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10 CFR 50.54(f)

Serial: RNP-RA/14-0013

MAR 3 1 2014

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261 / RENEWED LICENSE NO. DPR-23

Subject: Seismic Hazard Evaluation, Response to NRC 10 CFR 50.54(f) Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3 and 9.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident

References:

1. NRC letter, *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*, dated March 12, 2012 (ADAMS Accession Number ML12056A046)

2. NRC letter, *Endorsement of EPRI Final Draft Report 1025287, "Seismic Evaluation Guidance*," dated February 15, 2013 (ADAMS Accession Number ML12319A074)

3. EPRI Report 1025287, *Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*, dated February 2013 (ADAMS Accession Number ML12333A170)

4. NEI letter, *Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations*, dated April 9, 2013 (ADAMS Accession Number ML13101A319)

5. NRC letter, *Electric Power Research Institute Final Draft Report XXXXXX, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," as an Acceptable Alternative to the March 12, 2012, Information Request for Seismic Reevaluations*, dated May 7, 2013 (ADAMS Accession Number ML13106A331)

6. NEI Letter, *Seismic Evaluations for Plants in the Central and Eastern United States*, dated March 12, 2014 (ADAMS Accession Nos. ML14083A584, ML14083A586 and ML14083A587)

A010
NRR

Ladies and Gentlemen:

On March 12, 2012, the Nuclear Regulatory Commission (NRC) issued Reference 1 to all power reactor licensees and holders of construction permits in active or deferred status. Enclosure 1 of Reference 1 requested each addressee in the Central and Eastern United States (CEUS) to submit a written response consistent with the requested seismic hazard evaluation information (items 1 through 7) by September 12, 2013. By letter dated February 15, 2013, the NRC issued Reference 2, endorsing the Reference 3 industry guidance for responding to the seismic evaluation in Reference 1. Section 4 of Reference 3 identifies the detailed information to be included in the seismic hazard evaluation submittals.

On April 9, 2013, the Nuclear Energy Institute (NEI) submitted Reference 4 to the NRC, requesting NRC agreement to delay submittal of part of the CEUS seismic hazard evaluation information so that an update to the Electric Power Research Institute (EPRI) (2004, 2006) ground motion attenuation model could be completed and used to develop that information. NEI proposed that descriptions of subsurface materials and properties and base case velocity profiles (items 3a and 3b in Section 4 of Reference 3) be submitted to the NRC by September 12, 2013, with the remaining seismic hazard and screening information submitted to the NRC by March 31, 2014. In Reference 5, the NRC agreed with this recommendation.

Reference 3 contains industry guidance and detailed information to be included in the Seismic Hazard Evaluation submittals. The attached Seismic Hazard Evaluation for H. B. Robinson Steam Electric Plant, Unit No. 2 provides the information described in Section 4 of Reference 3 in accordance with the schedule identified in Reference 4. As discussed in the Enclosure to this letter, seismic hazard curves and a Ground Motion Response Spectrum (GMRS) were developed using current methodology. This GMRS is compared to the design basis Safe Shutdown Earthquake (SSE) response spectrum and the Individual Plant Examination of External Events (IPEEE) High Confidence of Low Probability of Failure (HCLPF) spectrum in the Enclosure.

As discussed within Reference 1, NRC acknowledged that the current regulatory approach and the resultant plant capabilities provides reasonable confidence that an accident with consequences similar to the Fukushima event is unlikely with nuclear power plants located in the United States. The NRC concluded that continued plant operation does not pose an imminent risk to the public health and safety.

By letter dated March 12, 2014 (Reference 9), NEI provided the NRC with seismic core damage risk estimates based on updated seismic hazard information as it applies to operating nuclear reactors in the CEUS, which includes H. B. Robinson Steam Electric Plant, Unit No. 2. These risk assessments continue to support the conclusions of the NRC Generic Issue-199 "Safety/Risk Assessment" and indicate that current seismic design of operating reactors provide adequate protection and safety margin to withstand potential earthquakes that exceed the original design basis.

In accordance with Enclosure 1 of Reference 1, H. B. Robinson Steam Electric Plant, Unit No. 2 screens in for performing a seismic probabilistic risk assessment (SPRA).

This letter contains no new regulatory commitments.

If you have any questions or require additional information, please contact Richard Hightower, Manager, Nuclear Regulatory Affairs at (843)-857-1329.

I declare under the penalty of perjury that the foregoing is true and correct.

Executed on MAR 3 1 2014.

Sincerely,

R. Michael Glover /for

W. R. Gideon
Site Vice President

WRG/shc

Enclosure: Seismic Hazard Evaluation

cc: Mr. K. M. Ellis, NRC Senior Resident Inspector
Mr. S. P. Lingam, NRC Project Manager, NRR
Mr. V. M. McCree, NRC Region II Administrator

U. S. Nuclear Regulatory Commission
Enclosure to Serial: RNP-RA/14-0013
39 Pages including this cover

ENCLOSURE

SEISMIC HAZARD EVALUATION

FOR

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2

DOCKET NO. 50-261 / RENEWED LICENSE NO. DPR-23

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1.0 Introduction

Following the accident at the Fukushima Dai-ichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the NRC Commission established a Near Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations and to determine if the agency should make additional improvements to its regulatory system. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. Subsequently, the NRC issued a 50.54(f) letter on March 12, 2012 (Reference 1), requesting information to assure that these recommendations are addressed by all U.S. nuclear power plants. The 50.54(f) letter requests that licensees and holders of construction permits under 10 CFR Part 50 reevaluate the seismic hazards at their sites against present-day NRC requirements. Depending on the comparison between the reevaluated seismic hazard and the current design basis, the result is either no further risk evaluation or the performance of a seismic risk assessment. Risk assessment approaches acceptable to the staff include a seismic probabilistic risk assessment (SPRA), or a seismic margin assessment (SMA). Based upon the risk assessment results, the NRC staff will determine whether additional regulatory actions are necessary.

This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 50.54(f) letter pertaining to NTTF Recommendation 2.1 for the H.B. Robinson Steam Electric Plant (HBRSEP) site, located in Darlington County, South Carolina (SC). In providing this information, HBRSEP followed the guidance provided in the *Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (EPRI 1025287, 2013) (Reference 2). The Augmented Approach, *Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (EPRI 3002000704, 2013) (Reference 3), has been developed as the process for evaluating critical plant equipment as an interim action to demonstrate additional plant safety margin, prior to performing the complete plant seismic risk evaluations.

The original geologic and seismic siting investigations for HBRSEP were performed using a detailed geologic study of the region and the site to establish the geologic suitability of the site for the nuclear unit. Additional data utilized in the geologic and seismic siting investigations were obtained from the U. S. Atomic Energy Commission (USAEC) Savannah River Operations Office (Appendix 2.5A of Reference 7), Dr.'s J. L. Stuckey and L. L. Smith (Appendix 2.5C of Reference 7), and Perry Byerly (Appendix 2.5D of Reference 7).

The Safe Shutdown Earthquake (SSE) was developed based on evaluation of historic earthquake activity, regional and local geology, and recommendation of Dr. G. W. Housner of the California Institute of Technology. The SSE was used for the design of seismic Class I systems, structures and components.

The General Design Criteria (GDC) in existence at the time HBRSEP was licensed (July, 1970) for operation were contained in Proposed Appendix A to 10CFR50, General Design Criteria for Nuclear Power Plants, published in the Federal Register on July 11, 1967. (Appendix A to 10CFR50, effective in 1971 and subsequently amended, is somewhat different from the proposed 1967 criteria.) HBRSEP was evaluated with respect to the proposed 1967 GDC and the original Final Safety Analysis Report (FSAR) (Reference 7) contained a discussion of the criteria as well as a summary of the criteria by groups. FSAR, Sections 3.1.1.2 and 3.1.2 present that discussion without substantive change in order to preserve the original basis for licensing.

In response to the 50.54(f) letter and following the guidance provided in the SPID (Reference 2), a seismic hazard reevaluation was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed. Based on the results of the screening evaluation, HBRSEP screens in for risk evaluation, a Spent Fuel Pool evaluation, and a High Frequency Confirmation.

2.0 Seismic Hazard Reevaluation

HBRSEP is located in northwest Darlington County, SC, approximately 3 miles west-northwest of Hartsville, SC; 25 miles northwest of Florence, SC; 35 miles north-northeast of Sumter, SC; and 56 miles east-northeast of Columbia, SC. The plant is on the southwest shore of Lake Robinson, a cooling impoundment of Black Creek. The site is located in the Coastal Plain physiographic province about 15 miles southeast of the Piedmont province. The Coastal Plain is composed of largely unconsolidated sediments above a slightly sloping surface of crystalline rock. The basement crystallines in the Piedmont and below the Coastal Plain are composed largely of granite, gneiss, phyllite, and schist and dip to the southeast from 10 ft to 40 ft per mile. The normal regional dip of the Coastal Plain sediments is toward the southeast at about 8 ft to 30 ft per mile, the greater dips being in the deeper strata.

Only one earthquake with intensity of V or greater has ever been recorded within 50 miles of the site. In 1959, an earthquake with intensity of V-VI (Modified Mercalli Scale) occurred about 15 miles from the site in the vicinity of McBee, SC. No permanent effects of this shock are noted in the literature or in a geologic reconnaissance, although it is presumed to have been felt at the location of the site. It is estimated that this shock had a magnitude no greater than 4.5 with an epicentral acceleration of well under 0.10 g.

On the basis of the historical data, it is expected that the site area could experience a shock on the order of the 1959 McBee shock once during the life of the plant. A Magnitude 4.5 earthquake with an epicentral distance of less than ten miles was selected as the design earthquake. Although the probable ground acceleration for this earthquake would be 0.07 g to 0.09 g, a conservative value of 0.1 g is used for the Operational Basis Earthquake (OBE). An SSE with a maximum ground acceleration of 0.2 g was selected to provide an adequate margin of safety.

2.1 Regional and Local Geology

Regional Geology

In South Carolina, the Coastal Plain is composed of largely unconsolidated sediments which overlie a slightly sloping surface of crystalline rock. These crystallines are of Precambrian and early Paleozoic age with subordinate sandstones and intrusive diorities of Triassic age. Triassic sediments have been faulted into the ancient crystallines. Faulted Triassic basins are evident in the Piedmont province and deep wells have located Triassic rocks in widely divergent areas beneath the Coastal Plain. Overlying the Precambrian, Paleozoic, and Triassic rocks, are the sediments of the Coastal Plain. These sediments are composed of sands, gravels, clays, shales, and limestones which range in age from Cretaceous to Pleistocene.

The Coastal Plain itself is divided into the upper Coastal Plain and the lower Coastal Plain by what has been termed the Orangeburg Scarp, an erosional feature representing a shoreline formed during Miocene times. The elevation of the Upper Coastal Plain ranges from approximately 210 ft above Mean Sea Level, (MSL) at the Orangeburg Scarp, and 450 ft to 500 ft above MSL, at the Fall Zone. The Upper Coastal Plain is the outcrop zone of the Tuscaloosa (Middendorf) Formation of late Cretaceous age, but most of the area is blanketed by more recent alluvial deposits of sand and gravel. The elevation of the Lower Coastal Plain ranges from approximately 210 ft above MSL, at the Orangeburg Scarp to sea level at the coast. The major structural features of the region include Triassic grabens (downfaulted basins) and the Cape Fear Arch, a basement ridge which trends southeastward from the Fall Line to the Atlantic Coast just northeast of the North Carolina-South Carolina boundary. The Cape Fear Arch has caused the overlying Coastal Plain sediments to dip away from its structure, thereby modifying the normal regional dips on its flanks.

Local Geology

The surficial materials at the HBRSEP site are recent sands or soils developed from the Middendorf. Because of the high quartz content of the sands and the climatic environment, the surficial soils may not weather sufficiently to differ considerably from the parent material. From an engineering standpoint, the difference is minor.

The subsurface materials encountered in the test holes drilled at the site are completely consistent with recent alluvium and Middendorf Formations encountered throughout the vicinity. Discontinuities within the strata are sedimentary and no structural deformation is apparent in the Middendorf Formation in the site area.

Triassic basins are known in the area; however, it is believed that the likelihood of a Triassic basin at the site is quite small. The basement rock at the site is considered to be Piedmont crystalline since the results of the seismic surveys indicate a high velocity material at a depth consistent with the depth of Piedmont crystallines encountered in wells in the area.

The upper alluvial sands and gravels are moderately compact. Layers of compressible material occur in the upper 30 ft to 50 ft. Because of the quantity of fines in the sand and gravel, it cannot be considered free-draining material. The underlying Middendorf contains compact, relatively incompressible sands and firm to hard clayey soils. Several strata of cemented sandstone were encountered in the borings at depths of approximately 90 ft to 100 ft.

2.2 Probabilistic Seismic Hazard Analysis

2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the 50.54(f) letter and following the guidance in the SPID (Reference 2), a probabilistic seismic hazard analysis (PSHA) was completed using the recently developed Central and Eastern United States Seismic Source Characterization (CEUS-SSC) for Nuclear Facilities (Reference 4) together with the updated EPRI Ground-Motion Model (GMM) for the CEUS (Reference 5). A site-specific review of the CEUS-SSC earthquake catalog was also performed as described below, and these results are incorporated into the PSHA for the HBRSEP site. For the PSHA, a lower-bound moment magnitude of 5.0 was used, as specified in the 50.54(f) letter.

Site-Specific CEUS-SSC Catalog Review

A site-specific review (Reference, 13) of the CEUS-SSC catalog published in the CEUS-SSC was performed with regard to two issues: (1) identification of additional reservoir induced seismicity (RIS) earthquakes in the southeastern US and (2): locations of earthquakes in South Carolina near the time of the 1886 Charleston, SC earthquake sequence.

In developing the CEUS-SSC catalog, earthquakes identified as RIS were removed from the final earthquake listing. The source for this identification in the southeastern US was the set of available Southeast US Seismic Network (SEUSSN) Bulletins. The master list contained 120 earthquakes. Sixteen of these were large enough to be in the CEUS-SSC catalog. These earthquakes occurred primarily near Monticello Reservoir and Lake Keowee. These earthquakes were removed from the final (Version 7) CEUS-SSC catalog published in NUREG-2115.

Additional reviews were performed of available published information to identify potential additional RIS earthquakes that are in the CEUS-SSC catalog. The basis for each of the potential RIS records was reviewed, taking into consideration the magnitude of the earthquake and depth, proximity to a reservoir, timing of the earthquake versus the filling of the reservoir, and proximity to a nuclear plant.

Thirty additional RI or potentially RI earthquakes were identified in the CEUS-SSC catalog. Of these, thirteen were large enough ($E[M] \geq 2.9$) to potentially affect recurrence calculations. Some of these were identified as dependent events of other earthquakes in the catalog. After review, it was determined that all thirty RI or potentially RI earthquakes should be removed from the catalog. Table 2.2.1-1 lists the specific earthquake database records reviewed.

Seven additional earthquakes in the CEUS-SSC catalog from the time period 1799 to 1888 in South Carolina were also identified as being potentially mislocated (Table 2.2.1-2). The majority of these earthquakes have locations and times that come from the USGS's earthquake catalog used for seismic hazard mapping. The primary source of the USGS catalog is the NCEER-91 catalog. The events in question have alternative locations in the SUSN catalog that place them at the location of the 1886 Charleston, SC main shock. A review was performed of the identification of these earthquakes and assignment of these locations in the development of the CEUS-SSC catalog in light of additional information in the paper by W.H. Bakun and M.G. Hopper (2004, "Magnitudes and Locations of the 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes," Bulletin of the Seismological Society of America, 94, 64-75) and recent information provided by Donald Stevenson and Dr. Pradeep Talwani.

The review identified another potential duplicate record. Bakun and Hopper (2004) also studied the Charleston aftershock on 1886/11/5 17:20 and found a location near Charleston, but slightly inland from other locations. Talwani and Sharma (1999) also concluded that this earthquake occurred at a slightly different location than other Charleston aftershocks. This earthquake appears in the CEUS-SSC catalog as TMP02071. There is also an event TMP02072 that is listed in the USGS catalog with time 12:25 with a location to the northwest of Charleston. Both events were identified as Charleston aftershocks in the declustering, but the timing suggests that they may be duplicates. The recommendation was to remove TMP02072 and use the magnitude and location given in Bakun and Hopper for TMP02071.

An additional review was performed of earthquake locations provided by Seeber and Armbruster (1987). These locations and size assessments were incorporated into the NCEER-91 catalog and then into the USGS catalog used as the primary source for the CEUS-SSC catalog. The original Seeber and Armbruster (1987) listing was also incorporated into the CEUS-SSC catalog, along with their listed values of felt area. During the review, the classification of nine additional earthquakes at locations distance from Charleston significant to hazard (E[M]≥2.9) were changed from dependent to independent. Previously, these earthquakes had been classified as dependent earthquakes in clusters associated with the earthquakes identified above. The information for each of these earthquakes was reviewed, including additional information provided by Stevenson and Talwani.

Table 2.2.1-3 summarizes the assessment of the larger events in the CEUS-SSC catalog located at sufficient distance from Charleston to not be identified as aftershocks of the 1886/09/01 main shock.

Table 2.2.1-1
Summary of RIS Earthquake Review

TMPID	yr	mo	Dy	hr	mn	sec	lat	lon	depth	E[M]	Comment / Disposition
TMP07012	1969	12	13	10	19	29.7	35.04	-82.85	6	3.46	Retain as non RIS
TMP07159	1971	7	13	11	42	26	34.8	-83	n/a	3.63	Possible RIS
TMP07565	1974	8	2	8	52	11.1	33.91	-82.53	4	3.91	Retain as non RIS
TMP08078	1975	11	25	15	17	34.8	34.93	-82.9	10*	3.21	RIS
TMP08787	1977	9	7	14	41	32.7	34.982	-82.927	n/a	2.77	RIS
TMP08971	1978	1	25	8	29	39	34.301	-81.234	5**	2.6	RIS
TMP09354	1978	8	27	10	23	8	34.313	-81.337	2	2.93	RIS
TMP08998	1978	2	10	20	23	38.7	34.343	-81.348	1	2.77	Possible RIS
TMP08999	1978	2	11	0	19	0.7	34.343	-81.35	3	2.77	Possible RIS
TMP09000	1978	2	11	5	19	0.2	34.346	-81.349	1	2.93	Possible RIS
TMP09006	1978	2	14	12	45	7.2	34.342	-81.346	2	2.77	Possible RIS
TMP09007	1978	2	14	13	9	59.5	34.351	-81.343	2	2.85	Possible RIS
TMP09013	1978	2	15	21	14	34.2	34.349	-81.346	0	2.77	Possible RIS
TMP09014	1978	2	16	2	14	33.4	34.332	-81.362	2	2.85	Possible RIS
TMP09023	1978	2	22	7	13	25.1	34.327	-81.35	1	2.85	Possible RIS
TMP09024	1978	2	22	12	13	24.3	34.339	-81.35	1	3.00	Possible RIS
TMP09025	1978	2	22	13	4	59.2	34.356	-81.352	0	2.77	Possible RIS
TMP09027	1978	2	24	7	34	10.5	34.334	-81.348	1	2.93	Possible RIS
TMP09029	1978	2	25	4	2	42.7	34.345	-81.351	1	2.77	Possible RIS
TMP09031	1978	2	26	6	52	35.4	34.315	-81.297	1	2.85	Possible RIS
TMP09032	1978	2	26	11	52	33	34.391	-81.361	1	3.00	Possible RIS
TMP09033	1978	2	26	18	17	48.8	34.321	-81.348	0	3.08	Possible RIS
TMP09343	1978	8	24	10	23	7.6	34.311	-81.341	2	2.85	Possible RIS
TMP09355	1978	8	27	10	23	8	34.313	-81.337	7	2.77	Possible RIS
TMP09460	1978	10	27	16	27	18.1	34.302	-81.326	2	3.08	RIS
TMP09518	1978	11	24	11	54	40.9	34.296	-81.347	1	2.85	Possible RIS
TMP10034	1979	8	26	1	31	45	34.916	-82.956	1	3.64	RIS
TMP39374	1979	10	8	8	54	19.4	34.31	-81.33	2	2.85	RIS
TMP10104	1979	10	8	23	20	11	34.306	-81.344	1	3.16	RIS
TMP10109	1979	10	14	8	24	57.6	34.306	-81.338	2	3.08	RIS
TMP10506	1980	7	29	1	10	22.7	34.351	-81.364	1	3.31	Possible RIS
TMP16282	1988	1	27	22	5	42.9	34.189	-82.75	6.1	2.32	RIS

* depth 17 km in RANDJ

** depth 1 km in Stover & Coffman

Table 2.2.1-2
Potential Charleston SC Area Aftershocks from CEUS-SSC Catalog

TMPID	yr	Mo	Dy	hr	mn	sec	Lat	lon	E[M]	Source of Catalog Location
TMP00331	1799	4	11	8	20	0	33.95	-80.18	4.68	USGSnd_000145 Revised by Jeff Munsey of TVA based on Bakun and Hopper Method
TMP01089	1860	1	19	23	0	0	33.68	-80.57	4.21	USGSnd_000427
TMP01731	1886	9	1	6	0	0	33.91	-82.02	4.54	SeebArm87_000014
TMP01739	1886	9	1	9	45	0	34.3	-82.86	4.17	USGSnd_000771
TMP02019	1886	10	22	5	0	0	34.71	-81.66	4.13	USGSnd_000805
TMP02025	1886	10	22	14	45	0	33.87	-81.01	4.5	USGSnd_000807
TMP02360	1888	1	12	9	55	0	34.18	-80.17	4.33	USGSnd_000860

Table 2.2.1-3
Summary of Events Affected by the Charleston Aftershock Review

TMPID	yr	Mo	Dy	Hr	Mn	sec	lat	lon	Comment / Disposition
TMP00331	1799	4	11	8	20	0	33.95	-80.18	Retain as is
TMP01089	1860	1	19	23	0	0	33.68	-80.57	Move to Charleston and base E[M] on I0
TMP01731	1886	9	1	6	0	0	33.91	-82.02	Event removed from catalog as a duplicate of TMP01732. Location and magnitude of TMP01732 do not require modification
TMP01739	1886	9	1	14*	45	0	34.04	-82.9	Event removed from catalog as a duplicate of TMP01738. Location and magnitude of TMP01738 do not require modification
TMP01942	1886	9	28	3	0	0	34.7	-81.62	Consider as a false event
TMP02002	1886	10	12	11	0	0	34.14	-81.33	Not use reported felt area, event becomes < E[M] 2.9
TMP02019	1886	10	22	5	0	0	34.71	-81.66	Event removed from catalog as a duplicate of TMP02023
TMP02023	1886	10	22	10	20		32.9	-80	Magnitude taken from Bakun and Hopper (2004)
TMP02024	1886	10	22	10*	25		33.69	-81	Event removed from catalog as a duplicate of TMP02023
TMP02025	1886	10	22	14	45	0	33.87	-81.01	Location moved to Charleston, magnitude taken from Bakun

TMPID	yr	Mo	Dy	Hr	Mn	sec	lat	lon	Comment / Disposition
									and Hopper (2004)
TMP02068	1886	11	5	5	0	0	33.38	-82.49	Not use reported felt area, event becomes < E[M] 2.9
TMP02071	1886	11	5	17	20	0	32.9	-80	Magnitude taken from Bakun and Hopper (2004)
TMP02072	1886	11	5	12	25		33.4	-80.42	Event removed from catalog as a duplicate of TMP02071.
TMP02134	1886	12	8	10	25	0	34.039	-80.886	Revise I0 from 4.5 to 4
TMP02136	1886	12	11	21	0	0	34.18	-82.06	Retain as is
TMP02173	1887	1	12	11	0	0	34.35	-82.42	Retain as less than E[M] 2.9, remove felt area
TMP02210	1887	3	4	10	0	0	33.74	-81.5	Not use reported felt area, event becomes < E[M] 2.9
TMP02360	1888	1	12	9	55	0	34.18	-80.17	Event removed from catalog as a duplicate of TMP39326.
TMP02393	1888	4	5	0	0	0	34.21	-81.534	Retain, reduce to I0 4, E[M] less than 2.9
TMP02423	1888	8	15	23	30	0	34.37	-81.08	Retain as is

* Change in hour.

Probabilistic Seismic Hazard Analysis

For the PSHA, the CEUS-SSC (Reference 4) background seismic sources out to a distance of 400 miles (640 km) around the site were included. This distance exceeds the 200 mile (320 km) recommendation contained in Reg. Guide 1.208 (Reference 6) and was chosen for completeness. Background sources included in this site analysis are the following:

1. Atlantic Highly Extended Crust (AHEX)
2. Extended Continental Crust—Atlantic Margin (ECC_AM)
3. Extended Continental Crust—Gulf Coast (ECC_GC)
4. Mesozoic and younger extended prior – narrow (MESE-N)
5. Mesozoic and younger extended prior – wide (MESE-W)
6. Midcontinent-Craton alternative A (MIDC_A)
7. Midcontinent-Craton alternative B (MIDC_B)
8. Midcontinent-Craton alternative C (MIDC_C)
9. Midcontinent-Craton alternative D (MIDC_D)
10. Non-Mesozoic and younger extended prior – narrow (NMESE-N)
11. Non-Mesozoic and younger extended prior – wide (NMESE-W)
12. Paleozoic Extended Crust narrow (PEZ_N)
13. Paleozoic Extended Crust wide (PEZ_W)
14. Reelfoot Rift including the Rough Creek Graben (RR-RCG)
15. Study region (STUDY_R)

For sources of large magnitude earthquakes, designated Repeated Large Magnitude Earthquake (RLME) sources in CEUS-SSC (Reference 4), the following sources lie within 1,000 km of the site and were included in the analysis:

1. Charleston
2. Commerce
3. Eastern Rift Margin Fault northern segment (ERM-N)
4. Eastern Rift Margin Fault southern segment (ERM-S)
5. Marianna
6. New Madrid Fault System (NMFS)
7. Wabash Valley

For each of the above background and RLME sources, the mid-continent version of the updated CEUS EPRI GMM was used.

2.2.2 Base Rock Seismic Hazard Curves

Consistent with the SPID (Reference 2), base rock seismic hazard curves are not provided as the site amplification approach referred to as Method 3 has been used. Seismic hazard curves are shown below in Section 3 at the SSE control point elevation.

2.3 Site Response Evaluation

Following the guidance contained in Seismic Enclosure 1 of the 3/12/2012 50.54(f) Request for Information and in the SPID (CEUS-SSC, 2013a) for nuclear power plant sites that are not sited on hard rock (defined as 2.83 km/sec), a site response analysis was performed for HBRSEP.

2.3.1 Description of Subsurface Material

The HBRSEP is located in the Coastal Plain Physiographic Province of South Carolina. The general site conditions consist of about 50 ft (15.2 m) of recent alluvium overlying about 400 ft (122 m) of stiff sands, sandstones, and mudstones. Precambrian basement consisting of Piedmont crystalline rocks lie below the sedimentary section (Reference 16).

Table 2.3.1-1 shows the recommended geotechnical properties for the site.

Table 2.3.1-1 (Reference 16)
Summary of Site Geotechnical Profile for HBRSEP

Depth* Range (feet)	Soil/Rock Description	Density (pcf)	Shear Wave Velocity (fps)	Compressional Wave Velocity (fps)	Assumed Poisson's Ratio
0' to 56'	Recent Alluvium (Sand and Gravel)	125	1000**	1500	0.33
56' to 460'	Cretaceous Middendorf (Sands, Silty and Sandy Clay, Sandstone and Mudstone)	130	3600	7200	0.33
> 460'	Pre-Cambrian Crystalline (Granite, Gneiss, Phyllite Schist)	170	11200	17500	0.15

*Measured from EL. 226 ft.

**The original soil profile data obtained from Figure 2.5.1-2 of the HBR2 Updated FSAR has been adjusted based on recommendations of MACTEC in EC54720-Z00 Attachment A. Figure 2.5.1-2 had a shear wave velocity of 750 fps for the first 30ft of soil (measured from EL. 226 ft); whereas, MACTEC suggested an adjusted value of 1000 fps for the first 70ft of soil (measured from EL. 240 ft). All other soil profile data in Table 2 remains the same as given in Figure 2.5.1-2 of the Updated FSAR.

The following description of the general geology at the site is taken directly from URS (Reference 16):

> "The surficial materials at the HBRSEP site are recent sands or soils developed from the Middendorf.
>
> Because of the high quartz content of the sands and the climatic environment, the surficial soils may not weather sufficiently to differ considerably from the parent material. Thus, it is nearly impossible to distinguish the recent alluvial soils from the parent Middendorf sand since both the alluvial and weathered soils are derived from the Middendorf. Only their manner of placement would be different. From an engineering standpoint, the difference is minor.
>
> The subsurface materials encountered in the test holes drilled at the site are completely consistent with recent alluvium and Middendorf Formations encountered throughout the vicinity. Discontinuities within the strata are sedimentary and no structural deformation is apparent in the Middendorf Formation in the site area.
>
> The Middendorf is about 400 ft thick and overlies an eroded, slightly sloping surface of Piedmont crystallines that may be somewhat weathered near the surface.
>
> Triassic basins are known in the area; however, it is believed that the likelihood of a Triassic basin at the site is quite small. The basement rock at the site is considered to

be Piedmont crystalline since the results of the seismic surveys indicate a high velocity material at a depth consistent with the depth of Piedmont crystallines encountered in wells in the area.

In general, the upper alluvial sands and gravels are moderately compact. Layers of compressible material occur in the upper 30 to 50 ft. Because of the quantity of fines in the sand and gravel, it could not be considered free-draining material. The underlying Middendorf contains generally compact relatively incompressible sands and firm to hard clayey soils. Several strata of cemented sandstone were encountered in the borings at depths of roughly 90 to 100 ft.

From a geological standpoint, the Middendorf is considered to be an unconsolidated formation. From an engineering point of view, however, the materials are firm and compact and would provide good foundation support for the proposed construction. The materials range in texture from a hard or compact soil to a soft rock."

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

Table 2.3.1-1 shows the recommended shear-wave velocities and unit weights verses depth for the profile. Based on Table 2.3.1-1 and the location of the SSE at surface (Reference 16), the profile consists of 460 ft (140.2 m) of soils and soft rock overlying hard crystalline basement rock.

Shear-wave velocities for the profile were based on measurements of compressional-wave velocities (Reference 16), likely through refraction surveys, and assumed Poisson ratios. More recent downhole testing at the nearby ISFSI revised the surficial alluvium shear-wave velocity from 750 ft/s (228.6 m/s) to 1,000 ft/s (304.8 m/s) (Table 2.3.1-1) and confirmed the deeper shear-wave velocities (Reference 16).

For the stiff soils and soft rock of the Cretaceous Middendorf Formation (Table 2.3.1-1), a depth dependent shear-wave velocity gradient, rather than a constant velocity or constant gradient over a 400 ft depth range, was assumed to more accurately, reflect in-situ conditions. To model a representative velocity gradient for the Middendorf Formation, a 760 m/s ($\overline{V_s}$ (30 m)) generic profile (Reference 2) was adopted and adjusted to reflect the average shear-wave velocity for the Middendorf Formation as specified in Table 2.3.1-1 (Reference 16). The adopted gradient profile is shown in Figure 2.3.2-1.

Based on the specified shear-wave velocities, reflecting measured compressional-wave velocities and assumed Poisson ratios, a scale factor of 1.57 was adopted to reflect upper and lower range base-cases. The scale factor of 1.57 reflects a $\sigma_{\mu ln}$ of about 0.35 based on the SPID (Reference 2) 10th and 90th fractiles which implies a 1.28 scale factor on σ_{μ}.

Using the shear-wave velocities specified in Table 2.3.2-1, three base-profiles were developed using the scale factor of 1.57. The specified shear-wave velocities were taken as the mean or best estimate base-case profile (P1) with lower and upper range base-cases profiles P2 and P3 respectively. The three base-case profiles P1, P2, and P3, have a mean depth below the SSE of 460 ft (140.2 m) to hard reference rock, randomized ± 93 ft (± 28.4 m). The base-case profiles (P1, P2, and P3) are shown in Figure 2.3.2-1 and listed in Table 2.3.2-2. The depth randomization reflects ± 20% of the depth and was based on both borehole and refraction confirmation as well as to provide a realistic broadening of the fundamental resonance rather than reflect actual random variations to basement shear-wave velocities across a footprint.

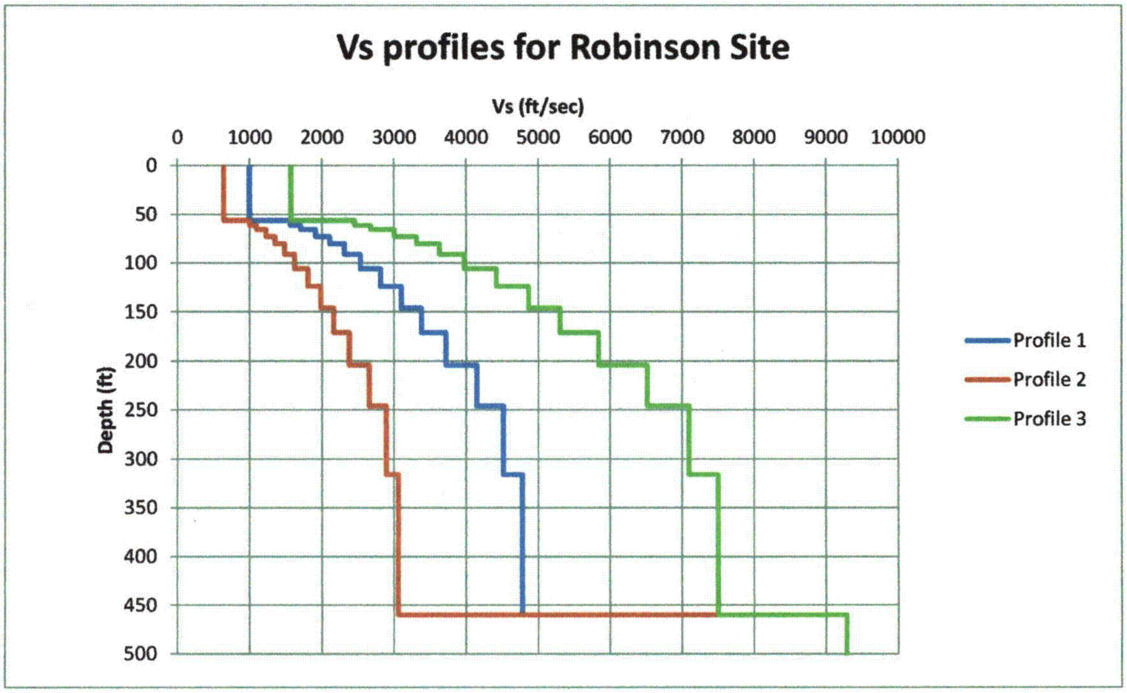


Figure 2.3.2-1. Shear-wave velocity profiles for the HBRSEP site.

Table 2.3.2-2
Layer thicknesses, depths, and shear-wave velocities (Vs) for 3 profiles, the HBRSEP site

Profile 1			Profile 2			Profile 3		
thickness(ft)	depth (ft)	Vs(ft/s)	thickness(ft)	depth (ft)	Vs(ft/s)	thickness(ft)	depth (ft)	Vs(ft/s)
	0	1000		0	640		0	1570
5.6	5.6	1000	5.6	5.6	640	5.6	5.6	1570
5.6	11.2	1000	5.6	11.2	640	5.6	11.2	1570
5.6	16.8	1000	5.6	16.8	640	5.6	16.8	1570
5.6	22.4	1000	5.6	22.4	640	5.6	22.4	1570
5.6	28.1	1000	5.6	28.1	640	5.6	28.1	1570
5.6	33.7	1000	5.6	33.7	640	5.6	33.7	1570
5.6	39.3	1000	5.6	39.3	640	5.6	39.3	1570
5.6	44.9	1000	5.6	44.9	640	5.6	44.9	1570
5.6	50.5	1000	5.6	50.5	640	5.6	50.5	1570
5.6	56.1	1000	5.6	56.1	640	5.6	56.1	1570

5.0	61.1	1566	5.0	61.1	1002	5.0	61.1	2458
4.0	65.1	1706	4.0	65.1	1092	4.0	65.1	2679
7.4	72.5	1914	7.4	72.5	1225	7.4	72.5	3005
7.5	80.1	2110	7.5	80.1	1350	7.5	80.1	3312
11.0	91.0	2312	11.0	91.0	1480	11.0	91.0	3630
15.0	106.0	2531	15.0	106.0	1620	15.0	106.0	3974
18.0	124.0	2815	18.0	124.0	1802	18.0	124.0	4420
22.0	146.1	3100	22.0	146.1	1984	22.0	146.1	4867
25.0	171.1	3380	25.0	171.1	2163	25.0	171.1	5306
33.0	204.1	3720	33.0	204.1	2381	33.0	204.1	5840
42.0	246.1	4150	42.0	246.1	2656	42.0	246.1	6515
35.0	281.1	4520	35.0	281.1	2893	35.0	281.1	7096
35.0	316.1	4520	35.0	316.1	2893	35.0	316.1	7096
33.3	349.4	4780	33.3	349.4	3059	33.3	349.4	7504
33.3	382.7	4780	33.3	382.7	3059	33.3	382.7	7504
33.3	416.1	4780	33.3	416.1	3059	33.3	416.1	7504
44.0	460.1	4780	44.0	460.1	3059	44.0	460.1	7504
3280.8	3740.9	9285	3280.8	3740.9	9285	3280.8	3740.9	9285

2.3.2.2 Shear Modulus and Damping Curves

No site-specific nonlinear dynamic material properties were determined for the soil and soft rock materials in the initial siting of the HBRSEP. For both the shallow recent alluvium and the stiff sands and soft rock of the Middendorf Formation, EPRI cohesionless soil and Peninsular Range G/G_{max} and hysteretic damping curves we considered appropriate (Reference 2). To more adequately accommodate epistemic uncertainty in nonlinear dynamic material properties, since the relatively high shear-wave velocities coupled with Peninsular Range modulus reduction and hysteretic damping curves results in largely linear response in the Middendorf Formation, a third case comprising a combination of EPRI soil and EPRI rock curves was added. The third case (model M3) consisted of EPRI soil curves for the shallow recent alluvium combined with EPRI rock curves for the Middendorf Formation. The three cases of nonlinear dynamic material properties was considered to reflect a realistic range in response from largely linear with Peninsular Range curves throughout to significant nonlinearity with the use of EPRI (soil and rock) curves throughout. The three combinations of EPRI and Peninsular Range G/G_{max} and hysteretic damping curves with a depth distribution based on assuming the Middendorf Formation behaves either as all soil or all soft rock, were considered to equally reflect in-situ conditions (Table 2.3.2-3).

2.3.2.3 Kappa

For the HBRSEP profile of about 460 ft (140.2 m) of soil and soft rock over hard reference rock, the kappa value of 0.006s for hard rock (Reference 2) was combined with the low strain damping in the hysteretic damping curves to give the values listed in Table 2.3.2-3. The low strain kappa values range from 0.008s for the stiffest profile (P3) and EPRI or Peninsular Range curves to 0.019s for the softest profile (P2) combined with EPRI soil and rock curves (Table 2.3.2-3). The full epistemic uncertainty in overall profile damping has contributions from kappa at low strain in the soil and soft rock but also the wide range in hysteretic damping curves at higher loading levels of significance to design.

Table 2.3.2-3

Kappa Values and Weights Used for Site Response Analyses

Velocity Profile	Kappa(s)	
	M1, M2	M3
P1	0.009	0.014
P2	0.011	0.019
P3	0.008	0.011
	Weights	
P1	0.4	
P2	0.3	
P3	0.3	
G/G_{max} and Hysteretic Damping Curves		
M1	0.3	
M2	0.3	
M3	0.3	

2.3.3 Randomization of Base Case Profiles

To account for the aleatory variability in dynamic material properties that is expected to occur across a site at the scale of a typical nuclear facility, variability in the assumed shear-wave velocity profiles has been incorporated in the site response calculations. For the HBRSEP site, random shear wave velocity profiles were developed from the base case profiles shown in Figure 2.3.2-1. Consistent with the discussion in Appendix B of the SPID (Reference 2), the velocity randomization procedure made use of random field models which describe the statistical correlation between layering and shear wave velocity. The default randomization parameters developed in Toro (1997) for USGS "A" site conditions were used for this site. Thirty random velocity profiles were generated for each base case profile. These random velocity profiles were generated using a natural log standard deviation of 0.25 over the upper 50 ft and 0.15 below that depth. As specified in the SPID (Reference 2), correlation of shear wave velocity between layers was modeled using the footprint correlation model. In the correlation model, a limit of +/- 2 standard deviations about the median value in each layer was assumed for the limits on random velocity fluctuations.

2.3.4 Input Spectra

Consistent with the guidance in Appendix B of the SPID (Reference 2), input Fourier amplitude spectra were defined for a single representative earthquake magnitude (**M** 6.5) using two different assumptions regarding the shape of the seismic source spectrum (single-corner and double-corner). A range of 11 different input amplitudes (median peak ground accelerations (PGA) ranging from 0.01 to 1.5 g) were used in the site response analyses. The characteristics of the seismic source and upper crustal attenuation properties assumed for the analysis of the HBRSEP site were the same as those identified in Tables B-4, B-5, B-6 and B-7 of the SPID (Reference 2) as appropriate for typical CEUS sites.

2.3.5 Methodology

To perform the site response analyses for the HBRSEP site, a random vibration theory (RVT) approach was employed. This process utilizes a simple, efficient approach for computing site-specific amplification functions and is consistent with existing NRC guidance and the SPID (Reference 2). The guidance contained in Appendix B of the SPID (Reference 2) on incorporating epistemic uncertainty in shear-wave velocities, kappa, non-linear dynamic properties and source spectra for plants with limited at-site information was followed for the HBRSEP site.

2.3.6 Amplification Functions

The results of the site response analysis consist of amplification factors (5% damped pseudo absolute response spectra) which describe the amplification (or de-amplification) of hard reference rock motion as a function of frequency and input reference rock amplitude. The amplification factors are represented in terms of a median amplification value and an associated standard deviation (sigma) for each oscillator frequency and input rock amplitude. Consistent with the SPID (Reference 2) a minimum median amplification value of 0.5 was employed in the present analysis. Figure 2.3.5-1 illustrates the median and +/- 1 standard deviation in the predicted amplification factors developed for the eleven loading levels parameterized by the median reference (hard rock) peak acceleration (0.01g to 1.50g) for profile P1 and EPRI soil G/G_{max} and hysteretic damping curves. The variability in the amplification factors results from variability in shear-wave velocity, depth to hard rock, and modulus reduction and hysteretic damping curves. To illustrate the effects of nonlinearity at the HBRSEP site, Figure 2.3.5-2 shows the corresponding amplification factors developed with Peninsular Range G/G_{max} and hysteretic damping curves resulting in the most linear analyses. Finally, Figure 2.3.5-3 shows the effects of treating the shallow alluvium with EPRI soil curves and the Middendorf Formation with EPRI rock curves, reflecting the most nonlinear analyses.

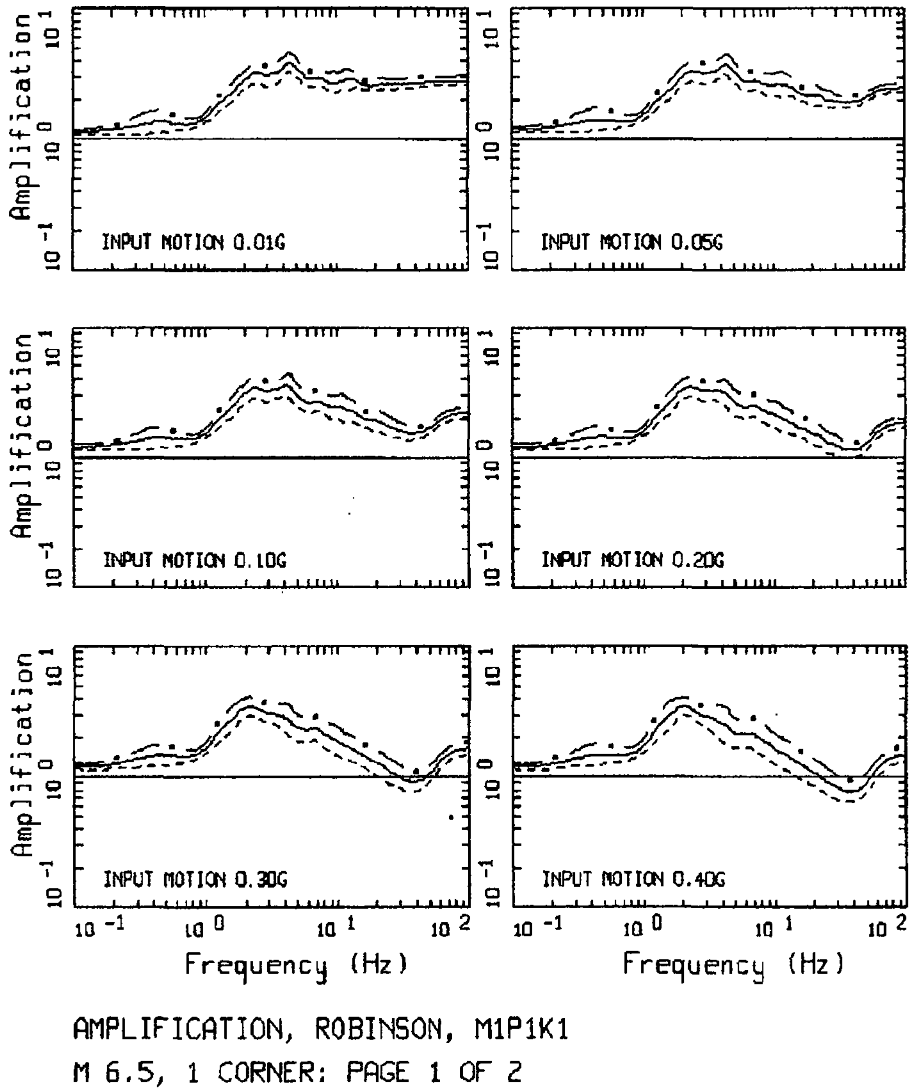
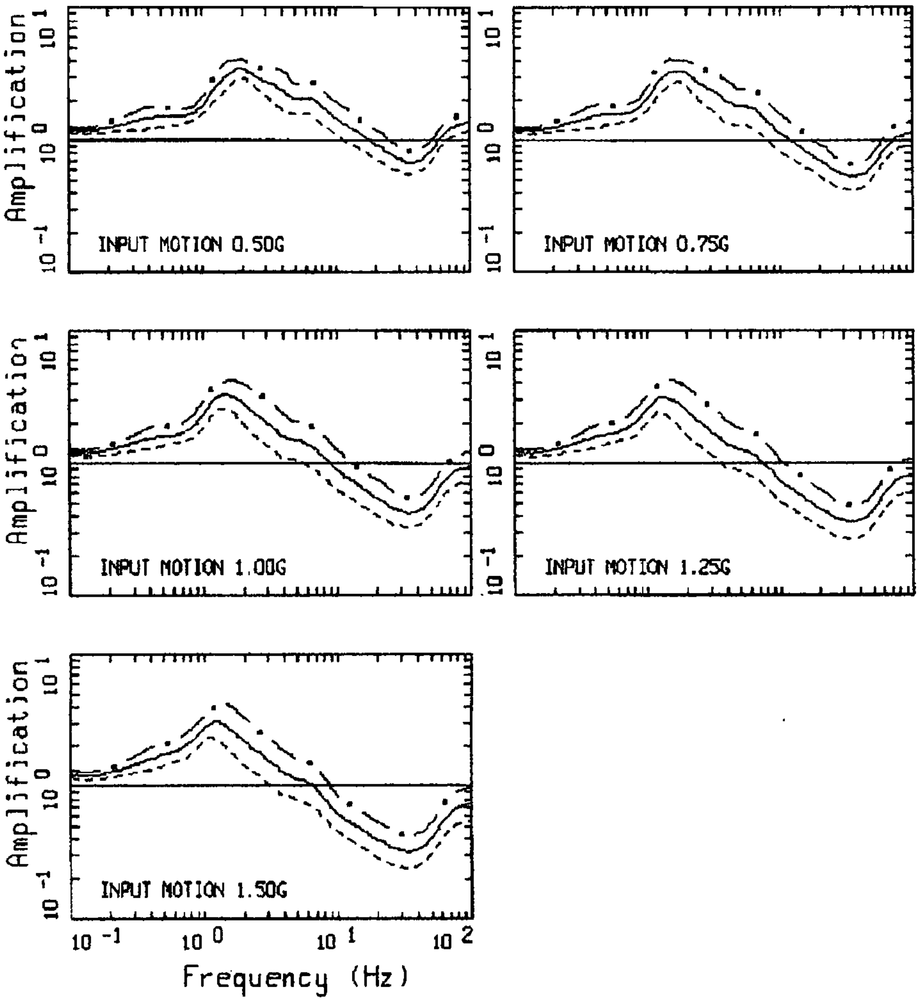


Figure 2.3.5-1. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI soil modulus reduction and hysteretic damping curves (model M1), and base-case kappa at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (Reference 2).



AMPLIFICATION, ROBINSON, M1P1K1
M 6.5, 1 CORNER: PAGE 2 OF 2

Figure 2.3.5-1.(cont.)

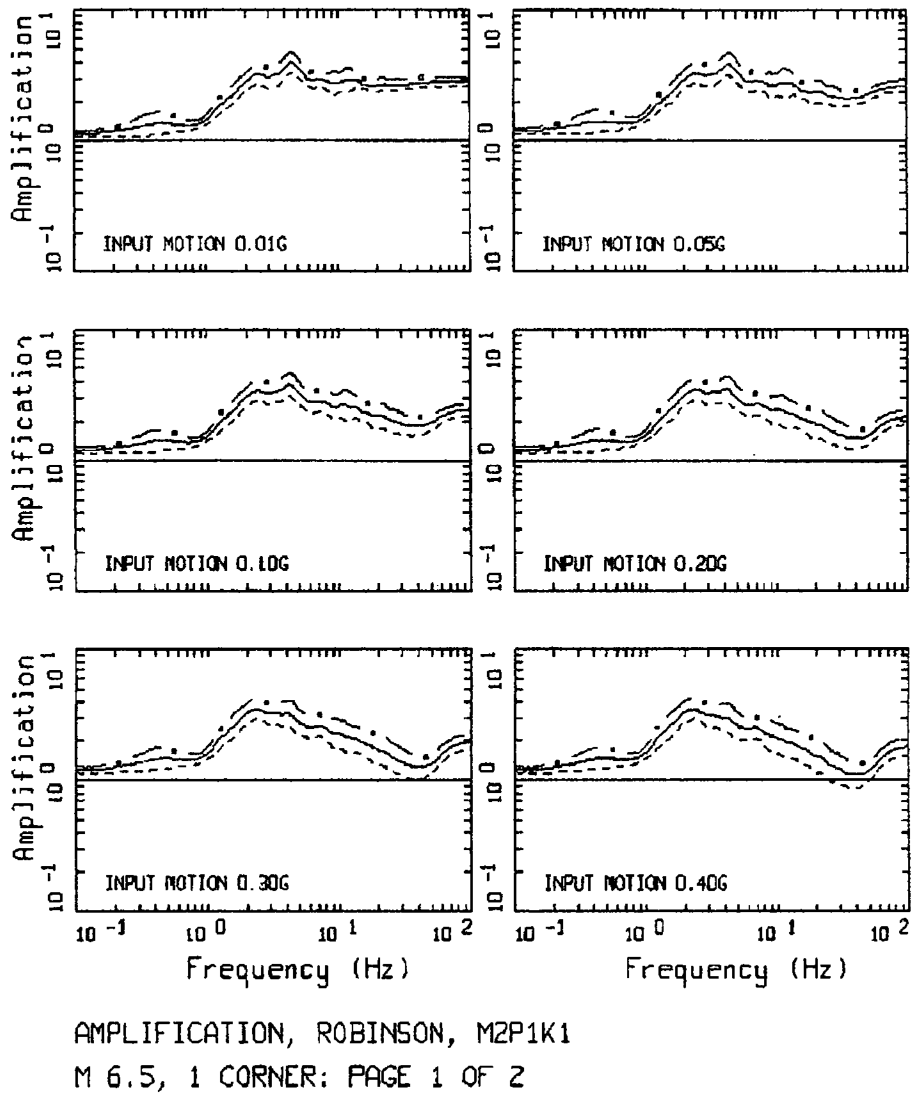
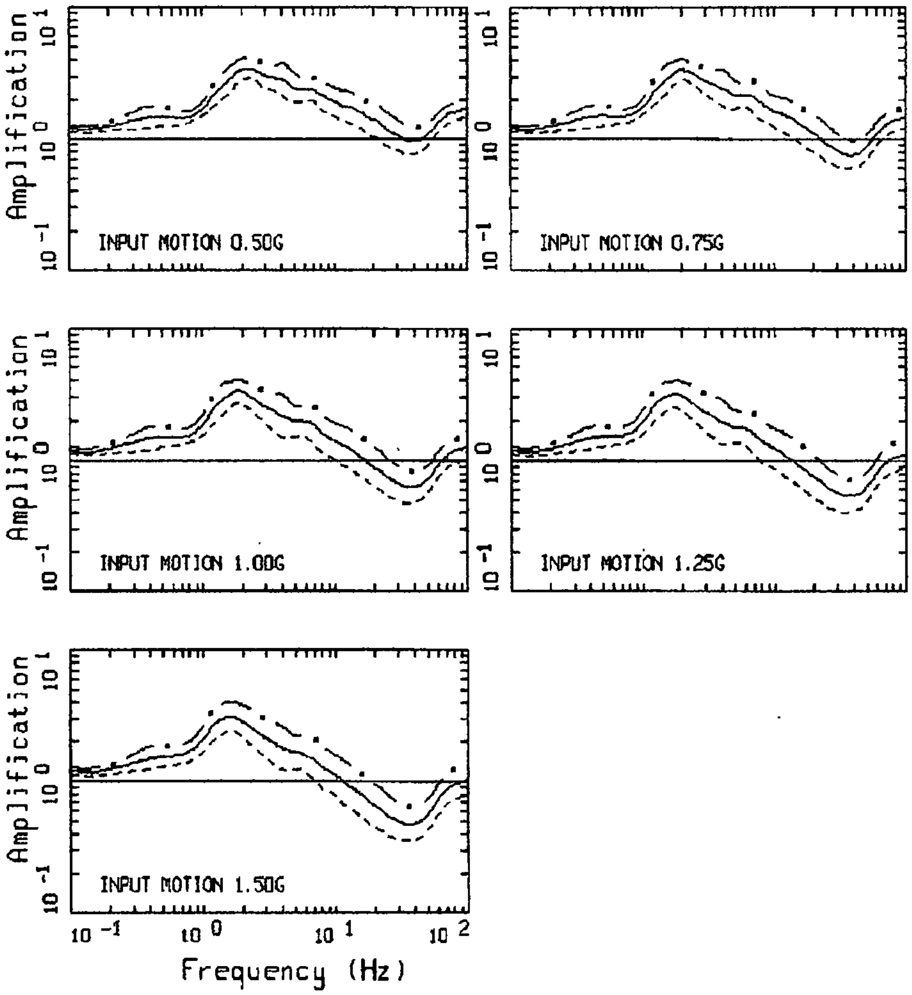


Figure 2.3.5-2. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), Peninsular Range Modulus reduction and hysteretic damping curves (model M2), and base-case kappa at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (Reference 2).



AMPLIFICATION, ROBINSON, M2P1K1
M 6.5, 1 CORNER: PAGE 2 OF 2

Figure 2.3.5-2.(cont.)

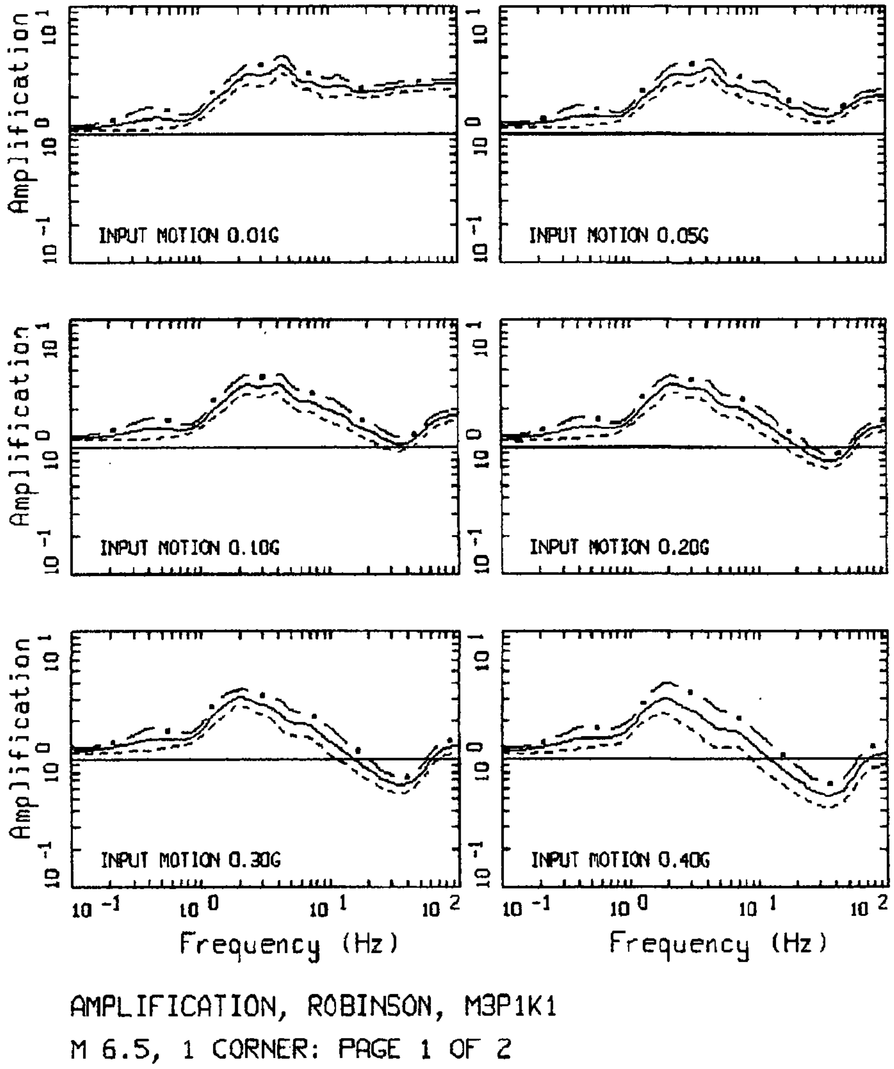
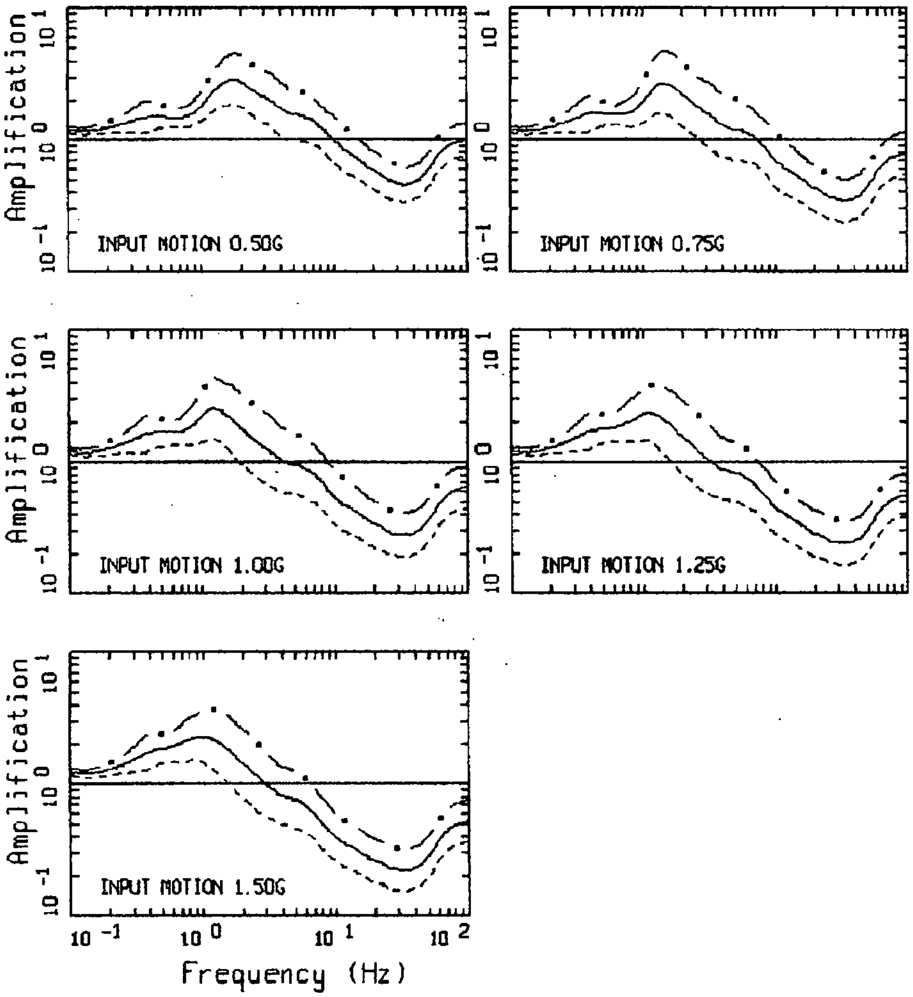


Figure 2.3.5-3. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI soil (alluvium) and rock (Middendorf Formation) modulus reduction and hysteretic damping curves (model M3), and base-case kappa at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (Reference 2).



AMPLIFICATION, ROBINSON, M3P1K1
M 6.5, 1 CORNER: PAGE 2 OF 2

Figure 2.3.5-3:(cont.)

2.3.7 Control Point Seismic Hazard Curves

The procedure to develop probabilistic site-specific control point hazard curves used in the present analysis follows the methodology described in Section B-6.0 of the SPID (Reference 2). This procedure (referred to as Method 3) computes a site-specific control point hazard curve for a broad range of spectral accelerations given the site-specific bedrock hazard curve and site-specific estimates of soil or soft-rock response and associated uncertainties. This process is repeated for each of the seven spectral frequencies for which ground motion equations are available. The dynamic response of the materials below the control point was represented by the frequency- and amplitude-dependent amplification functions (median values and standard deviations) developed and described in the previous section. The resulting control point mean hazard curves for HBRSEP are shown in Figure 2.3.7-1 for the seven spectral frequencies for which ground motion equations are defined. Tabulated values of mean and fractile seismic hazard curves and site response amplification functions are provided in Appendix A.

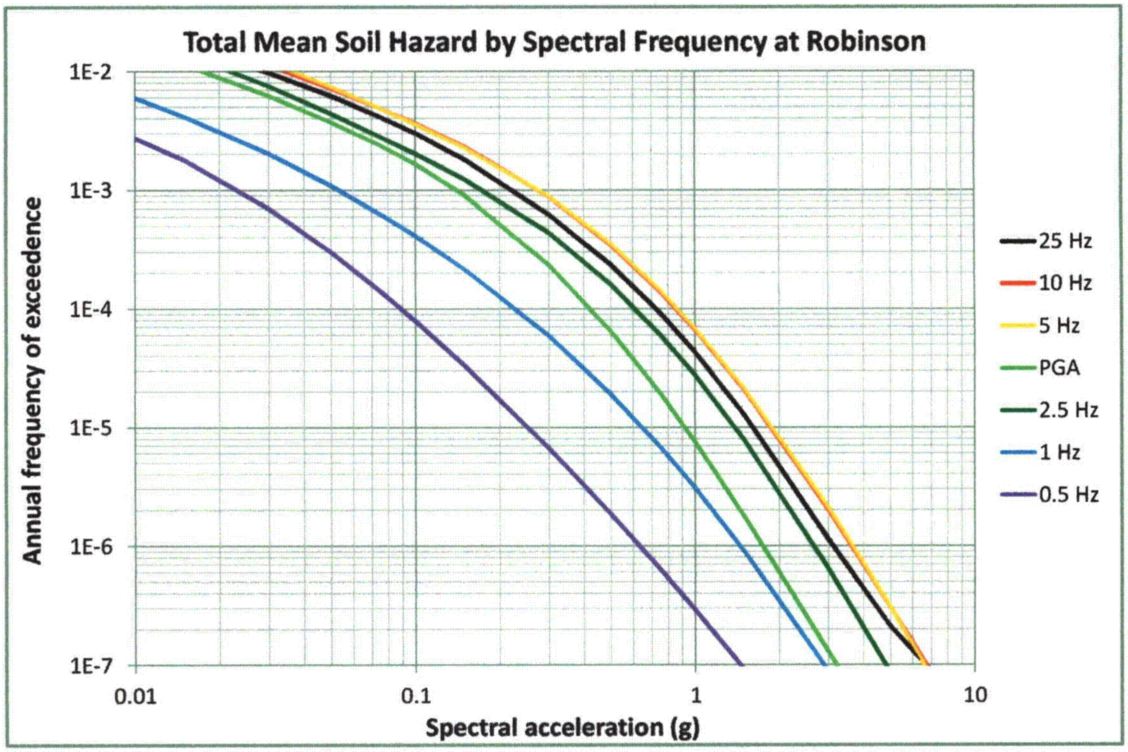


Figure 2.3.7-1. Control point mean hazard curves for oscillator frequencies of 0.5, 1, 2.5, 5, 10, 25 and 100 Hz at HBRSEP.

2.4 Ground Motion Response Spectrum

The control point hazard curves described above have been used to develop uniform hazard response spectra (UHRS) and the ground motion response spectrum (GMRS). The UHRS were obtained through linear interpolation in log-log space to estimate the spectral acceleration at each spectral frequency for the 1E-4 and 1E-5 per year hazard levels. Table 2.4-1 shows the UHRS and GMRS accelerations for each of the seven frequencies.

Table 2.4-1. UHRS and GMRS for HBR2.

Freq. (Hz)	10^{-4} UHRS (g)	10^{-5} UHRS (g)	GMRS
100	4.20E-01	9.17E-01	4.71E-01
90	4.23E-01	9.31E-01	4.77E-01
80	4.27E-01	9.48E-01	4.85E-01
70	4.35E-01	9.73E-01	4.97E-01
60	4.54E-01	1.02E+00	5.19E-01
50	4.98E-01	1.11E+00	5.66E-01
40	5.74E-01	1.25E+00	6.43E-01
35	6.21E-01	1.35E+00	6.95E-01
30	6.63E-01	1.46E+00	7.50E-01
25	7.23E-01	1.61E+00	8.21E-01
20	7.92E-01	1.75E+00	8.97E-01
15	8.09E-01	1.82E+00	9.27E-01
12.5	8.35E-01	1.82E+00	9.36E-01
10	8.52E-01	1.86E+00	9.55E-01
9	8.40E-01	1.84E+00	9.42E-01
8	8.58E-01	1.84E+00	9.49E-01
7	8.98E-01	1.92E+00	9.88E-01
6	8.87E-01	1.95E+00	9.99E-01
5	8.57E-01	1.87E+00	9.61E-01
4	8.40E-01	1.83E+00	9.39E-01
3.5	7.71E-01	1.76E+00	8.94E-01
3	6.79E-01	1.59E+00	8.04E-01
2.5	6.08E-01	1.38E+00	7.04E-01
2	5.37E-01	1.30E+00	6.52E-01
1.5	3.97E-01	1.05E+00	5.20E-01
1.25	3.23E-01	8.58E-01	4.23E-01
1	2.26E-01	6.44E-01	3.13E-01
0.9	1.87E-01	5.52E-01	2.67E-01
0.8	1.56E-01	4.69E-01	2.26E-01
0.7	1.31E-01	3.95E-01	1.90E-01
0.6	1.10E-01	3.25E-01	1.57E-01
0.5	8.86E-02	2.51E-01	1.22E-01
0.4	7.09E-02	2.01E-01	9.79E-02
0.35	6.20E-02	1.76E-01	8.57E-02
0.3	5.32E-02	1.51E-01	7.34E-02
0.25	4.43E-02	1.26E-01	6.12E-02
0.2	3.55E-02	1.00E-01	4.90E-02
0.15	2.66E-02	7.54E-02	3.67E-02
0.125	2.22E-02	6.28E-02	3.06E-02
0.1	1.77E-02	5.02E-02	2.45E-02

The 1E-4 and 1E-5 UHRS are used to compute the GMRS at the control point and are shown in Figure 2.4-1.

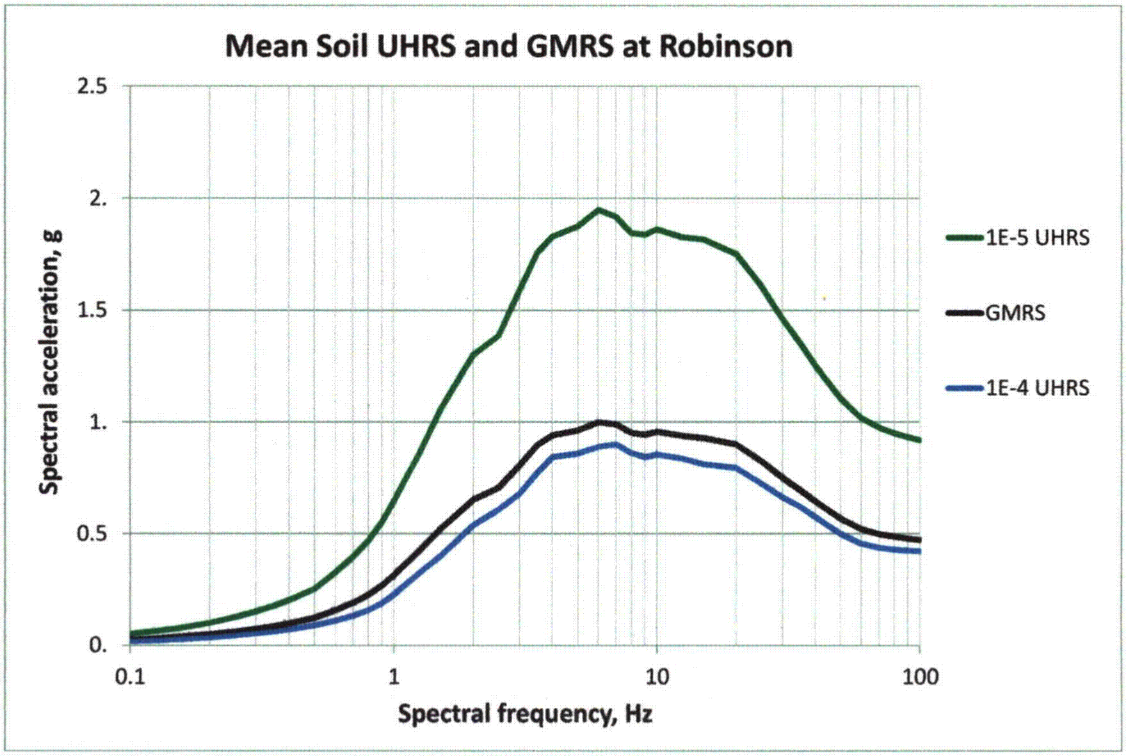


Figure 2.4-1. Plots of 1E-4 and 1E-5 uniform hazard spectra and GMRS at control point for HBRSEP (5%-damped response spectra).

3.0 Safe Shutdown Earthquake Ground Motion

The design basis for HBRSEP is identified in the Updated Final Safely Analysis Report (Reference 7).

3.1 Description of Spectral Shape and Anchor Point

The Safe Shutdown Earthquake (SSE) was developed based on evaluation historic earthquake activity, regional and local geology, and recommendation of Dr. G. W. Housner of the California Institute of Technology.

Only one earthquake of intensity V or greater has ever been recorded within 50 miles of the site. In 1959, an earthquake of intensity V-VI (Modified Mercalli Scale) occurred about 15 miles from the site in the vicinity of McBee, SC. No permanent effects of this shock are noted in the literature or in a geologic reconnaissance, although it is presumed to have been felt at the location of the site. It is estimated that this shock had a magnitude no greater than 4.5 with an epicentral acceleration of well under 0.10 g.

On the basis of historical data, it is expected that the site area could experience a shock in the order of the 1959 McBee shock once during the life of the plant. This shock could be as far distant as in 1959, or perhaps closer. On a conservative basis, Magnitude 4.5 earthquake was selected with an epicentral distance of less than ten miles. This earthquake is the design earthquake and although the probable ground acceleration would be .07 to .09g, a value of 0.1g is used. To provide an adequate margin of safety, a maximum earthquake ground acceleration of 0.2g was selected for the hypothetical SSE.

The SSE is defined in terms of a PGA and a design response spectrum. The SSE response spectra used for the Seismic Class I SSCs for the HBRSEP site have a spectral shape conforming to a Housner curve (Section 2.5 of Reference 7). The horizontal design response spectrum for the SSE was normalized to 0.2g PGA as noted in HBRSEP UFSAR Figure 2.5.2-3 (Reference 7). Table 3.1-1 shows the spectral acceleration values as a function of frequency for the 5% damped horizontal SSE.

Table 3.1-1. SSE for HBRSEP (Reference 16)

Frequency (Hz)	Spectral Acceleration (g)
100	0.2
33	0.2
13.33	0.2
10	0.23
8	0.26
5	0.3
4	0.32
3	0.3
1.641	0.24
0.33	0.07

3.2 Control Point Elevation

Based on information in Table 1 from URS (Reference 16), the SSE control point elevation is defined at the top of ground surface (i.e., El. 226 feet MSL-NGVD 29, 0 ft depth).

4.0 Screening Evaluation

In accordance with SPID (Reference 2) Section 3, a screening evaluation was performed as described below.

4.1 Risk Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz part of the response spectrum, the GMRS exceeds the SSE. Therefore, the plant screens in for a risk evaluation.

4.2 High Frequency Screening (> 10 Hz)

For a portion of the range above 10 Hz, the GMRS exceeds the SSE. The high frequency exceedances can be addressed in the risk evaluation discussed in 4.1 above.

4.3 Spent Fuel Pool Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz range of the response spectrum, the GMRS exceeds the SSE. Therefore, the plant screens in for a spent fuel pool evaluation.

5.0 Interim Actions and Assessments

As described in Section 4, the GMRS developed in response to the NTTF 2.1: Seismic portion of the 10 CFR 50.54(f) Request for Information of 3/12/2012 exceeds the design basis SSE. The NRC 50.54(f) letter requests: "interim evaluation and actions taken or planned to address the higher seismic hazard relative to the design basis, as appropriate, prior to completion of the risk evaluation." These evaluations and actions are discussed below.

Consistent with NRC letter dated February 20, 2014 [Reference 10], the seismic hazard reevaluations presented herein are distinct from the current design and licensing bases of HBRSEP. Therefore, the results do not call into question the operability or functionality of SSCs and are not reportable pursuant to 10 CFR 50.72, "Immediate notification requirements for operating nuclear power reactors," and10 CFR 50.73, "Licensee event report system."

5.1 Expedited Seismic Evaluation Process

An expedited seismic evaluation process (ESEP) is being performed at HBRSEP in accordance with the methodology in EPRI 3002000704 as proposed in a letter to NRC dated April 9, 2013 (Reference 8) and agreed to by the NRC in a letter dated May 7, 2013 (Reference 9). Duke Energy plans to submit a report on the ESEP to NRC in accordance with the schedule in the April 9, 2013 letter (Reference 8)(prior to the end of December 2014).

The ESEP is essentially complete. An equipment list was developed, inspections were completed and evaluations were performed per EPRI Guidance as described in Reference 3. Insights from the process revealed one case where cabinet anchorage analysis warranted increased capacity for higher than design basis loading, and another case where the seismic capacity of a group of instrument racks could be increased by relatively minor work scope.

Modifications were implemented for two cabinets. One cabinet (MCC 'A') required modification to achieve seismic capacity greater than two times SSE (2 X SSE). The second cabinet was related to the first in configuration and function. Therefore, a similar modification was implemented for the second electrical cabinet (MCC 'B') to add seismic margin above 2 X SSE. Seismic margin above 2 X SSE was also added to a group of instrument racks (Hagen Racks) by validating the bolting integrity of the top braces (a relatively minor scope of work).

5.2 Seismic Risk Estimates

The NRC letter (Reference 10) also requests that licensees provide an interim evaluation or actions to address the higher seismic hazard relative to the design basis while the expedited approach and risk evaluations are conducted. In response to that request, NEI letter dated March 12, 2014 (Reference 11), provides seismic core damage risk estimates using the updated seismic hazards for the operating nuclear plants in the Central and Eastern United States. These risk estimates continue to support the following conclusions of the NRC GI-199 Safety/Risk Assessment:

> "Overall seismic core damage risk estimates are consistent with the Commission's Safety Goal Policy Statement because they are within the subsidiary objective of 1E-4/year for core damage frequency. The GI-199 Safety/Risk Assessment, based in part on information from the U.S. Nuclear Regulatory Commission's (NRC's) Individual Plant Examination of External Events (IPEEE) program, indicates that no concern exists regarding adequate protection and that the current seismic design of operating reactors provides a safety margin to withstand potential earthquakes exceeding the original design basis."

HBRSEP is included in the March 12, 2014 (Reference 11) risk estimates. Using the methodology described in the NEI letter, the seismic core damage risk estimates for all plants were shown to be below 1E-4/year; thus, the above conclusions apply.

5.3 Individual Plant Examination of External Events

The IPEEE investigations for HBRSEP followed the methodology for a full scope Seismic Margins Assessment (SMA) presented in NUREG-1407 entitled "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities,". Methodology from EPRI NP-6041-SL were applied. Walkdown screening was performed using a 0.30g NUREG/CR-0098 median soil spectrum as a Review Level Earthquake (RLE). The plant level IPEEE High Confidence of Low Probability of Failure (HCLPF) was 0.28g. The HCLPF was dependent on resolution of USI A-46 outlier conditions which have been completed.

5.4 Walkdowns to Address NRC Fukushima NTTF Recommendation 2.3

Walkdowns have been completed for HBRSEP in accordance with the EPRI seismic walkdown guidance (Reference 17); including inaccessible items. Potentially adverse seismic conditions (PASC) found were entered into the corrective action program (CAP) and resolved. None of the PASC items challenged the operability of the plant. There were no vulnerabilities identified under IPEEE, however, identified enhancements were reviewed and found to be complete. Duke confirmed through the walkdowns that the existing monitoring and maintenance procedures keep the plant consistent with the design basis.

6.0 Conclusions

In accordance with the 50.54(f) request for information, a seismic hazard and screening evaluation was performed for HBRSEP. A GMRS was developed solely for the purpose of screening for additional evaluations in accordance with the SPID (Reference 2).

Based on the results of the screening evaluation, HBRSEP screens in for risk evaluation, a spent fuel pool evaluation and a High Frequency Confirmation.

7.0 References

1. United States Nuclear Regulatory Commission (USNRC), E. Leeds and M. Johnson, Letter to All Power Reactor Licensees et al., "Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident", March 12, 2012.

2. Electric Power Research Institute (EPRI), Final Report 1025287, "Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic", February 2013.

3. Electric Power Research Institute (EPRI), Final Report No. 3002000704, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic", May 2013.

4. United States Nuclear Regulatory Commission (USNRC), NUREG-2115, Department of Energy/Office of Nuclear Energy (DOE/NE)-0140, EPRI 1021097, "Central and Eastern United States Seismic Source Characterization for Nuclear Facilities", 6 Volumes, 2012.

5. Electric Power Research Institute (EPRI), Final Report No. 3002000717, "EPRI (2004, 2006) Ground-Motion Model (GMM) Review Project", June 2013.

6. United States Nuclear Regulatory Commission (USNRC), Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion", March 2007.

7. Progress Energy, "H.B. Robinson Nuclear Power Plant Unit 2 Updated Final Safety Analysis Report", Revision 24.

8. Nuclear Energy Institute (NEI), A. Pietrangelo, Letter to D. Skeen of the USNRC, "Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations", April 9, 2013 (ML13101A379).

9. United States Nuclear Regulatory Commission (USNRC), E. Leeds, Letter to J. Pollock of NEI, "Electric Power Research Institute Final Draft Report XXXXXX, 'Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic,' as an Acceptable Alternative to the March 12, 2012, Information Request for Seismic Reevaluations", May 7, 2013.

10. United States Nuclear Regulatory Commission (USNRC), E. Leeds, Letter to All Power Reactor Licensees and Holders of Construction Permits, "Supplemental Information Related to Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Seismic Hazard Reevaluations for Recommendation 2.1

of the Near-Term Task Force Review of Insights From the Fukushima Dai-Ichi Accident", February 20, 2014 (ML14030A046).

11. Nuclear Energy Institute (NEI), A. Pietrangelo, Letter to D. Skeen of the USNRC, "Seismic Core Damage Risk Estimates Using the Updated Seismic Hazards for the Operating Nuclear Plants in the Central and Eastern United States", March 12, 2014.

12. W.H. Bakun and M.G. Hopper (2004), "Magnitudes and Locations of the 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes," Bulletin of the Seismological Society of America, 94, 64-75

13. *Review of EPRI 1021097 Earthquake Catalog for RIS Earthquakes in the Southeastern U. S. and Earthquakes in South Carolina Near the Time of the 1886 Charleston Earthquake Sequence,* transmitted by letter from J. Richards to R. McGuire on March 5, 2014.

14. McGuire, R.K. (2004). *Seismic Hazard and Risk Analysis,* Earthquake Eng. Res. Inst., Monograph MNO-10.

15. Appendix of: Silva, W.J., Abrahamson, N., Toro, G., and Costantino, C. (1997). "Description and validation of the stochastic ground motion model", Report Submitted to Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York 11973, Contract No. 770573.

16. *Site Geologic Conditions for H.B Robinson Steam Electric Plant, Unit 2,* Letter Rept. PE-RNP-A07-12128 dated July 9, 2012, transmitted by letter from B. Alumbaugh to C. Albers dated July 9, 2012.

17. Electric Power Research Institute (EPRI), Final Report No. 1025286, "Seismic Walkdown Guidance for Resolution of Fukushima Near-Term Task Force Recommendation 2.3: Seismic", June 2012.

Appendix A (Additional Tables)

Table A-1a. Mean and Fractile Seismic Hazard Curves for PGA at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	4.87E-02	3.68E-02	4.31E-02	4.90E-02	5.50E-02	5.83E-02
0.001	4.43E-02	2.92E-02	3.79E-02	4.50E-02	5.12E-02	5.50E-02
0.005	2.44E-02	1.21E-02	1.82E-02	2.42E-02	3.09E-02	3.68E-02
0.01	1.56E-02	7.55E-03	1.07E-02	1.51E-02	2.01E-02	2.68E-02
0.015	1.15E-02	5.42E-03	7.45E-03	1.08E-02	1.46E-02	2.13E-02
0.03	6.20E-03	2.64E-03	3.68E-03	5.66E-03	8.12E-03	1.29E-02
0.05	3.72E-03	1.29E-03	1.92E-03	3.28E-03	5.27E-03	8.12E-03
0.075	2.38E-03	6.09E-04	1.02E-03	2.01E-03	3.63E-03	5.66E-03
0.1	1.66E-03	3.28E-04	5.83E-04	1.31E-03	2.68E-03	4.31E-03
0.15	9.09E-04	1.20E-04	2.22E-04	6.09E-04	1.60E-03	2.76E-03
0.3	2.33E-04	1.42E-05	2.96E-05	9.93E-05	4.01E-04	9.24E-04
0.5	6.44E-05	1.95E-06	4.98E-06	2.13E-05	9.24E-05	2.68E-04
0.75	1.94E-05	3.33E-07	1.07E-06	6.17E-06	2.60E-05	7.45E-05
1.	7.51E-06	9.93E-08	3.68E-07	2.32E-06	1.04E-05	2.80E-05
1.5	1.76E-06	1.82E-08	8.12E-08	5.05E-07	2.64E-06	6.73E-06
3.	1.29E-07	6.73E-10	3.28E-09	3.05E-08	2.07E-07	5.50E-07
5.	1.90E-08	1.32E-10	2.84E-10	3.19E-09	2.64E-08	8.35E-08
7.5	3.92E-09	1.01E-10	1.32E-10	5.27E-10	4.63E-09	1.77E-08
10.	1.19E-09	9.37E-11	1.23E-10	2.01E-10	1.32E-09	5.58E-09

Table A-1b. Mean and Fractile Seismic Hazard Curves for 25 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	4.98E-02	3.95E-02	4.43E-02	5.05E-02	5.50E-02	5.83E-02
0.001	4.65E-02	3.42E-02	4.07E-02	4.70E-02	5.27E-02	5.58E-02
0.005	2.94E-02	1.69E-02	2.32E-02	2.92E-02	3.57E-02	4.13E-02
0.01	2.07E-02	1.13E-02	1.53E-02	2.01E-02	2.53E-02	3.28E-02
0.015	1.62E-02	8.47E-03	1.16E-02	1.55E-02	1.98E-02	2.76E-02
0.03	9.73E-03	4.83E-03	6.54E-03	9.11E-03	1.23E-02	1.79E-02
0.05	6.19E-03	2.80E-03	3.79E-03	5.75E-03	8.23E-03	1.18E-02
0.075	4.11E-03	1.55E-03	2.25E-03	3.73E-03	5.75E-03	8.12E-03
0.1	2.98E-03	9.24E-04	1.46E-03	2.68E-03	4.37E-03	6.26E-03
0.15	1.80E-03	3.84E-04	6.73E-04	1.51E-03	2.88E-03	4.25E-03
0.3	6.20E-04	5.05E-05	1.11E-04	3.95E-04	1.11E-03	1.98E-03
0.5	2.33E-04	1.02E-05	2.46E-05	1.13E-04	4.13E-04	8.72E-04
0.75	9.18E-05	3.63E-06	8.47E-06	3.73E-05	1.51E-04	3.63E-04
1.	4.30E-05	1.87E-06	4.13E-06	1.57E-05	6.64E-05	1.67E-04
1.5	1.27E-05	6.09E-07	1.38E-06	4.50E-06	1.95E-05	4.70E-05
3.	1.13E-06	2.60E-08	8.60E-08	4.77E-07	1.95E-06	4.13E-06
5.	2.10E-07	1.05E-09	6.45E-09	7.55E-08	3.95E-07	8.47E-07
7.5	7.50E-08	1.53E-10	7.55E-10	1.21E-08	1.32E-07	3.57E-07
10.	4.03E-08	1.32E-10	2.13E-10	2.84E-09	6.93E-08	2.07E-07

Table A-1c. Mean and Fractile Seismic Hazard Curves for 10 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	5.11E-02	4.25E-02	4.56E-02	5.12E-02	5.66E-02	5.91E-02
0.001	4.91E-02	4.01E-02	4.37E-02	4.90E-02	5.42E-02	5.75E-02
0.005	3.40E-02	2.29E-02	2.76E-02	3.42E-02	4.01E-02	4.43E-02
0.01	2.43E-02	1.46E-02	1.84E-02	2.42E-02	3.01E-02	3.47E-02
0.015	1.89E-02	1.08E-02	1.38E-02	1.87E-02	2.35E-02	2.84E-02
0.03	1.13E-02	6.00E-03	7.77E-03	1.08E-02	1.44E-02	1.84E-02
0.05	7.18E-03	3.57E-03	4.77E-03	6.83E-03	9.37E-03	1.21E-02
0.075	4.85E-03	2.19E-03	3.01E-03	4.56E-03	6.54E-03	8.60E-03
0.1	3.61E-03	1.46E-03	2.10E-03	3.37E-03	5.05E-03	6.64E-03
0.15	2.29E-03	7.34E-04	1.15E-03	2.07E-03	3.42E-03	4.63E-03
0.3	8.80E-04	1.64E-04	2.96E-04	6.93E-04	1.46E-03	2.25E-03
0.5	3.44E-04	3.90E-05	7.55E-05	2.22E-04	6.00E-04	1.08E-03
0.75	1.38E-04	9.51E-06	2.04E-05	7.23E-05	2.42E-04	4.90E-04
1.	6.63E-05	3.14E-06	7.23E-06	3.05E-05	1.11E-04	2.49E-04
1.5	2.06E-05	6.45E-07	1.62E-06	8.12E-06	3.33E-05	7.89E-05
3.	2.01E-06	4.98E-08	1.51E-07	6.54E-07	3.28E-06	8.00E-06
5.	3.02E-07	5.66E-09	1.84E-08	9.51E-08	5.12E-07	1.23E-06
7.5	6.66E-08	6.00E-10	2.46E-09	2.07E-08	1.15E-07	2.76E-07
10.	2.39E-08	1.74E-10	6.09E-10	6.93E-09	4.07E-08	1.05E-07

Table A-1d. Mean and Fractile Seismic Hazard Curves for 5 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	5.15E-02	4.31E-02	4.63E-02	5.20E-02	5.66E-02	6.00E-02
0.001	5.02E-02	4.13E-02	4.50E-02	5.05E-02	5.50E-02	5.83E-02
0.005	3.70E-02	2.49E-02	2.96E-02	3.73E-02	4.43E-02	4.83E-02
0.01	2.70E-02	1.60E-02	2.04E-02	2.68E-02	3.37E-02	3.73E-02
0.015	2.10E-02	1.16E-02	1.53E-02	2.07E-02	2.68E-02	3.05E-02
0.03	1.20E-02	6.26E-03	8.35E-03	1.16E-02	1.57E-02	1.87E-02
0.05	7.36E-03	3.73E-03	4.98E-03	7.13E-03	9.79E-03	1.20E-02
0.075	4.85E-03	2.29E-03	3.09E-03	4.63E-03	6.54E-03	8.12E-03
0.1	3.56E-03	1.53E-03	2.16E-03	3.37E-03	4.98E-03	6.17E-03
0.15	2.26E-03	7.77E-04	1.20E-03	2.10E-03	3.33E-03	4.31E-03
0.3	8.86E-04	1.82E-04	3.28E-04	7.34E-04	1.44E-03	2.13E-03
0.5	3.51E-04	4.63E-05	8.85E-05	2.39E-04	6.09E-04	1.04E-03
0.75	1.41E-04	1.21E-05	2.46E-05	7.66E-05	2.42E-04	4.90E-04
1.	6.71E-05	3.90E-06	8.47E-06	3.09E-05	1.11E-04	2.53E-04
1.5	2.10E-05	6.00E-07	1.49E-06	7.66E-06	3.23E-05	8.35E-05
3.	2.09E-06	1.77E-08	6.73E-08	5.66E-07	3.09E-06	8.12E-06
5.	3.05E-07	1.46E-09	8.23E-09	6.54E-08	4.77E-07	1.27E-06
7.5	6.02E-08	2.84E-10	1.29E-09	1.11E-08	9.37E-08	2.68E-07
10.	1.87E-08	1.42E-10	3.47E-10	3.01E-09	2.76E-08	8.47E-08

Table A-1e. Mean and Fractile Seismic Hazard Curves for 2.5 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	5.05E-02	4.19E-02	4.50E-02	5.05E-02	5.58E-02	5.91E-02
0.001	4.76E-02	3.68E-02	4.13E-02	4.77E-02	5.35E-02	5.75E-02
0.005	2.95E-02	1.60E-02	2.04E-02	2.92E-02	3.90E-02	4.43E-02
0.01	1.95E-02	8.85E-03	1.20E-02	1.87E-02	2.72E-02	3.23E-02
0.015	1.43E-02	5.91E-03	8.12E-03	1.36E-02	2.04E-02	2.53E-02
0.03	7.49E-03	2.64E-03	3.84E-03	6.93E-03	1.11E-02	1.42E-02
0.05	4.36E-03	1.31E-03	2.10E-03	4.01E-03	6.64E-03	8.60E-03
0.075	2.79E-03	7.03E-04	1.23E-03	2.53E-03	4.31E-03	5.75E-03
0.1	2.01E-03	4.19E-04	7.89E-04	1.79E-03	3.23E-03	4.37E-03
0.15	1.23E-03	1.87E-04	3.84E-04	1.02E-03	2.07E-03	2.96E-03
0.3	4.36E-04	3.52E-05	8.00E-05	2.84E-04	7.89E-04	1.38E-03
0.5	1.60E-04	8.12E-06	1.90E-05	7.55E-05	2.80E-04	6.00E-04
0.75	6.03E-05	2.16E-06	5.20E-06	2.16E-05	9.51E-05	2.49E-04
1.	2.73E-05	7.77E-07	1.90E-06	8.23E-06	3.79E-05	1.13E-04
1.5	7.79E-06	1.55E-07	4.13E-07	1.90E-06	9.11E-06	3.05E-05
3.	6.43E-07	6.17E-09	2.07E-08	1.31E-07	7.03E-07	2.19E-06
5.	8.57E-08	4.56E-10	1.64E-09	1.51E-08	1.04E-07	3.19E-07
7.5	1.73E-08	1.40E-10	2.68E-10	2.39E-09	2.07E-08	7.23E-08
10.	5.66E-09	1.08E-10	1.42E-10	6.36E-10	6.54E-09	2.49E-08

Table A-1f. Mean and Fractile Seismic Hazard Curves for 1 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	3.82E-02	2.16E-02	2.80E-02	3.90E-02	4.83E-02	5.27E-02
0.001	2.92E-02	1.38E-02	1.87E-02	2.88E-02	3.95E-02	4.50E-02
0.005	1.05E-02	3.47E-03	5.27E-03	9.93E-03	1.55E-02	1.95E-02
0.01	5.96E-03	1.53E-03	2.60E-03	5.42E-03	9.24E-03	1.21E-02
0.015	4.14E-03	8.47E-04	1.57E-03	3.68E-03	6.73E-03	8.98E-03
0.03	2.02E-03	2.25E-04	5.20E-04	1.67E-03	3.52E-03	5.12E-03
0.05	1.09E-03	6.45E-05	1.77E-04	8.00E-04	2.01E-03	3.09E-03
0.075	6.30E-04	2.01E-05	6.45E-05	4.07E-04	1.21E-03	1.98E-03
0.1	4.12E-04	8.35E-06	2.88E-05	2.32E-04	8.12E-04	1.42E-03
0.15	2.15E-04	2.32E-06	8.60E-06	9.51E-05	4.19E-04	8.35E-04
0.3	5.87E-05	2.76E-07	1.10E-06	1.57E-05	1.01E-04	2.64E-04
0.5	1.90E-05	6.64E-08	2.88E-07	3.52E-06	2.80E-05	8.85E-05
0.75	6.82E-06	2.22E-08	1.02E-07	1.04E-06	8.72E-06	3.14E-05
1.	3.07E-06	1.01E-08	4.83E-08	4.31E-07	3.63E-06	1.38E-05
1.5	8.99E-07	2.96E-09	1.49E-08	1.23E-07	1.01E-06	3.90E-06
3.	8.93E-08	3.79E-10	1.62E-09	1.31E-08	1.05E-07	3.95E-07
5.	1.57E-08	1.42E-10	3.19E-10	2.19E-09	1.84E-08	7.03E-08
7.5	4.08E-09	1.15E-10	1.44E-10	5.42E-10	4.37E-09	1.77E-08
10.	1.56E-09	1.01E-10	1.32E-10	2.35E-10	1.60E-09	6.73E-09

Table A-1g. Mean and Fractile Seismic Hazard Curves for 0.5 Hz at Robinson

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	2.14E-02	1.25E-02	1.60E-02	2.10E-02	2.68E-02	3.09E-02
0.001	1.40E-02	7.45E-03	9.93E-03	1.36E-02	1.79E-02	2.16E-02
0.005	4.81E-03	1.60E-03	2.53E-03	4.50E-03	7.13E-03	9.11E-03
0.01	2.72E-03	6.00E-04	1.11E-03	2.35E-03	4.37E-03	6.00E-03
0.015	1.78E-03	2.84E-04	5.91E-04	1.44E-03	2.96E-03	4.37E-03
0.03	7.00E-04	5.75E-05	1.49E-04	4.77E-04	1.23E-03	2.13E-03
0.05	2.99E-04	1.36E-05	4.01E-05	1.57E-04	5.42E-04	1.08E-03
0.075	1.40E-04	3.90E-06	1.20E-05	5.66E-05	2.46E-04	5.66E-04
0.1	7.85E-05	1.55E-06	4.77E-06	2.46E-05	1.29E-04	3.42E-04
0.15	3.30E-05	3.84E-07	1.20E-06	6.93E-06	4.63E-05	1.53E-04
0.3	6.63E-06	2.76E-08	1.01E-07	6.83E-07	6.26E-06	3.01E-05
0.5	1.85E-06	3.05E-09	1.38E-08	1.25E-07	1.31E-06	7.55E-06
0.75	6.36E-07	5.12E-10	2.60E-09	3.23E-08	3.79E-07	2.39E-06
1.	2.89E-07	2.01E-10	8.12E-10	1.23E-08	1.60E-07	1.08E-06
1.5	9.15E-08	1.32E-10	2.10E-10	3.01E-09	4.77E-08	3.42E-07
3.	1.15E-08	1.01E-10	1.32E-10	3.09E-10	5.27E-09	4.37E-08
5.	2.25E-09	9.11E-11	1.01E-10	1.42E-10	9.79E-10	8.23E-09
7.5	5.70E-10	9.11E-11	1.01E-10	1.32E-10	2.92E-10	1.98E-09
10.	2.04E-10	9.11E-11	1.01E-10	1.32E-10	1.67E-10	7.34E-10

Table A-2. Amplification Functions for HBRSEP

PGA	Median AF	Sigma ln(AF)	25 Hz	Median AF	Sigma ln(AF)	10 Hz	Median AF	Sigma ln(AF)	5 Hz	Median AF	Sigma ln(AF)
1.00E-02	2.78E+00	1.01E-01	1.30E-02	2.52E+00	1.05E-01	1.90E-02	2.58E+00	1.61E-01	2.09E-02	3.27E+00	1.93E-01
4.95E-02	2.31E+00	1.13E-01	1.02E-01	1.83E+00	1.61E-01	9.99E-02	2.30E+00	1.84E-01	8.24E-02	3.07E+00	2.08E-01
9.64E-02	2.04E+00	1.20E-01	2.13E-01	1.59E+00	1.81E-01	1.85E-01	2.15E+00	1.96E-01	1.44E-01	2.91E+00	2.15E-01
1.94E-01	1.74E+00	1.37E-01	4.43E-01	1.30E+00	2.04E-01	3.56E-01	1.91E+00	2.23E-01	2.65E-01	2.65E+00	2.33E-01
2.92E-01	1.56E+00	1.44E-01	6.76E-01	1.12E+00	2.19E-01	5.23E-01	1.73E+00	2.38E-01	3.84E-01	2.46E+00	2.38E-01
3.91E-01	1.42E+00	1.56E-01	9.09E-01	9.94E-01	2.35E-01	6.90E-01	1.58E+00	2.49E-01	5.02E-01	2.30E+00	2.46E-01
4.93E-01	1.31E+00	1.71E-01	1.15E+00	8.93E-01	2.50E-01	8.61E-01	1.46E+00	2.59E-01	6.22E-01	2.17E+00	2.52E-01
7.41E-01	1.12E+00	1.97E-01	1.73E+00	7.19E-01	2.74E-01	1.27E+00	1.24E+00	2.78E-01	9.13E-01	1.92E+00	2.74E-01
1.01E+00	9.82E-01	2.16E-01	2.36E+00	6.01E-01	2.93E-01	1.72E+00	1.07E+00	2.98E-01	1.22E+00	1.70E+00	2.93E-01
1.28E+00	8.77E-01	2.45E-01	3.01E+00	5.14E-01	3.14E-01	2.17E+00	9.48E-01	3.36E-01	1.54E+00	1.52E+00	3.36E-01
1.55E+00	8.02E-01	2.63E-01	3.63E+00	5.00E-01	3.30E-01	2.61E+00	8.56E-01	3.58E-01	1.85E+00	1.39E+00	3.69E-01
2.5 Hz	**Median AF**	**Sigma ln(AF)**	**1 Hz**	**Median AF**	**Sigma ln(AF)**	**0.5 Hz**	**Median AF**	**Sigma ln(AF)**			
2.18E-02	2.94E+00	2.03E-01	1.27E-02	1.83E+00	1.54E-01	8.25E-03	1.43E+00	1.65E-01			
7.05E-02	2.92E+00	1.95E-01	3.43E-02	1.95E+00	1.67E-01	1.96E-02	1.48E+00	1.66E-01			
1.18E-01	2.83E+00	1.98E-01	5.51E-02	2.04E+00	1.86E-01	3.02E-02	1.50E+00	1.69E-01			
2.12E-01	2.66E+00	2.30E-01	9.63E-02	2.15E+00	2.71E-01	5.11E-02	1.54E+00	1.89E-01			
3.04E-01	2.53E+00	2.37E-01	1.36E-01	2.18E+00	3.35E-01	7.10E-02	1.58E+00	2.06E-01			
3.94E-01	2.42E+00	2.55E-01	1.75E-01	2.17E+00	3.59E-01	9.06E-02	1.63E+00	2.38E-01			
4.86E-01	2.30E+00	2.78E-01	2.14E-01	2.13E+00	3.85E-01	1.10E-01	1.64E+00	2.51E-01			
7.09E-01	2.11E+00	3.11E-01	3.10E-01	2.09E+00	4.01E-01	1.58E-01	1.70E+00	2.87E-01			
9.47E-01	1.96E+00	3.51E-01	4.12E-01	2.11E+00	4.03E-01	2.09E-01	1.74E+00	3.13E-01			
1.19E+00	1.85E+00	3.81E-01	5.18E-01	2.12E+00	4.03E-01	2.62E-01	1.77E+00	3.25E-01			
1.43E+00	1.81E+00	3.78E-01	6.19E-01	2.14E+00	3.96E-01	3.12E-01	1.80E+00	3.30E-01			

Table A2-b1. Median AFs and sigmas for Model 1, Profile 1, for 2 PGA levels.

M1P1K1		Rock PGA=0.292		M1P1K1		PGA=1.28	
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.485	1.658	0.116	100.0	1.056	0.824	0.281
87.1	0.487	1.620	0.117	87.1	1.057	0.797	0.281
75.9	0.491	1.553	0.119	75.9	1.058	0.752	0.281
66.1	0.497	1.429	0.122	66.1	1.060	0.672	0.282
57.5	0.509	1.238	0.129	57.5	1.063	0.556	0.283
50.1	0.531	1.067	0.141	50.1	1.068	0.457	0.285
43.7	0.562	0.954	0.156	43.7	1.076	0.390	0.289
38.0	0.601	0.932	0.173	38.0	1.088	0.365	0.295
33.1	0.642	0.948	0.186	33.1	1.105	0.357	0.300
28.8	0.688	1.021	0.203	28.8	1.129	0.371	0.304
25.1	0.734	1.087	0.215	25.1	1.164	0.387	0.315
21.9	0.778	1.216	0.221	21.9	1.207	0.429	0.330
19.1	0.815	1.299	0.223	19.1	1.259	0.462	0.335
16.6	0.846	1.410	0.213	16.6	1.308	0.508	0.334
14.5	0.871	1.527	0.196	14.5	1.365	0.563	0.338
12.6	0.916	1.658	0.226	12.6	1.433	0.616	0.337
11.0	0.943	1.756	0.249	11.0	1.520	0.678	0.343
9.5	0.992	1.941	0.253	9.5	1.613	0.762	0.367
8.3	0.977	2.079	0.251	8.3	1.724	0.892	0.379
7.2	0.999	2.277	0.228	7.2	1.821	1.016	0.378
6.3	0.954	2.320	0.221	6.3	1.912	1.146	0.395
5.5	0.902	2.303	0.217	5.5	1.939	1.227	0.384
4.8	0.940	2.462	0.257	4.8	1.947	1.270	0.370
4.2	1.028	2.780	0.276	4.2	1.986	1.346	0.386
3.6	1.065	2.966	0.216	3.6	2.083	1.461	0.406
3.2	1.041	3.085	0.160	3.2	2.199	1.648	0.413
2.8	1.015	3.175	0.172	2.8	2.338	1.857	0.400
2.4	1.007	3.422	0.148	2.4	2.380	2.062	0.412
2.1	0.932	3.487	0.174	2.1	2.401	2.300	0.416
1.8	0.772	3.236	0.180	1.8	2.429	2.617	0.406
1.6	0.579	2.804	0.219	1.6	2.319	2.898	0.358
1.4	0.432	2.437	0.188	1.4	2.096	3.062	0.303
1.2	0.325	2.085	0.163	1.2	1.828	3.054	0.245
1.0	0.247	1.759	0.114	1.0	1.465	2.734	0.225
0.91	0.198	1.555	0.085	0.91	1.119	2.315	0.233
0.79	0.168	1.463	0.098	0.79	0.870	2.008	0.225
0.69	0.147	1.439	0.116	0.69	0.698	1.826	0.196
0.60	0.128	1.448	0.138	0.60	0.571	1.732	0.176
0.52	0.110	1.465	0.165	0.52	0.467	1.677	0.177
0.46	0.092	1.468	0.187	0.46	0.376	1.629	0.188
0.10	0.003	1.218	0.043	0.10	0.011	1.236	0.055

Table A2-b2. Median AFs and sigmas for Model 2, Profile 1, for 2 PGA levels.

M2P1K1		PGA=0.292		M2P1K1		PGA=1.28	
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.568	1.944	0.128	100.0	1.437	1.122	0.242
87.1	0.573	1.905	0.130	87.1	1.441	1.087	0.243
75.9	0.580	1.837	0.132	75.9	1.447	1.028	0.245
66.1	0.594	1.710	0.137	66.1	1.456	0.923	0.248
57.5	0.623	1.514	0.147	57.5	1.472	0.770	0.253
50.1	0.673	1.353	0.168	50.1	1.502	0.643	0.265
43.7	0.739	1.255	0.190	43.7	1.546	0.560	0.280
38.0	0.809	1.256	0.206	38.0	1.602	0.537	0.296
33.1	0.880	1.298	0.223	33.1	1.675	0.541	0.311
28.8	0.935	1.387	0.240	28.8	1.764	0.580	0.327
25.1	1.000	1.481	0.248	25.1	1.865	0.620	0.348
21.9	1.049	1.641	0.262	21.9	1.975	0.703	0.367
19.1	1.078	1.718	0.260	19.1	2.098	0.770	0.373
16.6	1.104	1.841	0.240	16.6	2.233	0.867	0.378
14.5	1.109	1.944	0.215	14.5	2.338	0.965	0.381
12.6	1.142	2.066	0.224	12.6	2.456	1.055	0.379
11.0	1.156	2.153	0.265	11.0	2.616	1.167	0.370
9.5	1.160	2.270	0.254	9.5	2.679	1.265	0.342
8.3	1.105	2.351	0.226	8.3	2.638	1.365	0.351
7.2	1.127	2.568	0.184	7.2	2.765	1.543	0.365
6.3	1.045	2.543	0.208	6.3	2.842	1.704	0.328
5.5	1.012	2.584	0.211	5.5	2.828	1.790	0.269
4.8	1.091	2.856	0.245	4.8	2.764	1.803	0.289
4.2	1.180	3.194	0.248	4.2	2.809	1.904	0.364
3.6	1.146	3.192	0.217	3.6	2.902	2.035	0.371
3.2	1.089	3.227	0.197	3.2	2.982	2.234	0.351
2.8	1.050	3.286	0.198	2.8	3.029	2.407	0.316
2.4	1.021	3.471	0.163	2.4	3.116	2.699	0.294
2.1	0.903	3.380	0.196	2.1	3.066	2.937	0.269
1.8	0.718	3.011	0.195	1.8	2.927	3.153	0.231
1.6	0.534	2.589	0.217	1.6	2.471	3.089	0.234
1.4	0.403	2.274	0.184	1.4	1.989	2.907	0.263
1.2	0.308	1.974	0.166	1.2	1.540	2.573	0.270
1.0	0.237	1.688	0.116	1.0	1.136	2.120	0.230
0.91	0.192	1.508	0.083	0.91	0.868	1.795	0.181
0.79	0.164	1.431	0.096	0.79	0.705	1.626	0.157
0.69	0.144	1.415	0.116	0.69	0.594	1.555	0.152
0.60	0.127	1.431	0.138	0.60	0.506	1.535	0.159
0.52	0.109	1.451	0.166	0.52	0.426	1.531	0.179
0.46	0.091	1.457	0.188	0.46	0.350	1.518	0.197
0.10	0.003	1.215	0.045	0.10	0.011	1.211	0.056

Tables A2-b1 and A2-b2 are tabular versions of the typical amplification factors provided in Figures 2.3.5-1 and 2.3.5-2. Values are provided for two input motion levels at approximately 10^{-4} and 10^{-5} mean annual frequency of exceedance.