SEISMIC HAZARD STUDIES FOR THE HIGH FLUX BEAM REACTOR AT BROOKHAVEN NATIONAL LABORATORY

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ABSTRACT

This paper presents the results of a calculation to determine the site specific seismic hazard appropriate for the deep soil site at Brookhaven National Laboratory (BNL) which is to be used in the risk assessment studies being conducted for the High Flux Beam Reactor (HFBR). The calculations use as input the seismic hazard defined for the bedrock outcrop by a study conducted at Lawrence Livermore National Laboratory (LLNL). Variability in site soil properties were included in the calculations to obtain the seismic hazard at the ground surface and compare these results with those using the generic amplification factors from the LLNL study.

INTRODUCTION

A numerical procedure has been developed to determine site specific seismic hazards appropriate for the deep soil site existing at BNL from comparable hazards defined at the rock outcrop. The input rock site hazard definition was obtained from the site study performed by LLNL [1]. The rock outcrop hazard is specified in terms of the annual probability of exceedance of the peak ground acceleration (PGA) and the associated uniform hazard spectra (UHS) corresponding to each return period of interest. This data is converted in the LLNL study to the corresponding site hazard appropriate to the top of the ground surface by using generic frequency dependent soil amplification factors. These factors account for the effects of the overburden soils on the seismic response and are typically 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 such as that at BNL. In several applications considered to date, it has been found that the conversion of the input rock hazard to the corresponding definition at the top of the soil column by means of these generic amplification factors may not be appropriate for any particular site in question.

To accomplish this objective, a Monte Carlo procedure has been developed which includes the effects of variability in the parameters describing the properties of the soil overburden which influence site response. This procedure has been applied to the deep soil site existing at HFBR. A convolution method of analysis is used, assuming upward propagating shear waves, to convert rock motions appropriate for the rock outcrop at the site to 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 determine the surface hazard predictions.

SITE DESCRIPTION

The site description was obtained from previous studies conducted at BNL as well as from studies of the nearby Shoreham Nuclear Power Plant and is summarized in [2]. A cross-section through the BNL site is shown in Fig. 1. The depth of the soil overburden at the site is approximately 1550 feet and consists of relatively dense gravels and sands interspersed with stiff clays and sandy clays. Blow count data obtained from standard penetration tests were obtained from several borings taken in the area through the upper 100 feet of sediments, with soil descriptions for the deeper sediments obtained from well logs appropriate to the area. No other strength or stiffness information was available for these soils. The variability in blow count data for the near surface soils, shown in Fig. 2, was significant and can be considered typical for the site. This variability was included in the site specific calculations to try to capture the effect of this uncertainty in the convolution studies.

SITE RESPONSE CALCULATIONS

The site specific response calculations made use of the standard assumption of horizontal shear waves traveling upward through the long soil column from the basement bedrock up to the ground surface, with nonlinear soil properties being included in each specific calculation by the usual iterative methods. In each calculation, the input rock motions were 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/soil interface as well as at all layer interfaces within the soil column. The CARES Computer Code [3] was used to perform these calculations.

Initially, the soil column calculations were made using the standard Seed-Idriss strain dependent soil properties typically used in site evaluations [4]. These effects are represented by the degradation in shear modulus and increase in hysteretic damping ratio which accompanies increased shear strain levels as shown in Fig. 3. However, recent studies ([5], [6]) have indicated that the degradation in soil properties postulated in the original Seed-Idriss formulation may in fact be too large so as to preclude the ability of significant high frequency energy from being transmitted upward through the soil column. As may be noted in Fig. 3, the modified models indicate significantly less degradation with strain as compared to the original Seed-Idriss model. 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, 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.

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) was used and converted to effective low strain (initial) shear modulus. Since this SPT data is used directly to estimate the low strain shear modulus, 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 ([7]). This corrected data was then used to obtain bounding estimates of blow counts for all soils in the column.

The initial soil shear stiffness at any depth in the soil column is obtained from standard relationships for the various soil types. For sandy soils, for example, the initial shear modulus is obtained directly from estimates of relative density and confining pressure where the parameters are directly related to the relative density of the sands and the confining pressure at depth. The relative density can in turn be estimated from the SPT blow counts for the soil from a variety of relations. However, as may be expected, the wide range of variability in estimated soil stiffness may be obtained, depending upon the particular relationship utilized. This variability was incorporated into the calculation by using bounds on these recommendations, with a further random generation to select relative density from the SPT blow count data. 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. The initial soil stiffness could then be computed directly from the relations mentioned above. An additional random number generator was included to account for additional scatter in the available data used to define these parameters.

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. A random number generator was then used to select the layer void ratio, from which the initial shear modulus of the clay soil layer calculated. Iterative convolution calculations were 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 various degradation models discussed above.

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, and this procedure is shown schematically in Fig. 4. First, the hazard data defined as the bedrock outcrop hazard was obtained for return periods of 100 to 1,000,000 years. This data was available in the form of PGA and spectral accelerations (at frequencies of 1, 2.5, 5, 10 and 25 hertz) at probability fractiles of 15%, 50% and 85%. The PGA hazard data is shown in Fig. 5 for both the bedrock input as well as at the ground surface using the generic amplification factors from the LLNL study. As may be noted from these data, no significant change in peak acceleration is postulated in this approach from bedrock to the ground surface, even for a soil column as long as 1550 feet.

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, 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.

SITE SPECIFIC RESULTS

For each of five return periods and three fractiles considered in the calculations, a number of column cases were run to obtain surface ground motions for each of the degradation models considered (100 runs for the Seed-Idriss model, 50 runs for the Geomatrix model and 100 runs for 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 suitably accounting for variability in these properties. Each surface spectra computed for a given spectral input was then stored in a data base associated with that input. After the surface spectral data was amassed, median and median plus/minus one sigma spectral accelerations were computed at each frequency of interest. An example of the results is shown in Fig. 6, in which median surface spectra are shown for the case of a median rock outcrop input motion at the 1,000 year return period. Although spectral values were computed at many frequencies, only the results at the six frequencies defined for the input spectra are shown.

Several important facts can be deduced from these results. First, the comparison between the LLNL spectra at bedrock and at the ground surface show relatively small differences at all frequency intervals, even at the lower frequencies associated with the deep soil column. Secondly, the impact of the soil degradation models assumed for the soils of the column completely dominate the magnitude and shape of the computed surface response spectra. For larger degradation values of the Seed-Idriss type, the magnitude of response at the ground surface is significantly reduced as compared to the input, particularly at frequencies above 10 hz, and increased at the lower frequencies (below 2.5 hz). The results associated with the Geomatrix model, on the other hand, show significantly higher surface response at all frequencies above about 1 hz. This is primarily due to the low damping, particularly at the deeper depths of the soil column, defined in this model. For higher input acceleration levels associated with longer return periods, it was found that even this model indicated shifts in column frequency to lower values due to soil degradation effects. Thus changes in spectral shape with return period can be significant in these calculations.

The Geomatrix degradation model was then selected for the surface hazard calculation since it leads to much higher predictions of surface motion than the other models considered, and therefore can be considered conservative for this site. The median output spectral results of these calculations for the 15th, 50th and 85th percentiles spectral definitions of the input motions are plotted in Fig. 7. The spectral accelerations shown in this figure are the average of the 5 and 10 hz responses which were deemed most important for the structural risk assessments to be made for the HFBR. As may be noted, at the higher acceleration levels associated with the bedrock inputs, the magnitudes of the surface response fall significantly below the initial slope, indicating the nonlinear behavior of the soil column at the higher acceleration levels. This result is even more striking at the higher frequency levels. This behavior can be thought of as a "saturation" of the soil column indicating that the column is no longer able to transmit the larger spectral accelerations associated with the higher input motions.

The impact of this column saturation on the surface seismic hazard curves is shown in Fig. 8. The hazard data plotted is return period as a function of the average spectral acceleration (5 to 10 hz), although similar conclusions would be reached for any other spectral acceleration of interest. The generic rock outcrop curves of Fig. 5 were then converted to the site specific surface hazard curves of Fig. 8 using the deterministic relationship of Fig. 7. The additional variability associated with this conversion, including the scatter shown, was incorporated into this calculation. The details of this computation are presented in [9]. The results of Fig. 8 suggest that at the lower input acceleration levels (or shorter return periods), the site specific hazard is greater than would be predicted using the generic soil amplification factors predicted with the generic approach. On the other hand, at higher input acceleration levels (longer return periods), the surface hazard is significantly reduced from that predicted from the use of the generic data.

ACKNOWLEDGEMENT

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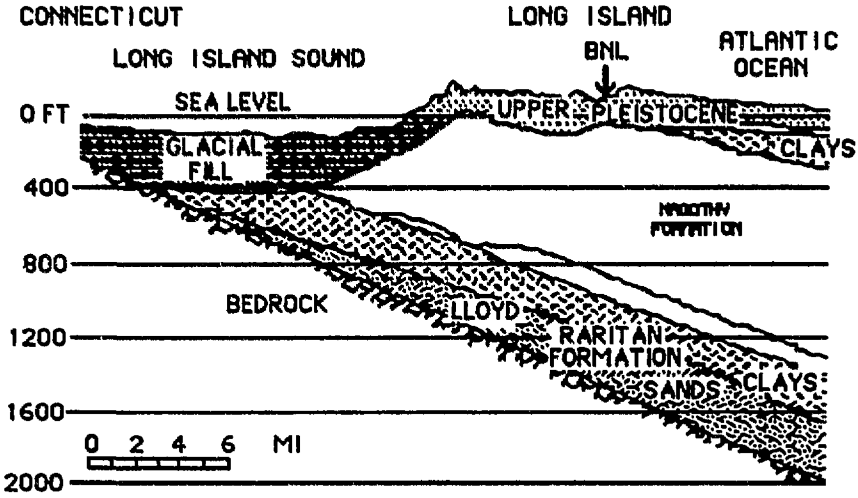

FIGURE 1 GENERALIZED CROSS-SECTION THROUGH BNL

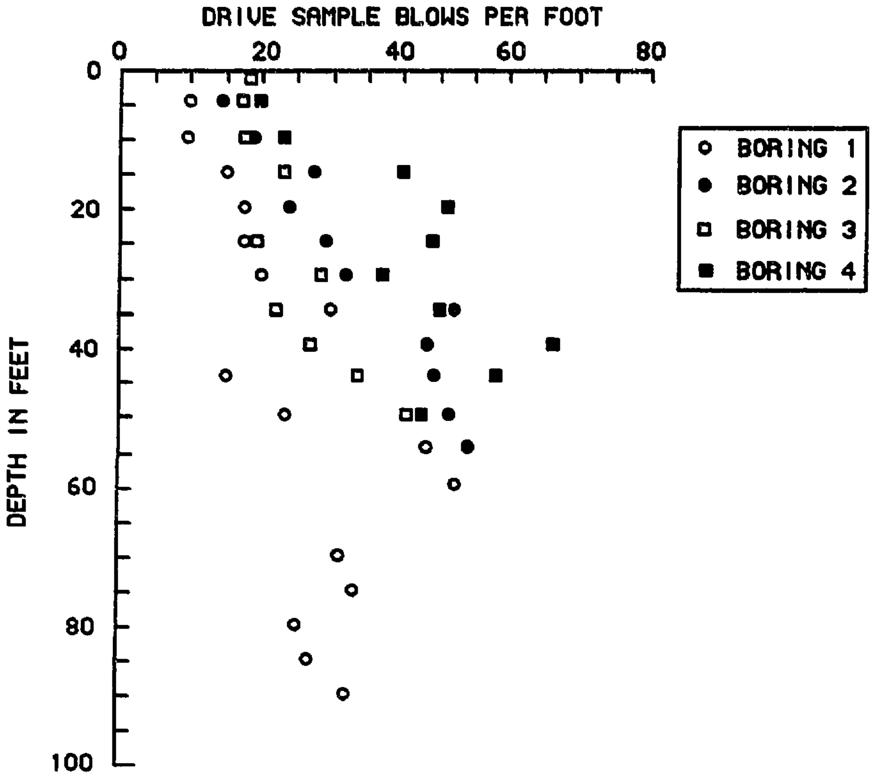

FIGURE 2 AVAILABLE DRIVE SAMPLE BLOWS PER FOOT

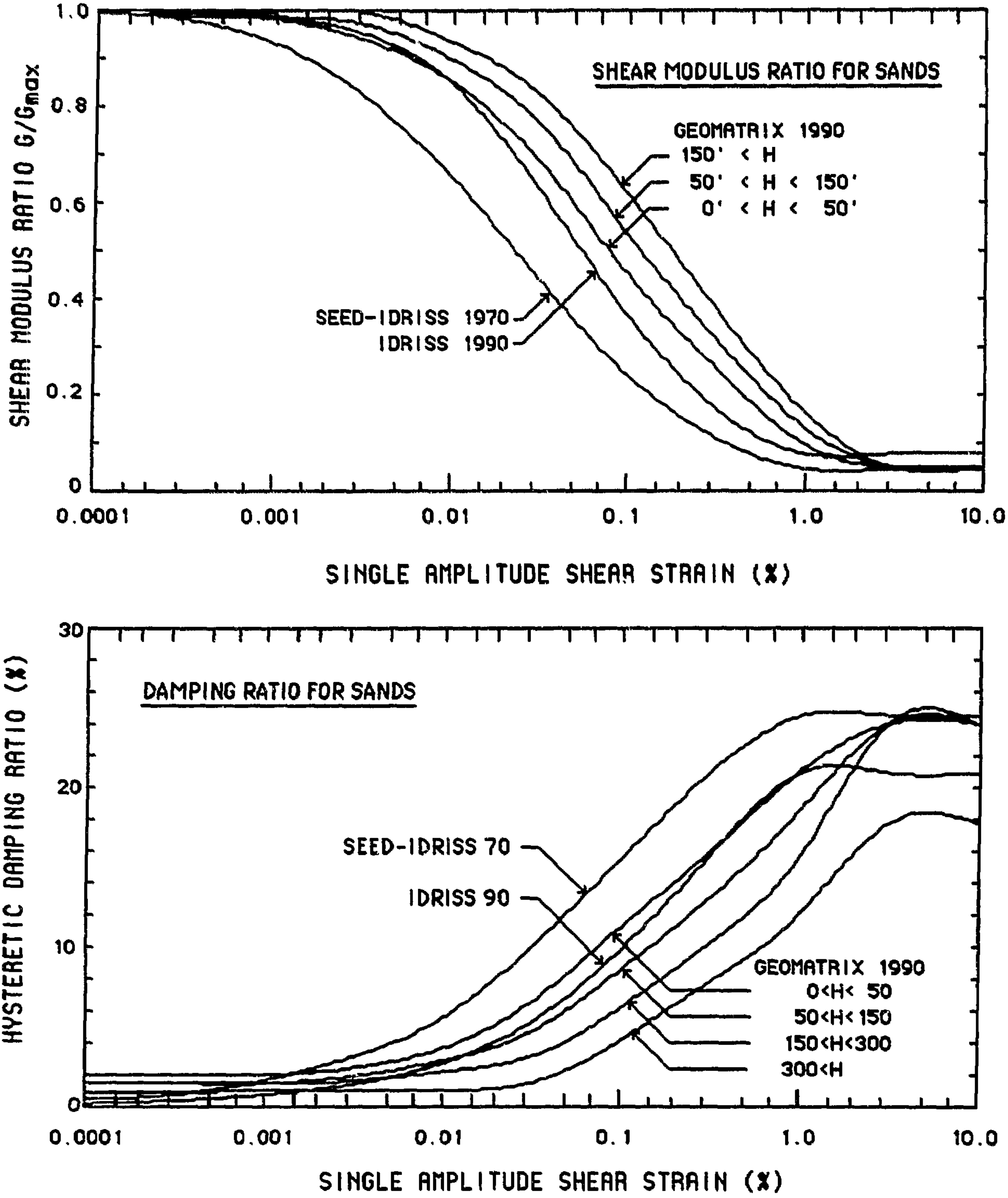

FIGURE 3 SHEAR DEGRADATION MODELS FOR SANDS

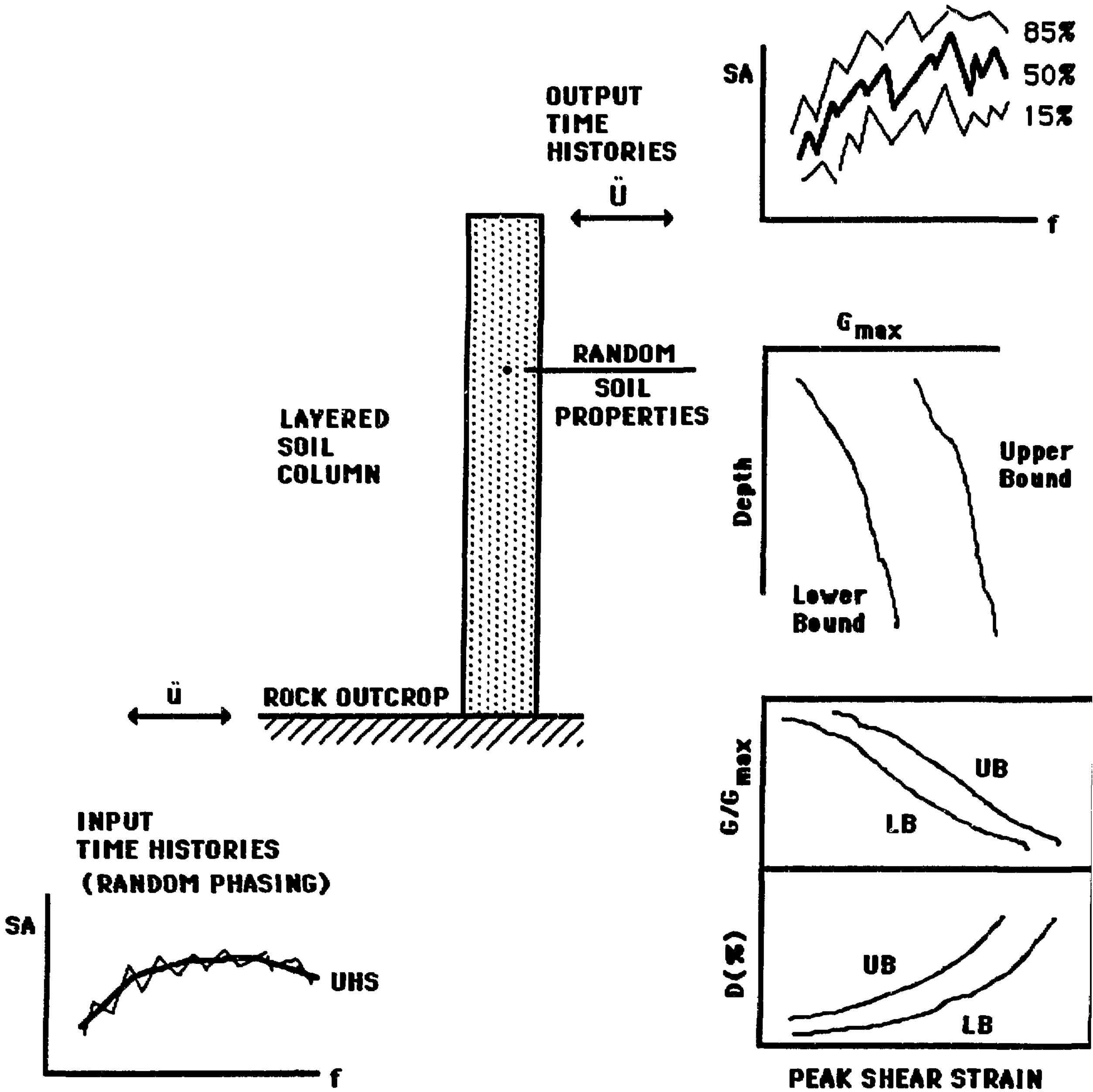

FIGURE 4 MONTE CARLO SIMULATION METHOD

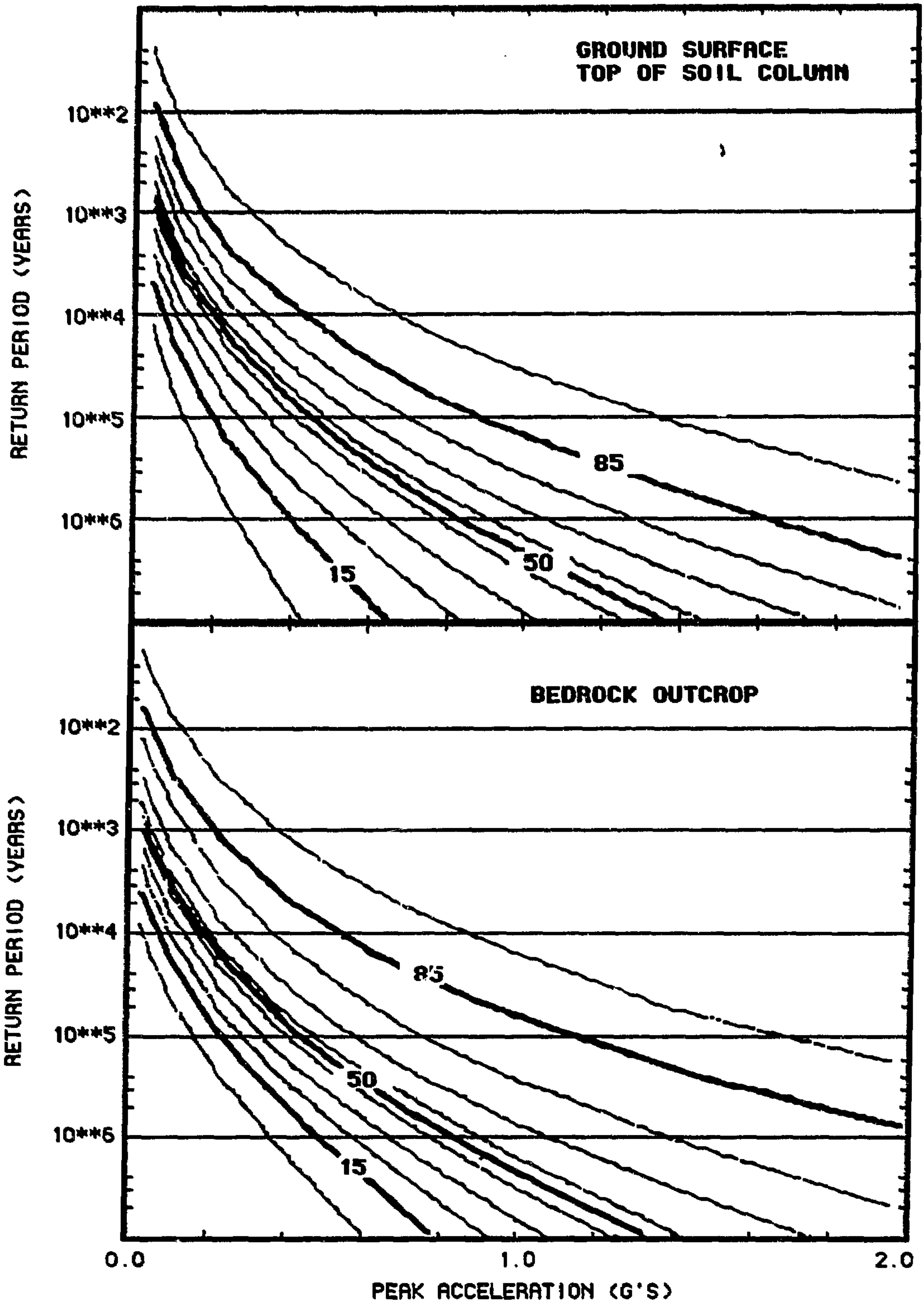

FIGURE 5 BEDROCK AND SURFACE HAZARD PREDICTION FOR HFBR SITE FROM LLNL USING 5 GM EXPERTS

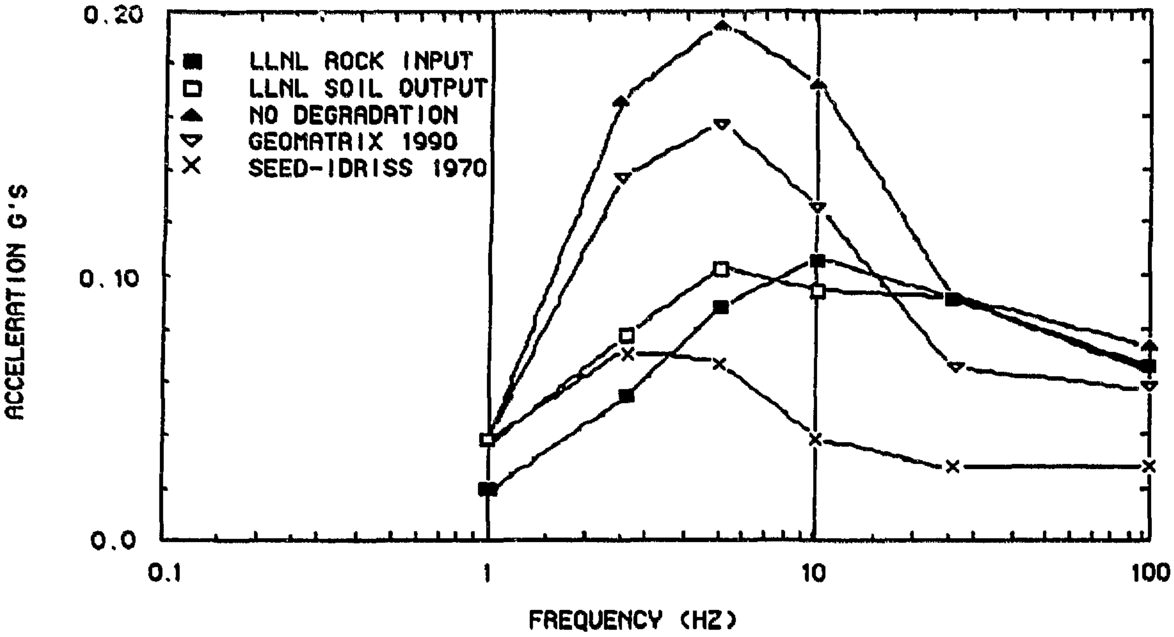

FIGURE 6 COMPUTED MEDIAN SURFACE SPECTRA FOR 1000 YEAR RETURN PERIOD AND 50TH PERCENTILE ROCK OUTCROP MOTION

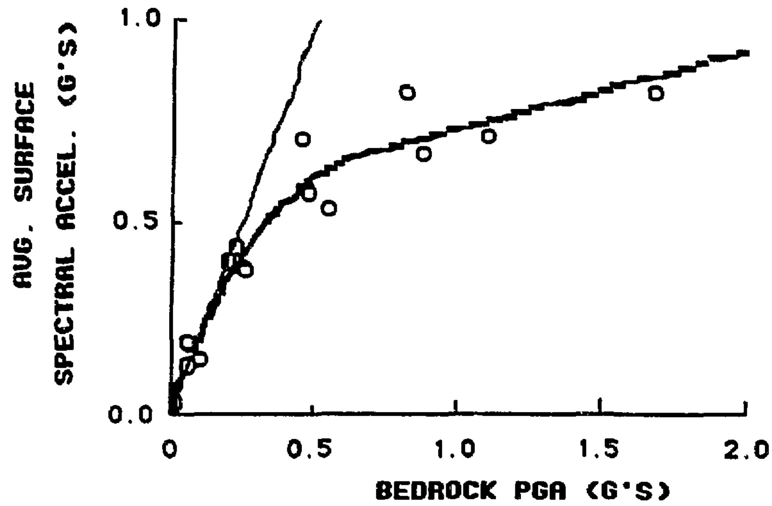

FIGURE 7 COMPUTED CONVERSION OF BEDROCK PGA TO SURFACE AVERAGE (5 TO 10 HZ) SPECTRAL ACCELERATION

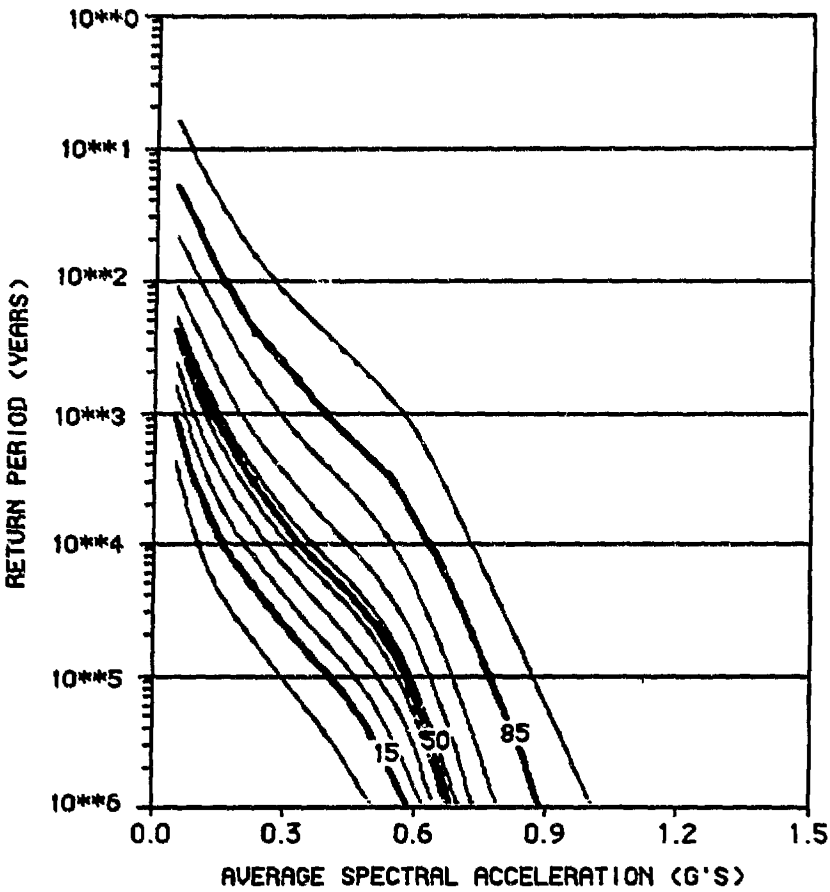

FIGURE 8 COMPUTED SURFACE SEISMIC HAZARD AVERAGE OF 5 TO 10 HZ SPECTRAL ACCELERATIONS