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COMPARISON OF DETERMINISTIC SSI RESULTS OBTAINED USING EITHER MEAN-BASED FIRS APPLIED AT THE FOUNDATION LEVEL OR SURFACE PSHA INPUT

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ABSTRACT

Current draft provisions of the American Society of Civil Engineers (ASCE) Standard 4 recommend either of two methods to generate seismic input to deterministic Soil-Structure Interaction analyses. Typically, Probabilistic Seismic Hazard Analysis (PSHA) spectral inputs are applied at the bedrock level and are used as input to probabilistic site response calculations using multiple realizations of the site profile accommodating uncertainty in layer velocity and damping properties. The results of these calculations are a series of strain-iterated profiles defined at the best estimate (BE), and ± one-sigma (upper (UB) and lower (LB) bound levels) together with the mean spectrum at the ground surface, as well as the mean in-column, and outcrop spectra at the foundation level. Two approaches are considered acceptable for performing deterministic soil-structure interaction (SSI) analyses with the BE, UB and LB soil profiles. In the first approach, the mean surface motions are used as input to the SSI analyses and the corresponding in-column motions are generated at the foundation depth. The envelope of the spectra calculated from the mean surface input must equal or exceed the mean in-column spectrum generated in the probabilistic site response calculations. In the second approach, the mean outcrop spectrum at the foundation level is used as input to the SSI analyses and the corresponding surface spectra computed for each profile. The envelope of these three spectra must then equal or exceed the mean surface spectrum.

These approaches for generating input motions for deterministic SSI calculations were used to determine seismic demands for an embedded facility with a site profile containing several velocity inversions. These inversions have a significant impact on the character of the spectral shapes at various depths associated with either the outcrop foundation motion or the corresponding in-column motions. The foundation is located above the highest strong velocity inversion in the profile. The results indicate that the deterministic calculations performed using the outcrop input motions lead to significantly higher seismic responses than those calculated from the mean-based surface motions.

INTRODUCTION

Draft ASCE 4 currently allows the use of the either the mean outcrop spectra at the foundation level (Foundation Input Response Spectrum or FIRS), or the mean surface spectrum (obtained from the PSHA) as input to the deterministic SSI calculations. The site profiles used in the deterministic SSI calculations are defined as the BE, LB, and UB velocity/damping profiles developed as described above. In the first approach, the FIRS motion is used as input to the three profiles at the depth of the structure's foundation. From this outcrop input motion, three corresponding surface motions are generated for use as input to the SSI calculations. The envelope of these three motions must equal or exceed the surface PSHA spectrum. In the second approach, the mean surface motions are used as input to the three SSI calculations using the BE, LB, and UB soil profiles. From these analyses, three corresponding in-column motions are generated at the depth of the structure's foundation. Following ASCE Standard 4, the envelope of these three spectra must equal or exceed the mean in-column spectrum generated in the probabilistic site response calculations. By comparing these envelope spectra with the targets, scale factors can be generated to indicate the conservatisms in the SSI calculations using these two approaches for a given site. For this evaluation, the foundation of the structure was located at a depth of 45 feet.

INPUT MOTION DEFINITIONS

The evaluations presented in this paper consist of calculations of SSI responses for an embedded facility using two approaches for defining equivalent input seismic motions allowed by ASCE Standard 4. These two approaches, herein referred to as the FIRS Approach and the Mean Surface Approach, are described in the following sections. These two approaches for generating input motions to the deterministic SSI calculations are used to determine seismic input demands for an embedded facility being designed for the Department of Energy at the Los Alamos National Laboratory. The site consists of a number of volcanic tuff layers over bedrock located at a depth of approximately 700 feet. For the probabilistic site response calculations, PSHA spectral inputs were first applied at the bedrock level. Figure 1 indicates the mean bedrock outcrop motion obtained from the PSHA together with the corresponding mean surface spectrum. In addition, a time history fit of the mean hazard bedrock outcrop spectra is shown.

The bedrock outcrop motion is used as input to probabilistic site response calculations using multiple realizations (at least 60 realizations) of the site soil column that is defined by low-strain velocity and hysteretic damping properties for each layer of the profile together with estimates of their uncertainty. For each realization, the corresponding strain-iterated profile is generated. The resulting BE, LB, and UB shear wave velocity/damping profiles are then defined for the site from the mean (assuming lognormal distributions) and ± one-sigma values of these layer properties. The resulting three profiles to be used in the deterministic SSI calculations are shown in Figure 2.

The mean bedrock outcrop motion is convolved upward through each of the strain-iterated soil column realizations. From these convolutions, mean in-column and outcrop spectra at the foundation level of 45 feet are obtained, along with mean surface spectra. These spectra are shown in Figure 3.

FIRS Approach

In this assessment, the mean FIRS outcrop motion shown in Figure 3 is first deconvolved downward from the foundation level through the BE, LB, and UB deterministic profiles to bedrock that is assumed to be a uniform halfspace. This bedrock outcrop motion is then input to the full column and convolved upward through the BE, LB, and UB profiles to obtain the surface spectra associated with the FIRS outcrop motion at the foundation level. Figure 4 shows surface envelope associated with the FIRS outcrop motion, along with an envelope of the BE, LB, and UB convolutions and the mean surface spectra computed from the site response realizations.

Mean Surface Approach

In the Mean Surface Approach, the mean surface spectra computed from the convolution of the mean response bedrock outcrop motion is used as input into three SSI analyses using the BE, LB, and UB profiles. In this approach, the mean surface spectra shown in Figure 3 is deconvolved through the BE, LB, and UB soil profiles down to the foundation level. The envelope of the three deconvolved motions must equal or exceed the mean in-column spectrum generated in the probabilistic site response, as described in the FIRS approach. Figure 5 shows the mean surface computed from the PSHA, along with the in-column motions computed from the deconvolution of the mean surface spectra through the BE, LB, and UB profiles. Figure 5 also shows the mean in-column target spectra generated from the probabilistic site response along with the envelope of the mean surface spectra deconvolutions through the BE, LB, and UB profiles.

SYNTHESIS OF RESULTS

Figure 5 shows that the deterministic in-column motion envelope does not envelope the mean in-column target in the frequency range between 10 and 15 Hz, as well as above 25 Hz. To remedy this unconservatism, the surface design spectra can be scaled to ensure the resulting BE, LB, and UB in-column spectra envelope at the foundation envelopes the mean in-column spectra from the probabilistic site response calculations. An alternate approach could be to select an additional deterministic soil profile in the SSI analysis to prevent excessive deamplification of the surface motion. Figure 6 shows mean surface spectra (black line), the surface design spectra corresponding to the envelope of the in-column motions (red line), and the surface design spectra that envelops the mean surface spectra computed from the FIRS approach (green line). The frequency ranges where the surface spectra corresponding to the envelope of the in-column motions is larger than the mean surface from the hazard corresponds to those frequency ranges where the deconvolution envelope does not bound the in-column mean in Figure 5 and the mean surface is scaled. As shown in Figure 6, the surface design spectra corresponding to the FIRS Approach significantly exceeds the spectra corresponding to the Mean Surface Approach across the entire frequency range of interest.

FIGURES

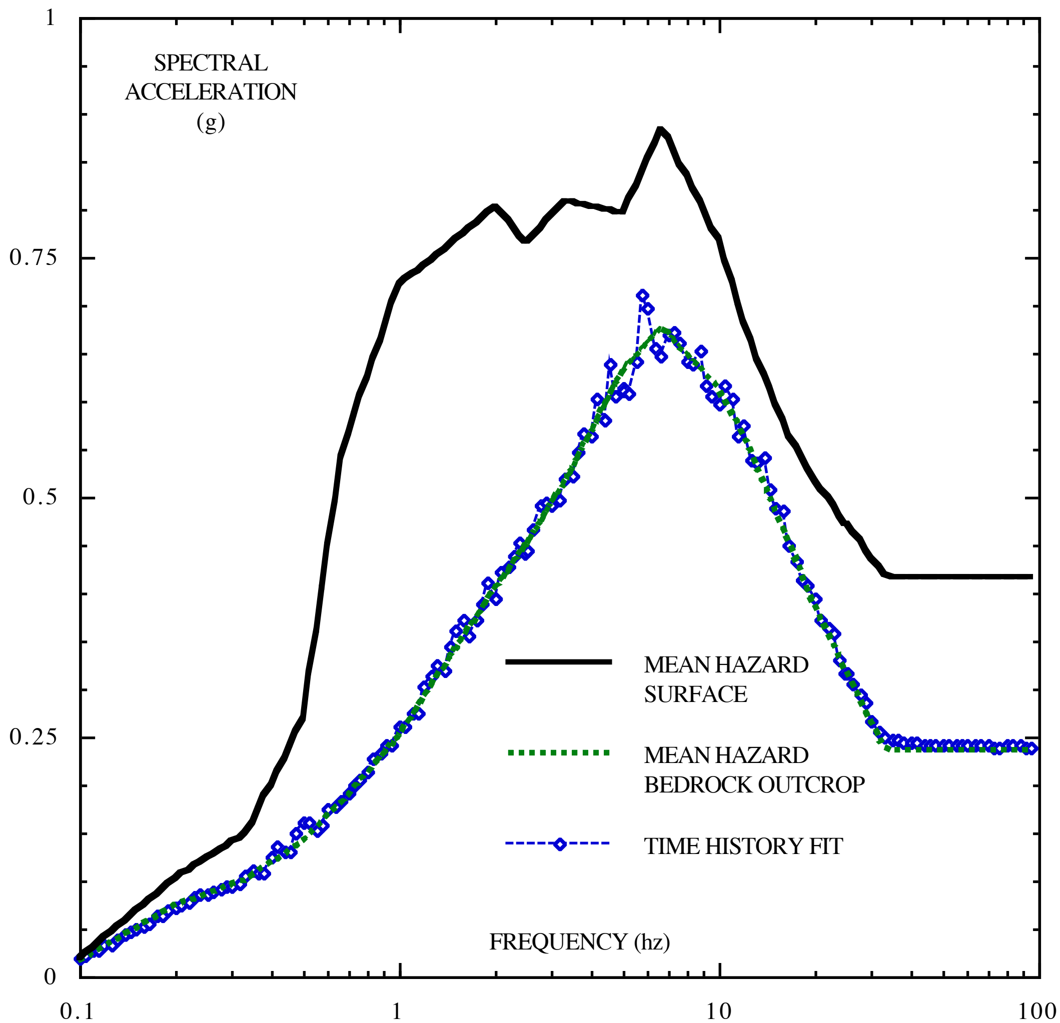

Figure 1. Mean Hazard Bedrock Outcrop and Surface Spectral Acceleration

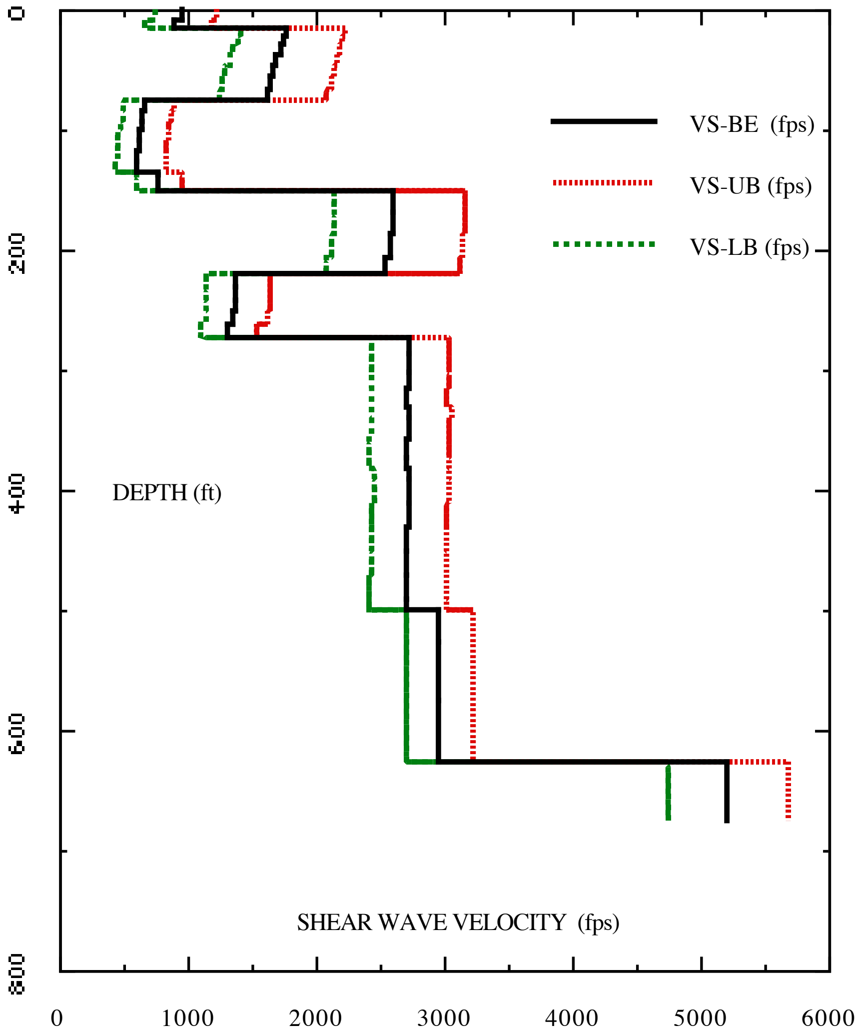

Figure 2. Deterministic Shear Wave Velocity Profiles

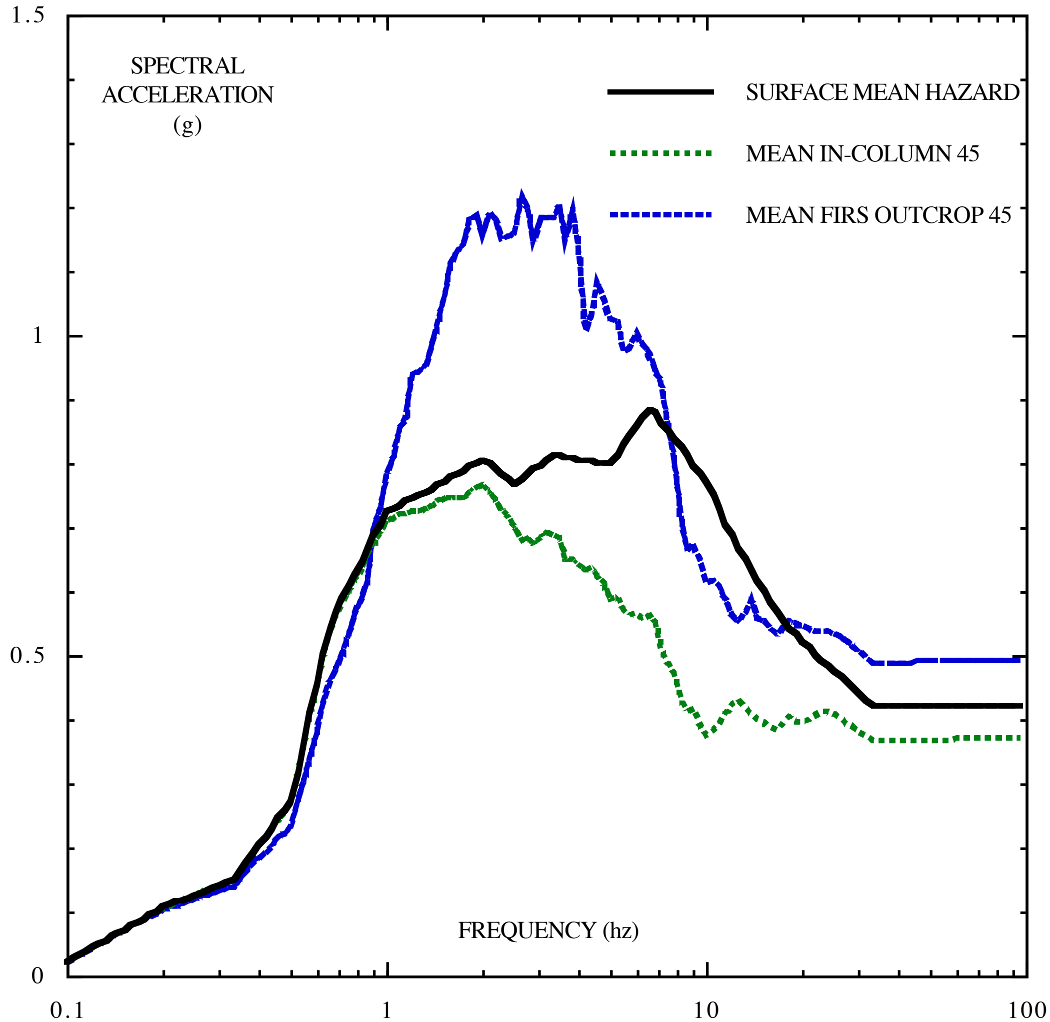

Figure 3. Mean Surface, In-Column, and FIRS Outcrop Spectra at Foundation Level

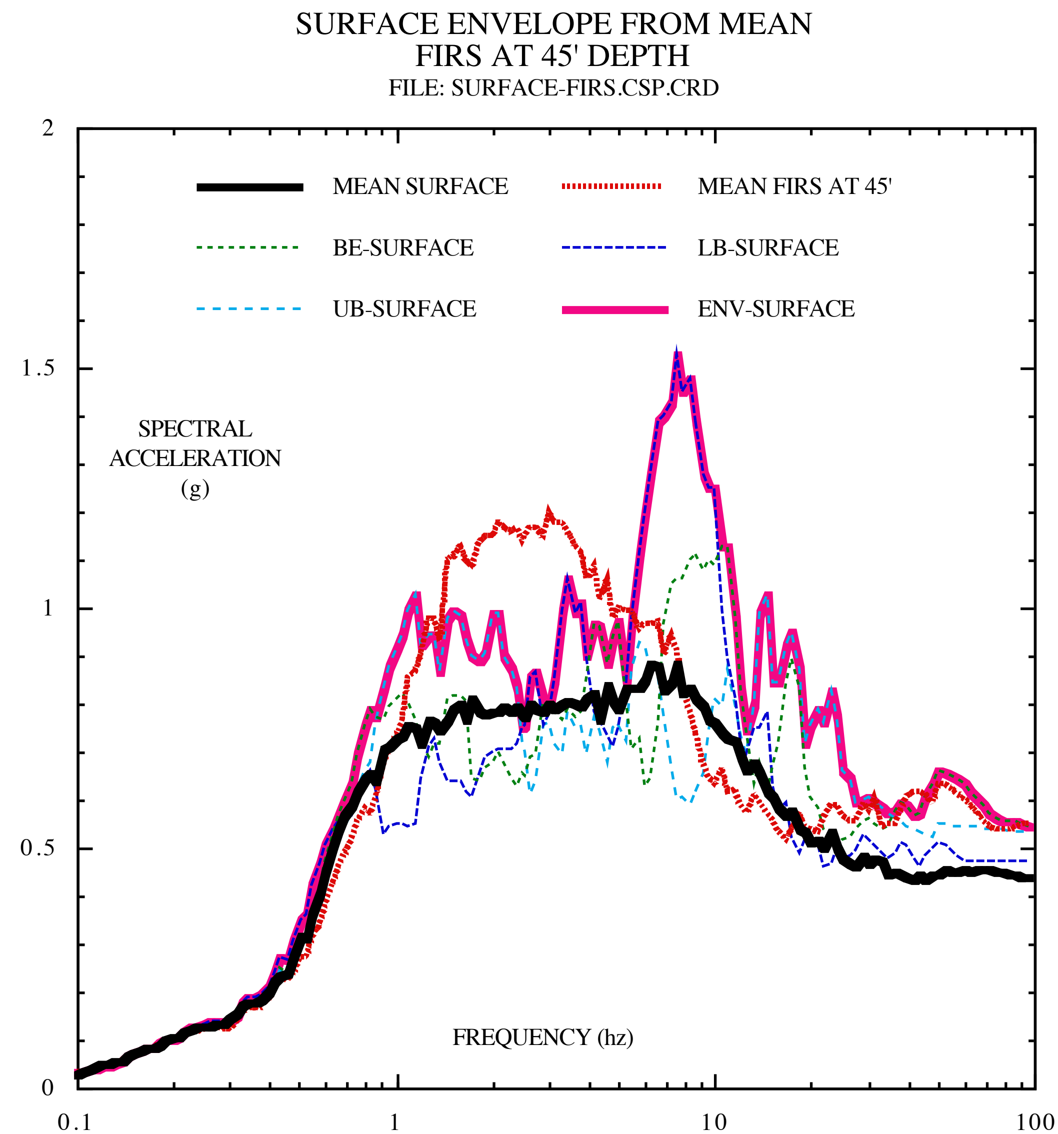

Figure 4. Surface Spectra Computed from Mean FIRS Outcrop at Foundation Level

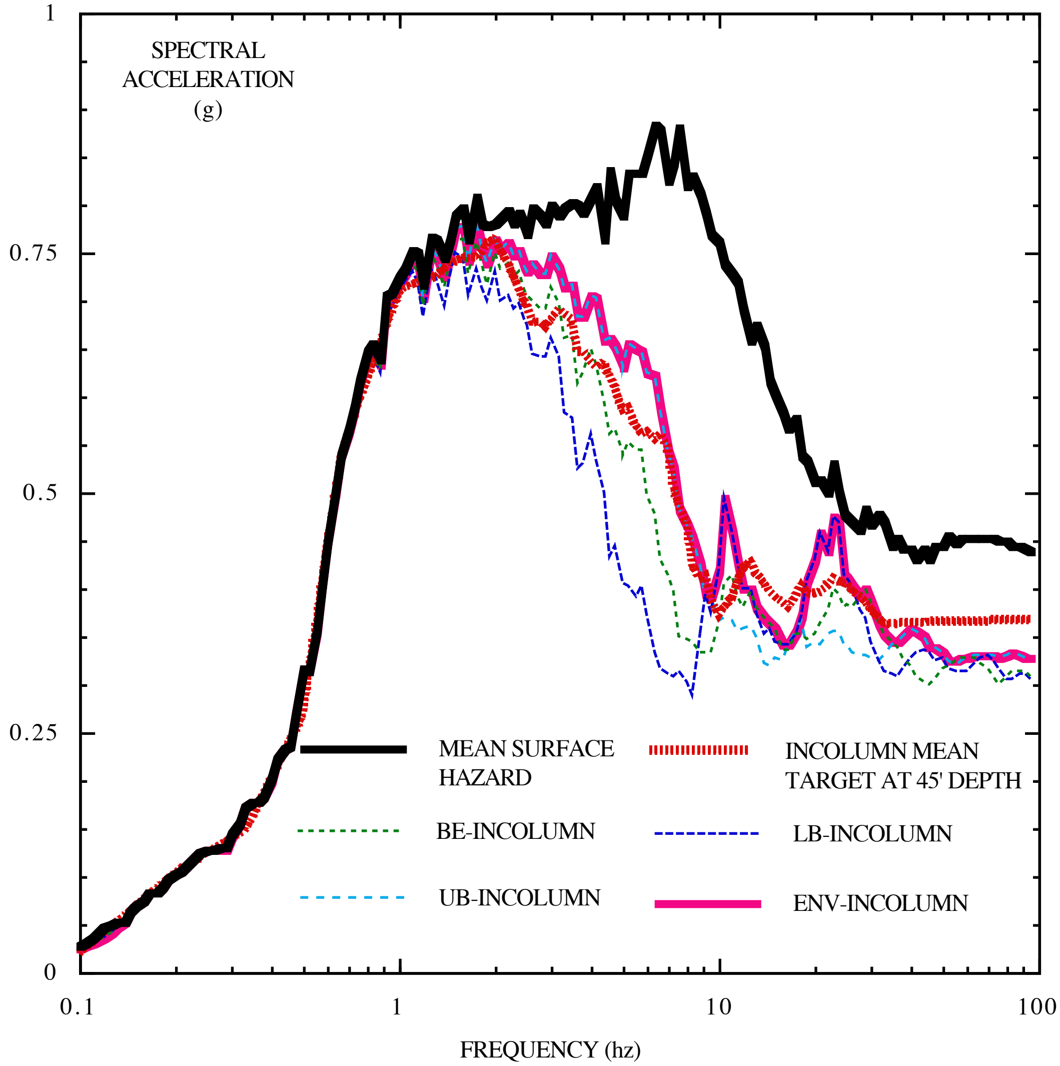

Figure 5. Deconvolutions of Mean Surface Spectra To Foundation Level

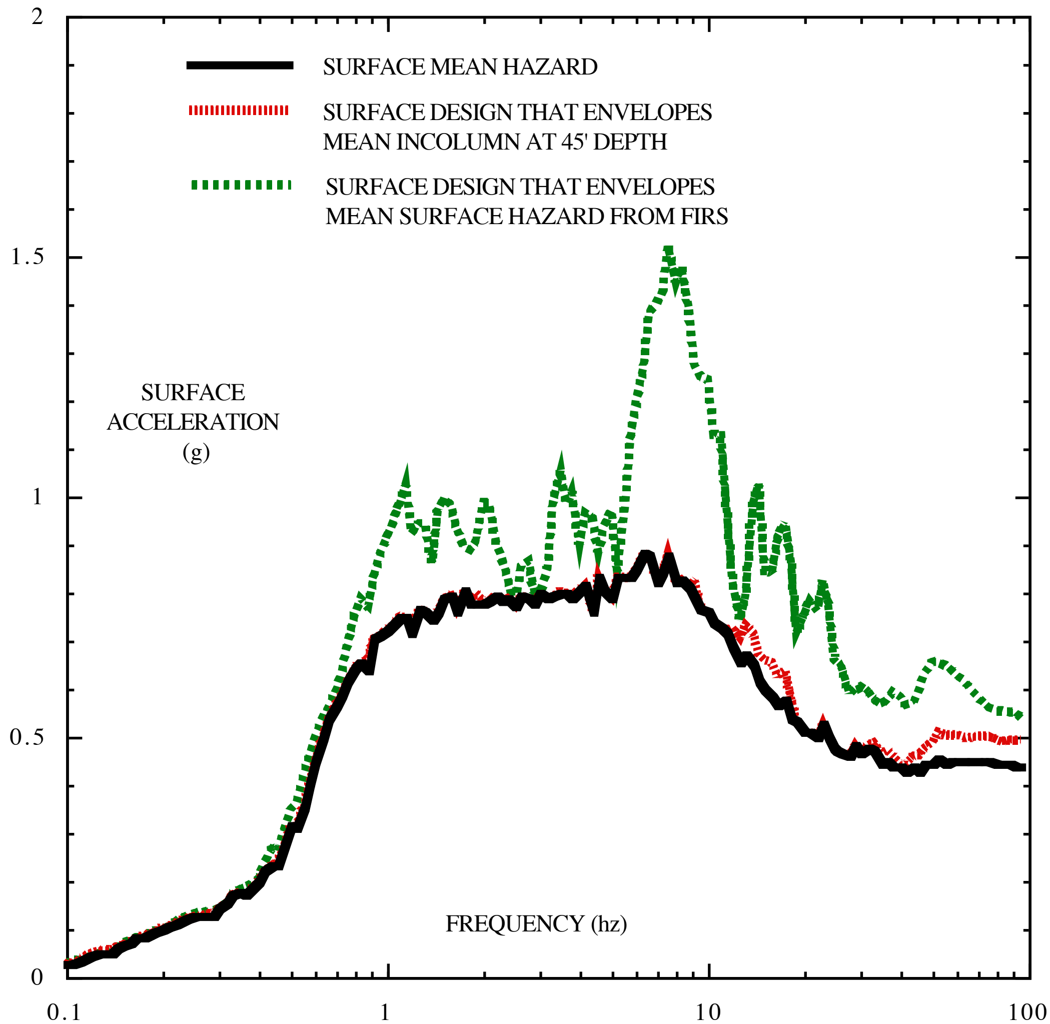

Figure 6. Comparison of Surface Design Spectra Corresponding to the FIRS and Mean Surface Approaches

CONCLUSION

These two different approaches for generating input motions to the deterministic SSI calculations were used to determine seismic demands for an embedded facility being designed for the Department of Energy at the Los Alamos National Laboratory. The site consists of a number of volcanic tuff layers over bedrock, which is at a depth of approximately 700 feet. The velocity profile contains several velocity inversions that have a significant impact on the character of the spectral shapes at various depths associated with either the outcrop FIRS or the corresponding in-column motions. For these calculations, the structural foundation is located at a depth of 45 feet, which is above the highest strong velocity inversion in the profile. The results indicate that the deterministic calculations performed using the outcrop FIRS input motions lead to significantly higher seismic responses than those calculated from the mean-based surface motions.

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