Determination of Seismic Hazard for Soil Sites Given Comparable Data for Rock Sites

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1 INTRODUCTION

A numerical procedure has been developed to determine site specific seismic hazards appropriate for soft soil sites from comparable hazard definitions determined by assuming that the site is a rock site. These input rock site hazard definitions are typically obtained from studies which provide both peak acceleration and spectral acceleration hazard estimates (e.g., Berreuter, et al., 1989) which are based on studies of previous site seismicity as well as contributing tectonic and geologic effects. This data is then converted to the equivalent soil site hazard definitions applicable to the top of the ground surface by using frequency dependent soil amplification factors. These factors are intended to account for the effects of the overburden soils on the site seismic response and are usually obtained from studies of upward propagating shear waves through the soil column. However, questions of the magnitudes of these factors have been raised, particularly for deep soil sites. In many applications considered to date, the conversion of the input rock hazard definition to the corresponding definition appropriate to the top of the soil column makes use of generic amplification factors which may not be appropriate for the particular site in question.

To accomplish this objective, a Monte Carlo procedure has been developed to include the effects of the variability in the stiffness parameters of the soil overburden on the site response, and this procedure has been applied to a deep soil site for which surface seismic hazard definitions were of interest. A convolution method of analysis is used, assuming upward propagating shear waves, to convert rock motions appropriate for a rock outcrop at the site with soil column effects to determine surface soil responses and corresponding hazard definitions. Variability effects from input rock motion, soil shear moduli, effective hysteretic damping ratio and strain dependency are included in the procedure to modify the site hazard definitions.

Numerical results were generated for the determination of the seismic hazard which can be anticipated at the ground surface at Brookhaven National Laboratory (BNL), located in Long Island, New York. The input bedrock hazard consisted of spectral accelerations defined for a fictitious rock outcrop at a number of return periods and probability fractiles. With these hazard definitions used as input, a large number of response calculations were performed to generate the corresponding seismic hazard data appropriate to the ground surface, at the top of the soil. Previously available ground surface hazard predictions made use of generic soil amplification factors to convert the outcrop bedrock hazard to the surface hazard. The relationship between the site specific and the generic soil amplification factors was of specific interest in this study.

2 RESPONSE CALCULATIONS FOR SOIL SITES

The site specific response calculations performed for this study made use of the standard assumption of upward propagating horizontal shear waves traveling through the long soil column from the basement bedrock up to the ground surface, with nonlinear soil properties being accounted for in each specific calculation by the usual iterative methods. The basement seismic inputs for each fractile and return period considered in the evaluation were defined in terms of spectral accelerations available for the site from a previous study. In each calculation of
propagation upward through the soil column, the input rock motions were then specified as outcrop motions applied at the top of bedrock. Compatible motions within the soil column were then calculated which suitably account for reflection and refraction effects at the bedrock/sediment interface as well as at all layer interfaces within the soil column. The CARES Computer Code was used to perform these calculations (Xu et al. 1990).

Initially, the soil column calculations were made using the standard strain dependent soil properties typically used in site evaluations for commercial nuclear power plants (Seed et al. 1970). These strain dependent effects are represented by the degradation in shear modulus and increase in hysteretic damping ratio which accompanies increased shear strain levels. However, recent studies (Coppersmith, 1991 and Idriss, 1990) have indicated that the degradation in soil properties described in the original Seed-Idriss presentation may in fact be too large so as to preclude the ability of significant high frequency seismic energy from being transmitted upward through the soil column from the bedrock inputs. At any deep soil site, such as at BNL, the form of the degradation properties used in the analyses becomes extremely important. For this investigation, therefore, seismic motions were calculated at the ground surface using additional postulates of the nonlinear properties of the foundation soils to obtain the sensitivity of the predictions to these assumptions.

3 FOUNDATION DESCRIPTION OF THE HFBR SITE

The definition of the site properties at the HFBR site was obtained from available data from previous site evaluations as well as from studies of the Shoreham Nuclear Power Plant located nearby. Boring logs available from deep wells drilled to basement provided verbal descriptions of site soils to bedrock depths (approximately 1500 feet below ground elevation), and they indicate that the site consists primarily of sandy soils to these depths, with some intermittent layers of clay and clayey sands. To obtain estimates of soil stiffness required for the hazard calculations, the number of blows required to drive the Standard Penetration Test (SPT) sampler (taken at five-foot intervals to depths of about 90 feet) were used and converted to effective low strain (initial) shear modulus. The SPT blow count data, however, was found to be highly variable. Since this SPT data is used directly to estimate soil stiffness, the variability in this data must be suitably accounted for in the hazard calculations. The SPT data was first modified for the effects of depth by converting to equivalent blows at a standard depth (e.g., Gibbs and Holz, 1957). This corrected data was then used to obtain bounding estimates of blow counts for all soils in the column. For the gravelly sands at the site, this ranged from 19 to 47 blows per foot, while for the clayey sands, the range in data was from 16 to 26 blows per foot.

The initial soil shear stiffness at any depth in the soil column is obtained from standard relationships (e.g., AJA & SW 1972). For sandy soils, for example, the initial shear modulus is obtained directly from estimates of relative density and confining pressure from

\[ G_{\text{max}} = 1000 \times K \sqrt{\rho} \]

where the parameter \( K \) is directly related to the relative density of the sands and the term \( \rho \) is the estimated confining pressure at depth. The relative density is in turn estimated from the SPT blow counts for the soil from a variety of relations such as are shown in Figure 1. As may be noted, a wide range of variability in estimated soil stiffness may be obtained, depending upon the particular relationship utilized. The lower and upper bound recommendations of Figure 1 were taken as the 15th and 85th percentiles respectively in this study. In a particular column calculation for any sandy soil layer in the column, random number generators were used to estimate first the corrected SPT blow count associated with that layer between the lower and upper bound values found from the site borings, and then the relative density for that particular blow count from the range indicated in Figure 1. The initial soil stiffness could then be computed directly from the relation above. An additional random number generator was included in this calculation to account for additional scatter in the available data shown for the \( K \) parameter defined above.

For the clay soils at the site, the relative density was not directly used in the calculation. Rather, the initial soil stiffness was related to the initial void ratio of the soil as well as the overburden pressure at depth and the overconsolidation ratio of the soil. For this site, the OCR was selected as 1.0 and the range of void ratios considered was 0.5 to 1.0 since the clays were considered as relatively stiff. A random number generator was then used to select the layer void ratio between these values, from which the initial shear modulus of the clay soil layer calculated.
4 DEGRADED SOIL MODULI AND HYSTERETIC DAMPING RATIOS

In any single soil column calculation, the initial value of shear modulus for each soil layer was estimated from
the relations discussed above for the soil types considered, appropriately using random number generators
for each soil layer as mentioned previously to obtain these properties. Iterative convolution calculations are then
performed suitably accounting for degradation in this stiffness with cyclic shear straining. Separate evaluations
of site response for a particular rock input motion were made using the degradation models proposed by
Seed-Idriss (1970), Idriss (1990) and Geomatrix (1991). Additional calculations were also made with no
degradation included in the model to obtain the total range in spectral response that could be expected for this
deep soil site. A comparison of the models for sands is shown in Figure 2. Both modified models indicate
significantly less degradation with cyclic shear strain as compared to the original Seed-Idriss recommendations as
well as smaller amounts of soil hysteretic damping.

5 SURFACE HAZARD CALCULATIONS

For the soil column defined for the site, the following procedure was then used to obtain estimates of the site
specific seismic hazards. First, the hazard data defined as the bedrock outcrop hazard was obtained for return
periods of 1000, 10,000 and 100,000 years. This data was available in the form of peak accelerations and
spectral accelerations (at frequencies of 1.25, 5, 10 and 25 hertz) at probability fractiles of 15%, 50% and 85%.
Peak accelerations were also provided at additional fractiles, but were not used directly in these studies. For each
return period and fractile, a recommended bedrock spectra was then available as the estimate of the seismic input
to the soil column. This spectra was considered to be the definition of the motion of the rock outcrop associated
with the site. For any one column evaluation, a time history was generated to match this defined bedrock spectra
using the CARES computer program, utilizing a random distribution of time phasing of the frequency
components making up the seismic pulse and matching the specified peak ground acceleration by "clipping".
The frequency range considered in any one time history development was up to 50 hertz at a frequency increment
of 0.05 hertz. Pulse durations used in the calculations were 20 seconds.

For each of the three return periods and three fractiles considered in the calculations, 100 column cases were
run to obtain surface ground motions for each of the degradation models considered, namely, the Seed-Idriss 1970
model, the Idriss 1990 model, the Geomatrix 1991 model and the no degradation model. Random number
generators were used throughout to select soil stiffness and damping properties used in these calculations and
provide a range of output motion data suitably accounting for variability in these properties. The results of these
calculations for the 15th, 50th and 85th percentiles spectral definitions of the input motions were combined
using appropriate weighting relationships to obtain an expanded data base for a given return period. Median
spectral accelerations were then computed from this combined data base and compared with those predicted from
the generic amplification factors. The results of these calculations are shown in Figure 3 for seismic motions
defined for a 1,000 year return period.

6 SITE SPECIFIC RESULTS

As may be noted from Figure 3, the site specific spectra calculated at the top of the soil column is significantly
different from the spectra obtained using the generic amplification factors. For each case considered, the spectral
shape and peak acceleration are completely controlled by the degradation models utilized in the computation. For
the 1,000 and 10,000 year return period computations, the no degradation and Geomatrix models indicate similar
spectral shapes with changes in magnitude at each frequency influenced by the amount of degradation considered.
The original Seed-Idriss 1970 model indicates significantly more decay as well as a shift in frequency to the peak
of the spectra. For the 100,000 year calculation, the Geomatrix model also indicated a similar shift of the
spectral peak to lower frequencies. This is obviously due to the lower shear moduli obtained with the higher
seismic accelerations associated with the longer return period.

Finally, the calculations indicate that the variance of the peak accelerations at the top of the soil column about
the median responses may not be as large as typically indicated in the bedrock hazard definitions. This may be
due to the fact that at these higher acceleration levels, the deep soil column cannot transmit the higher
frequencies well, essentially saturating the ability of the column to transmit high accelerations.
REFERENCES


I. M. Idriss, "Response of Soft Soil Sites During Earthquakes", Proceedings of the H. B. Seed Memorial Symposium, Berkeley, California, May, 1990


FIGURE 1  VARIABILITY OF RELATIVE DENSITY PREDICTIONS FOR SANDS

FIGURE 2  SHEAR MODULUS RATIO FOR SANDS
FIGURE 3 MEDIAN SPECTRAL ACCELERATIONS FOR 1,000 YEAR RETURN PERIOD