APPENDIX 2A

DESIGN SOIL PROFILES

This appendix describes the process used to select the design soil profiles used in the seismic soil-structure interaction analysis of the AP600 nuclear island and its components. As a first step, selected, existing nuclear power plant sites were surveyed to identify the range of soil profiles, properties, and parameters at these plant sites.

Based on the results of this survey, a subset of generic soil profiles was prepared, covering the range of typical sites where nuclear power plants have been constructed. These generic soil profiles were used in the free-field and the two-dimensional soil-structure interaction (SSI) studies carried out with the AP600 nuclear island structures and basement models.

Using the free-field and two-dimensional SSI responses, governing site conditions from the set of generic profiles were identified as "design soil profiles." These profiles were then used in the three-dimensional soil-structure interaction analysis to obtain the seismic responses of the nuclear island structures and its components.

From the SSI analysis point of view, the design soil profiles need to be characterized in terms of soil properties, most notably the shear wave velocity; depth to base rock; and, ground water level.

Additional studies are presented in Appendix 2B to supplement the selection of design soil profiles and to demonstrate the adequacy of various parameters related to the soil profiles established within this appendix.

2A.1 Survey of a Selection of Existing Nuclear Power Plant Sites in the U.S.

A survey of 22 commercial nuclear power plants in the United States was conducted to identify the subsurface soil profiles and the range of soil properties at these plant sites. Figure 2A-1 shows a map of the United States with the geographic distribution of the plant sites surveyed. The survey included nuclear power plant sites both east and west of the Rockies.

Table 2A-1 summarizes the information regarding the plant location, reactor type, embedment depth of major structures in the plant, depth to base rock, and water table elevation, along with the maximum safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) design input accelerations. Table 2A-1 also introduces the plant identification (ID) numbers used in the tables and figures presented within this appendix.

Based on the results of the survey shown in Table 2A-1, a set of histograms for depth to base rock, depth to water table, and embedment depth of major structures in the plants was prepared (Figures 2A-2 through 2A-4, respectively). Figure 2A-2 shows that the depth to base rock varies from shallow (rock sites) to very deep (deep-soil profiles). Similarly, Figure 2A-3 shows that the depth to water table also varies from shallow to deep.

Because of the wide variation of the depth to base rock and the depth to water table, these two parameters were included in the two-dimensional SSI parametric evaluation in order to identify the governing design soil profiles discussed in Section 2A.3.

The histogram of embedment depth shown in Figure 2A-4 shows that the embedment depth of 40 feet used for the design of the AP600 nuclear island is common among the plants surveyed.

Details on the soil profiles in terms of soil layering and layering sequence; types of material, both in-situ and structural backfill; and more significantly, the variation of the shear wave velocity with depth at each plant site were obtained from the FSARs of the 22 plants surveyed. Table 2A-2 summarizes these results. The results of the survey were used in the preparation of the generalized logs shown in Figure 2A-5.

As expected, soil profiles consist of a more or less random sequence of clay to silty and sandy clay to sand and gravel extending to shale and soft rock or competent bedrock at greater depths. The results of the survey in terms of shear wave velocity appear in Sheet 1 of Figure 2A-6 for plants where the shear wave velocity is less than 2000 feet per second. Sheet 2 of Figure 2A-6 shows the results for plants where the shear wave velocity is greater than 2000 feet per second.

The shear wave velocities above the basemat level shown in Figure 2A-6 correspond to either the in-situ material before excavation and removal or to the structural backfill. The shear wave velocity of the in-situ materials at the basemat level is larger than 1000 feet per second for all the plant sites surveyed. Thus, this limit was selected as a lower-bound shear wave velocity profile in the AP600 studies. Figure 2A-6 shows a range of velocities from 1000 to 10,000 feet per second with the majority of the velocities in the range of 1500 feet per second to 3000 feet per second.

To evaluate the effect of soil layering with depth on the variation of shear wave velocity, the velocity profiles shown in Figures 2A-6, Sheets 1 and 2, were normalized with respect to the shear wave velocity at the basemat level. (See sheet 3 of Figure 2A-6.)

In this figure, except for plant sites where base rock is present at a shallow depth, the maximum gradient corresponds to an increase of shear wave velocity by a factor of about 2 from the basemat level to the depth of about 240 feet from basemat. This ratio served as a guide to select one of the shear wave velocity profiles in the generic profiles.

2A.2 Generic Soil Profiles

To encompass most of the potential site conditions, a broad range of soil properties and soil profiles were included in the generic soil profiles as follows.

Soil Deposit Thickness

The results of the survey discussed in Section 2A.1 show that the depth to base rock may vary from shallow to deep. For the generic soil profiles, the following depths to base rock were included:

Depth to Base Rock (ft)	Notes
0	Rock site.
40	Nuclear island embedded to this depth.
120	This depth corresponds to the average width of the nuclear island basemat plan dimension.
Very deep	Deep soil profiles.

Depth to Water Table

Similarly, the following water table depths were considered:

Depth to Water Table (ft)	Notes
0	Submerged site.
40	Water table at the basemat level of the nuclear island.
Very deep	Deep water table locations.

Shear Wave Velocity Profiles

Four constant or linearly increasing with depth, shear wave velocity profiles and one shear wave velocity profile with step-wise change were considered in the generic studies. Figure 2A-7 shows these velocity profiles.

The velocity profile identified as hard rock (HR) site is a uniform profile with a constant shear wave velocity of 8000 feet per second. This velocity profile represents an upper bound for the generic sites considered.

Next to the hard rock velocity profile is the soft rock (SR) velocity profile, which has a shear wave velocity of 2400 feet per second at the ground surface, increasing linearly to 3200 feet per second at a 240-foot depth.

A lower-bound shear wave velocity identified as soft soil (S) was selected as a third profile in the generic studies. Based on the results of the survey, the lower-bound velocity profile was selected as having a shear wave velocity of 1000 feet per second at the ground surface, with a nominal increase to 1200 feet per second at a 240-foot depth.

The effect of site stratigraphy was considered by selecting the soil profile identified as soft-to-medium soil (SM). Using the results of the survey, this profile was modeled to have a shear wave velocity of 1000 feet per second at the ground surface, increasing linearly to 2400 feet per second at a 240-foot depth.

Finally, a layered soil profile with step-wise change in shear wave velocity profile similar to the WNP-2 nuclear station (see Table 2A-1, plant ID# 15) was considered. The step-wise layered profile has shear wave velocity equal to 1000 feet per second from ground surface to a 40-foot depth, 1800 feet per second between a 40-foot to 80-foot depth, and 4300 feet per second for depth greater than 80 feet.

Summary of Generic Sites Considered

For the profile with step-wise change in velocity, the shear wave velocity and depth to water table were taken to be similar to the WNP-2 nuclear station. The parametric variations for depth to hard rock and to water table location were not considered to maintain the step-wise characteristics of the profile.

For the remaining four subsurface site profiles, four soil deposit depths, three water table locations, and four soil profiles with shear wave velocity being constant or linearly increasing with depth were considered. The combination of these variables results in 48 different soil profiles. A subset of these profiles was selected as the generic profiles for SSI analysis. In selecting this subset, the combinations of soil properties and parameters that could affect the range of SSI responses of the structures were considered. The combination of soil properties and parameters considered are as follows:

	Shear Wave Velocity Profile			
	(HR)	(SR)	(SM)	(S)
1 - Parametric study for depth to base rock variation	no	yes	yes	yes
2 - Parametric study for depth to water table variation	no	no	yes	yes

Section 2A.5 presents the SSI analysis using the preceding five profiles.

2A.3 Applicability of Design Ground Motion to Generic Soil Profiles

The design ground motion used for the seismic analysis of the AP600 is based on the site-independent, smoothed, broad-band Regulatory Guide (R.G.) 1.60 spectra. A single set of three artificial acceleration time histories (two horizontal "H1" & "H2" and one vertical components) was subsequently developed to match the design response spectra scaled to a maximum acceleration of 0.30g for the SSE analysis (see subsection 3.7.1.2). The time histories were prescribed at the finished grade level. The AP600 is intended for use at a wide range of sites with a range of generic soil properties and profiles. It is imperative, therefore, that the design input motion when scaled to maximum acceleration of 0.30g adequately envelopes the ground motion characteristic of the design soil profiles selected.

To verify this, a literature survey was conducted to identify the earthquake records and the local geology of the stations used to derive the R.G. 1.60 response spectra. The R.G. 1.60 response spectra are the results of two independent studies on the statistical properties of recorded ground motions by Newmark, Hall, and Mohraz (Reference 1), and Blume, Sharp, and Dalal (Reference 2). A summary of the earthquake data and of the characteristics of the station sites appears in Table 2A-3. The data were obtained from the referenced Newmark and Blume studies, Newmark, Blume and Kapur (Reference 3), and NUREG/CR-1643 (Reference 4). In the Newmark study, 14 earthquakes with two components of horizontal motion and one component of vertical motion were used for each event. The maximum ground acceleration varied from 0.016g to 0.718g in the vertical direction and from 0.031g to 1.20g in the horizontal direction. In the Blume study, 16 earthquakes with two components of horizontal motion were used for each event. The maximum ground acceleration for these earthquakes ranged from 0.11g to 0.51g. An examination of the local soil conditions at the stations where the preceding motions were recorded (see Table 2A-3) indicates a wide range of soil profiles with shear wave velocities from less than 1000 feet per second to rock profiles with much higher velocities. The depth to base rock also varies from very shallow (rock profile) to very deep. Hence, the R.G. 1.60 response spectra were derived using seismic records from stations having a wide range of soil conditions and seismic excitation magnitudes. The design input motions, based on the R.G. 1.60 spectra, therefore adequately addresses the effects of the local soil conditions and applies to the design soil profiles considered in the AP600 seismic SSI analysis.

2A.4 Free-Field Site Response Analysis

A series of one-dimensional free-field soil column analyses, using the computer program SHAKE (Reference 5), was performed to obtain the strain-compatible soil properties for SSI analysis. Strain-compatible soil properties obtained from these analyses were used in the two-dimensional and the three-dimensional SSI analyses of the nuclear island.

Computer Program SHAKE

The program SHAKE computes the responses of a soil system of horizontal layers resting on an elastic half-space subjected to vertically propagating seismic waves. The theory and the computer program are described by Schnabel et al. (Reference 5). The program is based on the continuum solution of the wave equation. The nonlinearities in soil shear modulus and damping are taken into account by using the equivalent linear method to obtain the strain-compatible shear modulus and damping.

Free-Field Analysis Cases

The design input motion at the ground surface was used to perform free-field analysis for the five velocity profiles (hard rock, soft rock, soft-to-medium soil, soft soil, and step-wise layered). Since the input motion is specified at the surface using prescribed shear wave velocity profile, free-field analysis of the profiles with intermediate and shallow depths to base rock and water table are not necessary for obtaining strain-compatible soil properties. The effects of these parameters on the SSI responses are, however, evaluated as described in Section 2A.5.

The strain-dependent shear modulus and damping curves used in the free-field SHAKE analysis were obtained from Seed et al. (References 6 and 7) and Schnabel et al. (Reference 8). The shear modulus and damping curves are shown in Figure 2A-8 for soil materials and in Figure 2A-9 for rock materials. Based on the SRP Section 3.7.2, Revision 2 criteria, the strain-dependent soil material damping is limited to 15 percent. Because the generic soil profiles considered include a wide range of shear wave velocities, the customary ±50 percent variation in low strain shear modulus (G_{max}) for each profile was not applied in the analysis.

Free-Field Analysis Results Using H1 Time History

The free-field analysis results that follow are based on the SHAKE analysis using the horizontal H1 SSE component of the input motion. These results were computed to examine the free-field motion and properties during SSE excitation.

The free-field analysis results in terms of strain-compatible soil properties and maximum accelerations, along with the initial properties used in the analysis, appear in Tables 2A-4 through 2A-8 for hard rock, soft rock, soft-to-medium soil, soft soil, and step-wise layered soil profiles, respectively. The variation of initial (maximum) and strain-compatible shear wave velocity with depth appear in Figures 2A-10 through 2A-14.

As shown in these figures, the softening effect due to shear strain is larger for the softer soil profiles as compared to that for the stiffer soil profiles. Furthermore, the variations of maximum acceleration with depth appear in Figures 2A-15 through 2A-19. The maximum acceleration does not show significant variation with depth in any of the profiles analyzed.

To evaluate the variation of the free-field motion with depth, acceleration response spectra of the free-field motion at the ground surface and at depths of 20 and 40 feet for 2 percent damping were computed and compared for all five velocity profiles, as shown in Figures 2A-20 through 2A-24. These spectral curves cover the variation of motion from the ground surface down to the embedment depth of the nuclear island.

As shown for each profile, the motion reduces with depth, and the reduction is larger at lower depths. However, this reduction is not uniform for all frequencies. For the hard rock site, the reduction of motion with depth is nominal, and the input motion at the ground surface is practically maintained throughout the embedment depth.

For the soft soil and the step-wise layered soil sites, on the other hand, the reductions of motion are more pronounced. The dip in the amplitude of the response spectrum corresponds to the fundamental soil column frequencies at the depth that the response is calculated.

Soil Properties for SSI Analysis

For SSI analysis, average soil properties obtained from the free-field analysis using both the H1 and H2 SSE components of input motion were used. The average properties appear in Tables 2A-9 through 2A-12 for the soft rock, soft-to-medium soil, soft soil, and step-wise layered soil profiles.

For the hard rock profile, because of large initial shear wave velocity (8000 feet per second) of this profile and nominal reduction of this property due to excitation, SSI effects were considered to be insignificant in this profile. Instead, as described in Section 2A.5, a fixed-base analysis case was considered to represent the results of the hard rock profile.

The following Poisson's ratios were used to obtain the P-wave velocities:

Subsurface Profile	Poisson's Ratio
Soft rock	0.25
Soft-to-medium soil	0.35
Soft soil	0.40
Step-wise layered	0.35

For submerged layers, the Poisson's ratios were adjusted, if necessary, to maintain the minimum P-wave velocity of 5000 feet per second (P-wave velocity of water).

2A.5 2D Soil-Structure Interaction Analysis

To identify the governing site properties and profiles from the set of generic site conditions, a series of two-dimensional SSI analyses were performed using representative AP600 nuclear island structures and basement models. The results of the analysis in terms of acceleration response spectra and seismic forces at key locations in the structure were computed and compared. From a comparison of these results, the governing site conditions, defined as design soil profiles, were identified. The design soil profiles were then used in the three-dimensional SSI analysis to obtain the seismic SSI response of the AP600 nuclear island structures and components.

SSI Analysis Method

The seismic SSI response of the AP600 structures was obtained using the linear finite element SSI computer program SASSI, Lysmer et al. (Reference 9) and Ostadan (Reference 10). This program is capable of rigorously handling the SSI problems with embedded and flexible foundations.

In performing the analysis using the SASSI program, structural responses in terms of accelerations and forces can be computed directly. The program has an extensive finite element library that permits the direct use of detailed structural models for SSI response analysis. Floor response spectra can also be computed directly within the program from the calculated response acceleration time histories.

These capabilities in SASSI eliminate the need for a second-step structural response analysis in which the fixed-base structural model is subjected to the base motions resulting from the first-step SSI analysis. The direct solution using the SASSI program has the added advantage that the structural response to all components of base motion, including rocking for an embedded foundation, is automatically accounted for in the solution.

Structural Models

Representative, two-dimensional, lumped-mass stick models of the AP600 nuclear island structures and basement suitable for analysis of seismic excitation in the XZ plane and the YZ plane were developed. Two dimensional, lumped-mass stick models were developed for the coupled auxiliary and shield buildings, the steel containment vessel, and the containment internal structure. The seismic models included masses of all major equipment and the reactor coolant loop. However, in the two dimensional containment internal structure model, the reactor coolant loop model was not included since the total weight of the reactor coolant loop is less than 10 percent of the containment internal structure weight, and it should not affect the SSI response of the containment internal structure model when selecting the design soil profiles.

A series of fixed-base modal analyses were performed for the coupled auxiliary and shield buildings, the containment internal structure, and the steel containment vessel using the XZ- and YZ- two-dimensional models. The modal properties computed for the coupled auxiliary and shield buildings, the containment internal structure, and the steel containment vessel appear in Tables 2A-13, 2A-14, and 2A-15, respectively.

SASSI Foundation Models

The foundation models were developed to model the basemat and side walls with the soil layered profile in both the XZ- and the YZ-planes.

The SASSI foundation model in the XZ-plane appears in Figures 2A-25 and 2A-26. Based on the formulation of program SASSI, the excavated soil model shown in Figure 2A-25 was developed consisting of 414 four-node, plane-strain elements with the properties of the excavated soil volume. The concrete basemat was modeled by 44 plane-strain elements as shown in Figure 2A-26. The nuclear island side walls below the ground surface were modeled using beam elements. Two columns of soil elements and one layer of soil were directly modeled around the foundation basement so that the seismic stresses on the walls and on the basemat could be computed from the SSI analysis.

The coupled auxiliary and shield buildings stick model is attached to the foundation basemat at elevation 66.5 feet. A set of rigid links are modeled at the top of the basemat (see Figure 2A-26) to fully integrate the stick model with the basemat. The other stick models, the containment internal structure and the steel containment vessel models, join the coupled auxiliary and shield buildings model at elevation 82.5 feet. From elevation 82.5 feet to elevation 66.5 feet, all three stick models have a common member. The coupled auxiliary and shield buildings model is connected to the side walls at floor elevations of 82.5 feet and 100 feet using the spring elements. (See Figure 2A-26.)

The SASSI foundation model in the YZ-model appears in Figures 2A-27 and 2A-28. The excavated soil volume was modeled in this plane by 252 four-node, plane-strain elements.

For each SSI analysis case, the average strain-compatible soil properties obtained from the free-field analysis of the same case using H1 and H2 time histories are used as input. (See Tables 2A-9 through 2A-12.) The soil densities used in the SSI analyses are the typical densities that are expected from materials under the in-situ conditions. Representative densities were used for the rock and soil materials. The densities are the total weight densities. No correction is made to adjust the densities for cases where the water table is shallow. The change in the total density for saturated soils is expected to be small and the effect on the dynamic soil properties is negligible.

Input Motion

For the horizontal analysis, the H1 and H2 components of time history developed in Section 3.7.1 were used in the X- and Y-directions, respectively. The vertical component was used in the Z-direction. The control motions were all defined at the finished grade at elevation 100 feet in the free-field.

SSI Analysis Cases

Table 2A-16 summarizes the two-dimensional soil-structure interaction analysis performed. Variation of depth to the base rock was considered for the soft rock, soft-to-medium, and soft soil profiles, where the effect on the SSI response is expected to be more pronounced. Variation to water table was considered for the soft-to-medium and soft soil profiles. Depth to base rock and to water table are expected to affect the SSI responses in the vertical direction and the horizontal X-direction along which the foundation basemat has the longest dimension. For this reason, the XZ-model was used for the vertical analyses, and only a few cases of shaking in the Y-directions were considered for the two-dimensional SSI analysis. Variations of depth to water table were selected for the profiles with the base rock at the depth of 120 feet. This depth of base rock governed the responses of the corresponding profiles when the depth to base rock effect was studied.

Site parametric variation was not considered for the step-wise layered soil profile. The site parameters for the layered profile were taken to be similar to the WNP-2 nuclear station, using similar shear wave velocity profile and depth to water table at 60 feet below ground surface.

SSI Analysis Results

All SSI cases shown in Table 2A-16 have been analyzed. The SSI analysis results were evaluated in terms of the acceleration response spectra and maximum loads at key locations in the buildings. The results from the horizontal and vertical analyses were determined separately, and co-directional responses were not combined for this study. The key locations at which the response spectra were computed are as follows:

Location	Note
Nuclear island model at elevation 100 ft	Grade level in the building
Nuclear island model at elevation 153 ft	Top of the auxiliary building
Nuclear island model at elevation 180 ft	Top of the fuel building
Nuclear island model at elevation 307.5 ft	Top of the shield building roof structure
Concrete internal structure at elevation 107 ft	At grade level inside containment
Concrete internal structure at elevation 135 ft	Operating deck
Steel containment vessel at elevation 205.3 ft	At polar crane support girder on containment vessel

SSI responses of each case were compared with the rigid base (hard rock) results to evaluate the SSI effects, and identify the governing site conditions for each soil profile.

The SSI results of the soft rock cases (A1 and A2 cases in Table 2A-16) with depth to base rock at very deep and 120-foot depth were compared with the rigid base results (R1 case). Comparison of these results showed that the horizontal X- and Y-responses exceed the rigid base results between frequencies 2 to 4 cycles per second. The vertical responses were governed by the rigid base results. The results of A1 and A2 cases were relatively close, with A2 case results exceeding the A1 case results by a relatively low margin. Comparison of these results indicated that for the soft rock profile, A2 case with depth to base rock of 120 feet is the governing site condition.

The corresponding results for the soft-to-medium soil profiles (B1, B2, and B3 cases in Table 2A-16) to study the effect of depth to base rock were also compared with the rigid base results (R1 case). Comparison of these results showed that B2 case horizontal results governed the responses at frequencies between 1.5 to 2.5 cycles per second, with the dominant SSI frequency at about 1.8 cycles per second. At higher frequencies, the results were governed by the rigid base case. The results of the B3X case, north-south direction, were generally governed by the rigid base results in the frequency range of analysis. For this reason, a horizontal analysis for the B3 case in the Y-direction was not performed. For vertical responses, the B2 case results governed the responses in the frequency range of 2 to 4 cycles per second, with the dominant SSI frequency at about 3.7 cycles per second. Comparison of the results for the soft-to-medium soil cases indicated that under dry conditions, the B2 case with depth to base rock of 120 feet is the governing condition.

The corresponding results for the soft soil profiles (C1, C2, and C3 cases in Table 2A-16) were compared with the rigid base results (R1 case). Comparison of the horizontal responses showed that the C2 case (base rock at the 120-foot depth) exceeded the rigid base results in the frequency range of 0.70 to 1.4 cycles per second, with the SSI frequency at about 1.35 cycles per second. The exceedance, however, was nominal. Comparison of vertical responses showed that the C2 case results governed the response in the frequency range of 1 to 3 cycles per second. Overall comparison of the soft soil profile under dry conditions indicated that the C2 case with base rock at the depth of 120 feet is the governing site condition for the soft soil.

The effect of depth to the water table was also studied for the soft-to-medium and the soft soil profiles. For each profile, the governing depth to base rock condition (120-foot depth) was selected. The water table was placed at two elevations, the W1 case with the water table at the free-field grade level and the W2 case with the water table corresponding to the basemat level at the depth of 40 feet.

For the soft-to-medium soil profile, the results of the B2W1 case (water table at grade) and the B2W2 case (water table at the 40-foot depth) were compared with the corresponding dry condition (B2 case) and the rigid base results (R1 case). Comparison of X-direction responses showed that a change of water table elevation has insignificant effect on the results. For this reason, studying the effect of the water table on the horizontal responses in the Y-direction was not warranted. Comparisons of the vertical responses showed that the water table at the grade level controlled the responses in the frequency range of 2 to 8 cycles per second. The increase in the response was mainly due to an increase in foundation effective motion, which results from an increase in the P-wave velocity in conjunction with the SSI frequency for this case. For this reason, for the soft-to-medium soil profile, the water table at the grade level (B2W1 case) is considered to be the governing site condition.

For the soft soil profile, the results of the C2W1 case (water table at grade level) and the C2W2 case (water table at the 40-foot depth) were compared with the corresponding dry condition (C2 case) and rigid base results (R1 case). Similarly, the effect of the water table on the horizontal response was found to be insignificant. The vertical responses were, however, increased because of an increase of foundation effective motion. The increase in the response was in the frequency range in which rigid base results governed the responses. In the low-frequency range of 1 to 3 cycles per second, the C2 case results continued to govern the responses. Therefore, for the soft soil case, the C2 case under dry conditions is selected as the governing site condition.

For the step-wise layered soil profile, the results of the B2A case were compared with the soft rock soil profile (A2 cases), the soft-to-medium soil profile (B2 cases), and the rigid base results (R1 case). The B2A cases results were generally enveloped by the A2, B2, and R1 cases result envelope at all locations.

The results of analysis in terms of maximum seismic member forces at key locations for the governing SSI cases were compared and presented on Table 2A-17. As shown on this table, maximum seismic forces for the nuclear island and the containment internal structure are governed by the rigid base results. For the steel containment vessel, the maximum forces are generally governed by the A2 and B2 cases, depending on the component of the force.

2A.6 AP600 Design Soil Profiles

Based on the series of two-dimensional soil-structure interaction results for the generic soil profiles cases shown on Table 2A-16, the conclusions listed below were derived to identify the design soil profiles. Additional studies, presented in Appendix 2B, supplement the selection of design soil profiles and demonstrate the adequacy of the design soil profiles, with modification to the soft-to-medium soil profile as described in Section 2B.2.

1. The hard rock site was identified as one of the design profiles to envelope the high-frequency response motions and corresponding seismic loads in the design of the AP600 structures and its components. Because of the large shear wave velocity of this profile, rigid base analysis can be performed to obtain the seismic responses for this case.

2. Comparison of the soft rock results (A1 and A2 cases) with the rigid base results shows that the soft rock profile with the base rock at the depth of 120 feet (case A2) is the governing site condition for this profile.

3. For the soft-to-medium soil profiles, the governing site conditions were identified to include depth to the base rock of 120 feet and water table locations at the grade level (case B2W1). The effect of the water table on the horizontal responses was found to be insignificant.

4. The governing site conditions for the soft soil profile was identified to consist of depth to base rock of 120 feet with deep water table location (case C2). However, the soft soil profile gives an acceleration response only slightly higher than the enveloped response of the other three soil profiles at frequencies less than about 1.5 to 2 hertz.

At higher frequencies, as expected, the response of the soft-to-medium soil, the soft rock, and the hard rock profiles control. In addition, the seismic forces on the building elements for the soft soil profile are enveloped by the hard rock, soft rock, and soft-to-medium soil profiles.

Furthermore, based also on the consideration that the higher response of the soft soil profile occurs at frequencies of no practical significance for equipment and the conclusion of the seismic force comparison, the soft soil profile was eliminated from the design soil profiles.

5. Comparison of the step-wise layered soil profile (B2A case) results with the governing soft rock soil profile (A2 cases), soft-to-medium soil profile (B2W1 cases), and the rigid base results shows that the B2A cases results are generally enveloped by the enveloped results of A2, B2W1, and R1 cases at all locations. Therefore, together with the conclusion of the seismic force comparison, the step-wise layered soil profile was eliminated from the design soil profiles.

6. Comparison of seismic forces computed at the key locations in the structure shows a similar trend as was observed for the acceleration response spectra, and confirms the conclusions derived for the design soil profiles.

   Other site interface parameters specified in Section 2.5 are as follows:

   - AP600 plant site is capable of supporting the nuclear island foundation design for all specified site conditions.
   - There is no potential for liquefaction due to a safe shutdown earthquake.
   - There is no potential for fault displacement.

Based on the site interface requirements, together with the acceleration response considerations for the soft soil site noted in Item 4, it is concluded that enveloped responses for the design soil profiles adequately envelop the responses of the AP600 plant structures for plant sites with best-estimated shear wave velocity greater than or equal to 1000 feet per second.

In summary, acceleration response spectra obtained from the governing site conditions identified as design soil profiles (R1, A2, and B2W1 cases) are compared in Figures 2A-29, 2A-30, and 2A-31 for responses in the X-, Y- and Z-directions, respectively. As depicted in these figures, the design soil profiles cover a wide range of SSI frequencies at which the SSI results may exceed the rigid base results. The enveloped seismic responses of the R1, A2, and B2W1 cases are applicable for the design of structures, equipment, and systems for the AP600 and permit the plant to be located at the majority of potential plant sites in the United States.

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Table 2A-1

SUMMARY OF COMMERCIAL NUCLEAR POWER STATIONS SURVEYED

Plant ID Number	Nuclear Plant and Unit(s)	Location (State)	Type	CB or TB Embedment Depth (Ft)	Depth to Rock (Ft)	Backfill Under CB or TB Foundation (Ft)	Depth to Water (Ft)	ZPA (g)	
								SSE	OBE
1	Hope Creek, U-1	New Jersey	BWR	39-CB	1500-2000	10	0	0.2	0.1
2	Callaway, U-1	Missouri	PWR	30-CB	50	28	15	0.2	0.12
3	Palo Verde, U-1,2,3	Arizona	PWR	50-CB	334	None	44	0.2	0.1
4	Arkansas Nuclear One, U-2	Arkansas	PWR	30R-CB	30	None	11	0.2	0.1
5	Calvert Cliffs, U-1,2	Maryland	PWR	46-CB	2500	None	35	0.15	0.08
6	Wolf Creek, U-1	Kansas	PWR	40R-CB	20	None	3	0.12	0.06
7	Grand Gulf, U-1,2	Mississippi	BWR	47½-TB	>185	None	47½	0.15	0.075
8	Millstone, U-2	Connecticut	PWR	53R-CB	53	None	19	0.17	0.09
9	Farley, U-1,2	Alabama	PWR	60R-CB	59	None	5	0.1	0.05
10	Vogtle, U-1,2	Georgia	PWR	66-CB	950	12	55	0.2	0.12
11	Hatch, U-2	Georgia	BWR	55-TB	4000	None	55	0.15	0.08
12	Susquehanna, U-1,2	Pennsylvania	BWR	31R-CB	30	None	0	0.10	0.05
13	Monticello	Minnesota	BWR	40-CB	40	None	20	----	0.06(DBE)
14	Davis-Besse	Ohio	PWR	40R-CB	30	None	0	0.15	0.08
15	WNP-2	Washington	BWR	34-CB	557	9	60	0.25	0.125
16	South Texas, U-1,2	Texas	PWR	59-CB	4000-6000	None	5	0.10	0.05
17	San Onofre, U-2,3	California	PWR	44-CB	850	None	24	0.67	0.33
18	Fort St. Vrain	Denver	HTGR	55R-CB	55	None	23	0.10	0.05
19	Arnold	Iowa	BWR	49R-CB	49	None	17	0.12	0.06
20	Limerick, U-1,2	Pennsylvania	BWR	50R-CB	15	None	deep	0.15	0.075
21	Trojan	Oregon	PWR	33R-CB	<5	None	>33	0.25	0.15
22	Midland, U-1,2	Michigan	PWR	57-CB	300	None	39	0.12	0.06

Abbreviations: CB = Containment Building; TB = Turbine Building; R = Foundation on Rock; U = Unit

Table 2A-2 (Sheet 1 of 4)

LOCAL SOIL CONDITIONS AT THE PLANT SITES SURVEYED

Plant No.	Plant	From Plant Grade Depth (ft)	Soil/Rock* Description	V_s (fps)	Remarks (B.F. = Backfill)
1	Hope Creek	0-3	SM	164	C_s from 0'-39' is for in-situ material.
		3-22	CL	317	
		22-31	ML-CL	401	
		31-35	SP	1,060	
		35-39	ML	1,193	
		39-50	SW(B.F.)	791	C_s from 39'-50' is for structural backfill beneath foundation.
		50-65	CH	1,527	
		65-70	ML	1,200	
		70-75	SM-GW	1,214	
		75-210	SM	1,668	
		210-	SM	2,358	
2	Callaway	0-28	GW(B.F.)	1,107	C_s from 0'-28' is for structural backfill.
		28-50	CL	1,852	
		50-	Rock	10,607	
3	Palo Verde	0-20	SM,SC	996	C_s from 0'-50' is for in-situ material.
		20-30	SM,SC	1,116	
		30-50	SC-SM,CL	1,173	
		50-70	CL	1,194	
		70-77	SP-SM,SC,CL	1,209	
		77-105	CL	1,253	
		105-150	CL	1,281	
		150-159	CL	1,401	
		159-169	SC,CL,SM,ML	1,389	
		169-196	CL	1,308	
		196-206	SC,CL,SM,ML	1,308	
		206-228	CL,CH	1,776	
		228-238	SC,CL,ML,SM	1,984	
		238-265	CL,CH	2,040	
		265-300	CL,CH	2,270	
		300-311	CL,CH	2,701	
		311-334	SC,CL,SM	2,176	
4	ANO	0-30	CL	1,000-2,500	C_s from 0'-30' is for in-situ material.
		30-	Rock	5,350	
5	Calvert Cliffs	0-46		864	C_s for assumed structural backfill.
		46-1125	SP,ML	1,600	
		1125-2500	SM,CL	3,400	
		>2500	Rock	10,000	
6	Wolf Creek	0-20	CL	1,025	C_s from 0'-40' is for in-situ material.
		20-27	Shale	1,735	
		27-39	Limestone	6,200	
		40-55	Rock	3,500	
		55-82	Rock	6,200	
		82-152	Rock	4,000	
		152-292	Rock	4,250	
		292-857	Rock	5,000	
		857-1392	Rock	4,500	
		1392-	Rock	7,000	

* Unified Soil Classification (see sheet 4 of table for definition of classification symbols)

Table 2A-2 (Sheet 2 of 4)

LOCAL SOIL CONDITIONS AT THE PLANT SITES SURVEYED

Plant No.	Plant	From Plant Grade Depth (ft)	Description	Soil/Rock* (fps)	V^s (B.F. = Backfill) Remarks
7	Grand Gulf	0-5½	ML	670	C_S from 0'-47½ is for in-situ material.
		5½-25½	CL	1,100	
		25½-45	Sand	1,600	
		45-47½	CL	1,600	
		47½-65	CL	1,600	
		65-115	CL,ML,SC	1,640	
		115-165	CL,ML,SC	1,720	
		165-235	CL,ML,SC	1,715	
8	Millstone	0-53	SW(B.F.)	920	C_S from 0'-53' is for structural B.F.
		53-	Rock	6,500	
9	Farley	0-4	SM	600	C_S from 0'-60' is for in-situ material.
		4-24	SW	970	
		24-59	Weathered Rock	2,520	
		59-89	Rock	5,360	
		89-	Rock	2,600	
10	Vogtle	0-11	SM(B.F.)	600	C_S - assumed (B.F.)
		11-26	SP,SC	600	C_S from 11'-66' is for in-situ material.
		26-51	SP,SC	1,000	
		51-61	SP,SC	1,000	
		61-66	SP,SC	1,300	
		66-78	SW,SM(B.F.)	1,179	C_S from 66'-78' is for structural B.F.
		78-101	CL	1,650	
		101-137	CL	1,800	
11	Hatch	0-55	SC	1,024	C_S from 0'-55' is for structural B.F.
		55-	SP,CL	2,450	
12	Susquehanna	0-10	SP,SM	3,600	C_S from 0'-31' is for in-situ material.
		10-30	SP,SM,Boulders	6,500	
		30-120	Rock	7,500	
13	Monticello	0-40	SM,ML,SP,SC	879	C_S for assumed structural B.F.
		40-	CL	1,007	
14	Davis-Besse	0-10	SW(B.F.)	796	C_S from 0'-30' is for structural B.F.
		10-30	CL	796	
		30-	Rock	5,700-7,500	
15	WNP-2	0-13	SW	500	C_S from 0'-34' is for in-situ material.
		13-34	SW	800	
		34-43	SW(B.F.)	983	C_S from 34'-43' is for structural B.F.
		43-46	GP-GM	1,700	
		46-68	GP-GM	1,900	
		68-96	GP-GM	4,200	
		96-	GP-GM	4,500	

* Unified Soil Classification (see sheet 4 of table for definition of classification symbols)

Table 2A-2 (Sheet 3 of 4)

LOCAL SOIL CONDITIONS AT THE PLANT SITES SURVEYED

Plant No.	**Plant**	**From Plant Grade Depth (ft)**	**Description**	**Soil/Rock*** **(fps)**	**V_S (B.F. = Backfill)**	**Remarks**
16	South Texas	0-15	CH	625	C_S from 0'-59' is for in-situ material.	
		15-22	CH	800		
		22-42	SM,ML	900		
		42-46	SM	850		
		46-59	CH	1,125		
		59-79	SP-SM	1,125		
		79-89	SP-SM	1,300		
		89-109	CH	1,300		
		109-119	CH	1,400		
		119-129	CH	1,600		
		129-139	SM	1,200		
		139-159	CH	1,200		
		159-169	ML	1,200		
		169-219	CH	1,150		
		219-229	SM	1,600		
		229-239	SM	1,300		
		239-279	CH	1,300		
		279-289	CH	1,600		
		289-300	SM	1,350		
17	San Onofre	0-44	SW,SM,SC	2,200	C_S from 0'-44' is for in-situ material.	
		44-850	SW	2,750		
		850-1950	Rock	2,800		
		1950-2350	Rock	3,350		
		2350-3850	Rock	6,000		
18	Fort St. Vrain	0-8	SP	195	C_S from 0'-55' is for in-situ material.	
		8-43	SW	195		
		43-55	GP-GC	195		
		55-	Rock	1,890		
19	Arnold	0-30	SC-SM,SW	500	C_S from 0'-49' is for in-situ material.	
		30-49	SW	1,800		
		49-375	Rock	8,600		
		375-2500	Rock	9,800		
20	Limerick	0-15	GP(B.F.)	1,135	C_S from 0'-50' is for structural B.F.	
		15-	Rock	6,000		
21	Trojan	0-	Rock	4,500-5,000	C_S from 0'-33' is for in-situ rock.	
22	Midland	0-19	SW	500	C_S from 0'-19' is for structural B.F.	
		19-34	SW	850		
		34-57	CL	2,300	C_S from 19'-57' is for in-situ material.	
		57-134	CL	2,300		

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* Unified Soil Classification (see sheet 4 of table for definition of classification symbols)

Table 2A-2 (Sheet 4 of 4)

LOCAL SOIL CONDITIONS AT THE PLANT SITES SURVEYED

Unified Soil Classification *

Group Symbol	Group Description
GW	Well-graded gravels, gravel-sand mixtures, little or no fines
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
GM	Silty gravels, gravel-sand-silt mixtures
GC	Clayey gravels, gravel-sand-clay mixtures
SW	Well-graded sands, gravelly sands, little or no fines
SP	Poorly graded sands, gravelly sands, little or no fines
SM	Silty sands, sand-silt mixtures
SC	Clayey sands, sand-clay mixtures
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
CH	Inorganic clays of high plasticity, fat clays

* Unified soil classification system per ASTM D2487, Reference 11.

Table 2A-3 (Sheet 1 of 2)

R.G. 1.6-BASED RECORDED MOTION STATIONS

Earthquake Data							No. of Records Used for Developing RG 1.60 SpectrA		Station Site Characteristics		
Earthquake	**Location of Epicenter**	**Date**	**Magnitude**	**Recording Station**	**Component**	**Max. Acc.**	**Newmark Study**	**Blume Study**	**Depth to Rock (Ft)**	**Site Classification**	**Shear Wave Velocity Range (ft/sec)**
El Centro	El Centro,	1934	6.5	El Centro	NS	.26	--	√	deep	stiff	500 to 1,000
	CA				EW	.18	--	√			
Helena	Helena, MT	1935	6.0	Helena	NS	.13	--	√	rock	rock	----
					EW	.16	--	√			
El Centro	Imperial Valley, CA	1940	6.3	El Centro	NS	.33	√	√	deep	stiff	500 to 1,000
					EW	.22	√	√			
					V	.28	√	--			
Olympia	Western Washington	1949	7.1	Olympia	N4W	.19	--	√	420	deep cohesionless soil	500 to 2,000
					S86W	.31	--	√			
Ferndale	Northwest California	1951	5.8	Ferndale	N46W	.12	√	--	500	deep cohesionless soil	500 to 1,000
					S44W	.12	√	--			
					V	.03	√	--			
Kern County	Kern County,	1952	7.7	TAFT,	N21E	.18	--	√	rock	rock	----
	CA				N69E	.16	--	√			
				Hollywood Storage Basemat	NS	.06	√	--	200	deep cohesionless soil	700 to 2,500
					EW	.05	√	--			
					V	.02	√	--			
				Hollywood Storage Lot	NS	.06	√	--	200		
					EW	.04	√	--		deep	
					V	.02	√	--		cohesionless	
										soil	
Eureka	Eureka, CA	1954	6.6	Eureka	N79E	.26	√	√	400	deep cohesionless soil	700 to 2,000
					N11W	.18	√	√			
					V	.11	√	--			
				Ferndale	N46W	.21	√	--			500 to 1,500
					N44E	.17	√	--		deep	
					V	.05	√	--		cohesionless	
										soil	
El Centro	El Alamo,	1956	6.3	El Centro	NS	.04	√	--		stiff	500 to 1,000
	Baja CA				EW	.05	√	--	deep		
					V	.02	√	--			
San Francisco	Daly City, CA	1957	5.3	Golden Gate Park	N10E	.11	√	√	rock	rock	2,300
					N80W	.13	√	√			
					V	.05	√	--			
Hollister	Hollister, CA	1961	5.6	Hollister	S01W	.08	√	--	deep	deep cohesionless soil	500 to 2,000
					N89W	.19	√	--			
					V	.06	√	--			

Table 2A-3 (Sheet 2 of 2)

R.G. 1.60-BASED RECORDED MOTION STATIONS

Earthquake Data							No. of Records Used for Developing RG 1.60 Spectra		Station Site Characteristics		
Earthquake	**Location of Epicenter**	**Date**	**Magnitude**	**Recording Station**	**Component**	**Max. Acc.**	**Newmark Study**	**Blume Study**	**Depth to Rock (Ft)**	**Site Classification**	**Shear Wave Velocity Range (ft/sec)**
Olympia	Puget Sound, Washington	1965	6.5	Olympia	S4E	.20	--	√	420	deep cohesionless soil	500 to 2,000
					S86W	.16	--	√			
Parkfield	Parkfield, California	1966	5.6	Temblor	N65W	.28	--	√	rock	rock	----
					N25W	.33	--	--			
				Cholame-Shandon #2	N65E	.51	--	√	deep	stiff	500 to 1,500
					S25W	---	--	√			
				Colame-Shandon #5	N5W	.40	--	√	100	stiff	----
					N85E	.47	--	√			
Peru	Peru	1966	7.5	Lima	N8E	.42	--	√	----	----	----
					N82W	.27	--	√			
El Centro	Borrego, MT	1968	6.5	El Centro	NS	.14	√	--	deep	stiff	500 to 1,000
					EW	.06	√	--			
					V	.04	√	--			
Tikachi-Oki	Japan	1968	7.8	Hachinoche, Japan	NS	.19	--	√	deep	deep cohesionless soil	----
					EW	.23	--	√			
San Fernando	San Fernando, California	1971	6.5	Pacoima Dam	S74W	1.25	√	--	rock	rock	2,500
					S16E	1.24	√	--			
					V	.72	√	--			
				Castaic, CA	N21E	.34	√	√	120	stiff	500 to 2,000
					S69E	.29	√	√			
					V	.18	√	--			
				Bank of California	N11E	.23	√	√	70	stiff	----
					N79W	.14	√	√			
					V	.11	√	--			
				Sheraton Universal	NS	.18	--	√	--	stiff	----
					EW	.13	--	√			
					V	.28	--	--			
				V.N. Holiday Inn, Calif.	NS	.28	√	√	800	deep cohesionless soil	----
					EW	.15	√	√			
					V	.18	√	--			

Table 2A-4

SHAKE ANALYSIS RESULTS FOR HARD ROCK PROFILE

Depth (Ft)	Thick-ness (Ft)	Layer No.	Density (KCF)	Initial G (KSF)	Initial Vs (FPS)	SSE H1 (0.30 g) G(KSF)	Vs(FPS)	ACCE (g)	Damp
0								0.30	
10	10	1	0.15	298137	8000	298137	8000	0.30	0.006
20	10	2	0.15	298137	8000	298137	8000	0.30	0.006
30	10	3	0.15	298137	8000	298137	8000	0.30	0.006
40	10	4	0.15	298137	8000	297892	7997	0.30	0.007
60	20	5	0.15	298137	8000	296972	7984	0.30	0.007
100	40	6	0.15	298137	8000	295780	7968	0.29	0.008
Halfspace	-	-	0.15	298137	8000	298137	8000	-	0.005

Table 2A-5

SHAKE ANALYSIS RESULTS FOR SOFT ROCK PROFILE

						SSE H1 (0.30 g)			
Depth (Ft)	**Thickness (Ft)**	**Layer No.**	**Density (KCF)**	**Initial G (KSF)**	**Initial Vs (FPS)**	**G (KSF)**	**Vs (FPS)**	**ACCE (g)**	**Damp**
0								0.30	
10	10	1	0.15	27214	2417	27086	2411	0.30	0.007
20	10	2	0.15	27962	2450	27352	2423	0.30	0.009
30	10	3	0.15	28720	2483	27742	2440	0.29	0.010
40	10	4	0.15	29512	2517	28243	2462	0.29	0.011
60	20	5	0.15	30696	2567	28895	2491	0.29	0.012
80	20	6	0.15	32295	2633	29936	2535	0.28	0.013
120	40	7	0.15	34795	2733	31756	2611	0.28	0.014
160	40	8	0.15	38290	2867	34524	2722	0.25	0.015
200	40	9	0.15	41925	3000	37565	2840	0.22	0.015
Halfspace	-	-	0.15	47702	3200	47702	3200	-	0.010

Table 2A-6

SHAKE ANALYSIS RESULTS FOR SOFT-TO-MEDIUM SOIL PROFILE

Depth (Ft)	Thickness (Ft)	Layer No.	Density (KCF)	Initial G (KSF)	Initial Vs (FPS)	SSE H1 (0.30 g)			
						G (KSF)	Vs (FPS)	ACCE (g)	Damp
0								0.30	
10	10	1	0.11	3617	1029	3073	948	0.30	0.032
20	10	2	0.11	4044	1088	2988	935	0.29	0.056
30	10	3	0.11	4486	1146	2876	918	0.28	0.076
40	10	4	0.11	4952	1204	2870	917	0.28	0.088
60	20	5	0.11	5702	1292	3014	939	0.26	0.098
80	20	6	0.11	6772	1408	3476	1009	0.25	0.102
120	40	7	0.11	8560	1583	4721	1176	0.24	0.094
160	40	8	0.12	12304	1817	7391	1408	0.24	0.084
200	40	9	0.12	15661	2050	9386	1587	0.26	0.084
Halfspace	-	-	0.12	21466	2400	21466	2400	-	0.020

Table 2A-7

SHAKE ANALYSIS RESULTS FOR SOFT SOIL PROFILE

Depth (Ft)	Thickness (Ft)	Layer No.	Density (KCF)	Initial G (KSF)	Initial Vs (FPS)	SSE H1 (0.30 g) G (KSF)	Vs (FPS)	ACCE (g)	Damp
0								0.30	
10	10	1	0.11	3444	1004	2894	920	0.31	0.034
20	10	2	0.11	3506	1013	2414	841	0.30	0.066
30	10	3	0.11	3561	1021	2000	765	0.28	0.110
40	10	4	0.11	3617	1029	1728	711	0.25	0.131
60	20	5	0.11	3709	1042	1466	655	0.21	0.136
80	20	6	0.11	3824	1058	1431	647	0.24	0.147
120	40	7	0.11	4007	1083	1305	618	0.32	0.150
160	40	8	0.11	4262	1117	967	532	0.43	0.150
200	40	9	0.11	4518	1150	870	505	0.65	0.150
Halfspace	-	-	0.11	4919	1200	4919	1200	-	0.020

Table 2A-8

SHAKE ANALYSIS RESULTS FOR STEP-WISE LAYERED SOIL PROFILE

						SSE H1 (0.30 g)			
Depth (Ft)	**Thickness (Ft)**	**Layer No.**	**Density (KCF)**	**Initial G (KSF)**	**Initial Vs (FPS)**	**G (KSF)**	**Vs (FPS)**	**ACCE (g)**	**Damp**
0								0.30	
10	10	1	0.11	3416	1000	2879	918	0.30	0.034
20	10	2	0.11	3416	1000	2390	836	0.29	0.064
30	10	3	0.11	3416	1000	1942	754	0.28	0.090
40	10	4	0.11	3416	1000	1634	692	0.28	0.110
60	20	5	0.12	12075	1800	8832	1539	0.23	0.058
80	20	6	0.12	12075	1800	7984	1464	0.22	0.072
120	40	7	0.14	80391	4300	71994	4069	0.19	0.026
160	40	8	0.14	80391	4300	69951	4011	0.18	0.029
200	40	9	0.14	80391	4300	67819	3949	0.18	0.035
Halfspace	-	-	0.14	80391	4300	80391	4300	-	0.020

Table 2A-9

SHAKE ANALYSIS RESULTS FOR SOFT ROCK PROFILE (AVERAGE OF H1 & H2 ANALYSES)

				SSE Avg (H1 and H2)		
Depth (Ft)	**Thickness (Ft)**	**Layer No.**	**Density (KCF)**	**Vs(FPS)**	**Vp(FPS)**	**Damping**
0						
10	10	1	0.15	2411	4176	0.007
20	10	2	0.15	2423	4197	0.009
30	10	3	0.15	2440	4226	0.010
40	10	4	0.15	2461	4262	0.011
60	20	5	0.15	2490	4312	0.012
80	20	6	0.15	2535	4391	0.013
120	40	7	0.15	2610	4520	0.014
160	40	8	0.15	2720	4711	0.015
200	40	9	0.15	2835	4910	0.016
Halfspace	-	-	0.15	3200	5543	0.010

Table 2A-10

SHAKE ANALYSIS RESULTS FOR SOFT-TO-MEDIUM SOIL PROFILE (AVERAGE OF H1 & H2 ANALYSES)

				SSE Avg (H1 and H2)		
Depth (Ft)	**Thickness (Ft)**	**Layer No.**	**Density (KCF)**	**Vs(FPS)**	**Vp(FPS)**	**Damping**
0						
10	10	1	0.11	947	1972	0.033
20	10	2	0.11	928	1932	0.059
30	10	3	0.11	909	1892	0.078
40	10	4	0.11	907	1888	0.091
60	20	5	0.11	926	1928	0.102
80	20	6	0.11	988	2057	0.107
120	40	7	0.11	1149	2392	0.099
160	40	8	0.12	1384	2881	0.088
200	40	9	0.12	1577	3284	0.086
Halfspace	-	-	0.12	2400	4997	0.020

For submerged layers, Vp = 5,000 FPS is used

Table 2A-11

SHAKE ANALYSIS RESULTS FOR SOFT SOIL PROFILE (AVERAGE OF H1 & H2 ANALYSES)

Depth (Ft)	Thickness (Ft)	Layer No.	Density (KCF)	SSE Avg (H1 and H2) Vs(FPS)	Vp(FPS)	Damping
0						
10	10	1	0.11	921	2257	0.034
20	10	2	0.11	839	2054	0.067
30	10	3	0.11	759	1859	0.094
40	10	4	0.11	700	1714	0.114
60	20	5	0.11	631	1546	0.138
80	20	6	0.11	605	1482	0.143
120	40	7	0.11	597	1463	0.149
160	40	8	0.11	572	1400	0.150
200	40	9	0.11	542	1328	0.150
Halfspace	-	-	0.11	1200	2939	0.020

For submerged layers, Vp = 5,000 FPS is used

Table 2A-12

SHAKE ANALYSIS RESULTS FOR STEP-WISE LAYERED SOIL PROFILE (AVERAGE OF H1 & H2 ANALYSES)

Depth (Ft)	Thickness (Ft)	Layer No.	Density (KCF)	SSE Avg (H1 and H2) Vs(FPS)	SSE Avg (H1 and H2) Vp(FPS)	SSE Avg (H1 and H2) Damping
0						
10	10	1	0.11	917	1908	0.035
20	10	2	0.11	828	1724	0.067
30	10	3	0.11	745	1552	0.093
40	10	4	0.11	681	1417	0.114
60	20	5	0.12	1524	3173	0.061
80	20	6	0.12	1441	5000	0.076
120	40	7	0.14	4056	7025	0.027
160	40	8	0.14	3992	6915	0.031
200	40	9	0.14	3935	6816	0.036
Halfspace	-	-	0.14	4300	7448	0.020

Table 2A-13

MODAL PROPERTIES OF TWO-DIMENSIONAL, LUMPED-MASS STICK MODEL COUPLED AUXILIARY AND SHIELD BUILDING

	Modal Properties of 2D Model	
Direction of Modal Properties	**Frequency (cps)**	**Percent Mass(1)**
X-Modes	4.33	26.5
	9.78	49.9
	14.47	60.3
	24.0	71.5
	39.12	78.6
Y-Modes	3.84	28.9
	9.14	54.6
	13.94	63.6
	23.82	71.7
	36.29	77.8
Z-Modes	6.28	14.1
	17.86	45.7
	31.81	66.1

<u>Note:</u>

(1) The cumulative percentage of the mass with respect to the total mass in each direction

Table 2A-14

MODAL PROPERTIES OF TWO-DIMENSIONAL, LUMPED-MASS STICK MODEL CONTAINMENT INTERNAL STRUCTURE

Direction of Modal Properties	Modal Properties of 2D Model	
	Frequency (cps)	**Percent Mass(1)**
X-Modes	15.59	38.7
	27.25	41.7
	42.06	97.5
Y-Modes	13.12	35.2
	40.21	97.5
Z-Modes	38.20	41.7

Note:

(1) The cumulative percentage of the mass with respect to the total mass in each direction

Table 2A-15

MODAL PROPERTIES OF TWO-DIMENSIONAL, LUMPED-MASS STICK MODEL STEEL CONTAINMENT VESSEL

	Modal Properties of 2D Model	
Direction of Modal Properties	**Frequency (cps)**	**Percent Mass(1)**
Y-Modes	2.14	19.5
	3.47	77.7
	18.70	94.2
Z-Modes	4.44	13.0
	9.65	93.0

Note:

(1) The cumulative percentage of the mass with respect to the total mass in each direction

Table 2A-16

TWO-DIMENSIONAL SSI ANALYSIS CASE ID'S

Shear Wave Velocity Profile	Depth to Base Rock (Ft)	Depth to Water Table (Ft)	SSI Case ID (X-Shaking)	SSI Case ID (Y-Shaking)	SSI Case ID (Z-Shaking)	Notes
Hard Rock	----	----	R1X	R1Y	R1Z	rigid base
Soft Rock	deep	deep	A1X	A1Y	A1Z	depth to base rock study
	120	deep	A2X	A2Y	A2Z	
Soft-to-Medium Soil	deep	deep	B1X	B1Y	B1Z	depth to base rock study
	120	deep	B2X	B2Y	B2Z	
	40	deep	B3X	----	B3Z	
Soft Soil	deep	deep	C1X	C1Y	C1Z	depth to base rock study
	120	deep	C2X	C2Y	C2Z	
Soft-to-Medium Soil	120(1)	0	B2XW1	----	B2ZW1	depth to water table study
		40	B2XW2	----	B2ZW2	
		deep	B2X	----	B2Z	
Step-Wise Layered Soil	---(2)	60	B2XA	B2YA	B2ZA	layered site study
Soft Soil	120(1)	0	C2XW1	----	C2ZW1	depth to water table study
		40	C2XW2	----	C2ZW2	
		deep	C2X	----	C2Z	

Note:

(1) The governing case corresponding to the depth to base rock study is used

(2) Site parameters similar to the WNP-2 nuclear station is used

Table 2A-17

COMPARISON OF SEISMIC MEMBER FORCES TWO-DIMENSIONAL SSI ANALYSIS

	Coupled Auxiliary & Shield Bldgs. Elevation 100 ft					Containment Internal Structure Elevation 82.5 ft				
	Z-Shaking	X-Shaking		Y-Shaking		Z-Shaking	X-Shaking		Y-Shaking	
SSI Case ID	Axial (10^3K)	Shear (10^3K)	Moment (10^3K-ft)	Shear (10^3K)	Moment (10^3K-ft)	Axial (10^3K)	Shear (10^3K)	Moment (10^3K-ft)	Shear (10^3K)	Moment (10^3K-ft)
R1	37.2	41.4	4433	46.8	4954	15.3	20.0	630.7	18.2	619.7
A2	31.7	40.3	4366	46.6	4963	14.8	15.3	432.3	15.8	448.3
B2	24.1	31.4	3642	36.6	3541	13.2	11.3	306.0	12.1	385.6
B2W1	31.0	34.1	4323	-	-	13.9	12.3	314.5	-	-
C2	25.5	18.9	1960	23.8	2314	11.3	9.6	209.8	11.5	332.9
B2A	28.3	27.3	2774	36.3	3280	13.1	10.8	272.0	12.8	388.1

	Steel Containment Vessel Elevation 82.5 ft				
	Z-Shaking	X-Shaking		Y-Shaking	
SSI Case ID	Axial (10^3K)	Shear (10^3K)	Moment (10^3K-ft)	Shear (10^3K)	Moment (10^3K-ft)
R1	6.6	7.1	871.7	6.7	774.6
A2	5.4	4.5	994	7.5	971.7
B2	4.1	4.4	580.9	9.3	1127
B2W1	6.8	5.3	812.2	-	-
C2	3.7	5.0	620.0	6.6	1048
B2A	3.7	4.4	677.0	7.1	889.5

The B2W1 Case was not analyzed for excitation in the Y-direction.

Figure 2A-1

Commercial Nuclear Power Stations Surveyed

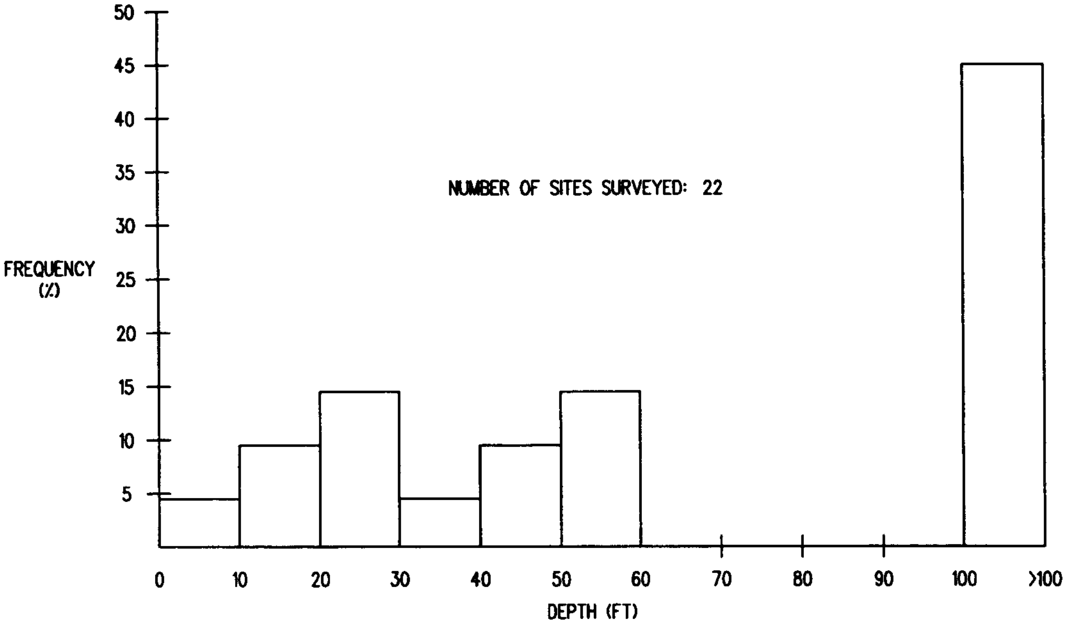

Figure 2A-2

Histogram for Depth to Base Rock

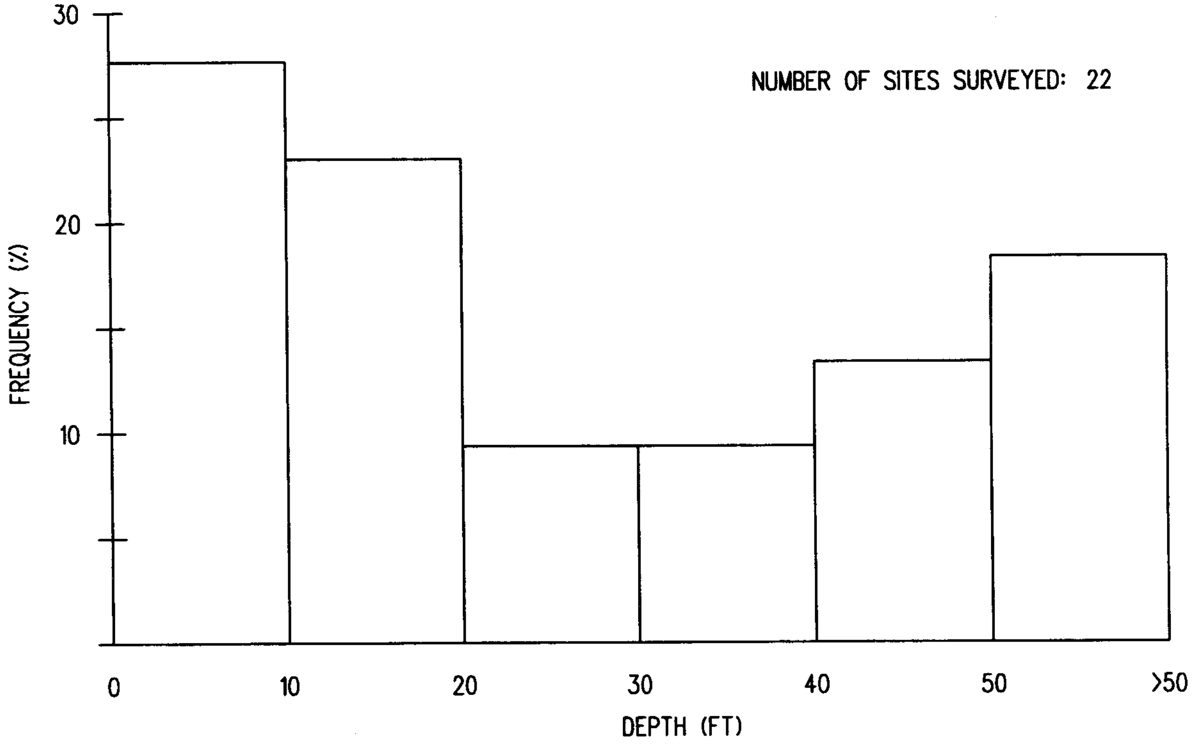

Figure 2A-3

Histogram for Depth to Water Table

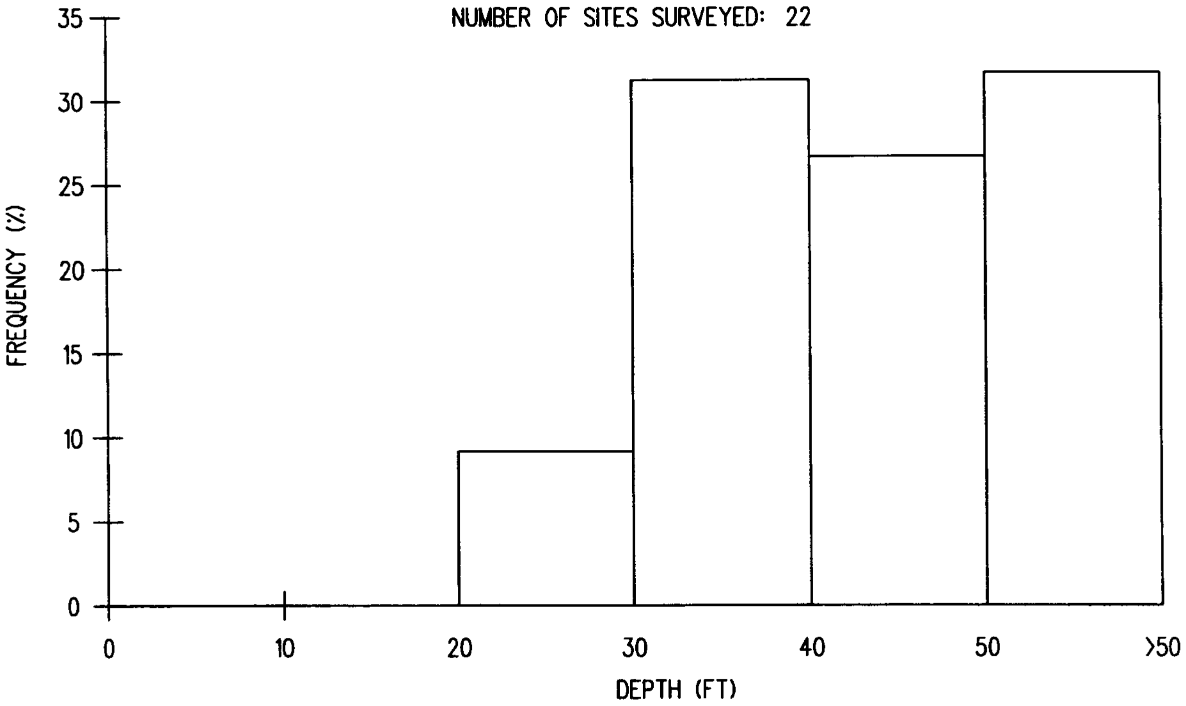

Figure 2A-4

Histogram for Embedment Depth

MATERIAL CONVENTION SYMBOLS

▦	GRAVELS:	Clean gravels, gravel with sand, silty gravels, clay gravels
▭	SANDS:	Clean sands, silty sands, clayey sands
▨	CLAYS:	Lean and fat clays, silts, silty clays, sandy clays, gravelly clays
☰	ROCK:	All types

Figure 2A-5 (Sheet 1 of 4)

Subsurface Profile of Commercial Nuclear Power Plant Sites Surveyed

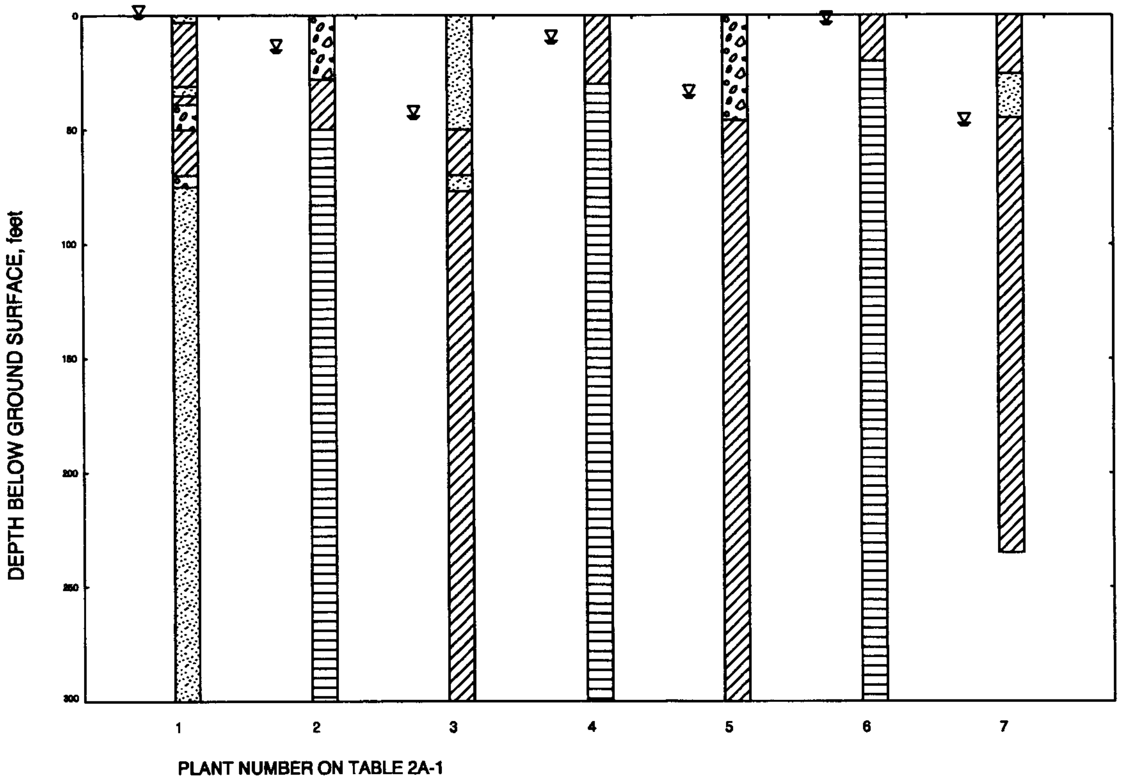

Figure 2A-5 (Sheet 2 of 4)

Subsurface Profile of Commercial Nuclear Power Plant Sites Surveyed

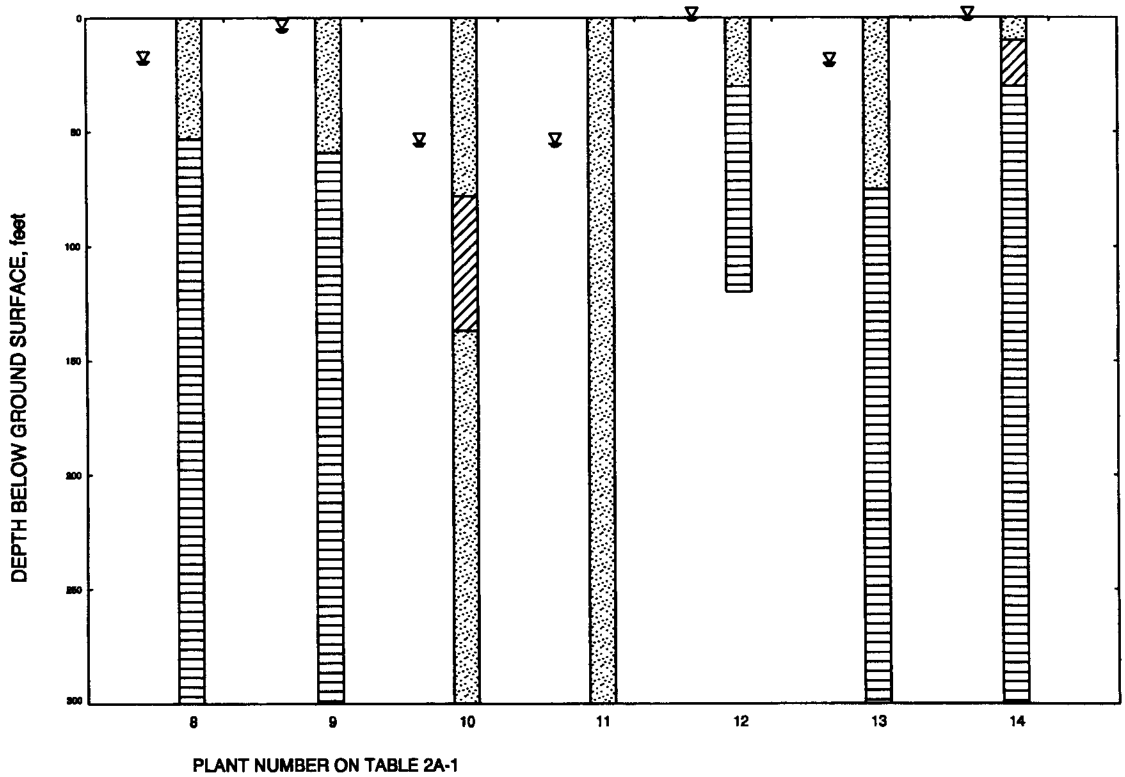

Figure 2A-5 (Sheet 3 of 4)

Subsurface Profile of Commercial Nuclear Power Plant Sites Surveyed

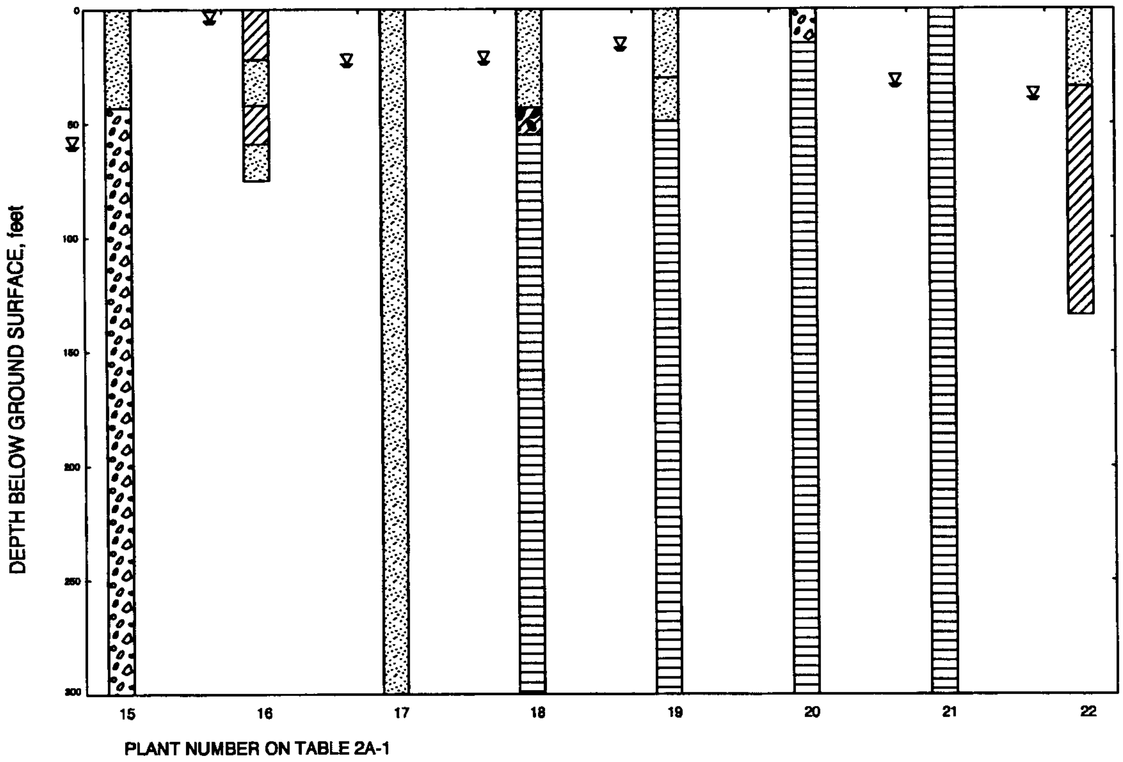

Figure 2A-5 (Sheet 4 of 4)

Subsurface Profile of Commercial Nuclear Power Plant Sites Surveyed

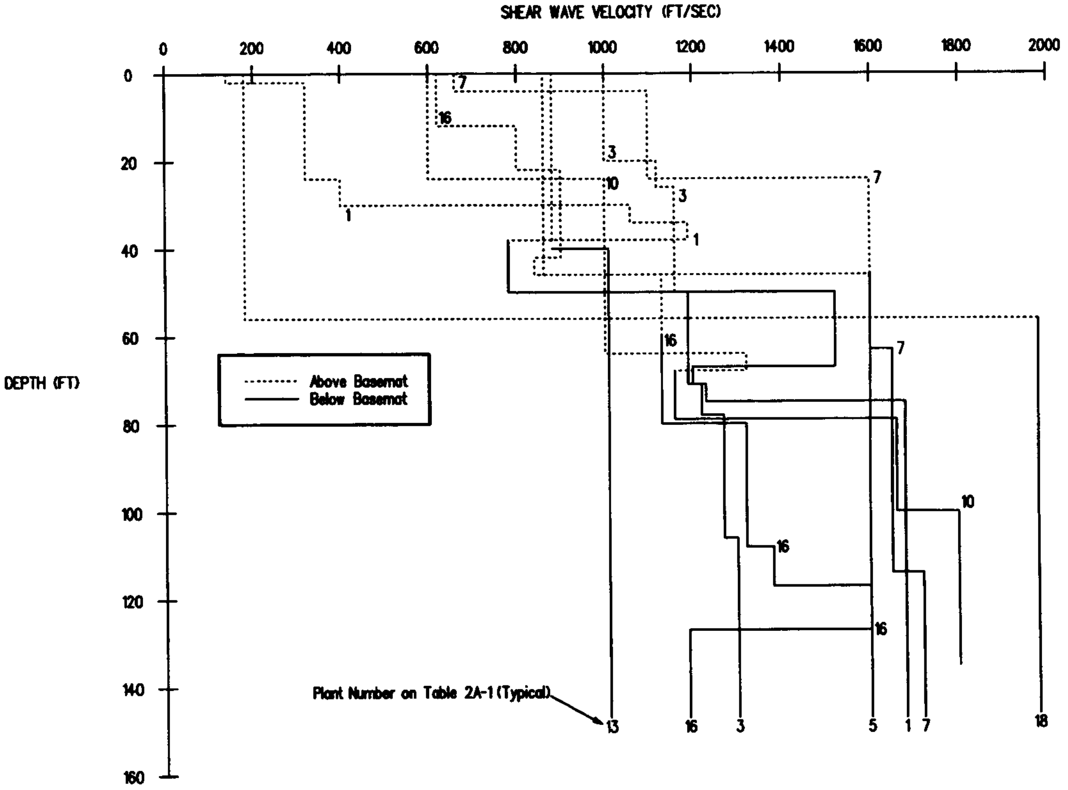

Figure 2A-6 (Sheet 1 of 3)

Soil Conditions for Existing Nuclear Power Plants (V_s Less than 2,000 ft/sec)

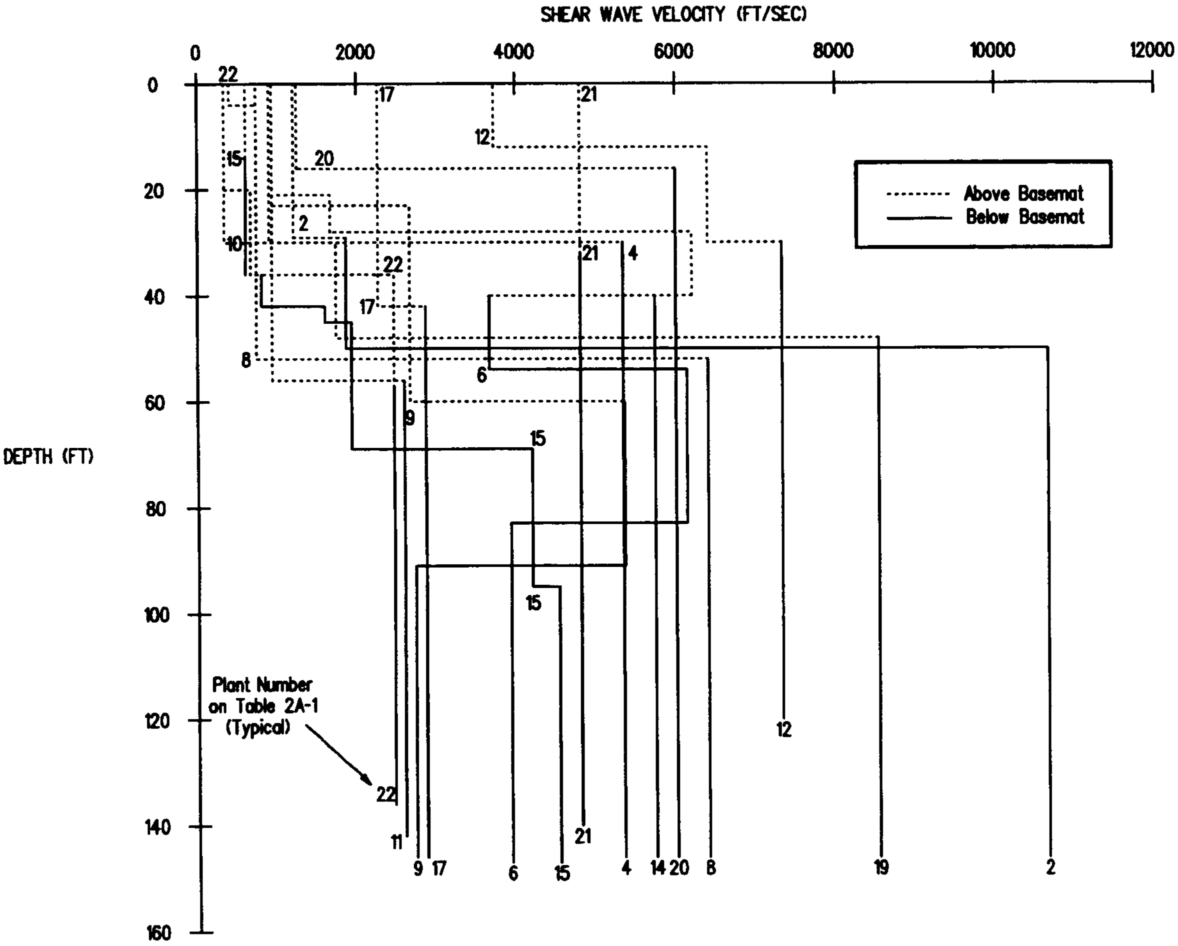

Figure 2A-6 (Sheet 2 of 3)

Soil Conditions for Existing Nuclear Power Plants (V_s Greater than 2,000 ft/sec)

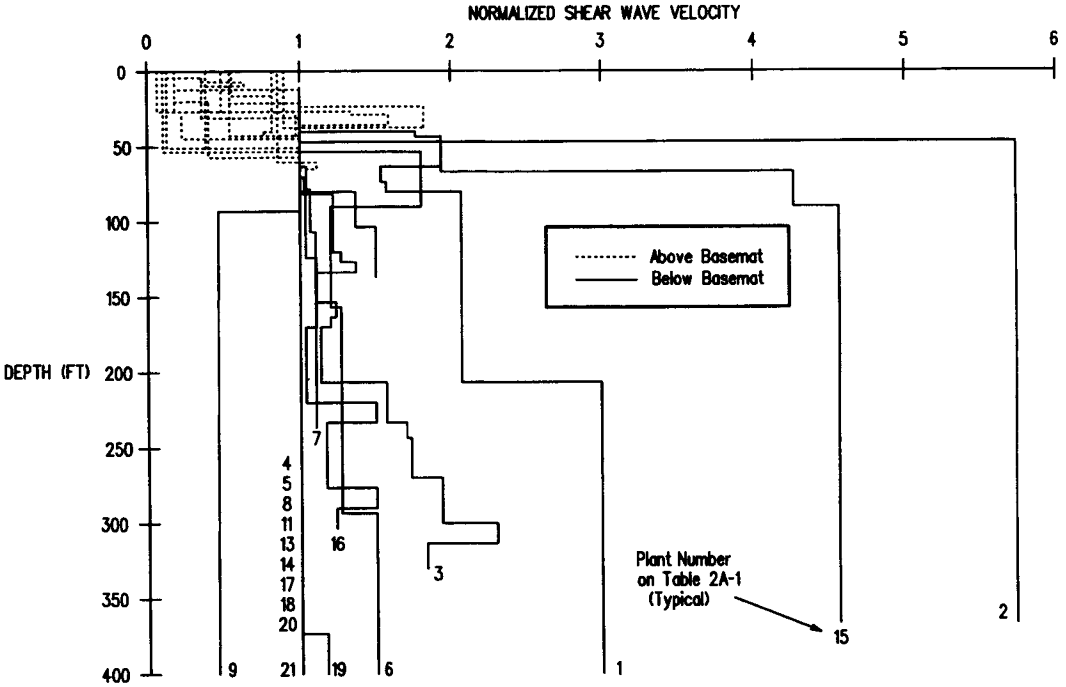

Figure 2A-6 (Sheet 3 of 3)

Soil Conditions for Existing Nuclear Power Plants (Normalized Shear Wave Velocity Profiles)

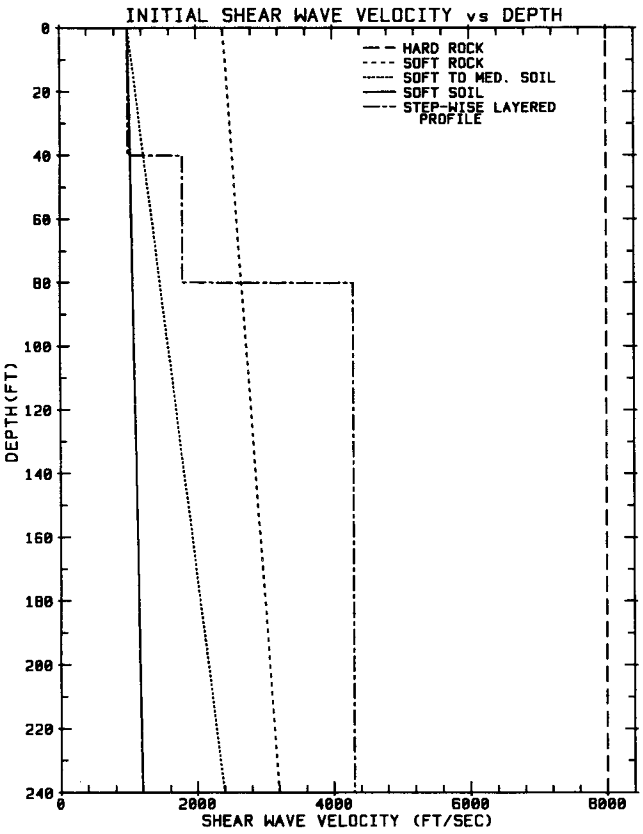

Figure 2A-7

Generic Shear Wave Velocity Profiles (Initial V_s vs. Depth)

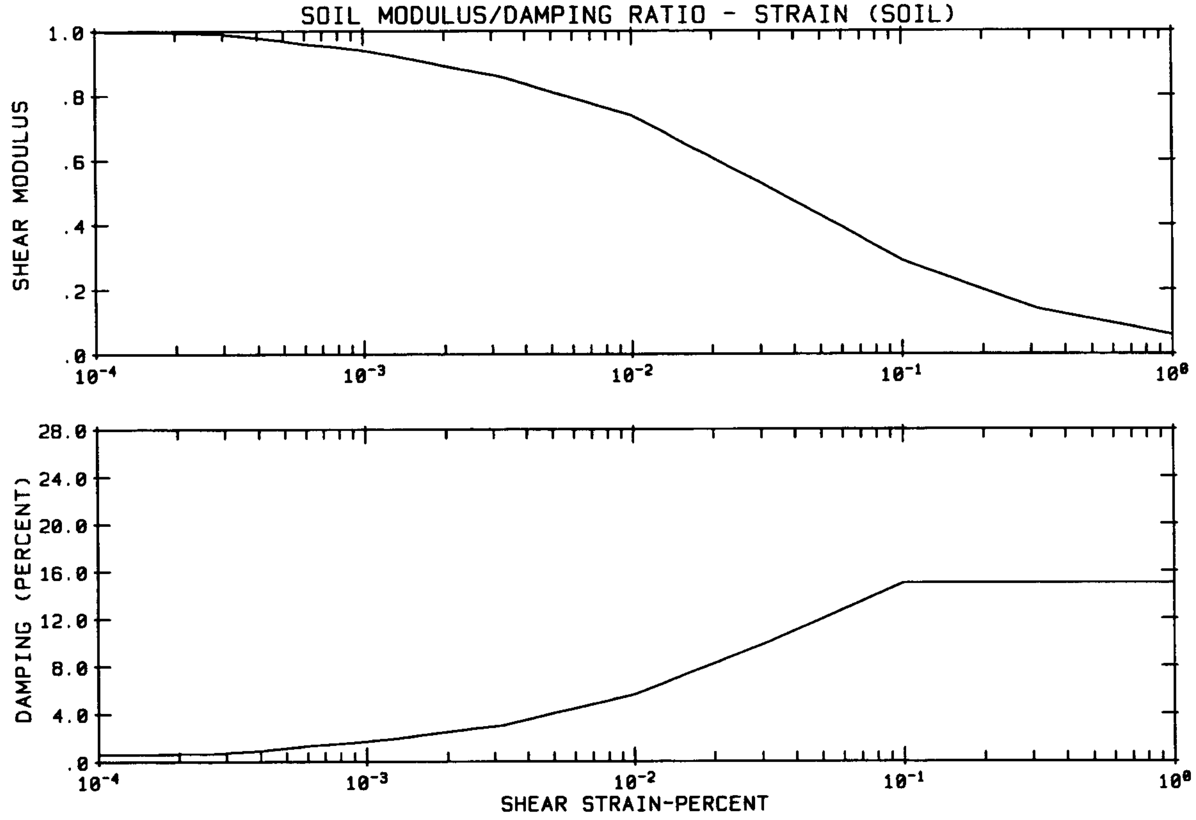

Figure 2A-8

Strain Dependent Damping & Shear Modulus (Soil Profiles)

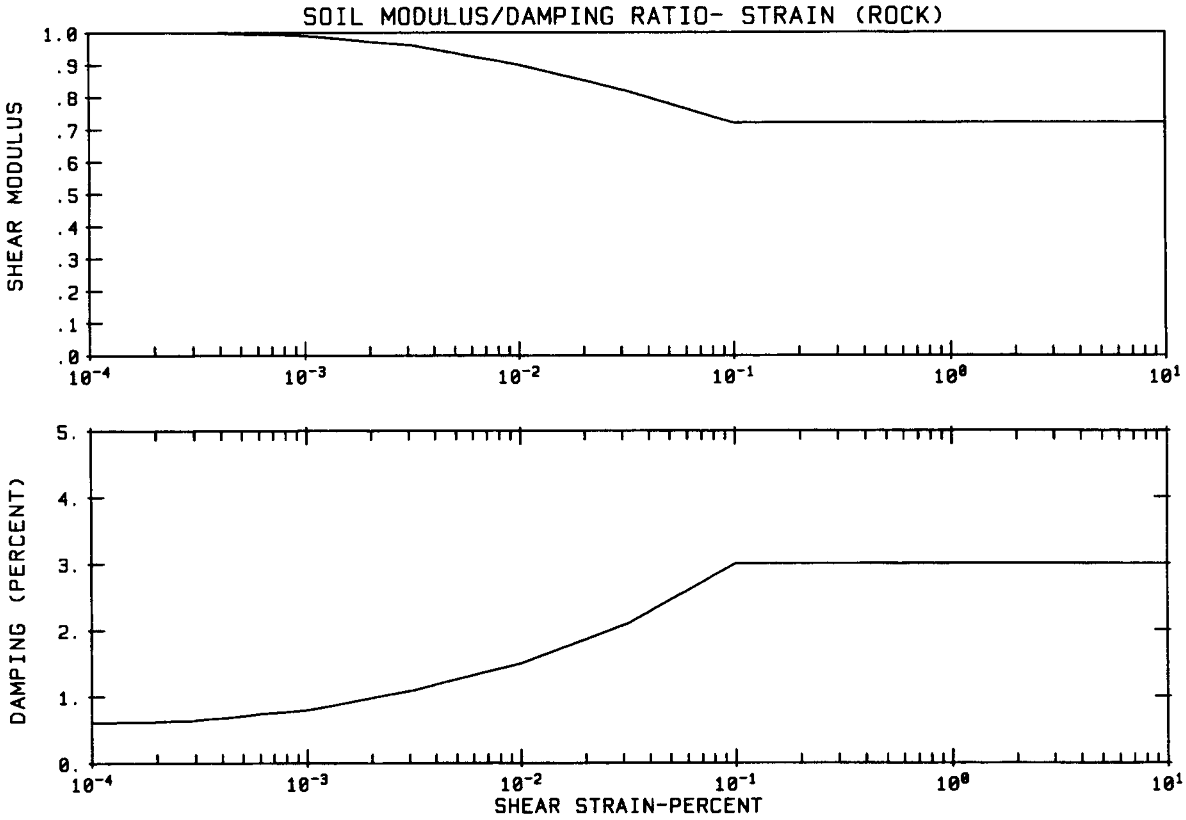

Figure 2A-9

Strain Dependent Damping & Shear Modulus (Rock Profiles)

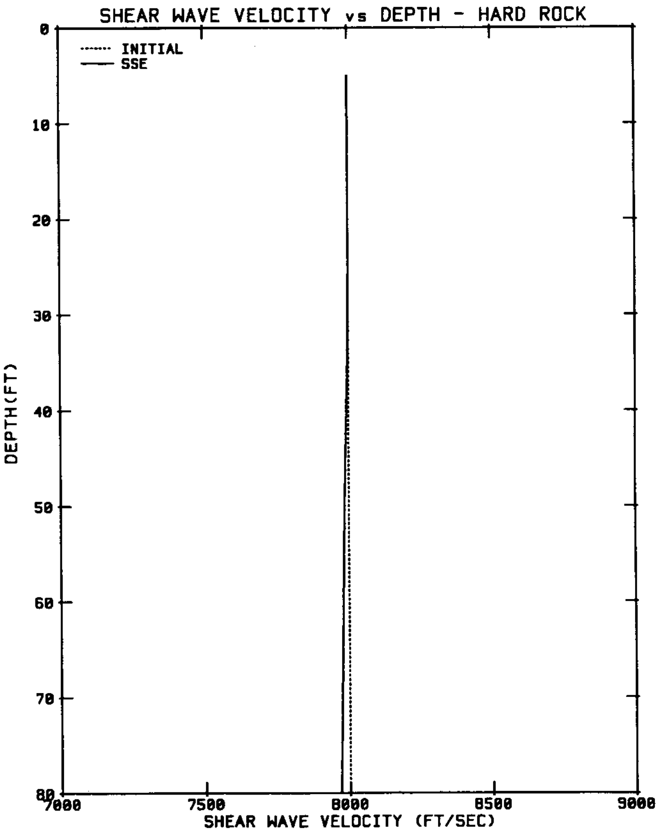

Figure 2A-10

SSE Strain Compatible Shear Wave Velocity (Hard Rock Site)

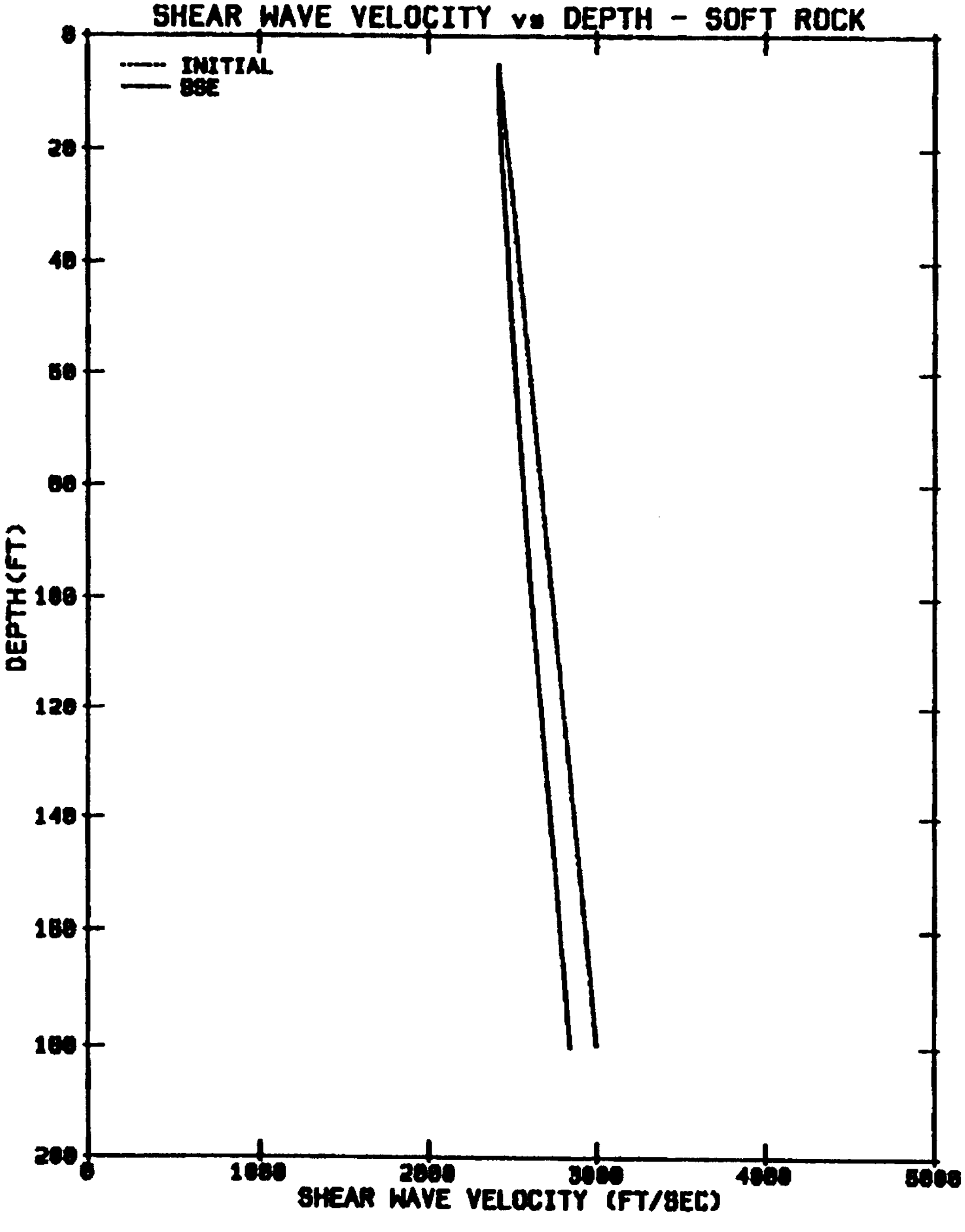

Figure 2A-11

SSE Strain Compatible Shear Wave Velocity (Soft Rock Site)

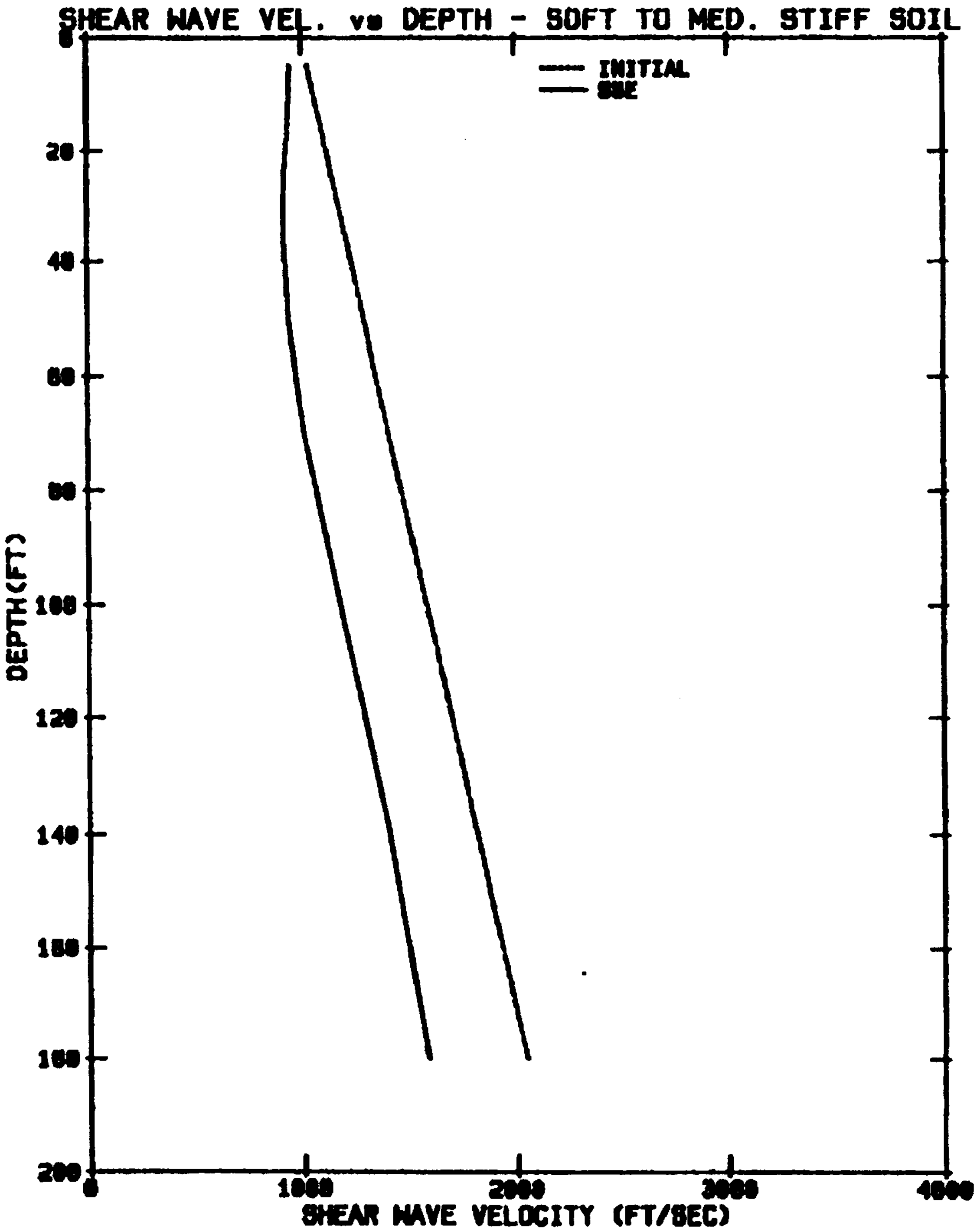

Figure 2A-12

SSE Strain Compatible Shear Wave Velocity (Soft to Medium Stiff Soil Site)

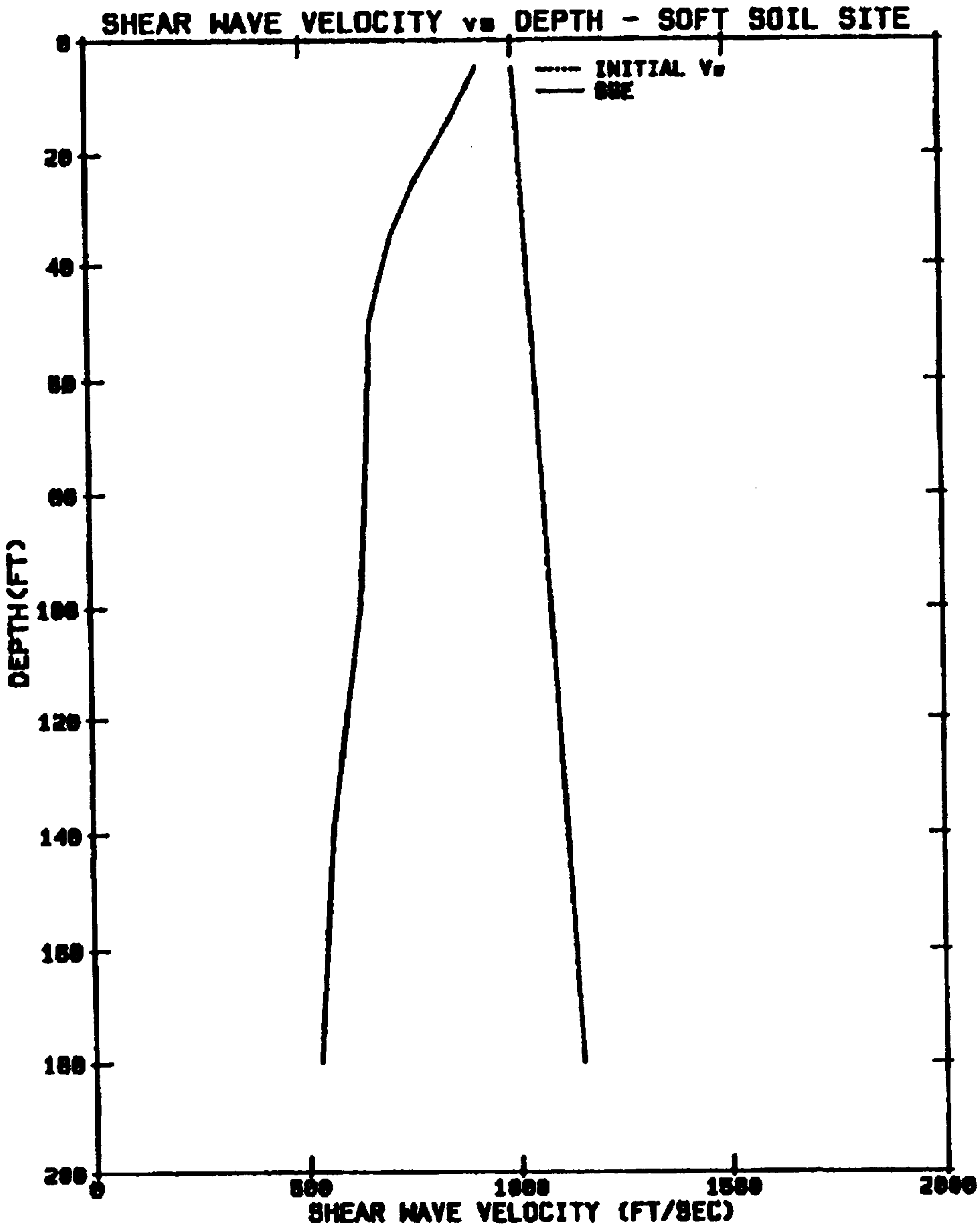

Figure 2A-13

SSE Strain Compatible Shear Wave Velocity (Soft Soil Site)

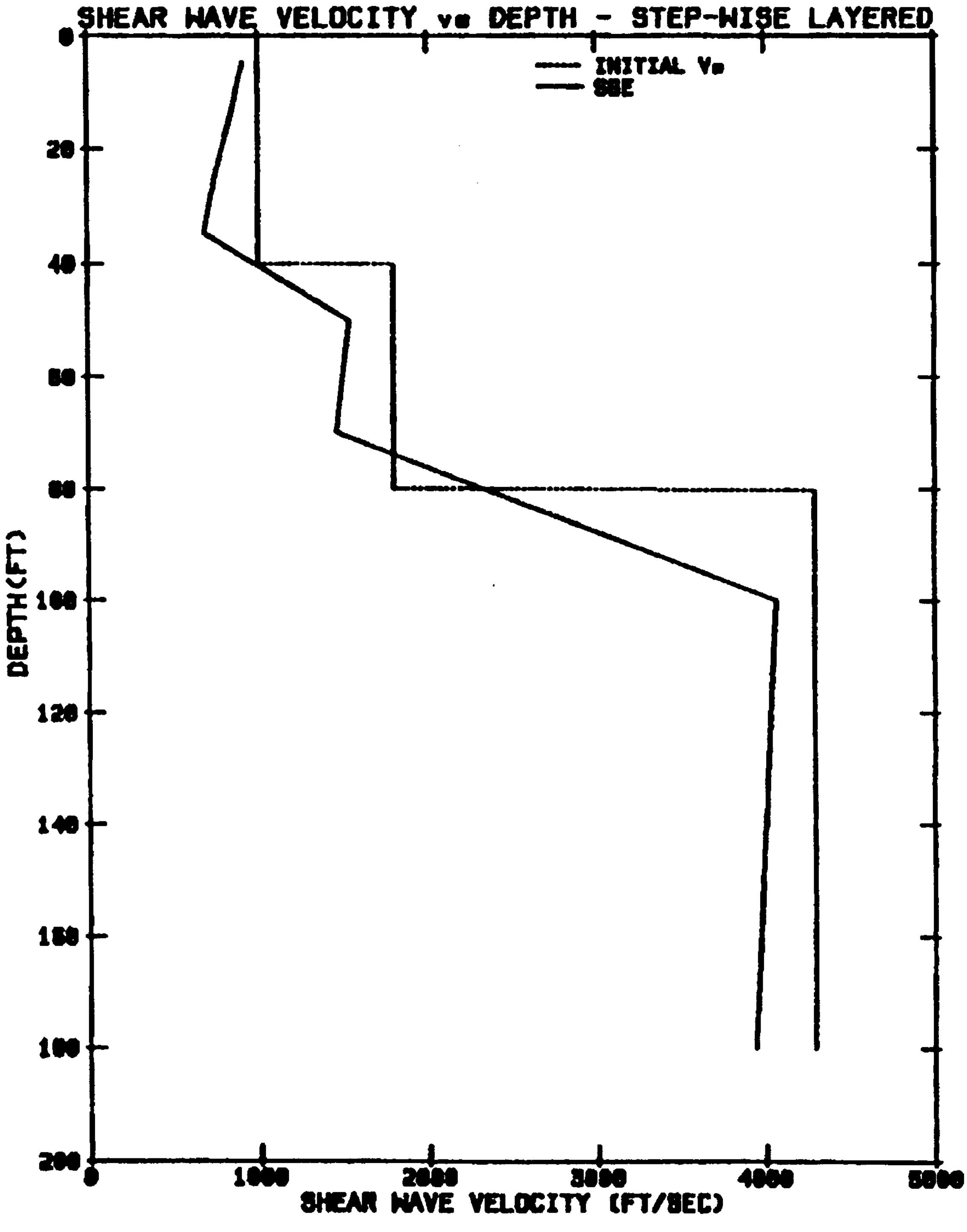

Figure 2A-14

SSE Strain Compatible Shear Wave Velocity (Step-Wise Layered Soil Site)

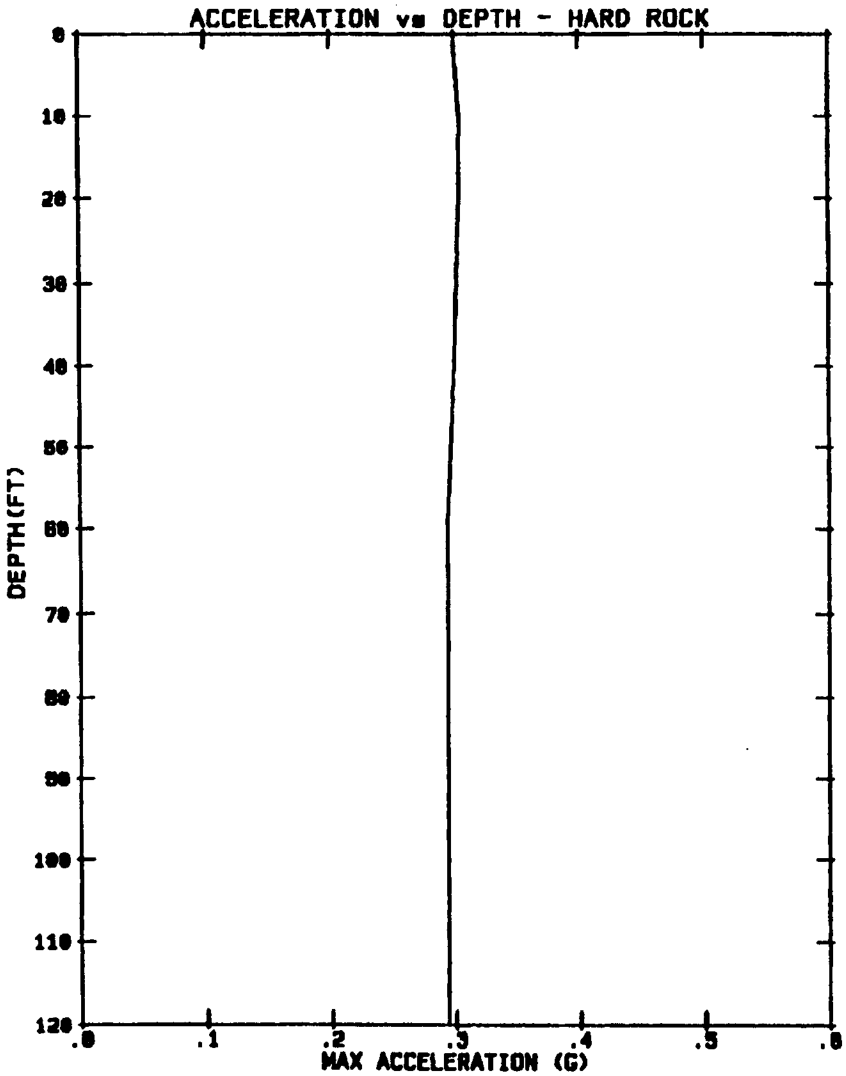

Figure 2A-15

SSE Acceleration vs. Depth of Soil Column (Hard Rock Site)

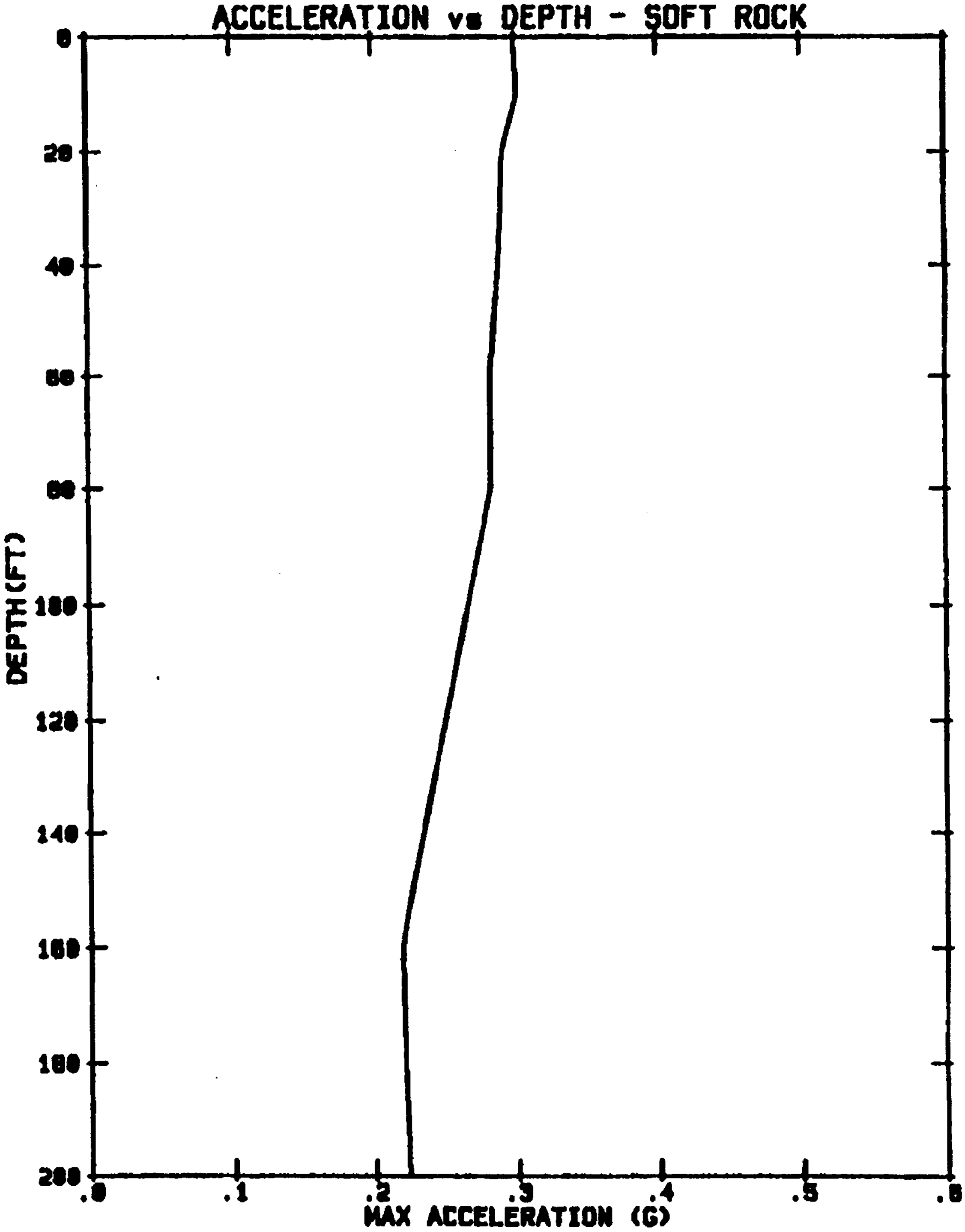

Figure 2A-16

SSE Acceleration vs. Depth of Soil Column (Soft Rock Site)

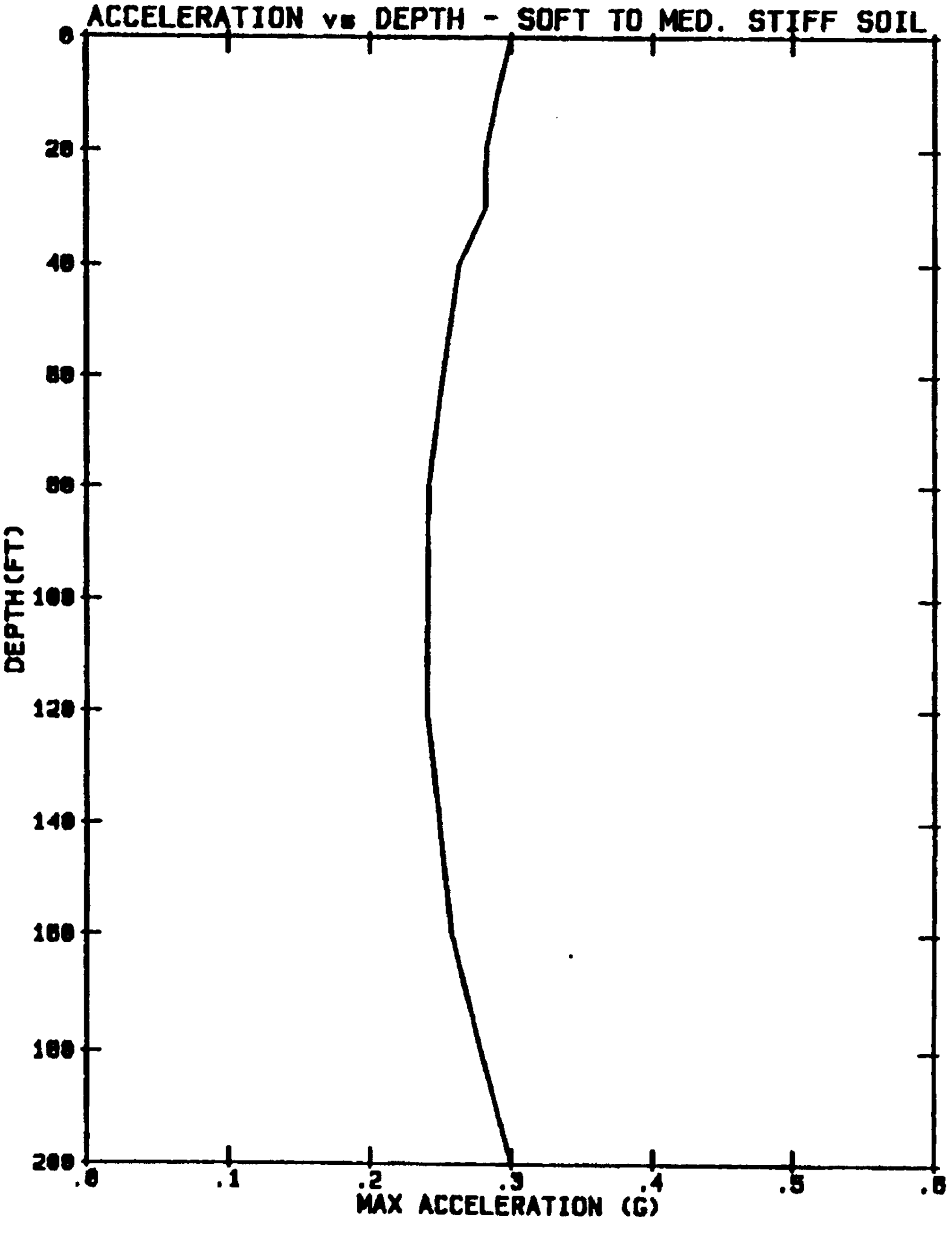

Figure 2A-17

SSE Acceleration vs. Depth of Soil Column (Soft to Medium Stiff Soil Site)

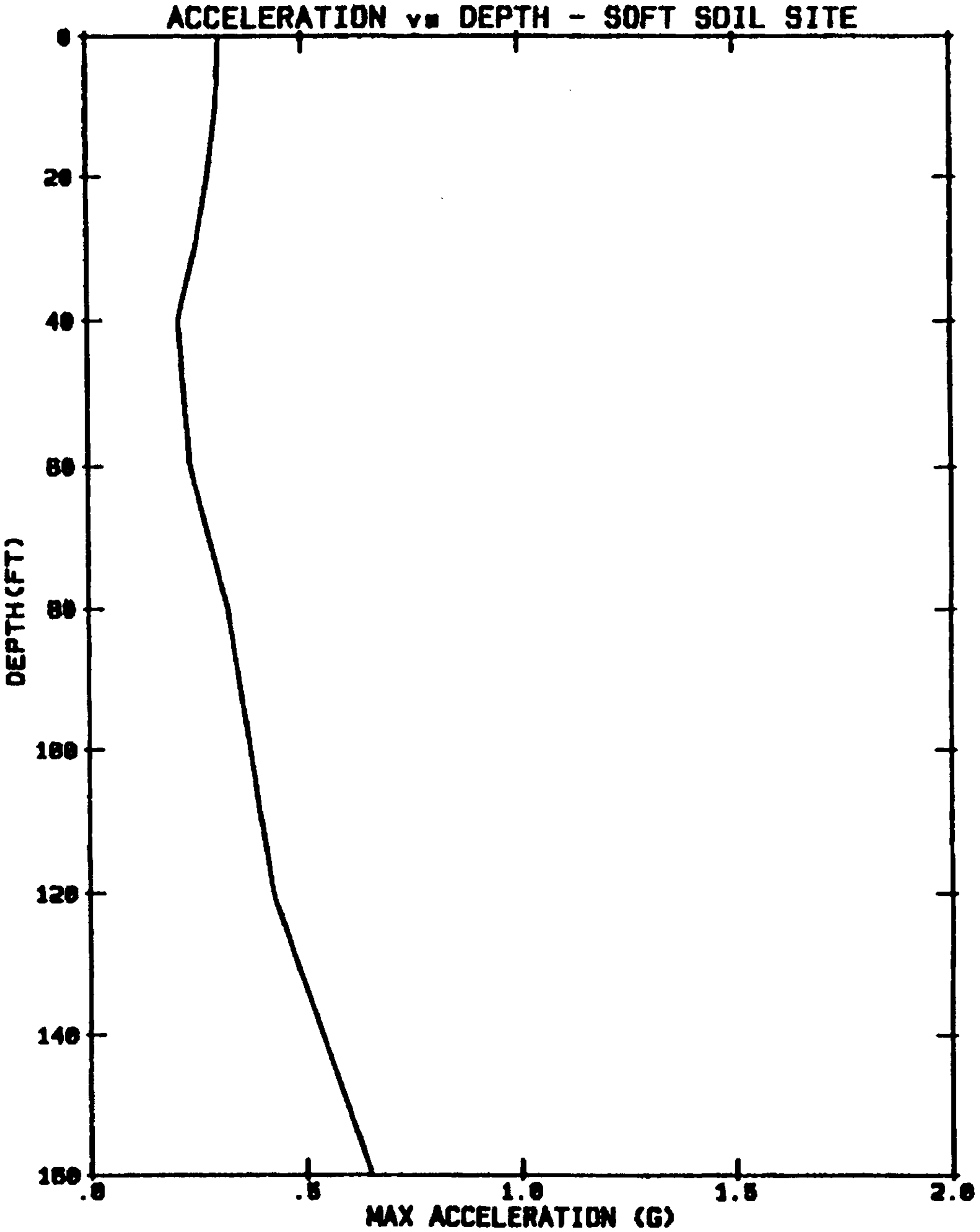

Figure 2A-18

SSE Acceleration vs. Depth of Soil Column (Soft Soil Site)

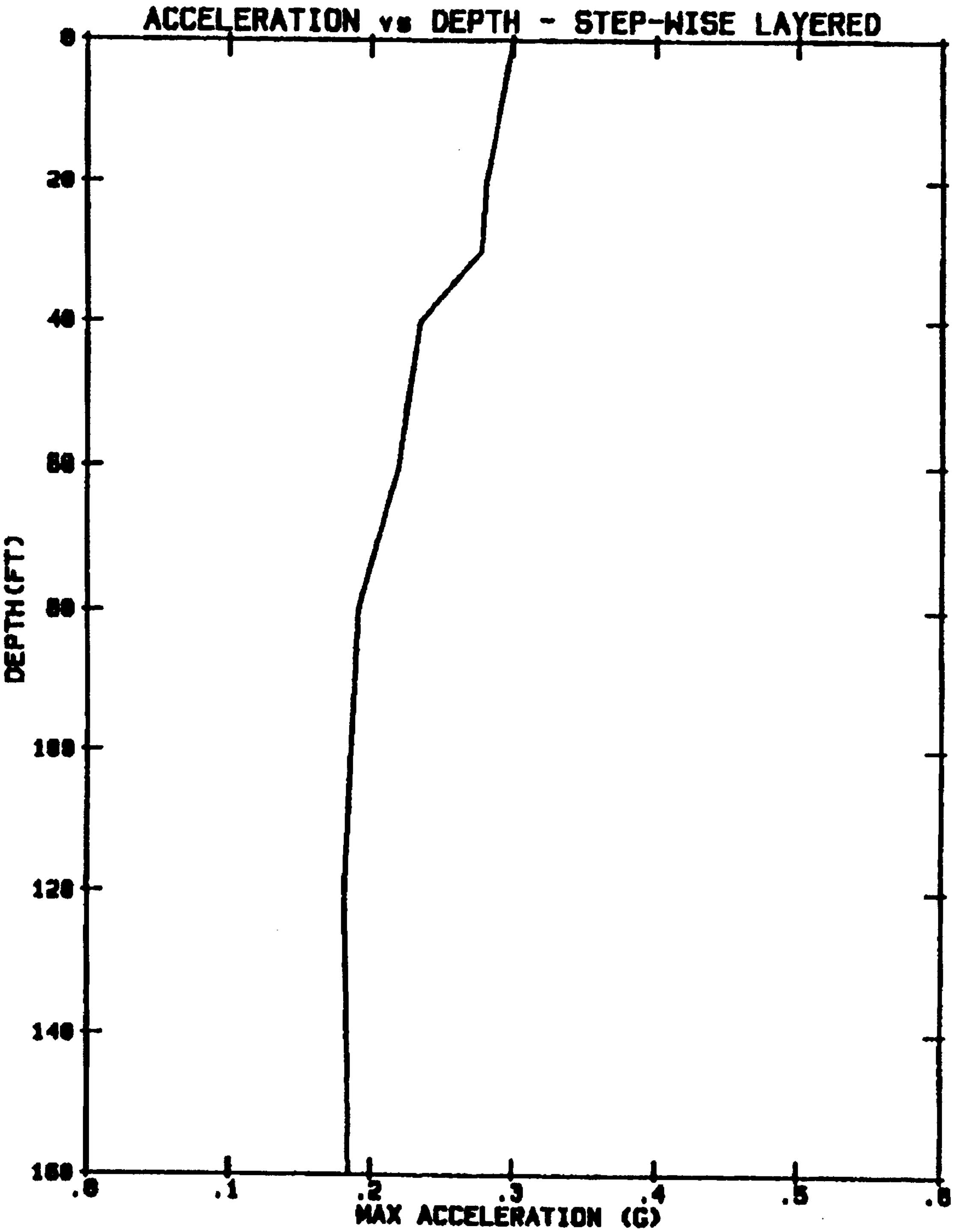

Figure 2A-19

SSE Acceleration vs. Depth of Soil Column (Step-Wise Layered Soil Site)

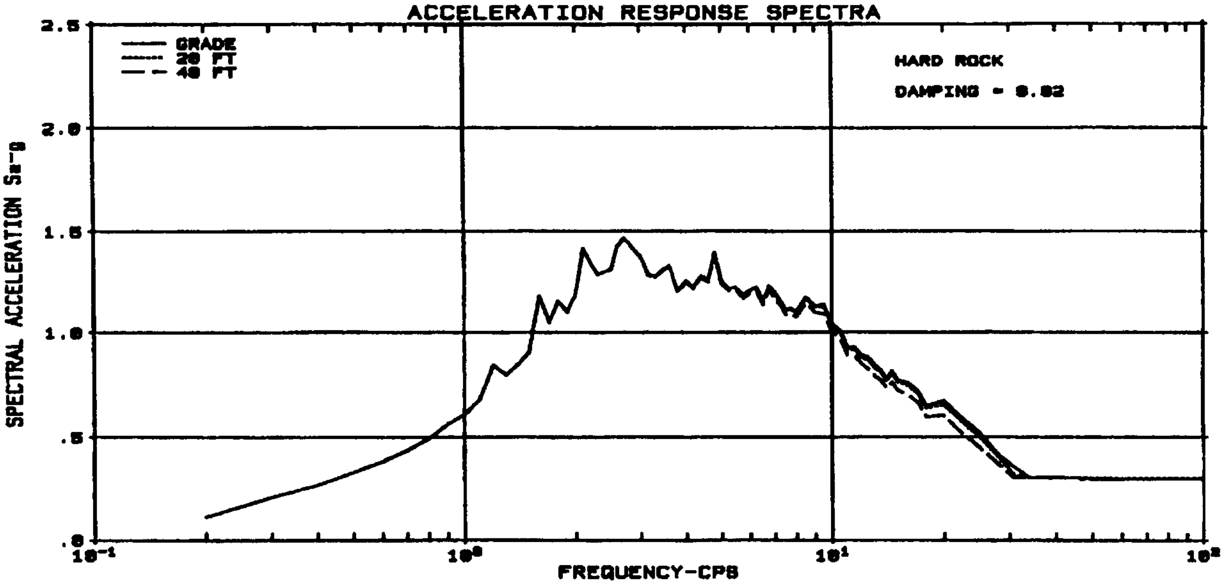

Figure 2A-20

Free Field Acceleration Response Spectra, 2% Damping (Hard Rock Site)

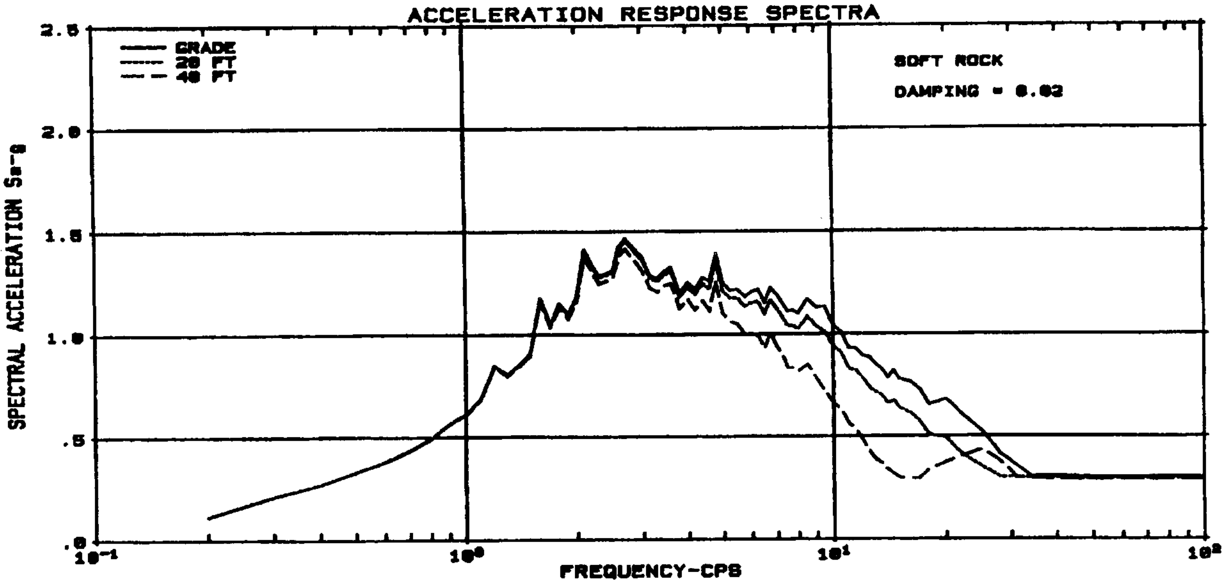

Figure 2A-21

Free Field Acceleration Response Spectra, 2% Damping (Soft Rock Site)

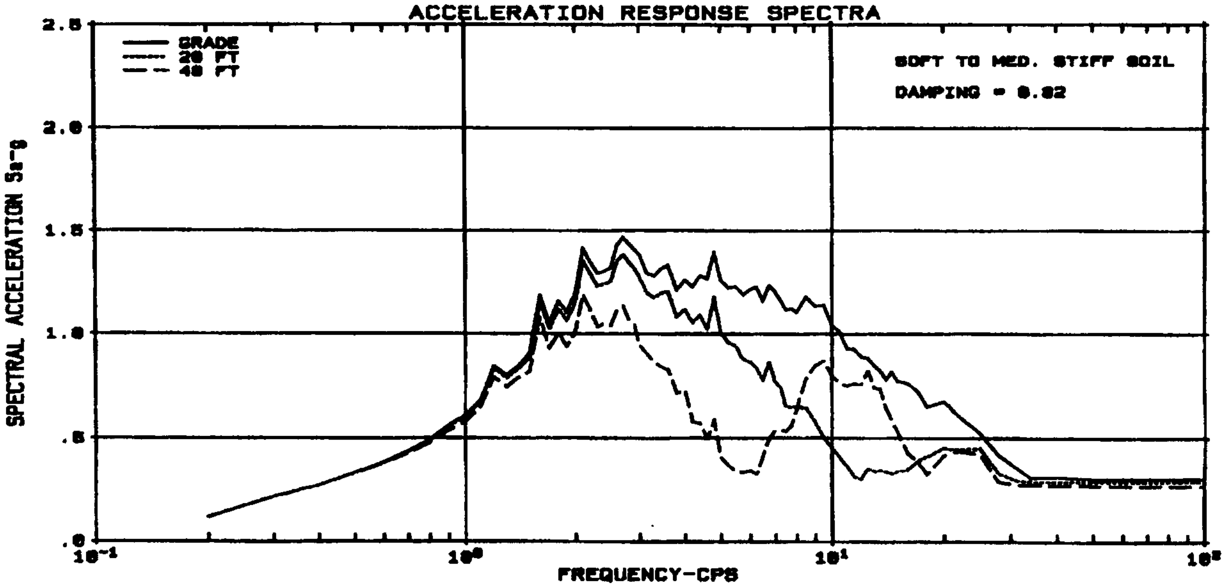

Figure 2A-22

Free Field Acceleration Response Spectra, 2% Damping (Soft to Medium Stiff Soil Site)

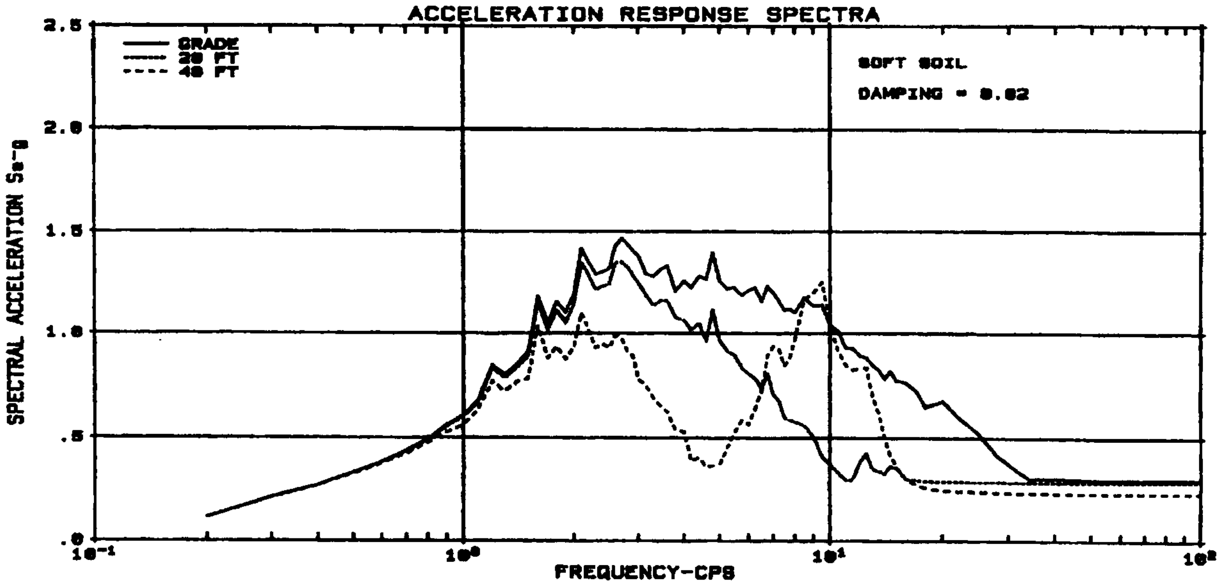

Figure 2A-23

Free Field Acceleration Response Spectra, 2% Damping (Soft Soil Soft)

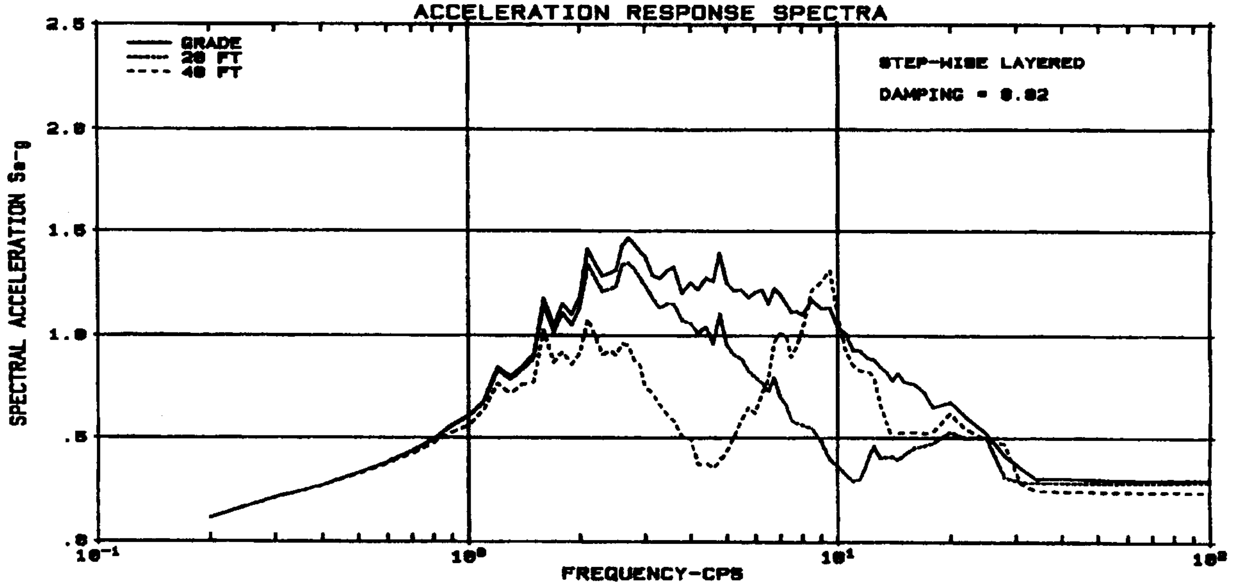

Figure 2A-24

Free Field Acceleration Response Spectra, 2% Damping (Step-Wise Layered Soil Site)

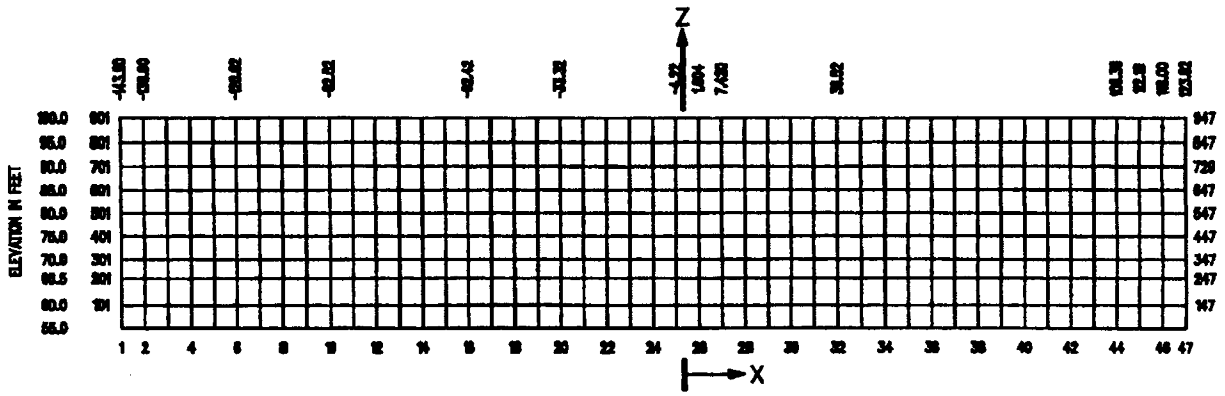

Figure 2A-25

SASSI Excavated Soil Model (XZ Plane)

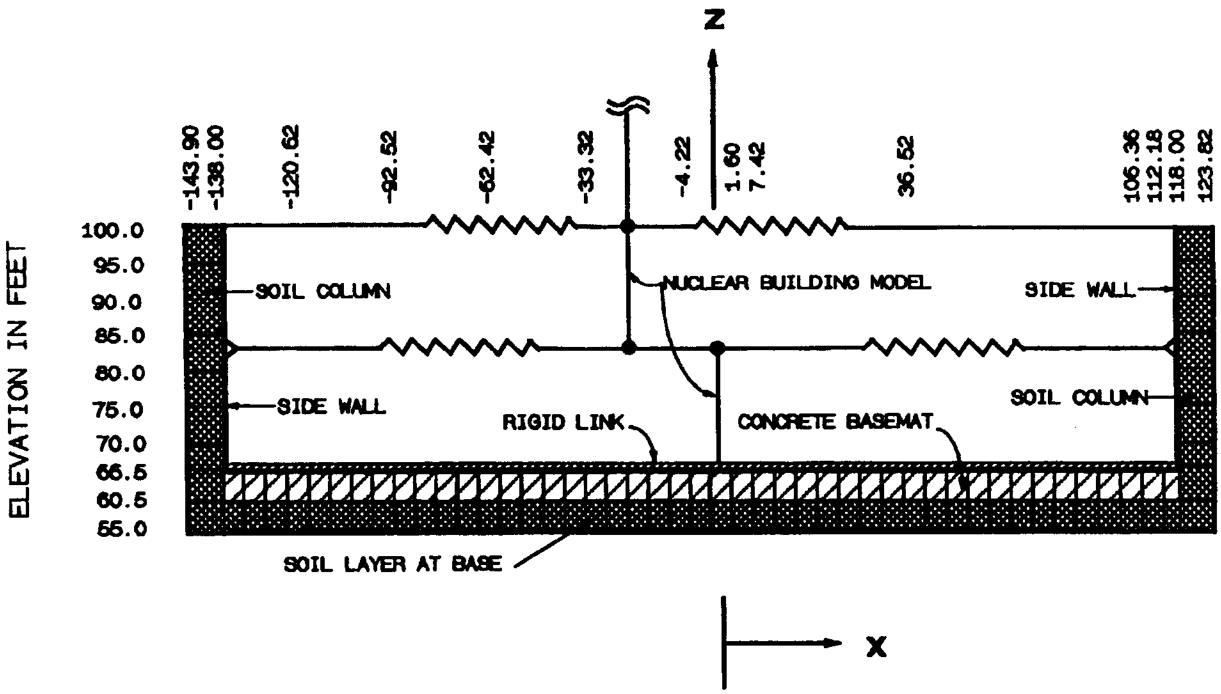

Figure 2A-26

SASSI Basement Model (XZ Plane)

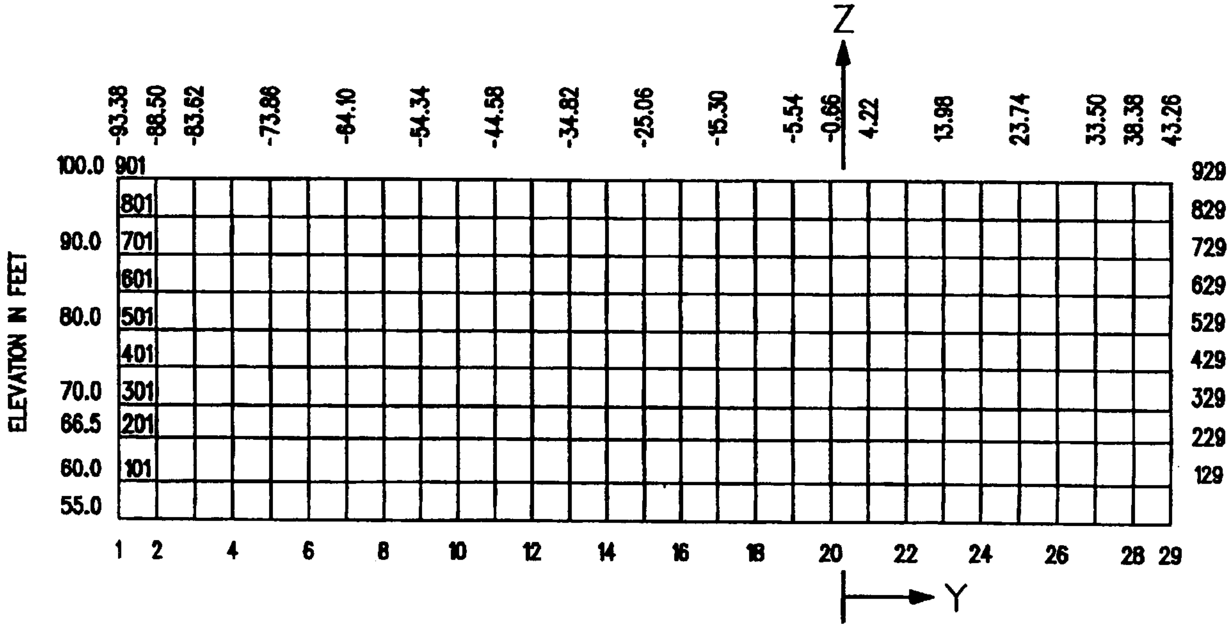

Figure 2A-27

SASSI Excavated Soil Model (YZ Plane)

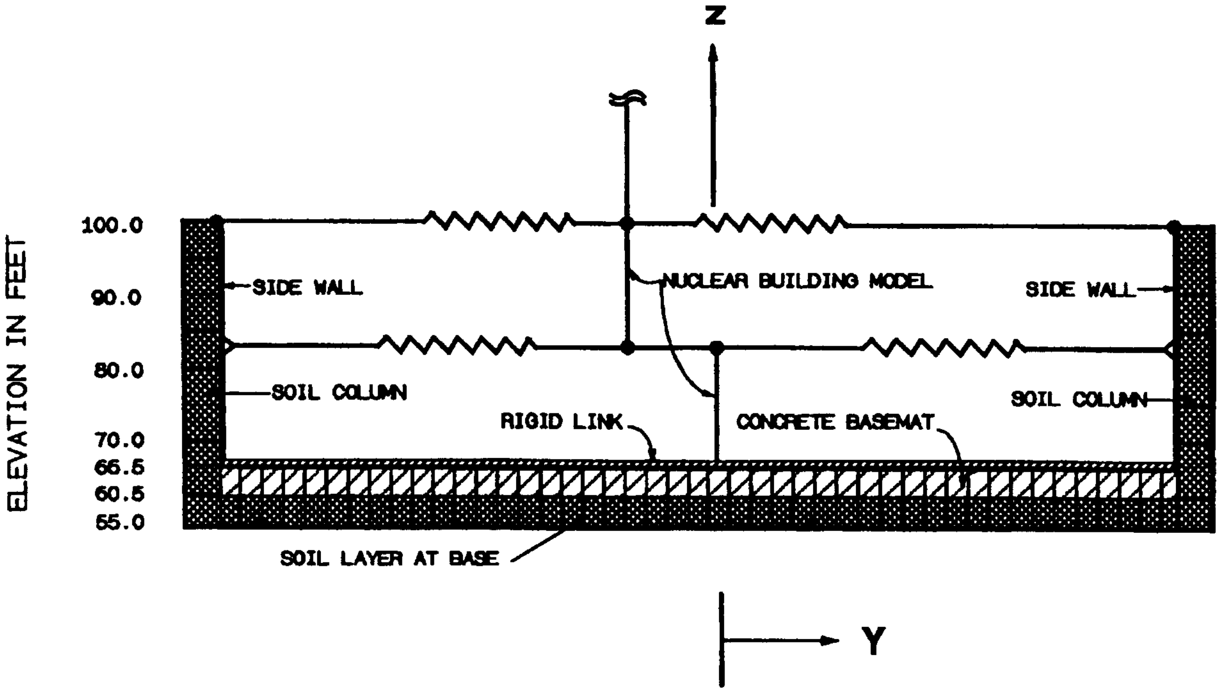

Figure 2A-28

SASSI Basement Model (YZ Plane)

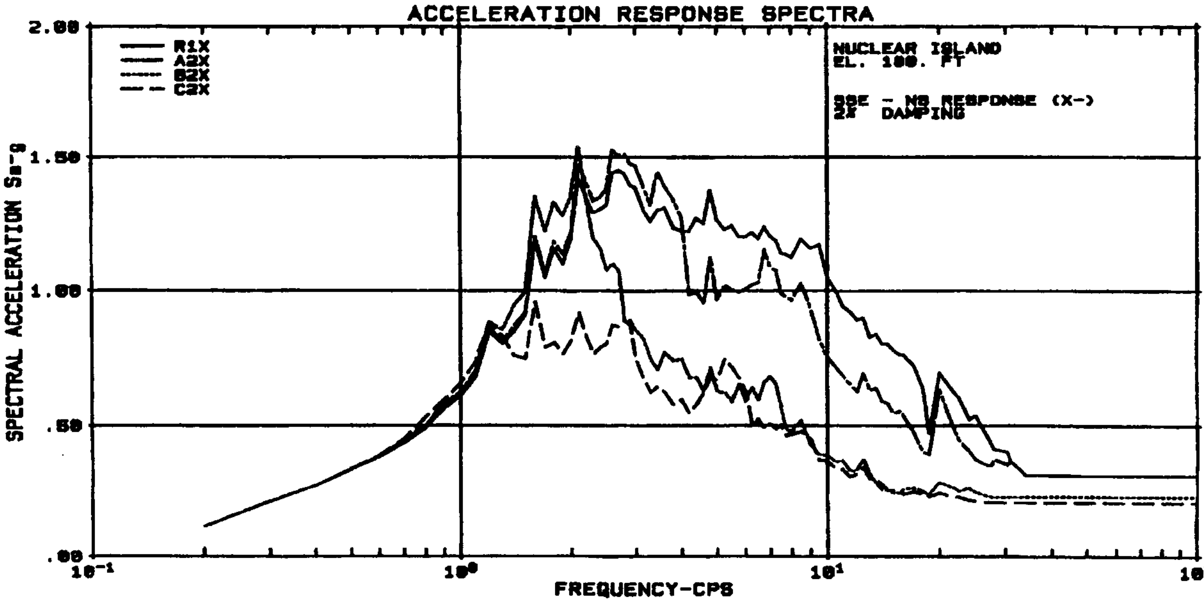

Figure 2A-29 (Sheet 1 of 7)

North-South Acceleration Response Spectra

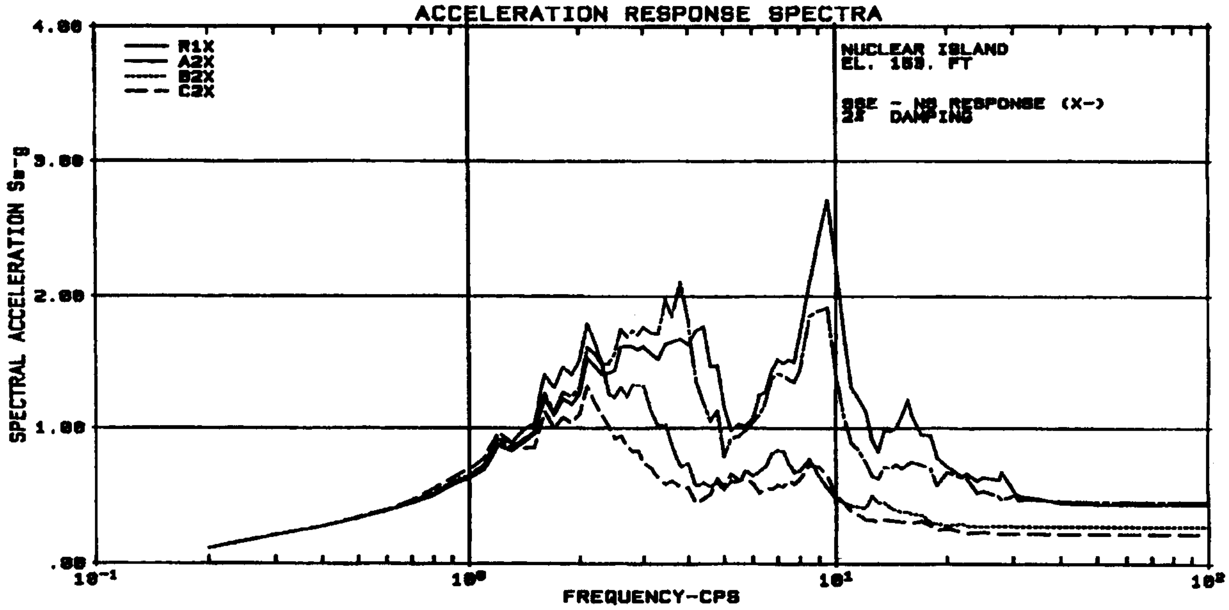

Figure 2A-29 (Sheet 2 of 7)

North-South Acceleration Response Spectra

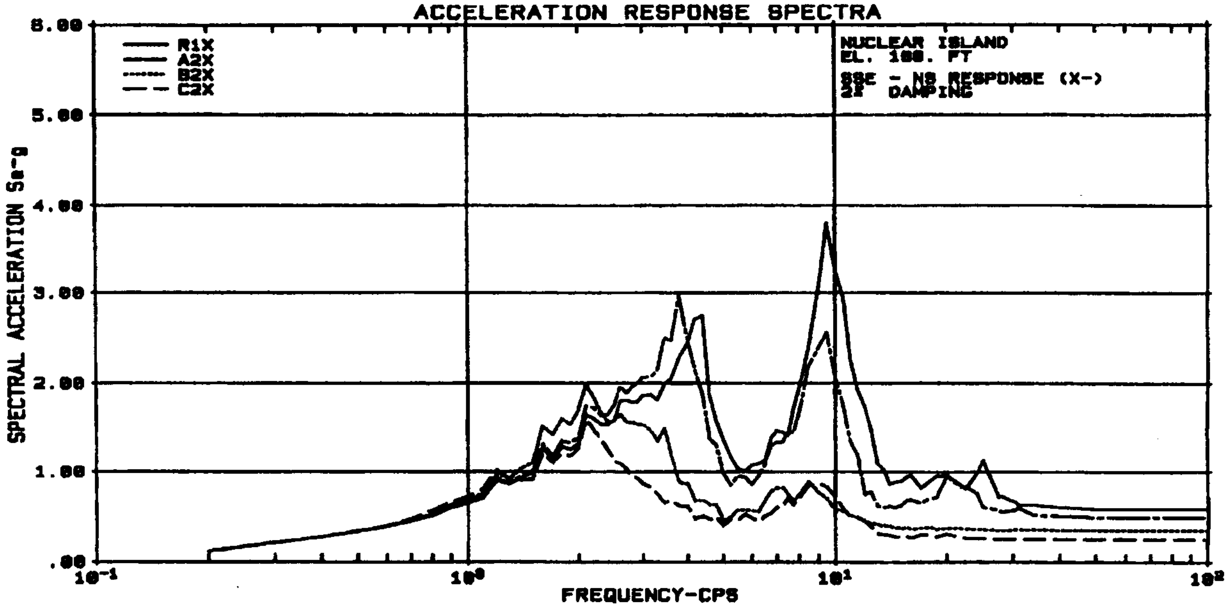

Figure 2A-29 (Sheet 3 of 7)

North-South Acceleration Response Spectra

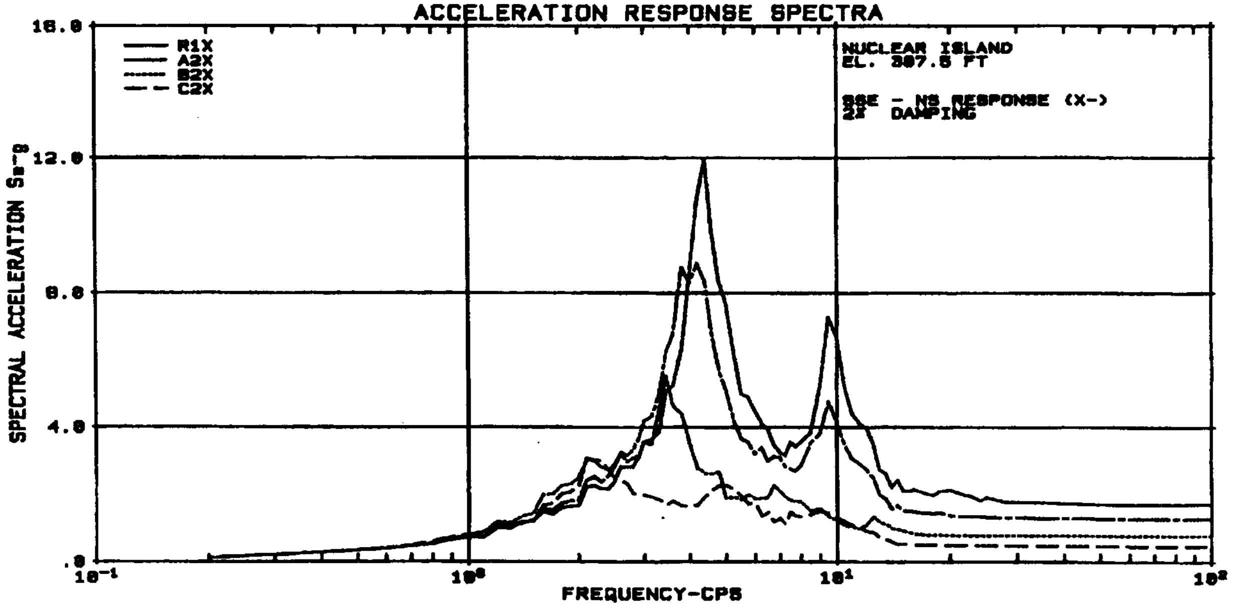

Figure 2A-29 (Sheet 4 of 7)

North-South Acceleration Response Spectra

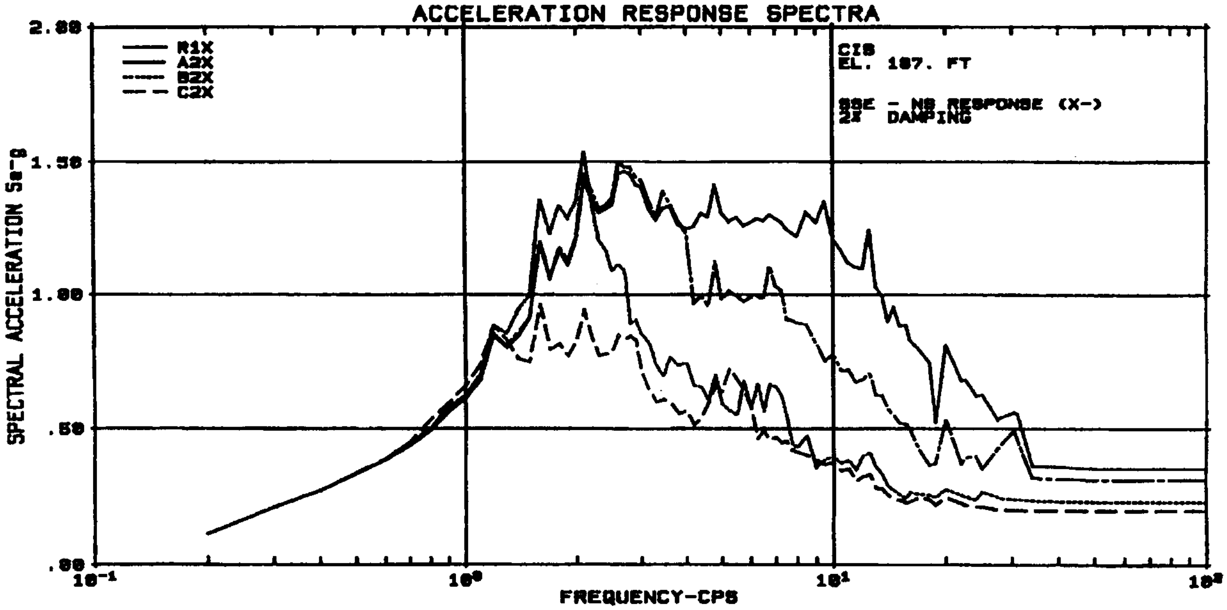

Figure 2A-29 (Sheet 5 of 7)

North-South Acceleration Response Spectra

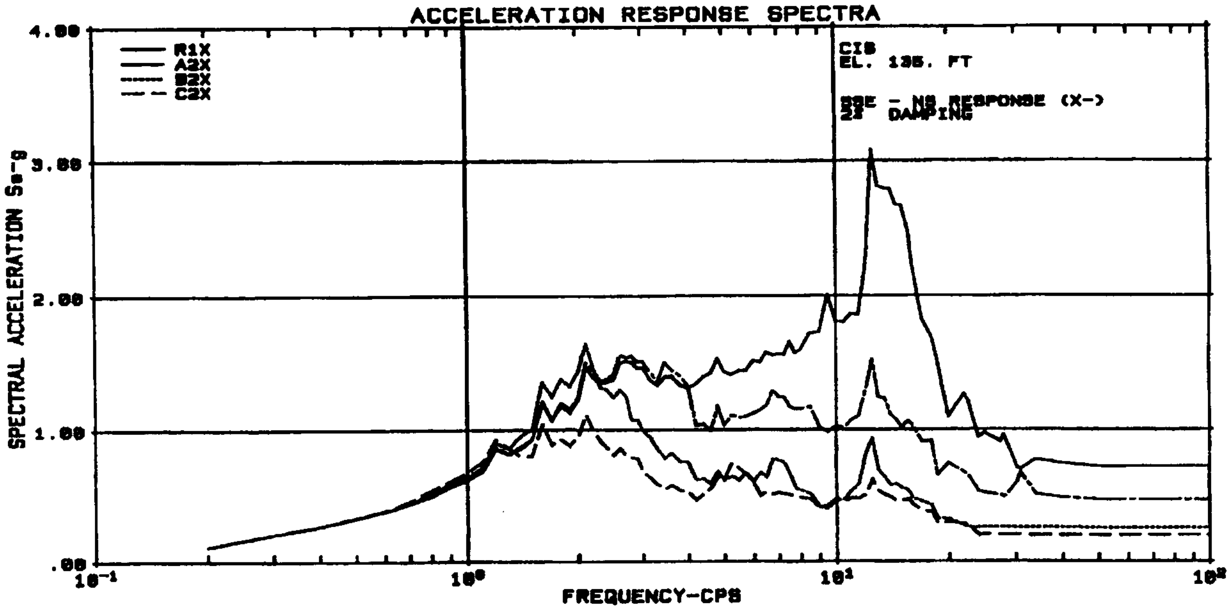

Figure 2A-29 (Sheet 6 of 7)

North-South Acceleration Response Spectra

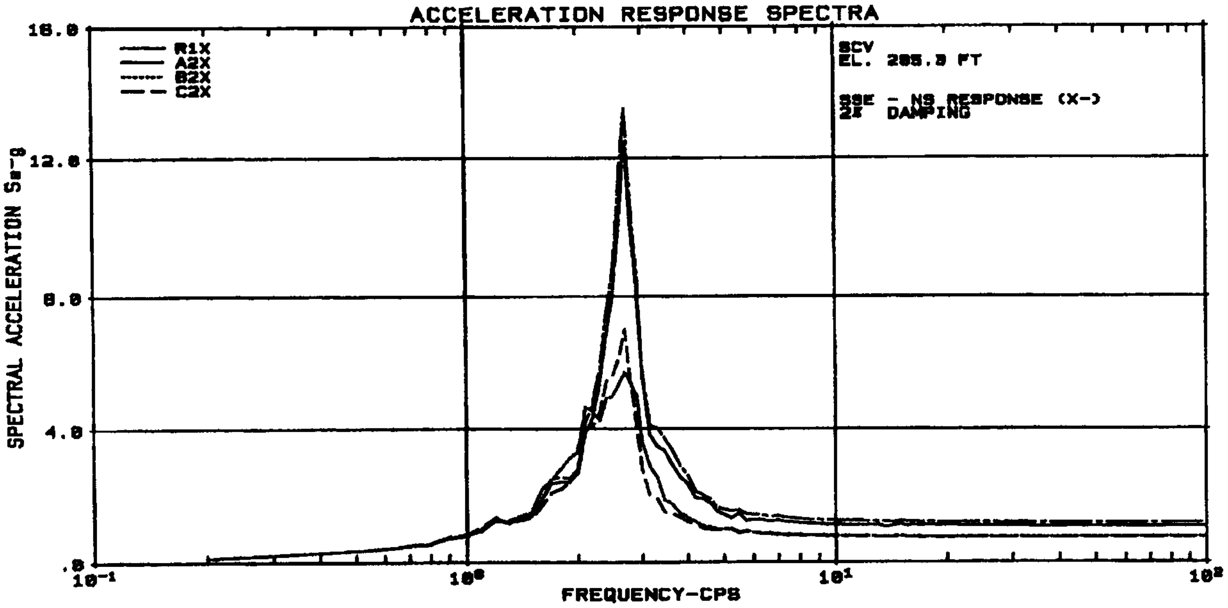

Figure 2A-29 (Sheet 7 of 7)

North-South Acceleration Response Spectra

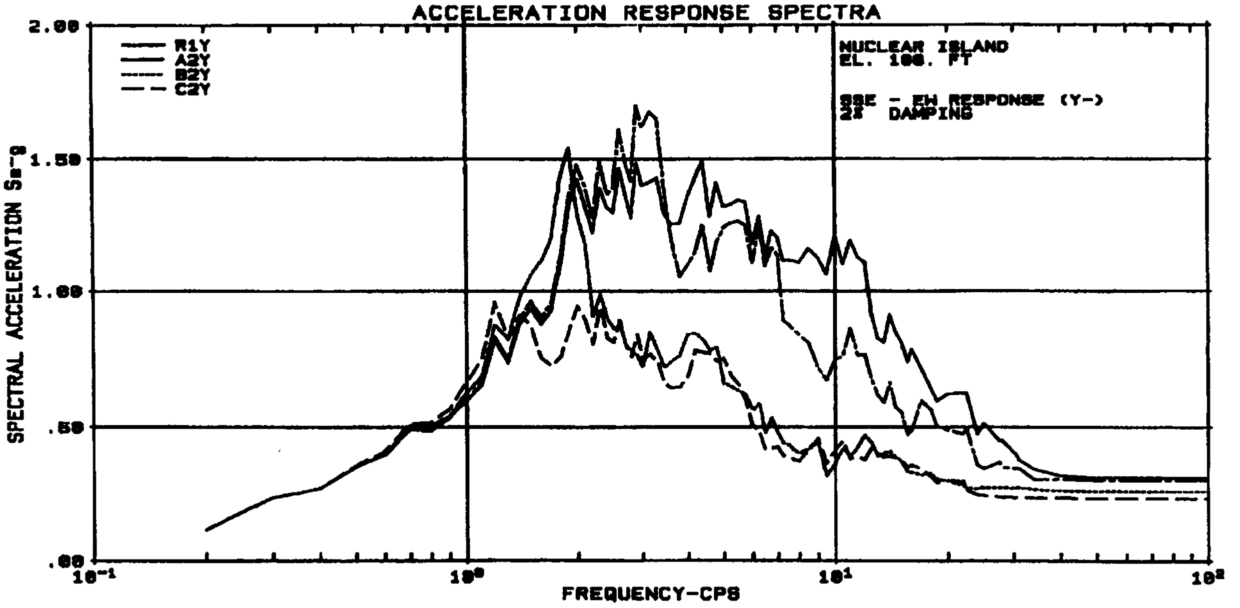

Figure 2A-30 (Sheet 1 of 7)

East-West Acceleration Response Spectra

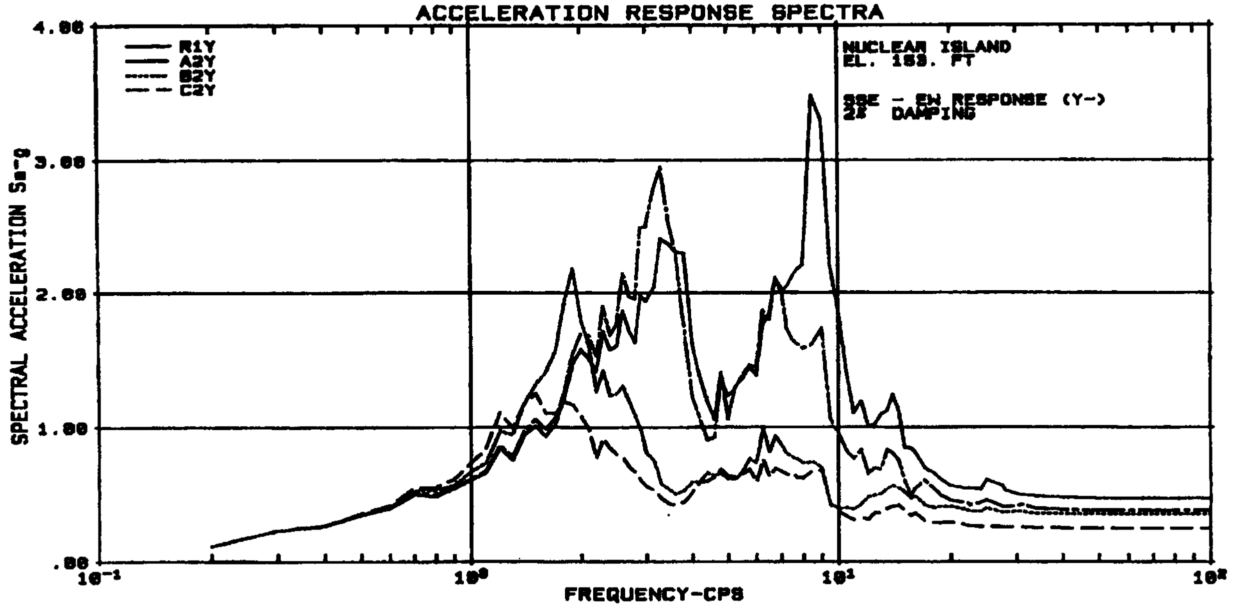

Figure 2A-30 (Sheet 2 of 7)

East-West Acceleration Response Spectra

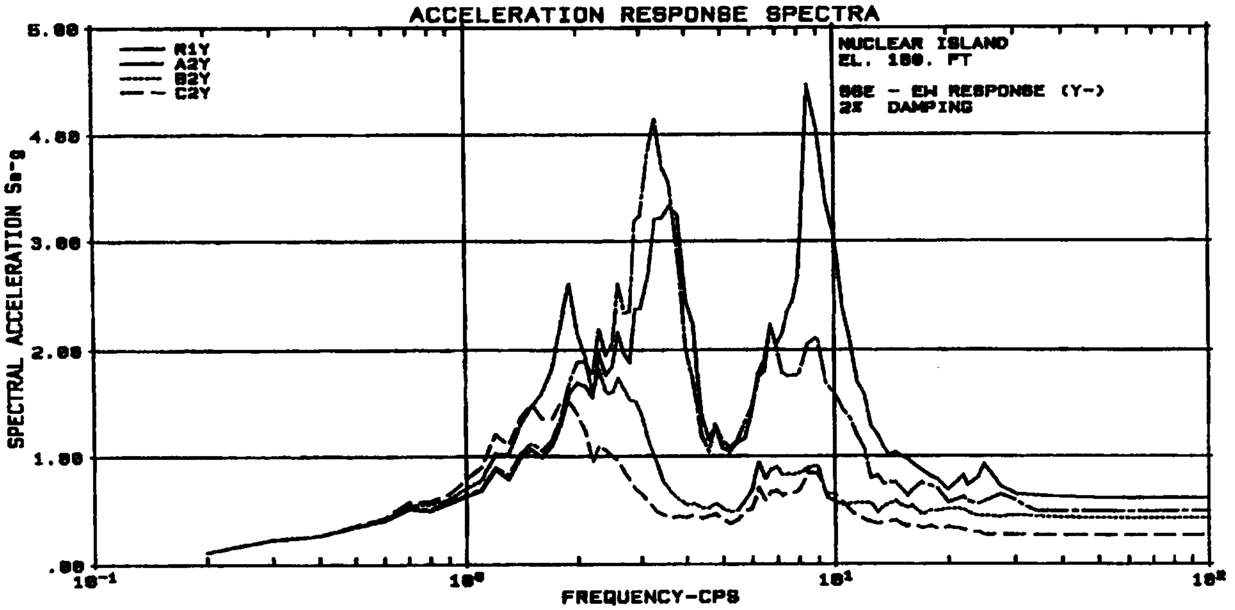

Figure 2A-30 (Sheet 3 of 7)

East-West Acceleration Response Spectra

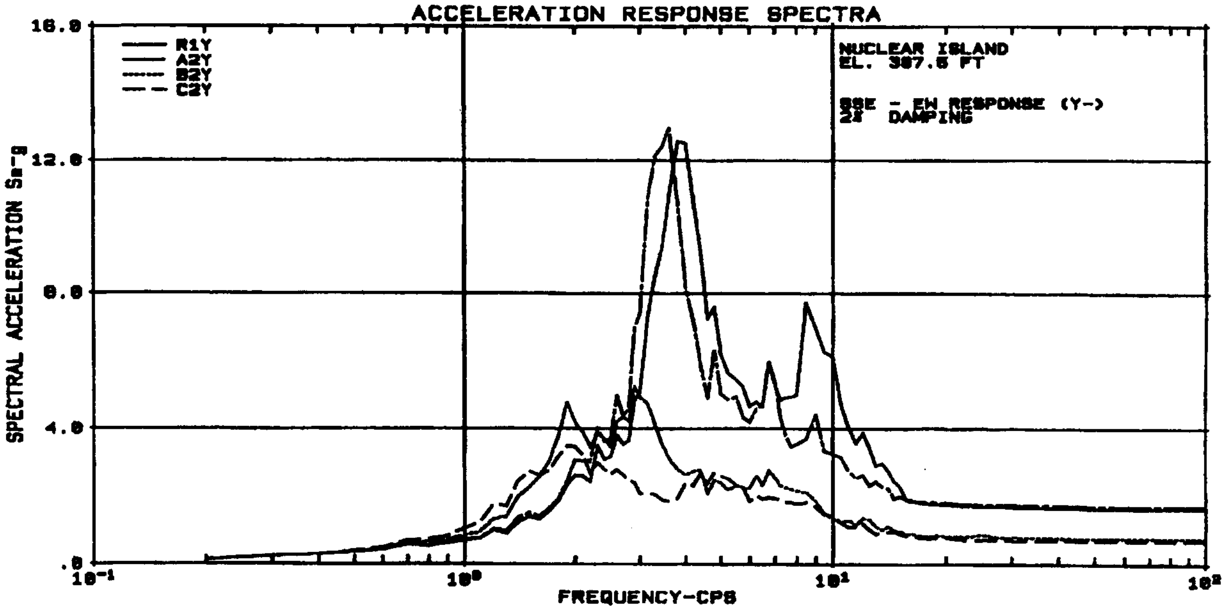

Figure 2A-30 (Sheet 4 of 7)

East-West Acceleration Response Spectra

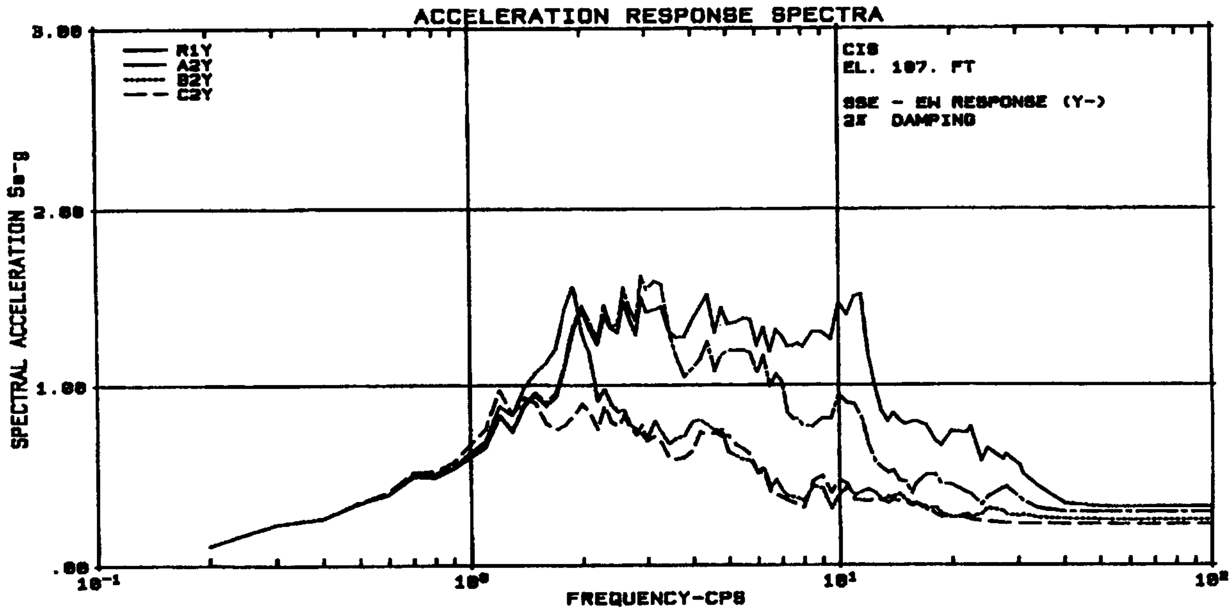

Figure 2A-30 (Sheet 5 of 7)

East-West Acceleration Response Spectra

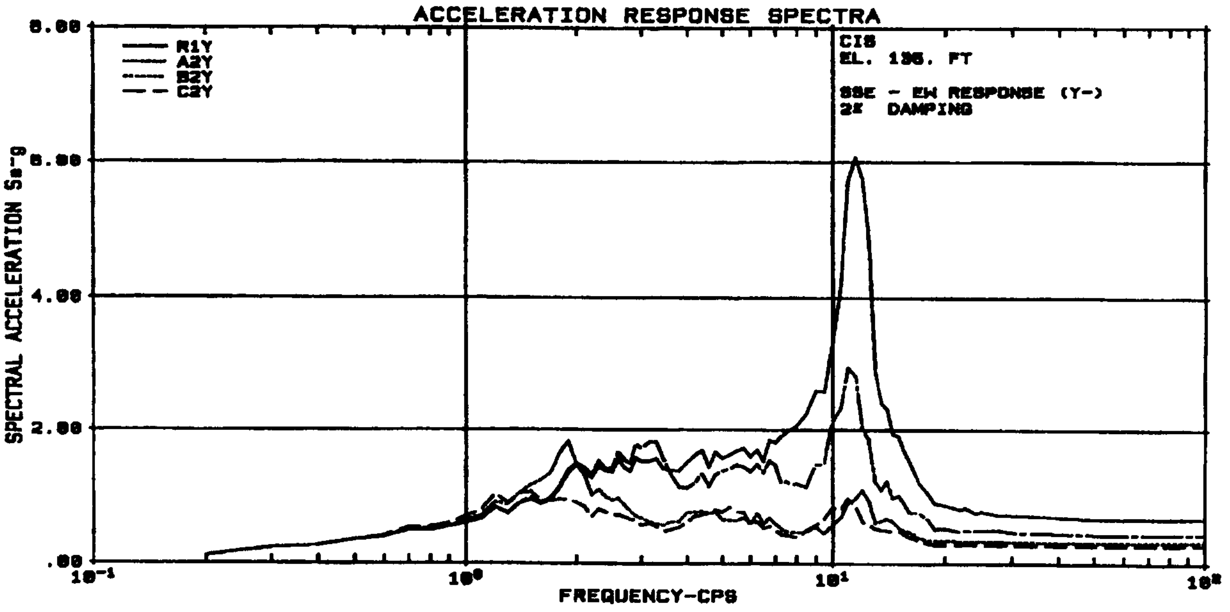

Figure 2A-30 (Sheet 6 of 7)

East-West Acceleration Response Spectra

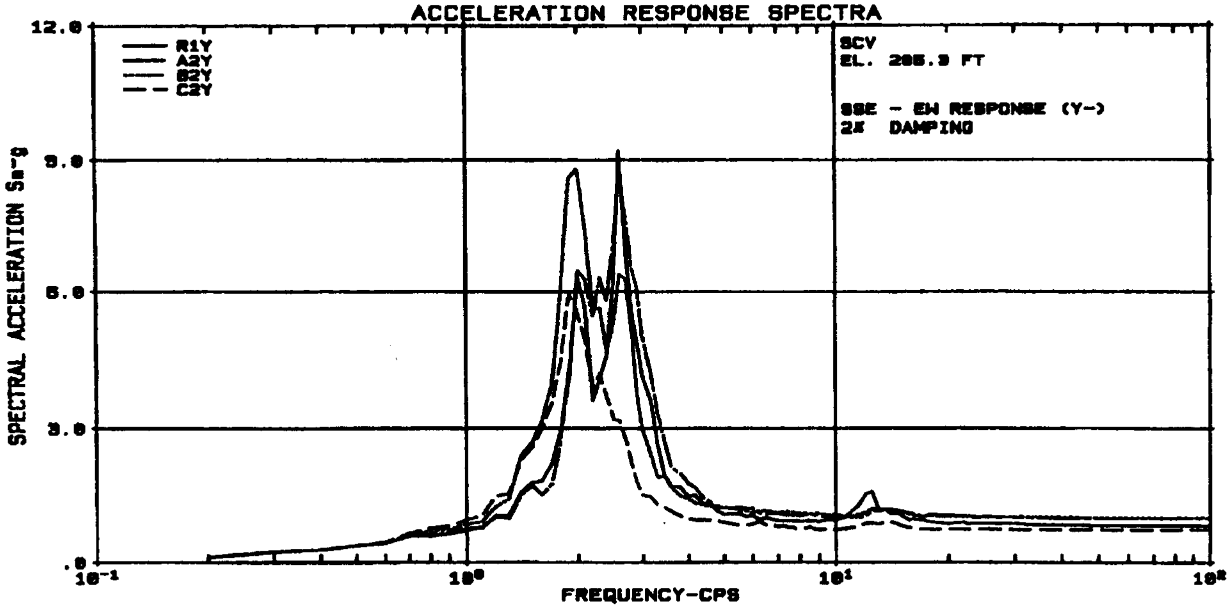

Figure 2A-30 (Sheet 7 of 7)

East-West Acceleration Response Spectra

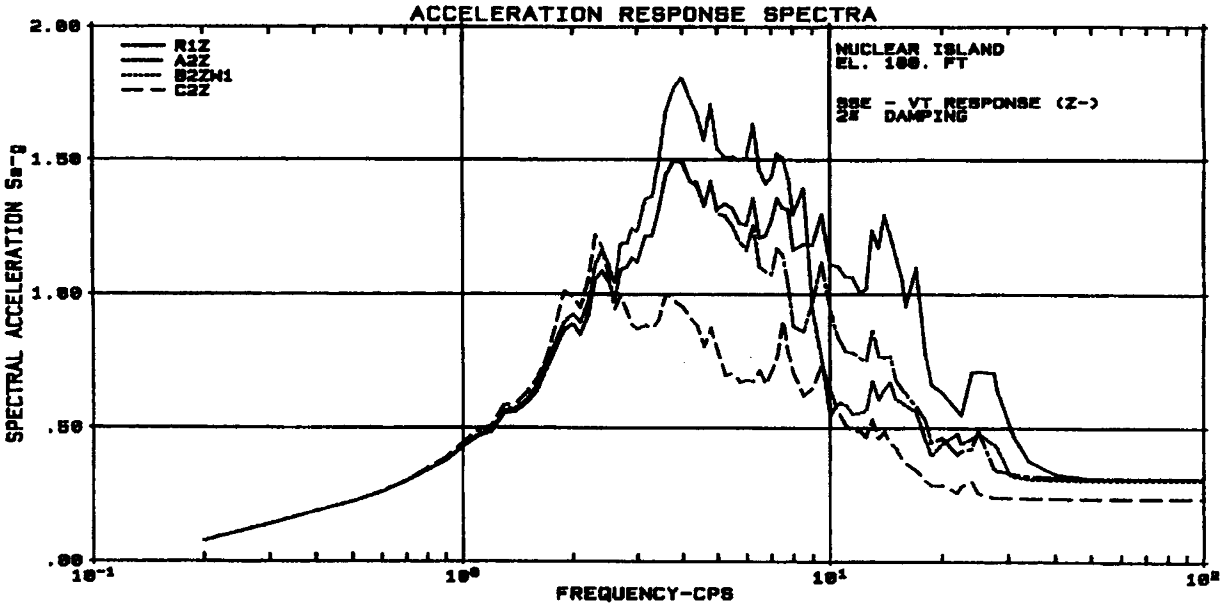

Figure 2A-31 (Sheet 1 of 7)

Vertical Acceleration Response Spectra

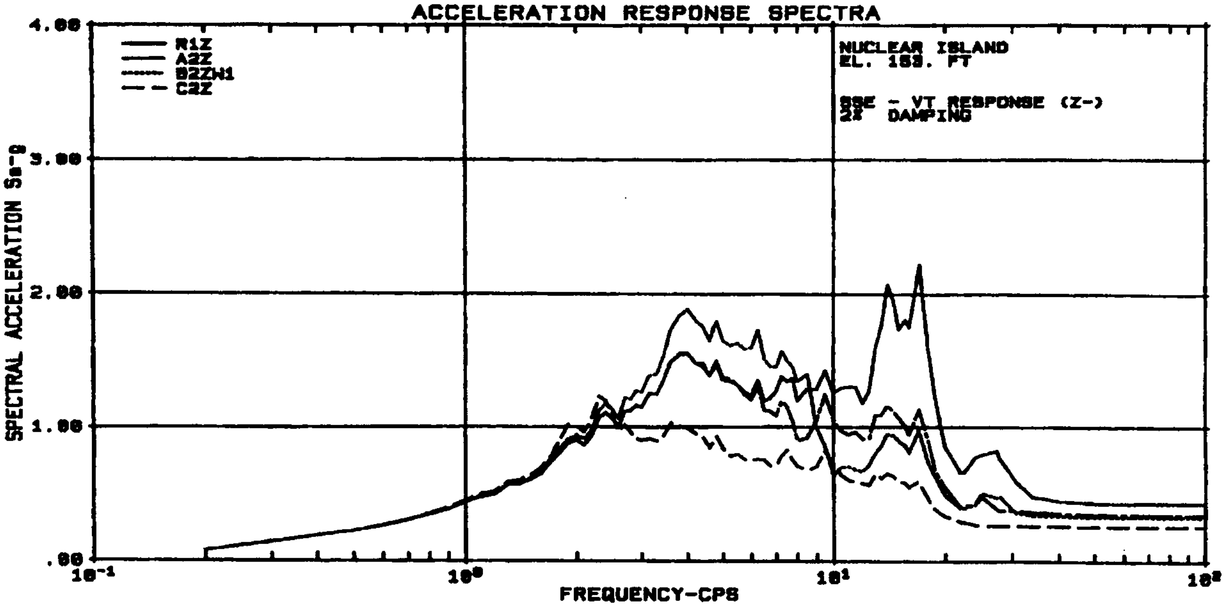

Figure 2A-31 (Sheet 2 of 7)

Vertical Acceleration Response Spectra

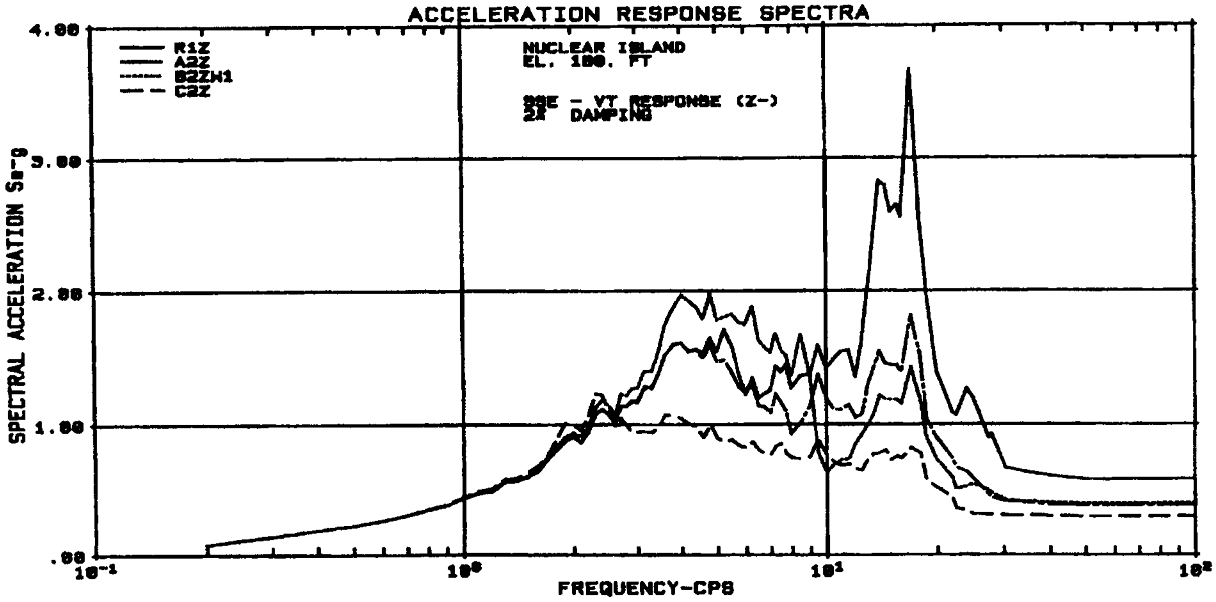

Figure 2A-31 (Sheet 3 of 7)

Vertical Acceleration Response Spectra

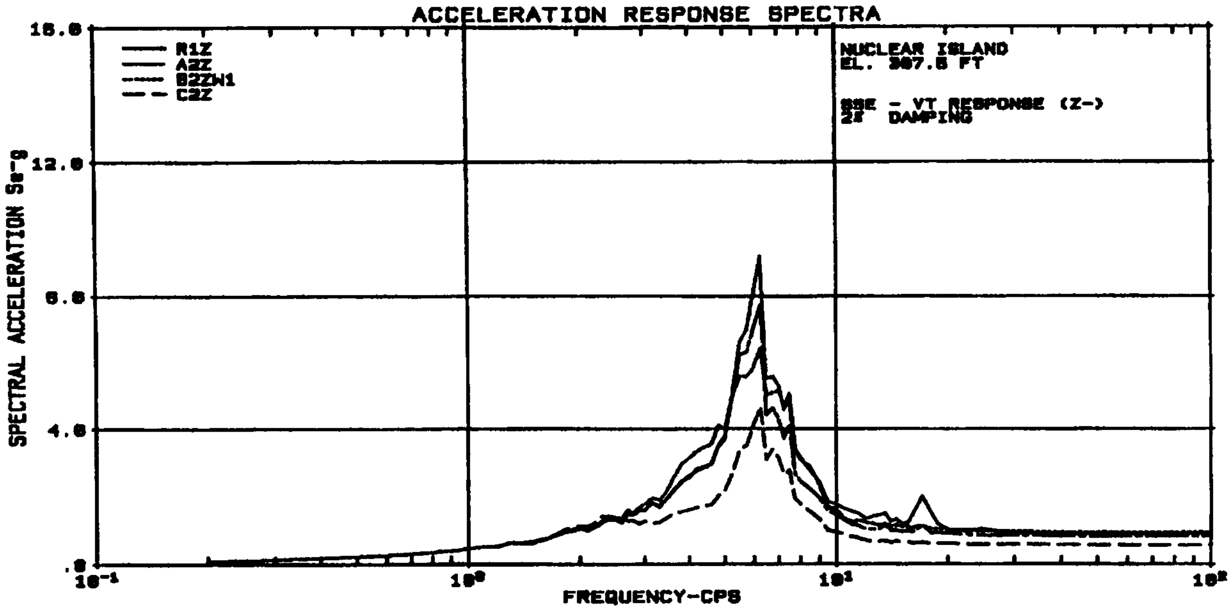

Figure 2A-31 (Sheet 4 of 7)

Vertical Acceleration Response Spectra

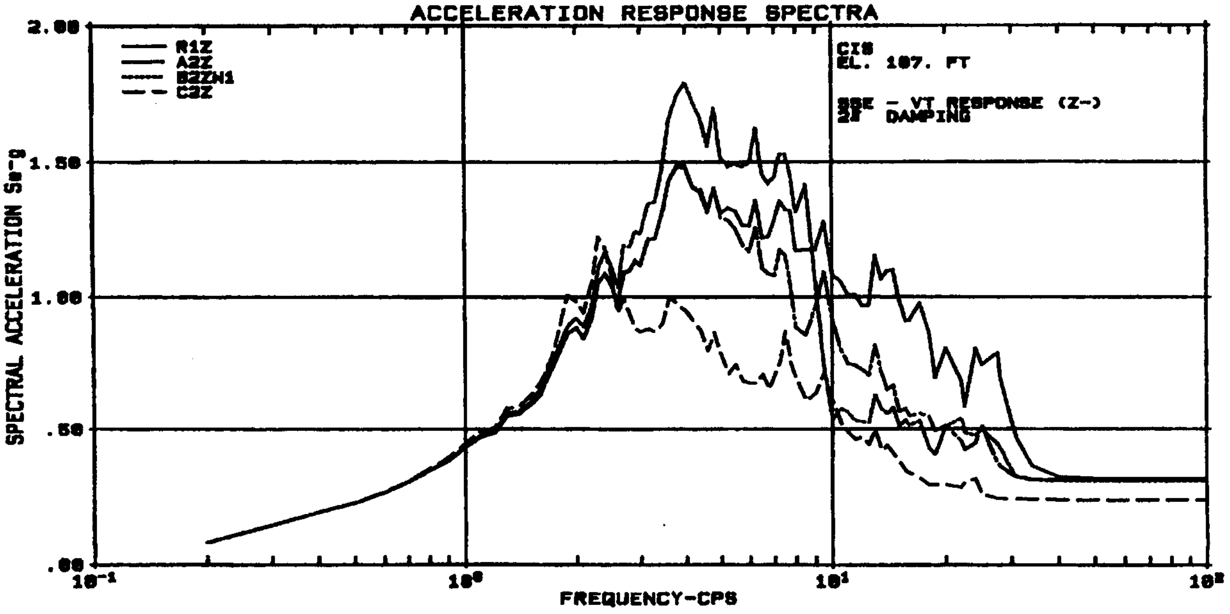

Figure 2A-31 (Sheet 5 of 7)

Vertical Acceleration Response Spectra

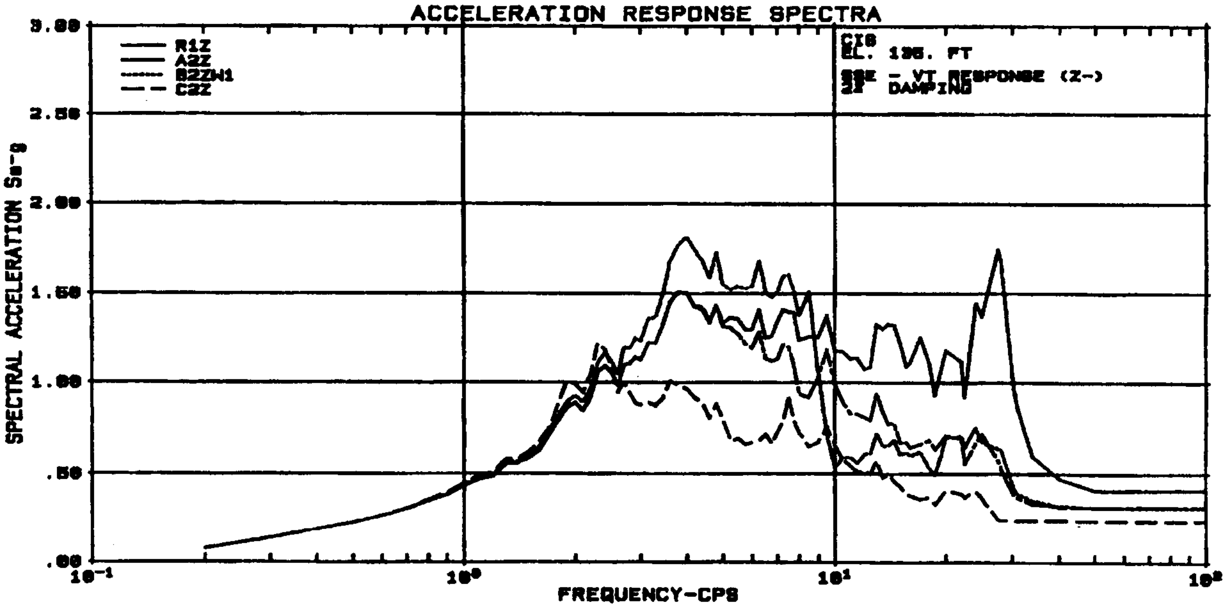

Figure 2A-31 (Sheet 6 of 7)

Vertical Acceleration Response Spectra

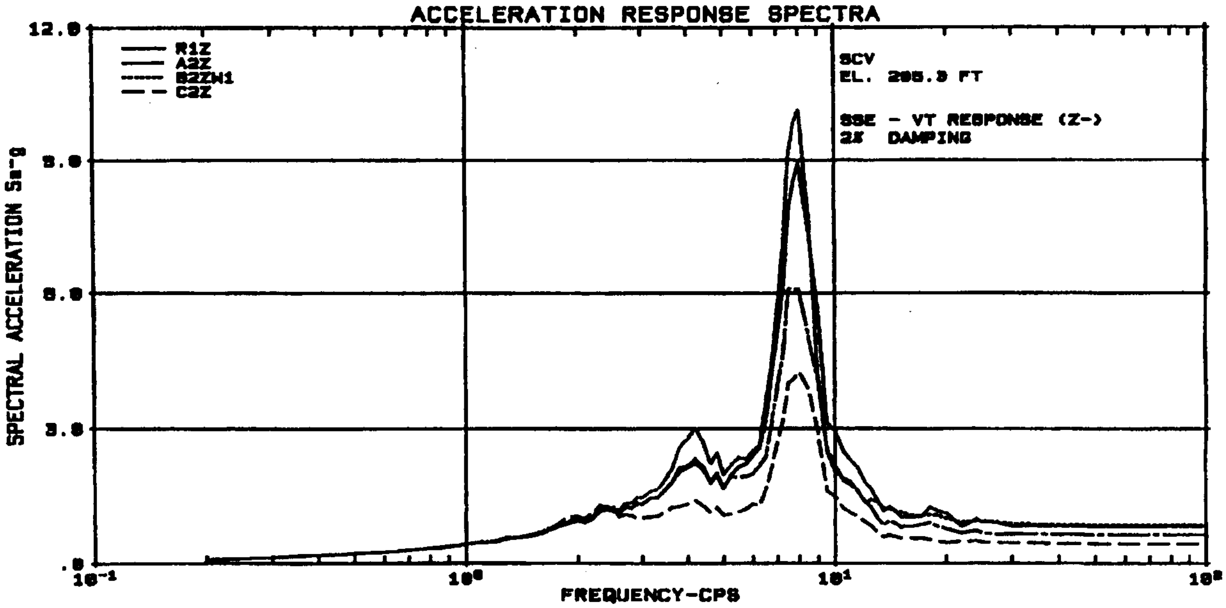

Figure 2A-31 (Sheet 7 of 7)

Vertical Acceleration Response Spectra