquake ground motions (*Draft 06.5*). [Chapter 13, *Engineering Guidelines for the Evaluation of Hydropower Project*].

Division of Dam Safety and Inspections, Office of Energy Projects, Federal Energy Regulatory Commission.

Plafker, G., Gilpin, L.M., and Lahr, J.C. 1993. Neotectonic Map of Alaska (Plate 12; scale 1:2,500,000): The Geology of Alaska (Plafker, G., and Berg, H.C., eds), The Geology of North America, Volume G-1. The Geological Society of America, Boulder, Colorado.

Ruppert, N.A., Ridgway, K.D., Freymueller, J.T., Cross, R.S., and Hansen, R.A. 2008. Active tectonics of interior Alaska: Seismicity, GPS geodesy, and local geomorphology. *In*: Active Tectonics and Seismic Potential of Alaska (Freymueller, et al. eds). *Geophysical Monograph 179*, American Geophysical Union, Washington, D.C.

URS (URS Corporation). 2008. Site-Specific Probabilistic and Deterministic Seismic Hazard Analyses and Development of Earthquake Ground Motions for the Port of Anchorage Expansion Project, Alaska. Prepared for Terracon Consultants, Inc.

Wesson, R.L., Boyd, O.S., Mueller, C.S., Bufe, C.G., Frankel, A.D., and Peterson, M.D. 2007. Revision of time-independent probabilistic seismic hazard maps of Alaska. *U.S. Geological Survey Open-File Report 2007-1043*.

Wesson, R.L., Frankel, A.D., Mueller, C.S., and Harmsen, S.C. 1999. Probabilistic seismic hazard maps of Alaska. *U.S. Geological Survey Open-File Report 99-36*.

WCC (Woodward-Clyde Consultants). 1982. Final Report on Seismic Studies for Susitna Hydroelectric Project. Prepared for Acres American Inc.

Youngs, R.R., Chiou, S.-J., Silva, W.J., and Humphrey, J.R. 1997. Strong ground motion attenuation relationships for subduction zone earthquakes. *Seismological Research Letters*, 68(1):58-73.

Zhao, J.X. et al., 2006. Attenuation relations of strong ground motion in Japan using site classification based on predominant period. *Bull. of the Seismological Society of America*, 96(3):898-913.

Zweck, C., Freymueller, J.T., and Cohen, S.C. 2002. Three-dimensional elastic dislocation modeling of the postseismic response to the 1964 Alaska earthquake. *J. of Geophysical Research*, 107(B4).

ATTACHMENTS

Tables:

1 Index Characteristics of Active Earthquake Sources
2 Ground Motion Attenuation Models
3 Estimated Peak Horizontal Ground Acceleration (on Rock), Watana Site

Figures:

1. Effect of Attenuation Models on the Mean 5% Damping Ratio Response Spectra, Watana Site
2. Probabilistic Peak Horizontal Ground Acceleration
3. 84th Percentile 5% Damping Ratio Response Spectra for a M_W9.2 Megathrust Subduction Earthquake
4. 5% Damping Ratio Response Spectra for the WCC "Detection Level Earthquake"
5. 84th Percentile 5% Damping Ratio Response Spectra at the Watana Site for Active Sources

TABLE 1: INDEX CHARACTERISTICS OF ACTIVE EARTHQUAKE SOURCES

ACTIVE SOURCE[a]	FAULT TYPE	WCC (1982)		RECENT LITERATURE	
		Distance[b], km	MCE[c]	Distance[b], km	MCE[c]
Denali Fault	Right-Lateral Strike-Slip	70	M_s 8	71.5[e]	M_w 7.9[e,f] M_w 8.1 (*7.6*)[g]
Susitna Glacier Fault[c]	Thrust	---	---	64.5[d]	M_w 7.2[d,e]
Castle Mountain Fault	Right-Lateral Strike-Slip	105	M_s 7.5	100[h]	M_w 7.1[f] M_w 7.7 (*7.4*)[g]
Megathrust Zone	Inter-Plate Subduction	64	M_s 8.5	150[h]	M_w 9.2[e,f] M_w 9.1-9.3[g]
Wadati-Benioff Zone	Intra-Plate Subduction	50	M_s 7.5	50[h,i]	M_w 7.5[f] M_w 7.25-7.75[g]
Susitna Seismic Zone[j]	Strike-Slip & Thrust	---	---	≈ >40-50[j]	M_s 7.4[e,k] (M_w 7.3)[f]
Random Unknown Local Fault	Strike-Slip & Thrust	<10[l]	M_s 6[l]	---	M_s 6.2[e,m] (M_w 7.3[f])

a. Evidence or suspicion of rupture within the past 100,000 years. Sources in italic not specifically recognized in WCC (1982)
b. Closest distance from the rupture surface to the Watana dam site.
c. Maximum characteristic earthquake: M_s - Surface wave (local) magnitude; M_w – Moment magnitude
d. Crone et al. (2004)
e. Maximum seismographic earthquake (i.e. post-1898): Alaska Earthquake Information Center (AEIC) database
f. Wesson, et al. (2007); ( ) value not specific to the Susitna Seismic Zone, but for shallow smoothed seismicity in interior Alaska
g. URS (2008) for rupture along entire fault (*for rupture only along segment closest to the Watana dam site*)
h. Plafker et al. (1993)
i. Zweck et al. (2002)
j. Ruppert et al. (2008)
k. 3 November 1943, epicenter approximately 200 km to the southwest of the Watana dam site (AEIC database)
l. "Detection Level Earthquake" - Interpreted maximum earthquake that could occur without causing a rupture at the surface.
m. 3 July 1929, epicenter approximately 45 km to the southwest of the Watana dam site (AEIC database)

TABLE 2: GROUND MOTION ATTENUATION MODELS[a,b]

<table>
<tr><th>GENERAL FAULT CATEGORY</th><th>R&M MODEL</th><th>FERC ENGINEERING GUIDELINES[c]</th><th>URS (2008)</th><th>WESSON ET AL. (2007)</th></tr>
<tr><td>Crustal</td><td>40 / 40/ 20%:
Campbell & Bozorgnia (2008)[d]
Chiou & Youngs (2008)[d]
Idriss (2008)[d]</td><td>Abrahamson & Silva (1997)
Boore et al. (1997)
Campbell (1997)
Idriss (2002)
Sadigh et al. (1997)</td><td>25% each:
Boore & Atkinson (2007)
Abrahamson & Silva (2008)
Campbell & Bozorgnia (2007)
Chiou & Youngs (2008)</td><td>25% each:
Abrahamson & Silva (1997)
Boore et al. (1997)
Campbell & Bozorgnia (2003)
Sadigh et al. (1997)</td></tr>
<tr><td>Megathrust Subduction (Inter-Plate)</td><td>25% each:
Youngs et al. (1997)
Atkinson & Boore (2003)
Gregor et al. (2002)
Zhao et al. (2006)</td><td rowspan="2">Youngs et al. (1997)
Atkinson & Boore (2003)
Zhao et al. (2006)</td><td>40 / 40 / 20%:
Youngs et al. (1997)
Atkinson & Boore (2003)
Gregor et al. (2002)</td><td>50% each:
Youngs et al. (1997)
Sadigh et al. (1997)[e]</td></tr>
<tr><td>Wadati-Benioff Subduction (Intra-Plate)</td><td>35-40 / 35-40 / 30-20%:
Youngs et al. (1997)
Atkinson & Boore (2003)
Zhao et al. (2006)</td><td>50% each:
Youngs et al. (1997)
Atkinson & Boore (2003)</td><td>50% each:
Youngs et al. (1997)
Atkinson & Boore (2003)</td></tr>
</table>

a. WCC (1982) used an attenuation model they developed based on works published between 1973 and 1980.
b. The references for the attenuation models listed in the R&M column are provided in this memorandum; references to the other attenuation models are provided in the reference heading that respective column. Percentages (in italic) refer to the weighting applied to each of the attenuation models.
c. Example attenuations models referenced in draft Chapter 13 (by Idriss & Archuleta, 2007).
d. NGA (Next Generation Attenuation) model available as a Microsoft Excel file from the PEER website.
e. Crustal fault attenuation model.

TABLE 3: ESTIMATED PEAK HORIZONTAL GROUND ACCELERATION (ON ROCK), WATANA SITE

EARTHQUAKE SOURCE, MCE	PEAK HORIZONTAL GROUND ACCELERATION, g (Value in WCC, 1982)	
	Mean	84^{th} Percentile
Wadati-Benioff Subduction Zone, M_w7.5	0.33	0.63
Megathrust Subduction Zone, M_w9.2 @ 64 km[a] @ 150 km[b]	 0.25 (0.35) 0.13	 0.48 (0.55) 0.25
Known Crustal Faults Denali, M_w8 Susitna Seismic Zone, M_w7.4	 0.08 {0.2} 0.08	 0.15 0.15
Unknown Local Source, M_w6 @ 5 km @10 km	 0.29-0.39 0.17-0.25 (0.5)	 0.50-0.66 0.31-0.42

a. Closest distance between the Watana dam site and the edge of the Megathrust (inter-plate) subduction zone assumed by WCC (1982).

b. Closest Distance between the Watana dam site and the Megathrust subduction zone, based on the rupture area of an M_w9.2 earthquake used in recent studies of the seismic hazard in Alaska (e.g. URS, 2008; and Wesson et al., 2007).

FIGURE 1: Effect of Attenuation Models on the Mean 5% Damping Ratio Response Spectra, Watana Site

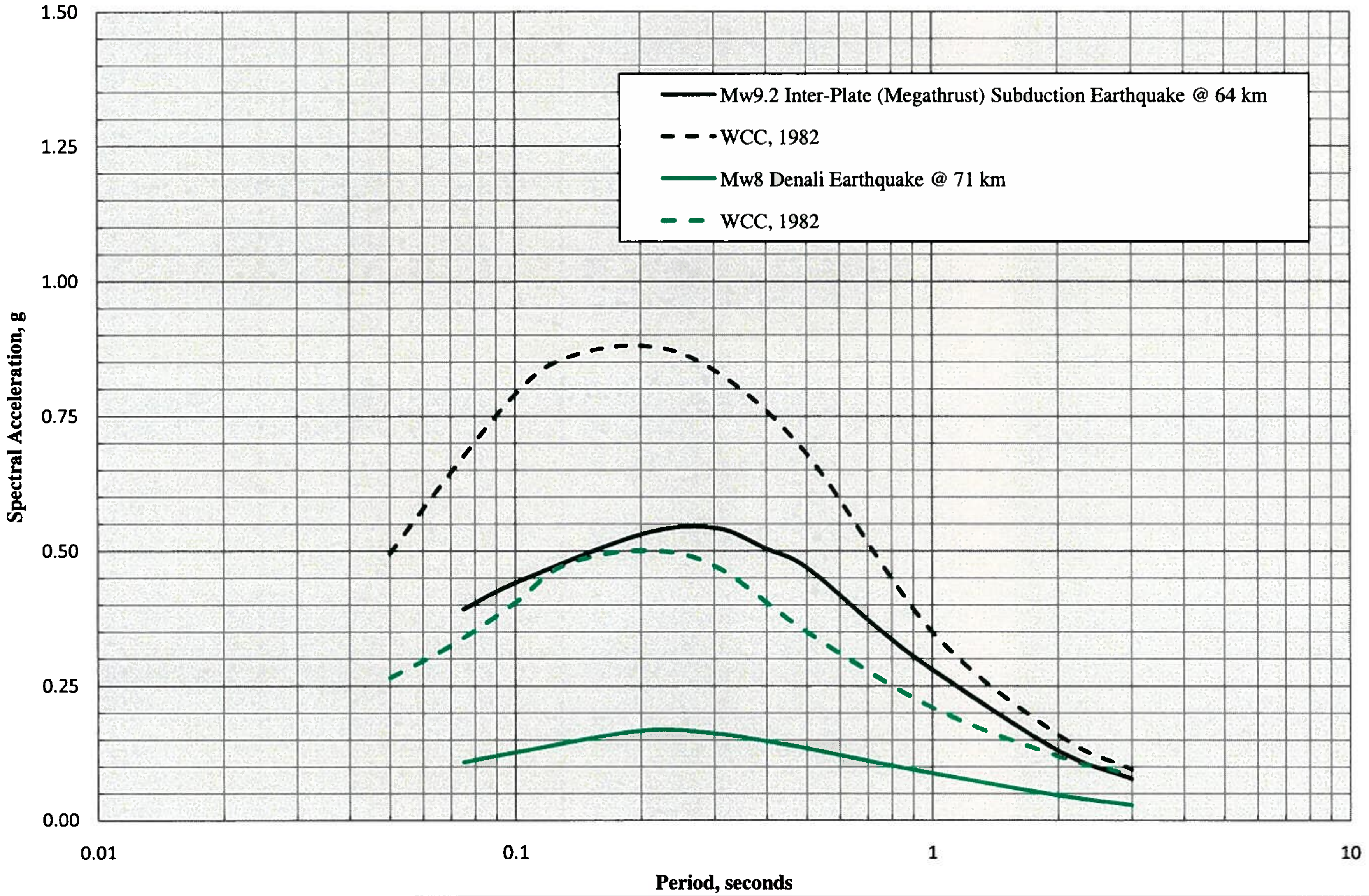
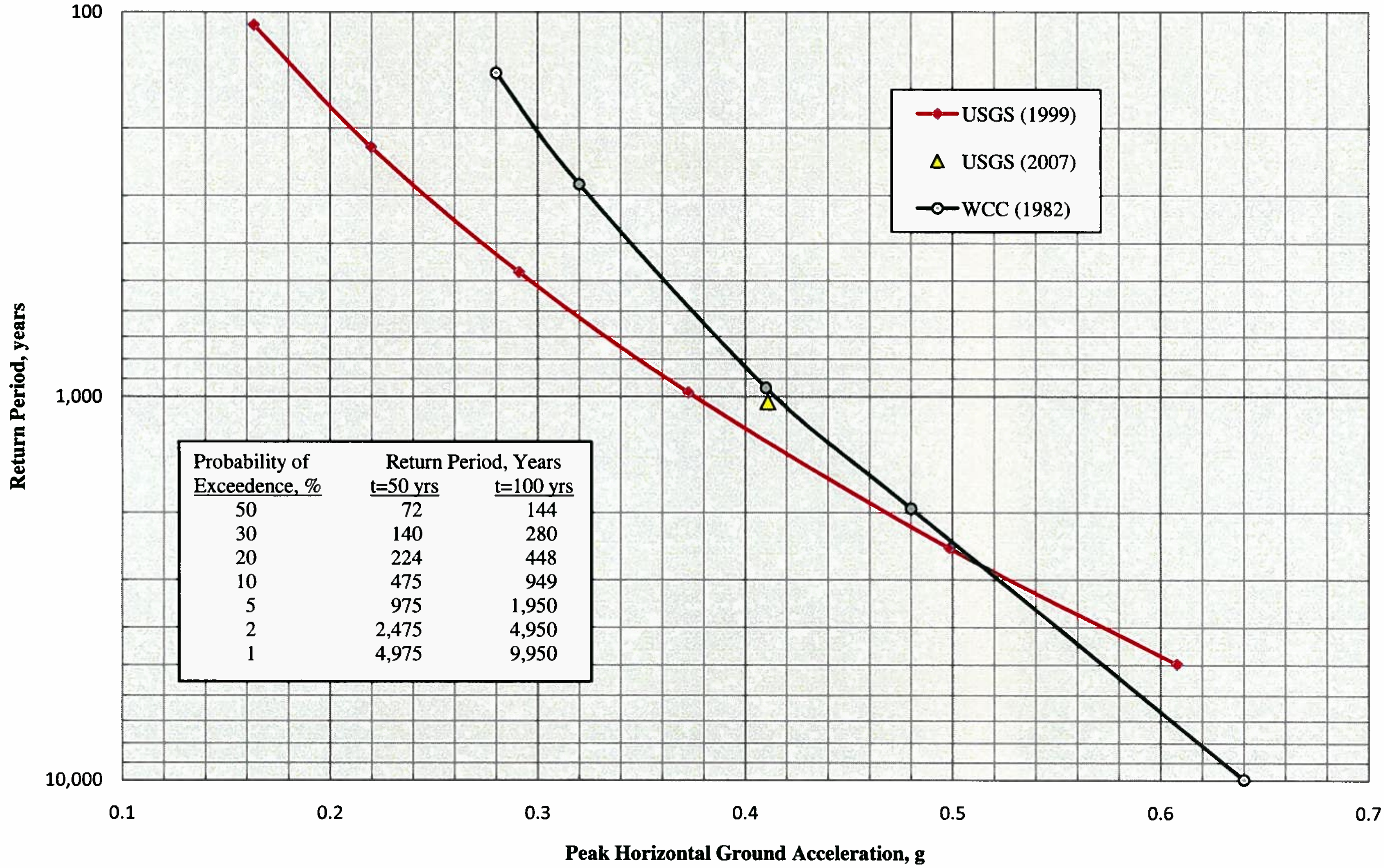


Figure 2: Probabilistic Peak Horizontal Ground Acceleration



Probability of Exceedence, %	Return Period, Years t=50 yrs	t=100 yrs
50	72	144
30	140	280
20	224	448
10	475	949
5	975	1,950
2	2,475	4,950
1	4,975	9,950

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FIGURE 3: 84th Percentile 5% Damping Ratio Response Spectra for a Mw9.2 Megathrust Subduction Earthquake

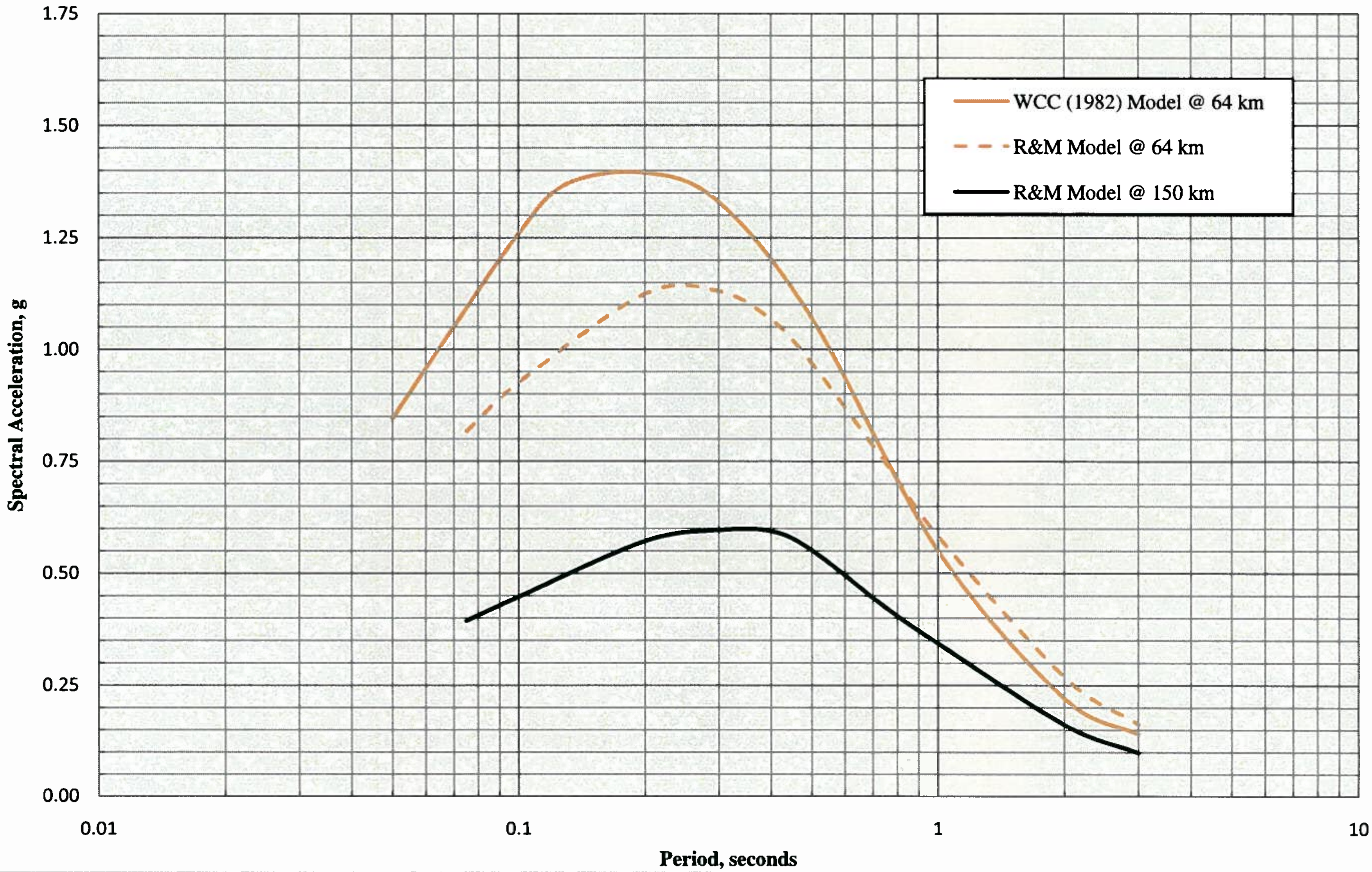


FIGURE 4: 5% Damping Ratio Response Spectra for the WCC "Detection Level Earthquake"

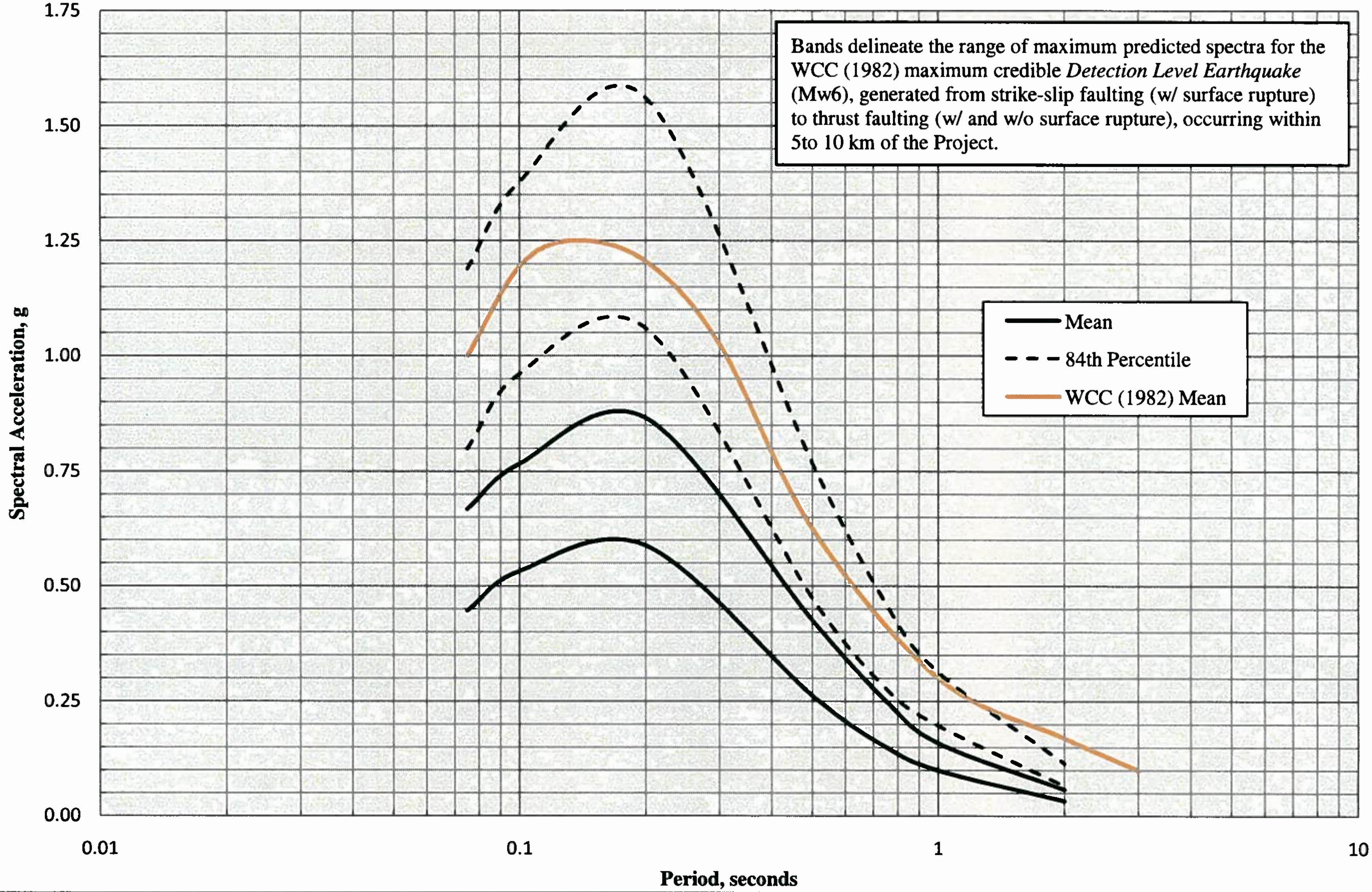
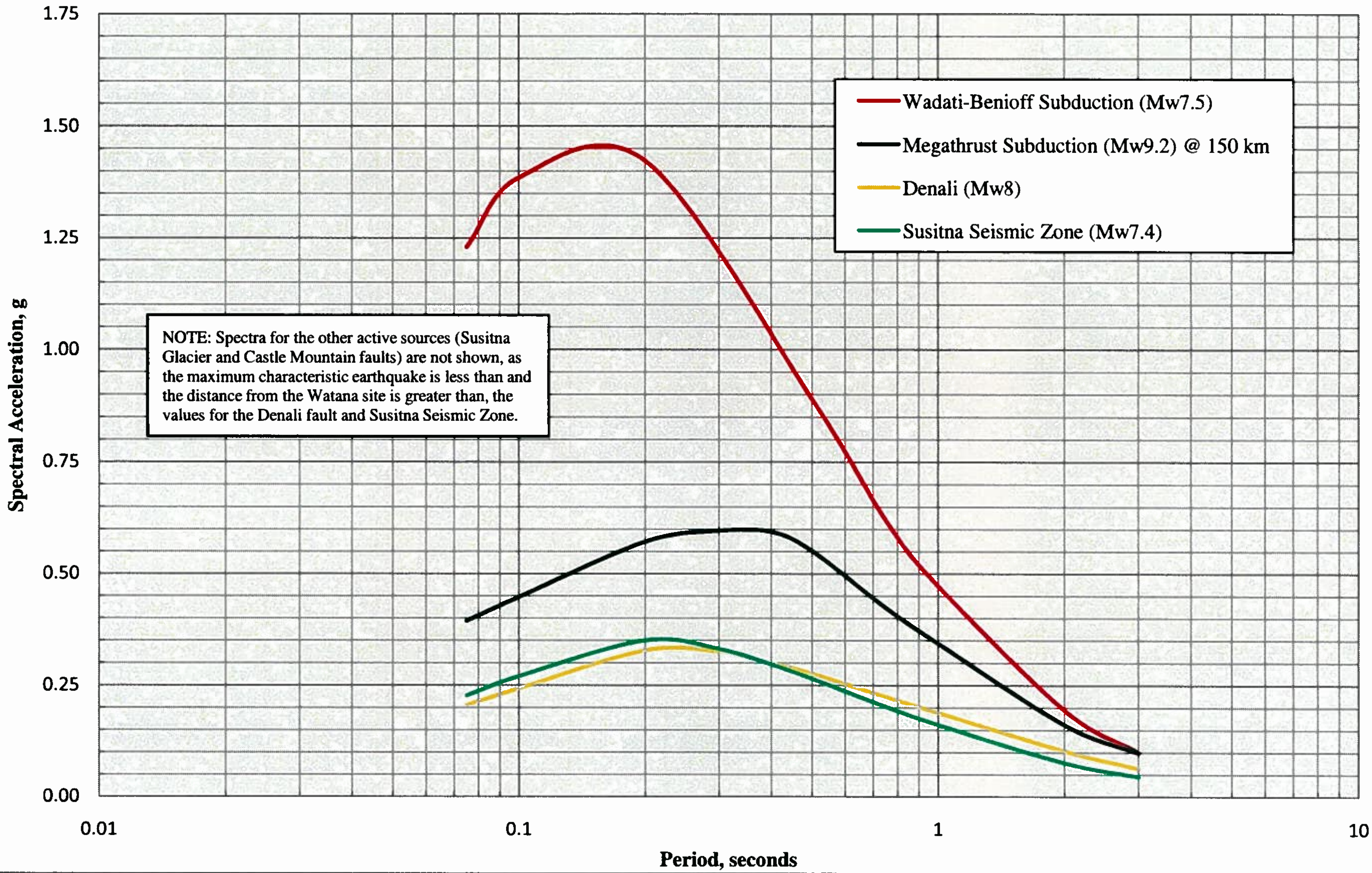


FIGURE 5: 84th Percentile 5% Damping Ratio Response Spectra at the Watana Site for Active Sources



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Memorandum

To: John Magee, P.E.

From: Charles Riddle, C.P.G.

Subject: Geologic and Geotechnical Data Reports Review: Susitna Hydroelectric Project

Date: June 4, 2009

Project #: 1158.21

The following reports were obtained from the Alaska Resources Library and Information Services as part of the above subject data review:

Acres American Incorporated (Acres). June 1981. Task 5 – Geotechnical Exploration 1980 Geotechnical Report, Susitna Hydroelectric Project. Prepared for Alaska Power Authority.

Acres. Not Dated. 1980-81 Geotechnical Report, Susitna Hydroelectric Project. Prepared for Alaska Power Authority. 3 volumes.

Woodward-Clyde Consultants. February 1982. Final Report on Seismic Studies for Susitna Hydroelectric Project. Prepared for Acres American Incorporated and Alaska Power Authority.

Acres. December 1982. 1982 Supplement to the 1980-81 Geotechnical Report, Susitna Hydroelectric Project. Prepared for Alaska Power Authority: 2 volumes.

Harza Ebasco. September 1983. Watana Development Winter 1983 Geotechnical Exploration Program, Susitna Hydroelectric Project. Prepared for Alaska Power Authority. 2 volumes.

Harza Ebasco. November 1985. Susitna Hydroelectric Project Draft License Application. Before the FERC. Volume 12, Exhibit E, Chapter 6, Geological and Soil Resources.

Specific issues and questions posed recently by Alaska Energy Authority centered on rock quality and seepage concerns. The following sections were taken from the Draft License Application, Volume 12, Geological and Soil Resources (Harza Ebasco, 1985). References to Devils Canyon and comments regarding the Devils Canyon Dam have been deleted.

Geological/Geotechnical Conditions
Watana Damsite

General Geology

(a) Overburden

Overburden thickness on the dam abutments may reach 70 feet or more. Above elevation 1,900 feet, overburden depth averages 20 feet with local zones to 50 feet on the south abutment. On the north abutment, this thickness reaches 50 to 60 feet. At the upper areas of the abutments, near the top of the slopes, overburden consists of glacial till, alluvium, and talus. Below elevation 1,900, overburden consists primarily of talus with an average thickness of 10 feet. Subsurface investigations show the contact between the overburden and bedrock to be relatively unweathered.

The river alluvium beneath the proposed dam is up to 140 feet deep, averaging about 80 feet. The material in the river channel is comprised primarily of well graded coarse-grained gravels, sandy gravels, and gravelly sands.

(b) Bedrock Lithology

The damsite is primarily underlain by an intrusive dioritic body which varies in composition from granodiorite to quartz diorite to diorite. The texture is massive and the rock is hard, competent, and fresh except within locally developed sheared and altered zones. These rocks have been intruded by mafic and felsic dikes which are generally only a few feet thick. The contacts are healed and competent. The rock immediately downstream and south of the damsite is an andesite porphyry. The nature of the contact zone of the andesite with the diorite is poorly understood. However, where mapped or drilled, the contact zone is generally weathered and fractured up to 10 to 15 feet.

(c) Bedrock Structures

(i) Joints

There are two major and two minor joint sets at the site. Set I, which is the most prominent set, strikes 320° and dips to 80° NE to vertical.

(ii) Shears and Fracture Zones

Several shears, fracture zones, and alteration zones are present at the site. For the most part, they are small and discontinuous.

Fracture zones range from 6 inches to 30 feet wide (generally less than 10 feet). These zones are closely spaced joints that are often iron oxide stained and/or carbonate coated. Where exposed, the zones trend to form topographic lows.

Alteration zones are areas where hydrothermal solutions have caused the chemical breakdown of the feldspars and mafic minerals. The degree of alteration encountered is highly variable across the site. These zones are rarely seen in outcrop as they are easily eroded into gullies, but were encountered in all the boreholes. The transition between fresh and altered rock is gradational. The thickness of these zones range up to 20 feet but are usually less than 5 feet.

Structural Features

The Watana site has several significant geologic features consisting of shears and fracture, and alteration zones as described previously.

The two most prominent areas have been named the "Fins" and the "Fingerbuster." The "Fins" is located on the north bank of the river upstream from the diversion tunnel intake. The area is characterized predominantly by sound, jointed bedrock. The rock mass also contains steeply inclined northwesterly trending zones of closely fractured rock up to 15-20 feet wide, 5-10 foot wide zones of weak, friable altered rock, and shears which measure one inch to approximately one foot in thickness. These zones have contributed to the erosion of steep gullies, which are separated by intact rock ridges.

The "Fingerbuster" is located downstream from the damsite and is exposed in a 40-foot-wide, deep, talus-filled gully just upstream of the andesite porphyry/diorite contact. The rock is moderately close to closely fractured rock with local shears and alteration zones. Slickenslides indicate vertical displacement.

A prominent alteration zone was encountered on the south bank where a drill hole encountered approximately 200 feet of hydrothermally altered rock. Although core recovery in this boring was good, the quality of rock was relatively poor.

Groundwater Conditions

The groundwater regime in the bedrock is confined to movement along fractures and joints. In general, the water table is a subdued replica of the surface topography. The groundwater table on the north abutment is generally from 5 to 30 feet below the surface except in areas with steep terrain, i.e. the "Fingerbuster", where it reaches depths of 60-90 feet. Numerous icing can be found on both abutments in the winter, particularly on the steep slopes of the south abutment. Groundwater conditions on the south abutment and on the lower north abutment are further complicated because of the existence of permafrost, discussed below.

Permafrost Conditions

Permafrost conditions exist on the north-facing slopes and below approximately elevation 1,750 feet on the north abutment of the damsite area. Measurements indicate that permafrost exists to a depths of approximately 120 feet on the south abutment and up to 60 feet on the north abutment.

Temperature measurements show the permafrost to be "warm" (within 1°F [1°C] of freezing).

Bedrock Transmissability

Transmissability of water through the bedrock does not vary significantly within the site area, generally ranging between 3.28 x 10^{-6} ft/sec to 3.3 x 10^{-8} ft/sec.

Relict Channels

(a) Watana Relict Channel

A relict channel exists north of the Watana damsite. The maximum depth of overburden in the thalweg channel, is approximately 450 feet.

(b) Fog Lakes Buried Channel

In the area between the Watana damsite and the higher ground some 5 miles to the southeast, the bedrock surface dips to 350 feet below ground surface, or 174 feet below maximum pool elevation. The channel is overlain by glacial deposits.

Borrow Sites

A total of seven borrow sites and three quarry sites have been identified for dam construction material delineated as sites A, B, C, D, E, F, H, I, J, and L. Of these, Borrow Sites D and H are considered as potential sources for impervious material; Sites C, E, and F for granular material; Sites I and J for pervious gravel; and Quarry Sites A, B, and L for rockfill. Of these sites, Quarry Site A and Borrow sites D and E are considered as the primary material sites for this project based on the exploration investigations to date. Quarry Site L and Borrow sites C, F, H, and I are considered as secondary (back-up) sources of material because of the lengthy haul distance to the damsite, adverse environmental impacts, insufficient quantities, and poor quality material. Due to the lack of bedrock outcrops, Quarry Site B is no longer considered as a viable material site. Borrow Site J would likely not be used because the water level in the river would be higher due to the damming and diversion of the river, which would not coincide with excavation of borrow material. Rockfill for the dam will come from required excavation such as the spillway and intake approach channels for Stage I and from Quarry A for Stage III.

In summary, estimated reserves of borrow and quarry materials from the primary sources are:

- Quarry Site A = 70-100 million cubic yards
- Borrow D = 180 million cubic yards
- Borrow E = 80-90 million cubic yards

Seepage

As the result of construction of the Watana Dam and the impoundment of the reservoir, there will be the tendency for seepage through the foundation rock. The potential for seepage in the foundation of the dam is not high and the bedrock foundations are amenable to grouting.

Buried channels which bypass the dam present the only other potential seepage paths. At the Watana site the Fog Lakes area is not expected to pose seepage problems because of the low gradient and long travel distance (approximately 4-5 miles) from the reservoir to Fog Creek.

During early evaluations, the relict channel north of the Watana site was presumed to pose the greatest potential for seepage, through the overburden deposits from the reservoir to Tsusena Creek. Preliminary evaluations also indicated seepage through the buried channel area could result in piping and erosion of materials at the exit point on Tsusena Creek.

A further potential impact was felt to be saturation of the various zones in the buried channel combined with the thawing of permafrost in this area. The stratigraphy of the relict channel was defined during 1980-82-83 explorations. The results of these explorations indicated that there are no apparent widespread or continuous units within the relict channel that are susceptible to liquefaction. In addition, it appears that multiple periods of glaciation resulted in overconsolidating the overburden deposits within the relict channel, thereby minimizing their potential for liquefaction.

Seepage normally occurring through the foundation rock below the dam will be controlled by two means: the installation of a grout curtain and by a pattern of drain holes drilled from the gallery below the dam. This treatment would reduce or prevent seepage as well as controlling the downstream internal pressures in the rock by the pressure relief affected by the drain holes.

Should excessive seepage develop during impoundment, provisions have been made by virtue of the grouting and drainage galleries beneath the dam foundation, to allow for remedial grouting and additional drain hole installations. In addition, extensive instrumentation of the dam and abutments will be placed during construction for long-term, post-construction monitoring of seepage.

Preliminary assessment of seepage rates through the Watana Relict Channel, assuming conservative permeability rates, indicate that the total seepage quantity during Stage III is negligible and that there appears to be no impact on project operation. Nevertheless, since some uncertainties still exist, remedial measures have been planned to control seepage. First, a drainage gallery would be constructed in overburden across the relatively narrow relict channel exit area at Tsusena Creek. Additionally if required, a positive seepage barrier similar to an I.C.O.S. wall would be built across the throat of the relict channel where the width of unit 'K' (alluvium) is minimal.

During Stage I, seepage potential through the Watana Relict channel is negligible to non-existent, because of an even lower hydraulic gradient between the reservoir and Tsusena Creek.

Permafrost

The effect of thawing permafrost will primarily affect reservoir slope stability and liquefaction potential.

In addition to these two impacts, thawing can also induce settlement to surface facilities constructed in areas of deep overburden north of the Watana damsite.

With regard to settlement, it is anticipated that the airstrip, and the camps, as well as site roads, will all encounter areas of permafrost. Although the soils in this area are not ice rich, some settlements may occur because of thawing of the permafrost.

Since fractures in the rock on the north and south abutment of the Watana dam are ice-filled to approximately 60 and 120 feet respectively, thawing of this permafrost may influence seepage (thawing will more than likely occur prior to grouting of the cutoff below the core). This thawing will be generated because of the thermal effect of the large reservoir which will remain several degrees above freezing throughout the year.

Possible impacts because of permafrost thaw at the Watana site could result in settlement of facilities in areas of deep overburden. Adequate structural design is possible to mitigate against the hazards of settlement in permafrost areas. In the case of the main construction camp, a large pad of granular material will be provided which will evenly distribute the load and insulate the subsoil, hence, retarding thaw. Regrading of the airstrip will be necessary as a maintenance program to offset the effects of differential settlement in these areas.

Geologic Hazards

There are only two main geologic structures which can have an affect on the construction and operation of the power facilities at the Watana site. These are the "Fins" feature upstream from the Watana site, and the "Fingerbuster" zone downstream from the Watana site.

At the Watana site, all of the main project features have been located between the two features, the "Fins" and the "Fingerbuster," thus avoiding the need to tunnel through these shear zones.