Conf-9110122--25

WSRC-MS--91-124

DE92 010823

GROUND MOTIONS ASSOCIATED WITH THE DESIGN BASIS EARTHQUAKE AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA, BASED ON A DETERMINISTIC APPROACH (U)

by

R. R. Youngs[1], K. J. Coppersmith[1], D. E. Stephenson[2], and W. Silva[3]

[1] Geomatrix Consultants, Inc.
San Francisco, California

[2] Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

[3] Pacific Engineering and Analysis
El Cerrito, California

A paper proposed for presentation and publication at the
Third DOE Natural Phenomena Hazard Mitigation Conference
St. Louis, Missouri
October 14 - 18, 1991

This paper was prepared in connection with work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

Authorized Derivative Classifier
D. B. Moore-Shedrow, Section Manager

GROUND MOTION FOR THE DESIGN BASIS EARTHQUAKE AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA BASED ON A DETERMINISTIC APPROACH

Robert R. Youngs and Kevin J. Coppersmith
Geomatrix Consultants
100 Pine Street, 10th Floor, San Francisco, CA 94111

Walter J. Silva
Pacific Engineering and Analysis
311 Pomona St., El Cerrito, CA 94530

Dale E. Stephenson
Westinghouse Savannah River Company
P.O. Box 616, Aiken, SC 29802

ABSTRACT

Ground motion assessments are presented for evaluation of the seismic safety of K-Reactor at the Savannah River Site. Two earthquake sources were identified as the most significant to seismic hazard at the site, a **M** 7.5 earthquake occurring at Charleston, South Carolina, and a **M** 5 event occurring in the site vicinity. These events control the low frequency and high frequency portions of the spectrum, respectively.

Three major issues were identified in the assessment of ground motions for the Savannah River site; specification of the appropriate stress drop for the Charleston source earthquake, specification of the appropriate levels of soil damping at large depths for site response analyses, and the appropriateness of western US recordings for specification of ground motions in the eastern US.

INTRODUCTION

This paper summarizes the results of a site-specific deterministic assessment of earthquake ground motions for the K-reactor at the Savannah River Site (SRS). The purpose of the study was to assist the Environmental Sciences Section of the Savannah River Laboratory in reevaluating the design basis earthquake (DBE) ground motion at SRS using approaches defined in Appendix A to 10 CFR Part 100. This work is in support of the Seismic Engineering Section's Seismic Qualification Program for reactor restart. Presented in this paper is a brief summary of the study that is documented in [1].

There have been considerable advances in ground motion assessment for eastern US earthquakes in recent years. In this paper we illustrate how these new approaches were applied to the assessment for SRS and discuss the significant issues raised during the course of the study. The focus of this paper is on ground motion assessment. However, prior to presenting that subject, we present a brief review of the assessment of the Design Basis Earthquakes (DBE).

SPECIFICATION OF THE DESIGN BASIS EARTHQUAKES

The identification and characterization of earthquake sources of significance to ground motions at the K-reactor site at SRS followed the methodologies established by precedent in applications of Appendix A for eastern U.S. commercial reactor sites and as represented in the Standard Review Plan for Chapter 2.5 [2]. Specifically, the potential causes and geologic structural controls of earthquakes were considered as well as the seismotectonic provinces within which earthquakes occur. After evaluating several local and regional seismic sources, the two potential sources of future earthquakes considered most significant to the K-reactor site are the Charleston source and a local random earthquake occurring in the upper coastal plain. Each of these are discussed below.

CHARLESTON SOURCE

Location The first earthquake source identified that may affect ground motions at the SRS is the source that gave rise to the 1886 Charleston, South Carolina earthquake. This earthquake was the largest historical earthquake in the Coastal Plain tectonic province (maximum intensity of MMI X) and is one of the largest earthquakes that has occurred in the eastern U.S. during the historical period. It is our interpretation that the source of future Charleston type earthquakes should be located in the meizoseismal region of the 1886 event. While the causative structure for the 1886 event has not been definitively identified [3], the ongoing seismicity in the region, the existence of several candidate structures, and most importantly, the evidence for repeated occurrence of similar events near Charleston over the previous several thousand years [4, 5, 6] with little evidence for other sources to the north or south [5, 7] argues for spatial stationarity of the source. Assuming that the source lies within the intensity X contour for the 1886 event or is oriented in the direction of isoseismal elongation (Figure 1), the Charleston source lies at a distance of about 120 km from the site.

Maximum Earthquake Magnitude In this deterministic assessment, we have followed the precedent set by the NRC in its recent application of Appendix A [8] and have assumed that an appropriate maximum earthquake for the Charleston source is one that is similar in size to the 1886 earthquake. We have adopted the most recent studies of the size--expressed as moment magnitude--of the Charleston.

Johnston [9] in his work for the Electric Power Research Institute Stable Continental Regions study [10] has developed relationships between isoseismal areas and seismic moment from an extensive earthquake data base for stable continental regions (SCR) that are tectonically similar to the eastern United States. Based on the smoothed isoseismal map of Bollinger [11] and assuming symmetry in the isoseismals at the

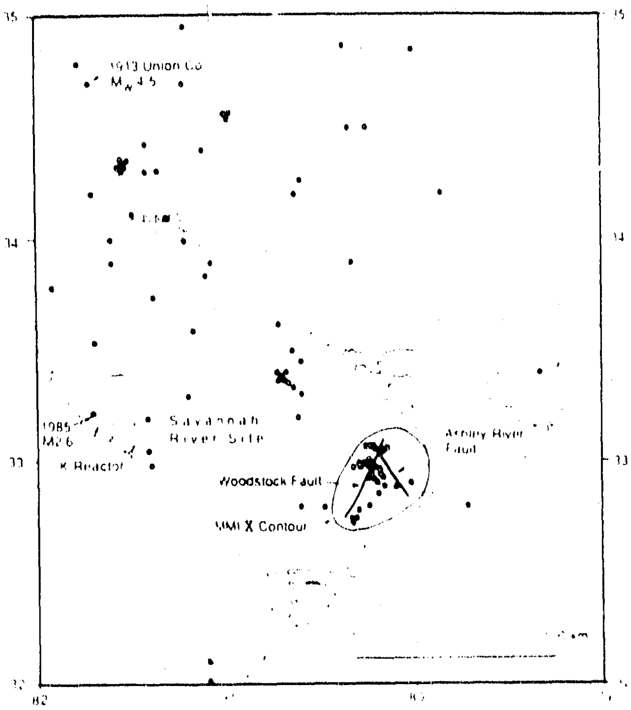

Figure 1 - Site vicinity map showing the Charleston source and the distribution of recorded seismicity.

coastline, Johnston [9] arrives at seismic moment estimates based on the isoseismal areas for felt area, and intensities IV, V, and VI. Averaging these moment values, Johnston arrives at a seismic moment estimate for the 1886 Charleston earthquake of about $2.75 \cdot 10^{27}$ dyne-cm, and, using Hanks and Kanamori [12], a moment magnitude estimate of **M** 7.5.

LOCAL SOURCE

Location Following the application of Appendix A as represented in the Standard Review Plan for Chapter 2.5 [2], we consider the possibility of a nearby source that may generate earthquakes within the local site vicinity. Based on the available data and interpretations, the known faults that exist in the local site vicinity, such as the Pen Branch fault and the border fault zone of the Dunbarton basin, are not considered to be capable. In the absence of an identifiable nearby seismic source, we allowed for the possible existence of a random "nearby" source that might exist within the local site vicinity. By convention, the "local site vicinity" is taken to be the region within about 25 km of the site.

Maximum Earthquake Magnitude Again following the approach of Appendix A, the magnitude assigned to the local source represents the largest event known to have occurred within the site tectonic province. The largest earthquakes that have occurred during the historical period within 25 km of the site have been in the magnitude range of about 2.0-3.0, including the 1985 m_{bLg} 2.6 earthquake [13] that occurred within the SRS boundary. However, we do not consider these events to be representative of the maximum magnitudes possible in the site vicinity. The site is underlain by crystalline basement rocks equivalent to those of the Piedmont province. Therefore, we consider the largest earthquakes that have occurred within the Piedmont tectonic province to provide a reasonable constraint on the maximum magnitude within the site vicinity. The 1913 Union County earthquake (moment magnitude **M** 4.5, see Figure 1) is the largest historical earthquake within the southeastern Piedmont province, and the 1875 Central Virginia earthquake (**M** 4.8) is the largest historical earthquake that has occurred within the Appalachian Piedmont. Therefore, we conclude that the maximum magnitude for the nearby seismic source is moment magnitude **M** 5.0. Relationships between seismic moment and m_{bLg} (e.g., [14, 15]) indicate that moment magnitude **M** 5.0 is equivalent to m_{bLg} 5.3.

ASSESSMENT OF STRONG GROUND MOTION

Site-specific strong ground motions resulting from the design basis earthquakes defined above were assessed using three approaches that have been employed in recent licensing efforts for commercial nuclear power plants. These are: estimation of site-specific ground motions using empirical ground motion attenuation relationships for the appropriate tectonic regime and site conditions, statistical analysis of strong motion data from earthquakes within similar tectonic environments recorded on sites with similar subsurface conditions, and estimation of site-specific ground motions using physical-numerical models. While empirical approaches have been the basis for the majority of seismic safety evaluations of commercial nuclear power plants, estimates of ground motion obtained from physical and numerical models have played an important role in recent safety reviews.

SITE CONDITIONS AND DYNAMIC SOIL PROPERTIES

The K-Reactor site at Savannah River is underlain by approximately 275 meters of coastal plain sediments, consisting of sandy soils with interbedded clays. The measured shear wave velocity in the upper 60 m are in the range of 300 to 400 m/sec [16]. Below 60 m, the shear wave velocity was assumed to increase smoothly to a value of 760 m/sec at the baserock interface (275 meter depth). The shear wave velocity gradient with depth was assumed to follow a generic deep soil site velocity profile developed by the Electric Power Research Institute to analyze ground motions at eastern US nuclear power plants [17]. Measured compression wave velocities at SRS in the depth interval of 60 to 250 meters are consistent with the postulated shear wave velocities.

The base rock consists of approximately 3 km of Triassic sedimentary rocks overlying crystalline basement. Measured compression wave velocities in the two materials range from 4.0 to 5.0 km/sec in the sedimentary rock and from 5.4 to 6.1 km/sec in the crystalline basement [18]. Assuming a Poisson solid, the average baserock shear wave velocity is approximately 2.5 km/sec in the sedimentary rock and 3.5 km/sec in the crystalline rock.

The strain-compatible soil modulus reduction and damping relationships used in site response analyses are shown in Figure 2. These relationships were developed by GEI [16] from laboratory tests of soil samples collected from the site. The shear modulus reduction and damping relationships shown in Figure 2 are similar to those developed for other locations at the Savannah River site. The relationships show in increase in stiffness and a decrease in damping as the confining pressure (depth) increases.

The selection of the appropriate modulus reduction and, more importantly, damping relationships for use in site response analyses of the deep soil profile has a major impact on the estimated site ground motions. Figure 3 shows the effect of the use of various modulus reduction and damping curves shown in Figure 2 on computed surface motions. Site response calculations were conducted using soil shear wave velocities similar to those at the site, but

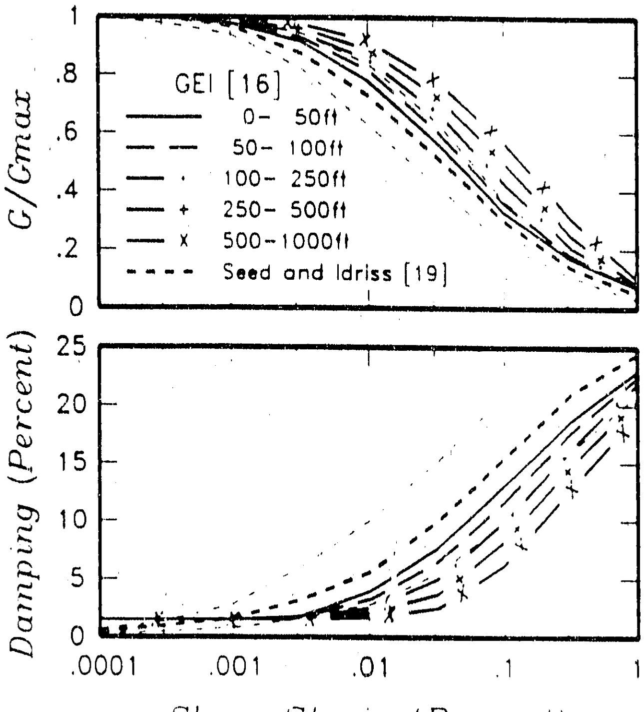

Figure 2 - Strain-compatible soil modulus and damping relationships used in site response analyses compared to the published relationships of Seed and Idriss [19].

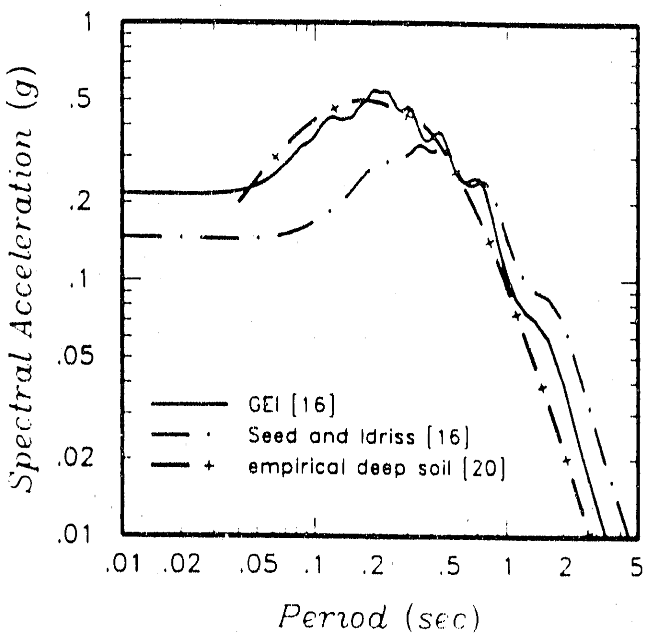

Figure 3 - Deep soil site response spectra (5% damping) computed using the two sets of modulus and damping relationships shown in Figure 2 compared to empirical western US spectrum [20] for a rock motion of 0.2g.

with a western US base rock velocity (1.2 km/sec). A western rock motion with a free field peak acceleration of 0.2g was used as an input motion. Two sets of modulus reduction and damping curves were used; those developed for the site profile [16] and the mid-range shear modulus reduction and damping curves of Seed and Idriss [19]. As can be seen, there is a significant reduction in the computed high frequency motion when greater modulus reduction and higher damping curves are used. Also shown in Figure 3 is the median response spectrum estimated using an western US empirical attenuation relationship for deep soil sites [20] for conditions that would produce 0.2g free field rock motions.

These comparisons indicate that the use of modulus reduction and damping curves similar to those originally developed by [19] over the entire 275-m depth range would tend to under predict the high frequency ground motions observed on western US deep soil sites. In addition, not accounting for the reduction in soil damping with depth would also lead to an under prediction of the observed high frequency ground motions.

GROUND MOTIONS ASSESSMENTS FOR THE CHARLESTON SOURCE

Two approaches were used to characterize the potential ground motions from this event, the use of published attenuation relationships and direct modeling of ground motions. Because most of the recently developed attenuation relationships for eastern US earthquake ground motions have been developed for rock site conditions, site response analyses were used to translate estimates of ground motion on rock to ground motion at the surface of the deep soil profile at the K-Reactor site. Statistical analysis of recorded strong motion data was not used as there are only a few recordings in this magnitude and distance range and they come from very different tectonic environments.

<u>Rock Site Motions</u> Figure 4 shows the variation of peak acceleration with distance for a magnitude **M** 7.5 earthquake predicted by the rock site attenuation relationships examined in this study [17, 21]. As there are only a limited number of strong ground motion recordings that have been obtained in the eastern US, these relationships rely to a large extent on theoretical scaling laws and/or numerical models to

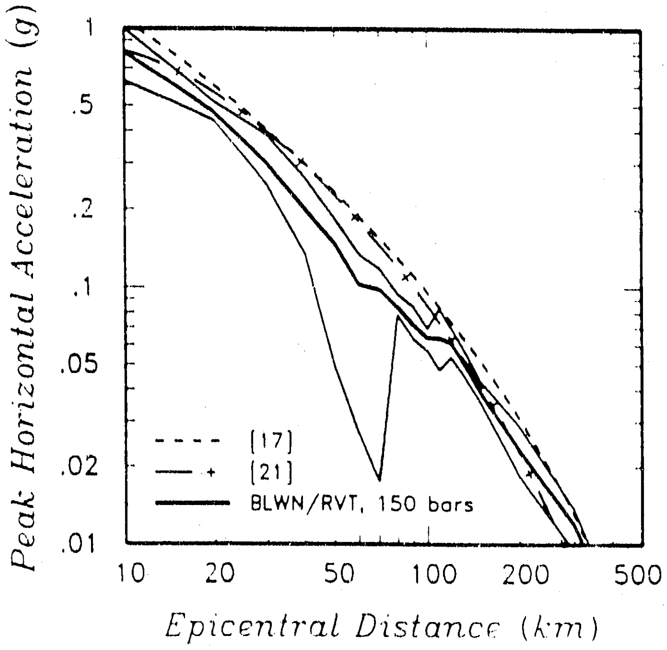

Figure 4 - Rock site attenuation relationships for a M 7.5 Charleston source event. Thin solid lines show range of BLWN/RVT predictions as a function of source depth.

constrain parameters in the attenuation relationships. These relationships have been used in the analyses of probabilistic seismic hazard at commercial nuclear power plants in the eastern US conducted by the Lawrence Livermore National Laboratory [22] and the Seismicity Owners Group [23].

Also shown in Figure 4 are rock site attenuation relationships developed for the site region using direct modeling of ground motions. The modeling technique used was the band-limited-white-noise/random-vibration-theory (BLWN/RVT) model [24, 25]. The BLWN/RVT model used in this analysis has been extended in two ways. First, nonlinear site-specific wave propagation characteristics have be included through the use of an equivalent-linear formulation for one-dimensional wave propagation in a layered medium [26], allowing direct estimates of ground motions at the surface of a soil profile. Second, the crustal wave propagation modeling techniques of Ou and Herrmann [27] have been included to account for both direct and critically reflected waves within the crust. Critically reflected waves have been suggested as the cause of the lack of significant attenuation in the distance range of 80 to 120 km observed in recent strong motion data in eastern and western North America (e.g. [28, 29]).

An important aspect of the model is the specification of the appropriate source scaling relationships. In the BLWN/RVT model, the source scaling is provided by the seismic moment and the corner frequency - the later specified by the assumed stress drop. In the past there has been considerable uncertainty in the appropriate scaling relationships to use in estimating high frequency ground motion in the eastern US. However, recent investigations have suggested that, in general, eastern and western US earthquakes have similar source characteristics. Somerville et al. [14] used teleseismic wave form modeling to estimate the source duration of large eastern US earthquakes and concluded that the source scaling relationship for eastern North American earthquakes is generally similar to that for other regions. Their results show that the source duration for large earthquakes can be represented by a source scaling model that assumes a constant stress drop, with the stress drop for eastern North American earthquakes slightly larger than that for western earthquakes. Wells and Coppersmith [30] have developed empirical relationships between moment magnitude and rupture dimensions measured from the pattern of young aftershocks. The data set is dominated by interplate events, but contains some earthquakes from stable continental regions. Comparison of the available SCR data with the data as a whole shows no discernable differences (Figure 5).

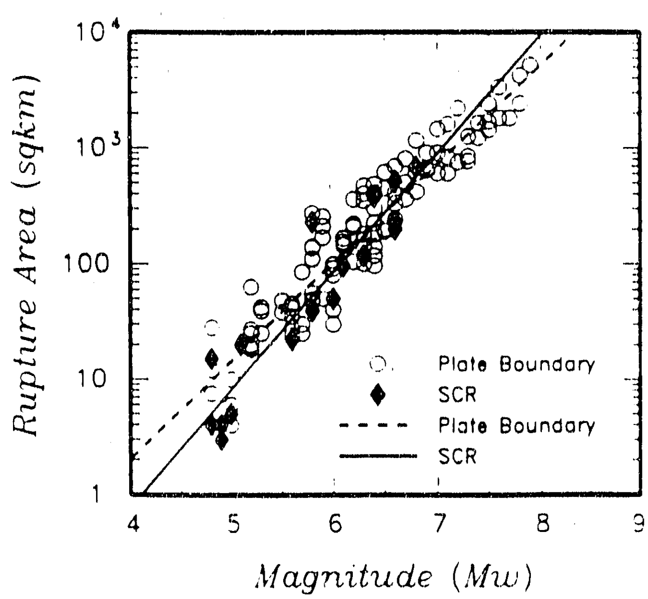

Figure 5 - Comparison of rupture dimensions for plate boundary and stable continental region (SCR) earthquakes.

In terms of ground motion prediction, Boore and Atkinson [15] found that the BLWN/RVT model provided a good overall fit to the empirical eastern US data using a RMS stress drop of 100 bars, which is higher than the stress drop of 50 bars used by Boore [31] to model western US ground motions. However, comparisons of the predictions of the BLWN/RVT model with recently developed empirical attenuation relationships [20] have suggested that a stress drop in the range of 75 to 100 bars is necessary to bring the two predictions into agreement.

The data reviewed as part of this study together with the preferred rupture dimensions for the maximum Charleston source earthquake argue in favor of an average stress drop not greatly different than that appropriate for western US earthquakes, perhaps the value of 100 bars used by [15]. However, there is only limited data for large magnitude events and higher average values could be possible. Accordingly, a stress parameter of 150 bars was adopted to account for the uncertainty in the appropriate average value for **M** 7.5 events. The assumed stress drop has a major impact on the predicted ground motions. Doubling the stress drop results in approximately 60 percent higher ground motions.

Rock site motions were computed using the BLWN/RVT model for a range of point source depths between 10 and 20 km. Shown in Figure 4 are the average and range of the rock site motions at each distance accounting for the effects of critically reflected waves. The BLWN/RVT model predictions at distances beyond 100 km are comparable to those of [17, 21], which are based on similar physical modeling (with a stress drop of 100 bars, however).

<u>Soil Site Motions</u> Ground motions at the K-Reactor site were computed from the rock motions shown in Figure 4 using site response analyses conducted using the BLWN/RVT model coupled with an equivalent-linear model for soil response [26]. Ground motion estimates were made for a range of input rock motion levels. Figure 6 shows typical smoothed response spectral ratios (ratio of soil response to input rock response spectra) for eastern US and western US conditions for input rock motions of

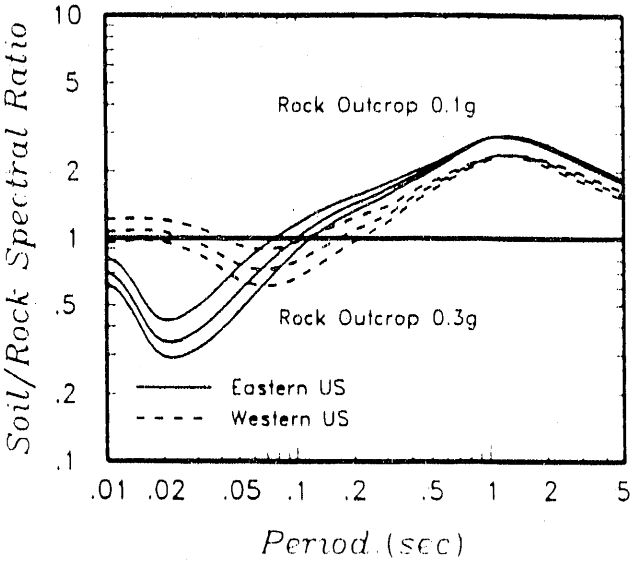

Figure 6 - Computed soil site/rock site spectral ratios (5% damping) for western and eastern US input motions for a **M** 6 earthquake and rock peak accelerations of 0.1g, 0.2g, and 0.3g.

0.1, 0.2, and 0.3 g. The results indicates that there is a greater amplification at low frequencies and a greater deamplification at high frequencies for the eastern US conditions. The greater low frequency amplification for eastern US conditions is primarily due to the much larger velocity contrast at the soil profile-baserock interface in the eastern US as compared to typical western US conditions. The larger deamplification at high frequencies for eastern US conditions is do to the greater high frequency content of eastern US rock motions. Figure 7 compares average spectral amplification for near field rock motions for **M** ~ 6 events in eastern and western North America. The response spectra for eastern US records peaks at a much higher frequency than the western US spectra.

Figure 8 presents the estimated median 5-percent damped response spectra at the Savannah River K-Reactor site from a **M** 7.5 Charleston source event at 120 km. The response spectra labeled as scaled to deep soil were obtained by multiplying the rock site spectra predicted by [17] and [21] by the appropriate soil/rock spectral ratios computed for **M** 7.5 events. The spectrum predicted by the BLWN/RVT was conservatively selected to be the maximum prediction over the range of point source depths.

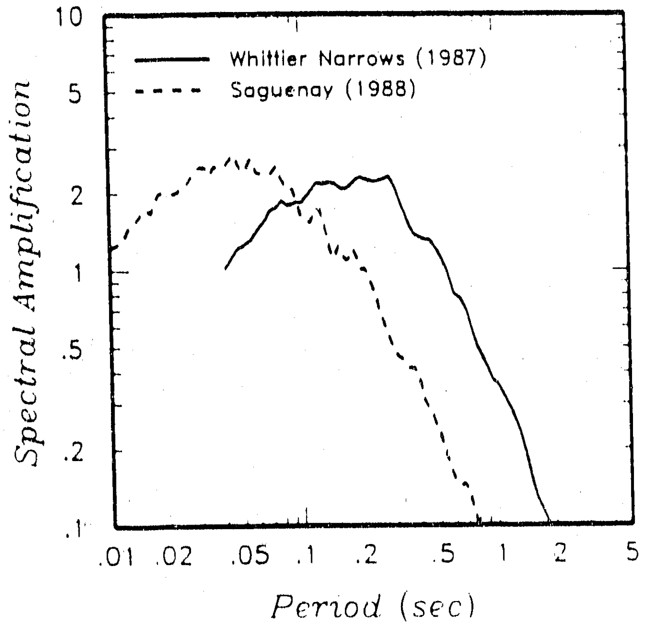

Figure 7 - Comparison of average near field rock site spectrum for a M ~ 6 western (Whittier Narrows, distance < 25 km) and eastern (Saguenay, distance 40-60km) earthquakes.

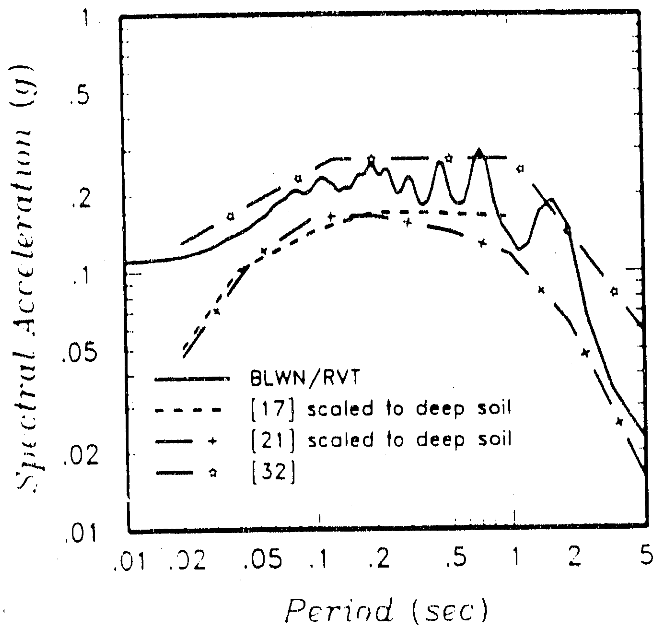

Figure 8 - Predicted median 5%-damped response spectra for the M 7.5 Charleston source event at the K-Reactor site.

Also shown in Figure 8 is the spectrum predicted by the relationships developed by Nuttli et al. [32] specifically for soil sites in South Carolina. (The spectral amplification factors of Newmark and Hall [33] were used to obtain the spectral values from the peak acceleration, velocity and displacement predictions of [32].) Nuttli et al.'s [32] relationships assume an increase is the stress drop with increasing magnitude, rather than the constant stress drop model favored in this study.

GROUND MOTION ESTIMATES FOR THE "NEARBY" EVENT

The "nearby" event is defined as a magnitude M 5.0±0.5 event occurring in the site vicinity (within 25 km). Ground motions for this event were estimated using the standard site-specific-spectra technique employed for evaluation of commercial nuclear power plants [34] involving statistical analysis of response spectra for ground motions recorded on similar site conditions. The BLWN/RVT model was used to examine possible differences between eastern and western US ground motions for a nearby M 5.0 event.

Statistical Analysis of Recorded Strong Motion Data Figure 9 shows the median and 84th-percentile 5%-damped response spectra for the available deep soil site (depth to rock greater than 40 m) recordings for M 4.5 to 5.5 earthquakes recorded within 25 km of the source. The statistical spectra were computed using weights to adjust for the unequal distribution of source-to site distances in the data set. The resulting spectra have a mean magnitude of 5.2 and a mean distance of 15.3 km. Also shown in Figure 9 are the response spectra for a M 5.0 earthquake at a distance of 15 km estimated using an empirical attenuation relationships for deep soil site ground motions in the western US [20]. As can be seen, the response spectra based on statistics of recorded motions are significantly higher that those based on general attenuation relationships.

One possible reason for the differences between the empirical attenuation and statistical spectra shown in Figure 9 is the bias introduced in the selection of recordings to be digitized. Processing agencies (e.g. USGS, CDMG) typically tend to process accelerograms from the larger recordings, rather than from all of the

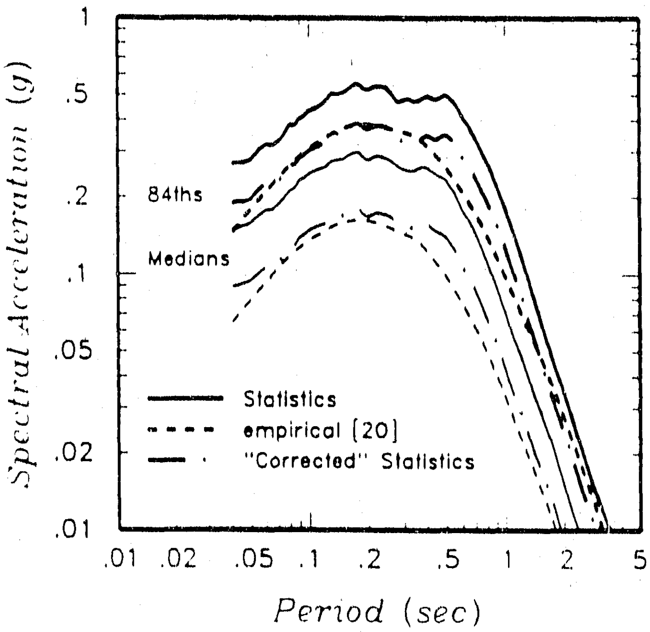

Figure 9 - Median and 84th-percentile 5%-damped response spectra for **M** 4.5-5.5, distance < 25 km recordings compared to empirical spectra from [20]

accelerograms. The statistical spectra shown in Figure 9 are based on 25 recordings within the specified magnitude and distance range that have been digitized and processed. However, there are an additional 106 recordings that have been obtained for which only measures peak accelerations are available. The computed median and 84th-percentile accelerations of this larger data set are 60% and 70%, respectively, of the median and 84th-percentile accelerations for processed accelerogram data set. It should also be noted that the mean magnitude of the larger data set is **M** 5.0. Thus part of the bias in the statistical spectrum shown in Figure 9 is due to a overestimate of the desired expected magnitude. The empirical attenuation relationships [20] would predict about a 20 percent difference in the median ground motions between a magnitude 5 and 5.2 earthquake.

Figure 9 shows "corrected" median and 84th-percentile random earthquake spectra that are 60% and 70%, respectively, of the original spectra under the assumption that the bias in peak acceleration applies throughout the spectrum (at least for frequencies of interest to the evaluation of the K-Reactor site). The "corrected" spectra are likely to be a better representation of what would be computed if the full data set of accelerograms were available for statistical analysis. These spectra are compatible with those developed from empirical attenuation relationships, further suggesting that the "correction" is appropriate. Accordingly, the "corrected" spectra shown in Figure 9 are assumed to be the appropriate representation of ground motions resulting from a **M** 5.0 random event.

<u>Assessment of eastern US motions</u> The data set used in the above analysis consists entirely of western US recordings, as there are no eastern US deep soil recordings that fall within the selection criteria. The BLWN/RVT model was used to examine the possible differences between eastern and western ground motions for the local event. These differences were examined by comparing the response spectra predicted by the model for a **M** 5.0 earthquake occurring 15 km from a deep soil site. Assuming that the source characteristics of eastern and western US earthquakes are generally similar, as indicated by similar stress drops and source scaling relationships, then the observed differences in recorded rock motions are likely due to travel path effects. To assess these differences predictions of response spectral ordinates were made for eastern US and western US crustal conditions assuming equal stress drop in both regions. Figure 10 shows the compute estimates of rock site motions from a **M** 5.0 event at a distance of 15 km for eastern and western US conditions. These spectra show similar differences to those observed for near field recorded motions (see Figure 7). Corresponding deep soil site motions were obtained using the soil/rock spectral ratios developed for **M** 5.0 events. The eastern deep soil site motions are significantly higher than the western deep soil site motions at frequencies greater than 5 Hz, suggesting that the western US statistical response spectra shown in Figure 9 may under estimate the high frequency ground motions that may occur from a random local event in the eastern US.

Figure 11 presents a comparison of the ground motion estimates for the two events considered. Estimates for the Charleston event are those obtained using BLWN/RVT model with a 150 bar stress drop. The 84th-percentile was estimated assuming a standard error of 0.5 on the natural log of ground motion amplitude. The estimate for the local event based on

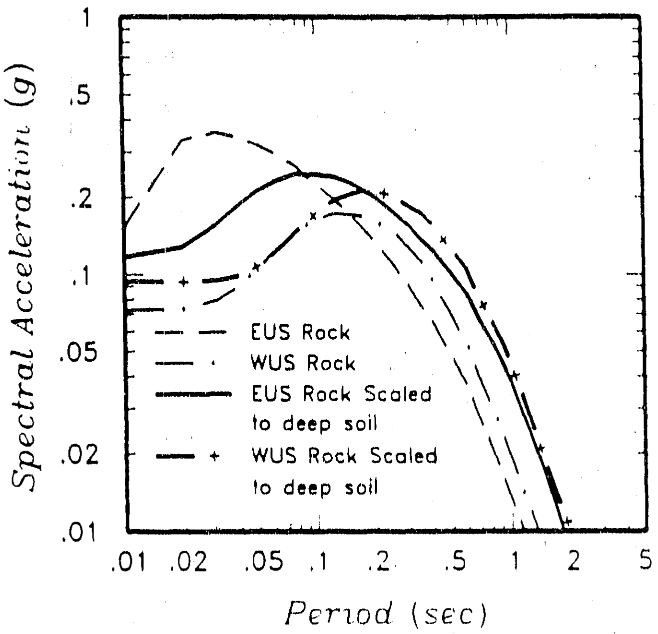

Figure 10 - Eastern and western US rock and soil site 5%-damped spectra predicted using the BLWN/RVT model.

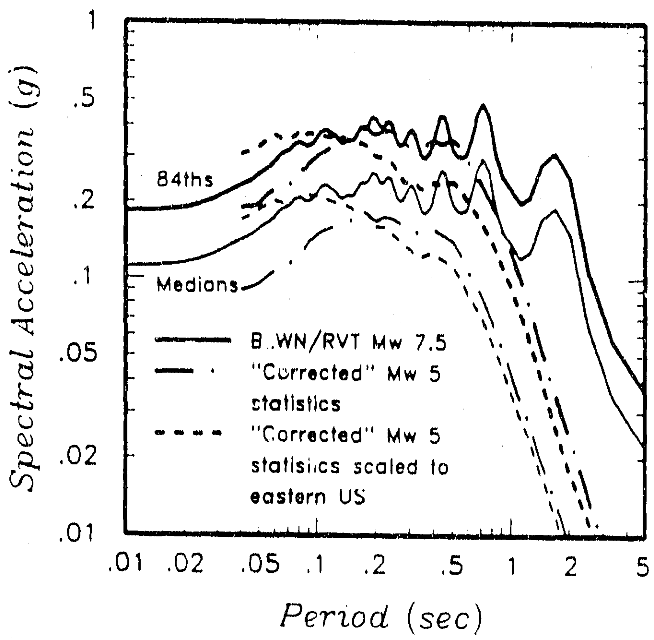

Figure 11 - Comparison of the predicted 5%-damped horizontal response spectra for the K-Reactor site for the Charleston and local events.

western US data, when scaled using the ratio of the soil site spectra shown in Figure 10, exceeds the Charleston source event spectra only at periods less than about 0.1 seconds.

SUMMARY

Three major issues were identified with respect to the assessment of ground motions for the Savannah River site. The first is specification of the appropriate stress drop for the Charleston source earthquake. Analyses of instrumentally recorded eastern North American earthquakes indicates that the average stress drop is about 100 bars. However, some proposed source scaling relationships and some postulated source dimensions would suggest that the stress drop should be higher by a factor of two or three, resulting in a prediction of a much higher level of ground shaking in the site region, perhaps much higher than indicated by the reported levels of shaking intensity. The second issue is specification of the appropriate levels of soil damping at large depths for site response analyses. The level of damping has a critical effect on the computed levels of shaking and the low damping values used in this study allow the propagation of high frequency energy upward through a deep soil column. The third issue is evaluation of the appropriateness of western US recordings for specification of ground motions in the eastern US. Analyses presented in this report suggest that an adjustment of the response spectra of western US deep soil recordings may be warranted to account for the expected greater high frequency content of eastern US rock site motions.

REFERENCES

[1] Geomatrix, "Ground motion following selection of SRS design basis earthquake and associated deterministic approach," report prepared for Westinghouse Savannah River, March 1991

[2] United States Nuclear Regulatory Commission, Standard Review Plan, Office of Nuclear Reactor Regulation, NUREG - 0800, Rev.2, 2.5.2 Vibratory Ground Motion, 15 p., 1990.

[3] G.S. Gohn, ed. "Studies related to the Charleston, South Carolina earthquake of 1886 -- Tectonics and seismicity," U.S. Geological Survey Professional Paper 1313, 375 p., 1983.

[4] P. Talwani and J. Cox, "Paleoseismic evidence for recurrence of earthquakes near Charleston, South Carolina," Science, v. 229, p. 379-381, 1985.

[5] S.F. Obermeir, Weems, R.E., and Jacobson, R.B., "Earthquake induced liquefaction features in the coastal South Carolina region," in Proceedings from the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America, Technical Report NCEER-87-0025, p. 480-493, 1987.

[6] D. Amick, R. Gelinas, G. Marauth, and R. Cannon, "Paleoliquefaction investigations along the Atlantic seaboard - implications for long-term seismic hazard " in Transactions of the Seventeenth Water Reactor Safety Information Meeting, U.S. Nuclear Regulatory Commission NUREG/CP-1040, 26 p., 1989.

[7] D. Amick, R. Gelinas, G. Maurath, D. Moore, E. Billington, and H. Kemppinen, "Paleoliquefaction features along the Atlantic seaboard," U.S. Nuclear Regulatory Commission NUREG/CR-5613, 146p. 1990.

[8] United States Nuclear Regulatory Commission, "Safety Evaluation Report for Vogtle NGS," 1985.

[9] A.C. Johnston, "Chapter 3--The SCR earthquake data base," in Coppersmith et al., Methods for Estimating Maximum Earthquakes within Stable Continental Regions, Electric Power Research Institute Project RP2556-12, in preparation.

[10] K.J. Coppersmith, A.C. Johnston, and W.J. Arabasz, "Estimating maximum earthquakes in the cental and eastern United States: A progress report," in Proceedings of the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America, Technical Report NCEER-87-0025, p. 217-232, 1987.

[11] G.A. Bollinger, "Reinterpretation of the intensity data for the 1886 Charleston, South Carolina, earthquake," in Rankin, D.W., ed., Studies Related to the Charleston, South Carolina, earthquake of 1886--A Preliminary Report, U.S.G.S. Prof. Paper 1028, p. 17-32, 1977.

[12] T.C. Hanks and H. Kanamori, "A moment magnitude scale," Journal of Geophysical Research, v. 84, p. 2348-2350, 1979.

[13] P. Talwani, J. Rawlins, D.and Stephenson, "The Savannah River Plant, South Carolina, earthquake of June 9, 1985, and its tectonic setting," Earthquake Notes, v. 56, p. 101-106, 1985.

[14] P.G. Somerville, J.P. Mclaren, L.V. LeFevre, R.W. Berger, and D.V. Helmberger, "Comparison of source scaling relations of eastern and western North American earthquakes," Bulletin of the Seismological Society of America, v. 77, p. 322-346, 1987.

[15] D.M. Boore and G.M. Atkinson, "Stochastic prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America," Bulletin of the Seismological Society of America, v. 77, p. 440-467, 1987.

[16] Geotechnical Engineers Inc., "K-Reactor area geotechnical investigation for seismic issues - Savannah River Site," draft report prepared for Westinghouse Savannah River Company, February 1991.

[17] R.K. McGuire, G.R. Toro, and W.J. Silva, "Engineering model of earthquake ground motion for eastern North America," prepared by Risk Engineering, Inc. for the Electric Power Research Institute, EPRI Final Report NP-6074, 1988.

[18] W.L. Chapman and M.P. DiStefano, "Savannah River Plant seismic survey, 1987-1988," Research report no. 1809-005-006-1-89 prepared by Conoco Inc, 1989.

[19] H.B. Seed and I.M. Idriss, "Soil modulii and damping factors for dynamic response analysis," Report No. EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, 1970.

[20] K. Sadigh, J.A. Egan, and R.R. Youngs, "Specification of ground motion for seismic design of long period structures (abs.)," Earthquake Notes, v. 57, n. 1, p. 13, 1986.

[21] G.M. Atkinson and D.M. Boore, "Recent trends in ground motion and spectral response relations for North America," Earthquake Spectra, v. 6, p. 15-36, 1990.

[22] D.L. Bernreuter, J.B. Savy, R.W. Mensing, and J.C. Chen, "Seismic hazard characterization of 69 nuclear plant sites east of the Rocky Mountains," NUREG/CR-5250, UCID-21517, 8 v., 1988.

[23] Electric Power Research Institute, "Seismic hazard methodology for the central and eastern United States - Volume 1: Methodology," Report NP-4726, prepared for Seismicity Owners Group and Electric Power Research Institute under research projects P101-38, -45, -46, 2256-14, February 1987.

[24] T.C. Hanks and R.K. McGuire, "The character of high-frequency strong ground motion," Bulletin of the Seismological Society of America, v. 71, p. 2071-2095, 1981.

[25] D.M. Boore, "Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra," Bulletin of the Seismological Society of America, v. 73, p. 1865-1894, 1983.

[26] W. Silva, "Site dependent specification of strong ground motion" in Proceedings of the Workshop on Dynamic Soil Properties and Site Characterization, sponsored by the National Science Foundation and the Electric Power Research Institute, Palo Alto, California, 1989.

[27] G.-B. Ou and R.B. Herrmann, "A statistical model for ground motion produced by earthquakes at local and regional distances," Bulletin of the Seismological Society of America, v. 80, p. 1397-1417, 1990.

[28] R.W. Burger, P.G. Somerville, J.S. Barker, R.B. Herrmann, and D.V. Helmberger, D.V., "The effect of crustal structure on strong ground motion attenuation relations in eastern North America," Bulletin of the Seismological Society of America, v. 77, p. 420-439, 1987.

[29] P.G. Somerville, J.P. McLaren, C.K. Saikia, and D.V. Helmberger, "The 25 November 1988 Saguenay, Quebec, earthquake: Source parameters and the attenuation of strong ground motion," Bulletin of the Seismological Society of America, v. 80, p. 1118-1143, 1990.

[30] D.L. Wells and K.J. Coppersmith, "Updated empirical relationships among magnitude, rupture length, rupture area, and surface displacement," submitted to Bulletin of the Seismological Society of America.

[31] D.M. Boore, "Short period P- and S-wave radiation from large earthquakes: Implications for spectral scaling relations," Bulletin of the Seismological Society of America, v. 76, p. 43-64, 1986.

[32] O.W. Nuttli, R. Rodriguez, and R.B. Herrmann, "Strong ground motion studies for South Carolina Earthquakes," U.S. Nuclear Regulatory Commission NUREG/CR3755, UCRL-15594, 88 p., 1984.

[33] N.W. Newmark and W.J. Hall, "Development of criteria for seismic review of selected nuclear power plants," U.S. Nuclear Regulatory Commission Report NUREG/CR-0098, 1978.

[34] J.K. Kimball, "The use of site dependent spectra," in Proceedings of the U.S. Geological Survey Workshop on Site Specific Effects of Soil and Rock on Ground Motions and the Implications for Earthquake-Resistant Design, U.S. Geological Survey Open File Report 83-845, p. 401-422, 1983.

END

DATE FILMED

5/07/92