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SSI RESPONSE OF A TYPICAL SHEAR WALL STRUCTURE

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SSI RESPONSE OF A TYPICAL SHEAR WALL STRUCTURE

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ABSTRACT

The Simplified Methods Project of the US NRC - funded Seismic Safety Margins Research Program (SSMRP) has as its goal the development of a methodology to perform routine seismic probabilistic risk assessments of commercial nuclear power plants. The study reported here develops calibration factors to relate best estimate response to design values accounting for approximations and simplifications in SSI analysis procedures. Nineteen cases were analyzed and in-structure response compared. The structure of interest was a typical shear wall structure.

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EXECUTIVE SUMMARY

The Seismic Safety Margins Research Program (SSMRP) is an U.S. Nuclear Regulatory Commission-funded multiyear research program conducted by Lawrence Livermore National Laboratory (LLNL). Its objective was to develop a complete, fully coupled analysis procedure (including methods and computer programs) for estimating the risk of earthquake-induced radioactive release from a commercial nuclear power plant. The full SSMRP analysis procedure is based on a state-of-the-art seismic and systems analysis process and explicitly includes the uncertainties inherent in such a process. It is readily apparent that the tools, codes, and data bases developed to-date by the SSMRP comprise a most complete and comprehensive seismic probabilistic risk assessment (PRA) methodology. However, application of the SSMRP methodology in its entirety on a routine basis for all commercial nuclear power plants is too time consuming and costly. The goal of the SSMRP Simplified Methods Project is to develop a simplified methodology for routine seismic PRA's of commercial nuclear power plants.

Estimating three aspects of seismic response of structures and components is essential to a seismic PRA: median-level response, variability of response, and correlation of response for each level of the seismic hazard. In the SSMRP to-date, these aspects were determined calculationaly using the computer program SMACS. To reduce the effort in a seismic PRA, it is proposed to use A-E and vendor developed seismic responses and/or models to the extent possible. Developing median level responses based on design information requires calibration, i.e. removing conservatism or non-conservatism from the design procedure. At least two procedures exist to do so: use generically developed calibration factors which quantify design

procedures and parameters vs. best estimate; or perform limited re-analysis of the nuclear power plant for which the seismic PRA is being performed using best estimate procedures and utilizing the results in the systems analysis and for calibration purposes. The seismic response of structures was the subject of this study.

The objectives of this study were two-fold:

- Develop building response calibration factors, i.e. factors which relate best estimate or median level response to responses calculated by selected design procedures. Soil-structure interaction was the phenomenon of interest because significant simplifications are frequently introduced in its treatment. This objective may be viewed as addressing the question: How much conservatism is introduced by ignoring SSI or by approximating SSI effects by a simplified procedure?
- The second objective can similarly be viewed in the context of a question: What effect does placing an identical structure on different sites and with different foundation conditions have on structure response?

The structure selected for this study is a part of the Zion AFT complex. Only the auxiliary, fuel-handling, and diesel generator buildings were studied. This structure is a connected group of shear-wall buildings constructed of reinforced concrete, typical of nuclear power plant structures. The bases of comparison for this study were structure responses: peak in-structure accelerations (27 components), and peak wall forces and moments (111 components). In-structure response spectra were considered to a limited extent.

The basic approach was to analyze the structure for a series of site and foundation conditions. Best estimate and design procedures were used. Comparisons between best estimate results allows one to quantify the effects of placing the identical structure on different sites and founding it in different manners. Comparisons between responses calculated by simplified SSI design procedures and those calculated by best estimate procedures, allows one to develop calibration factors. These factors can be used to estimate median level responses from design values accounting for SSI analysis procedures.

Two soil profiles were considered: a uniform half-space of varying stiffness characteristics ($V_s = 500$ fps, 1000 fps, 2000 fps, and 3500 fps); and a single soil layer overlying a stiff bedrock -- two thicknesses (71 ft. and 110 ft.) and two layer stiffnesses ($V_s = 1000$ fps and 2000 fps) were treated. Also, a fixed-base condition served as an additional case. One set of analyses treated the structure as being surface-founded; a second set assumed it to be embedded an average depth of 39 ft. which corresponds to an equivalent e/r ratio of 0.35.

Nineteen basic cases were analyzed. Cases 1-15 represent best estimate scenarios provided the analysis scenario matches the physical characteristics of the soil, structure, and foundation. Cases 16-19 represent scenarios with simplifications in the SSI analysis procedure -- namely, constant, frequency independent soil springs representing the behavior of the soil and no treatment of radiation damping. In these 19 cases, structure damping was a uniform 4% of critical for all structure modes. An additional sensitivity study on structure damping was performed for three site conditions (fixed-base, uniform half-spaces of 1000 fps and 2000 fps). The

effect of structure damping on in-structure response was assessed.

Each of the nineteen cases was analyzed for a series of ten earthquakes targeted to the NRC R.G. 1.60 design ground response spectra. Comparisons between cases were made earthquake-by-earthquake and point-by-point and combined ratios of response developed. Hence, mean response ratios and their variability are presented here.

From the nineteen cases, several basic comparisons were made:

- o Surface vs. embedded foundation. Mean ratios of peak accelerations and forces ranged from 1.17 to 1.75 with the surface-founded case higher.
- o Fixed-base vs. (surface and embedded foundations). Mean ratios of peak accelerations and forces ranged from .86 to 2.73 with the fixed-base case higher except for the 71 ft. soil layer over a stiff bedrock. In this latter case, a resonant condition occurs which increases its response.
- o Soil springs vs. (surface and embedded foundations). Mean ratios of peak accelerations ranged from 1.53 to 3.12.

These ratios serve as calibration factors when appropriate.

Finally, a comparison of peak accelerations and forces for different values of structure damping was made. Structure damping is shown to be an important parameter only for the

fixed-base foundation condition. Whenever SSI is properly modeled and the site can be characterized as soil rather than extremely stiff rock, changes in structure damping have a minimal effect on response.

1.0 INTRODUCTION

1.1 BACKGROUND

The Seismic Safety Margins Research Program (SSMRP) is a US NRC funded, multiyear research program conducted by Lawrence Livermore National Laboratory (LLNL) [1]. Its objective was to develop a complete, fully coupled analysis procedure (including methods and computer programs) for estimating the risk of earthquake - induced radioactive release from a commercial nuclear power plant, and to determine major contributors to the frequency of radioactive release. It is readily apparent that the tools, codes, and data bases developed to date by the SSMRP comprise a most complete and comprehensive seismic probabilistic risk assessment (PRA) methodology. Its application to the Zion nuclear power plant is documented in Ref. 2. However, application of the SSMRP methodology in its entirety on a routine basis for all commercial nuclear power plants is too time consuming and costly. The goal of the simplified methods project is to develop a simplified methodology for routine seismic PRA's of commercial nuclear power plants. This methodology will be based on the SSMRP Phases I and II methodology and results.

Seismic risk analysis can be considered in five steps: seismic hazard characterization (seismic hazard curve, frequency characteristics of the motion); seismic response of structures and components; structure and component failure descriptions; plant logic models (fault trees and event trees); and probabilistic failure and release calculations. This study concentrates on the seismic response of structures as it pertains to a seismic PRA.

To perform a seismic risk analysis, seismic responses are required for all structures and components contained in the plant logic models (typically, fault trees and event trees). Of course, some culling, preferably on a probabilistic basis, will be performed to reduce the total number of structures and components of importance to estimation of risk. Typical examples of items for which responses may be required are floor or line mounted valves, pipes, pumps, diesel generator, electrical components such as circuit breakers, electrical busses, etc., structures, structural elements, and so forth. A seismic risk analysis considers not simply one or two levels of earthquake (such as OBE and SSE) but the range of possible earthquakes at the site. Three aspects of seismic response, for each earthquake level, are necessary for seismic risk analysis: best estimate or median level response, variability of response, and correlation of responses.

Median level response. The best estimate or median level seismic response given an earthquake occurrence is required. In general, best estimate response differs from the design values, even for the design level earthquake, because, in the latter case, design analysis procedures, parameter selection, and qualification procedures are conservatively biased. An additional consideration due to analyzing for the range of earthquakes of the seismic hazard curve is the change in properties of the soil/structure/piping systems which occurs as higher excitations lead to lower soil shear moduli, lower structure frequencies, and higher soil and structure damping characteristics. Such changes need to be taken into account when determining best estimate response.

Variability of response. Variability in seismic response resulting from variations in the earthquake excitation, the

physical properties of the soil/structure/piping system and our ability to model them must be estimated.

Correlation of responses. Correlation of responses, i.e., the tendency for pairs of responses to have simultaneously high or low values, results from two sources--the level of the earthquake and the dynamic characteristics of the system. The level of the earthquake affects correlation since a large earthquake (large peak acceleration) may cause all responses to be large, whereas a small earthquake produces the opposite effect. The second source of correlation is due to system response itself. For example, floors within a structure may all experience high values of response simultaneously due to the dynamic characteristics of the structure itself. Hence, equipment supported on these floors may simultaneously have high response. The importance of response correlation on probabilities of system failure, core melt, and radioactive release depends on correlations between fragilities and the functional characteristics of the systems themselves.

For SSMRP seismic risk analysis methodology to date, these three aspects of seismic response were determined calculationaly using the computer program SMACS -- Seismic Methodology Analysis Chain with Statistics [3] . Considerable resources are required to perform the SMACS analysis from start to finish. The major effort is associated with developing models of soil-structure interaction (SSI), major structures, and piping systems and coordinating the models for input to SMACS. One proposed approach to reduce the effort in this aspect of the seismic PRA for the SSMRP Simplified Methodology is to use A-E and vendor developed seismic responses and/or models to the extent possible. In addition, use SSMRP Phases I and II information to define variability and correlation of the seismic responses.

1.2 OBJECTIVES AND SCOPE

Developing median level responses based on existing design information is desirable for performing a seismic PRA. At least two approaches exist to use A-E and vendor generated seismic responses in the seismic PRA. Both approaches are based on calibrating the data -- estimating median level responses (wall forces and moments, in-structure response spectra, in-structure accelerations, etc.), as a function of earthquake level removing conservatism or non-conservatism from the A-E procedure. The two approaches are:

- Develop a set of calibration factors for response quantities of interest based on comparing best estimate results with results of a design procedure.
- Perform limited re-analysis of the nuclear power plant for which the seismic PRA is being performed. Generate seismic responses to be used in the systems analysis and to calibrate the A-E generated data. The re-analysis would concentrate on the structures with minimal or no effort devoted to re-analyzing piping systems. In-structure response spectra could be generated to calibrate conservatism in input to piping systems. The cost of such a re-analysis could be significantly reduced by using A-E generated structural models if they were adequate and available.

The objectives of this study were two-fold:

- The first objective was to develop building response calibration factors, i.e. factors which relate best estimate or median level response to responses calculated by selected design procedures. The

phenomenon of interest for this objective and the following was SSI effects because significant simplifications are frequently introduced in its treatment. Also, the behavior of the structure is intimately coupled with the soil when founded on a soil site and the soil and structure must be treated as a system. This objective may be viewed as addressing the question: How much conservatism is introduced by ignoring SSI or by approximating SSI effects by a simplified procedure?

- The second objective can similarly be viewed in the context of a question: What effect does placing an identical structure on different sites and with different foundation conditions have on structure response?

This effort concentrates on structure response -- wall forces and moments and in-structure accelerations -- with only a limited effort on subsystem response as represented by in-structure response spectra. The structure of interest was a shear wall structure intended to be representative of a typical nuclear power plant building. A parallel study with the subject structure being a containment shell and internals was performed and reported separately. Section 2 describes the structure.

Section 3 describes the key elements of the SSI analyses performed: the free-field ground motion, the soil profiles, the foundation embedment conditions, the foundation impedances, the structure model, and simplified SSI parameters used in a selected number of cases.

Section 4 presents numerical results in the form of response comparisons.

2.0 TYPICAL SHEAR WALL STRUCTURE

2.1 PHYSICAL STRUCTURE

The structure of interest is a part of the Zion auxiliary-fuel handling-turbine building (AFT) complex of the Zion nuclear power plant. Only the auxiliary, fuel-handling, and diesel generator buildings were modelled for this investigation. These structures are a connected group of heavy, shear-wall buildings constructed of reinforced concrete, typical of nuclear power plant structures. In plan view, the buildings form a T-shaped unit with a plane of symmetry along the east-west axis, leading to uncoupled horizontal response along the plane of symmetry and coupled horizontal and torsional response in the perpendicular plane. Figure 2.1 shows a plan view of the Zion nuclear power plant; the portion of the AFT complex studied here is shown shaded. Figure 2.2 shows a cross-section through the structure [2].

The auxiliary building rests on a five ft. thick, soil-supported, reinforced concrete mat at elevation 542 ft. The reinforced concrete foundation walls are laterally supported by concrete floor slabs at elevations 560, 579, and 592 ft. The diesel generator rooms at the north and south ends of the auxiliary building rest on walls extending to a strip footing at elevation 557. Above grade, the lateral force resisting system is a combination of braced structural steel frames and concrete slabs and walls. The floors at elevations 617, 630, and 642 ft. are reinforced concrete slabs supported by horizontal braced steel framing. Between the auxiliary and turbine buildings is a common shear wall. It consists of vertical, braced steel frames encased in reinforced concrete. The total mass and stiffness of this wall was included in the model. The fuel-handling building also rests on a reinforced concrete mat foundation. Reinforced

concrete walls rise on the three exterior sides to the roof. There are partial floor slabs at elevations 602 and 617 ft. The roof is corrugated metal decking with a concrete slab supported by steel framing.

Fig. 2.1 Simplified Plan View of the Zion, Illinois, Nuclear Power Plant. The Shaded Area-- Comprising the Fuel-Handling, Auxiliary, and Diesel Generator Buildings-- is the Subject of this Study.

Fig. 2.2 Section of the Auxiliary/Fuel-Handling/Diesel-Generator Complex through the Plane of Symmetry.

2.2 STRUCTURE MODEL

The structure complex was represented by a finite element model. This represents a best-estimate idealization of the structure, as the fewest simplifying assumptions were applied during its development. Thin plate and shell elements were chosen to define the stiffness of both concrete shear walls and floor slabs. The additional stiffness due to the steel bracing frames in the common auxiliary turbine building wall was ignored. In discretizing the structure model, single elements were used to model the height of the shear walls between adjacent slabs. Whenever possible, element dimensions were chosen to give an aspect ratio close to unity. This discretization approach led to the use of 841 nodes and 1251 plate/shell elements. For the fixed-base model; there were a total of 3948 dynamic degrees-of-freedom. Several views of the model are shown in Figs. 2.3, 2.4, and 2.5. The mass of selected equipment was included in the floor slab densities.

Fig. 2.3 Perspective View of the Model Looking Southwest.

Fig. 2.4 Perspective View of the Model Looking West.

Fig. 2.5 Plan View of Model Shows (X, Y) Coordinates.

2.3 RESPONSE QUANTITIES

In-structure accelerations, in-structure response spectra, and wall forces and moments were the dynamic response quantities of interest for this study. Node point and element locations were selected to represent overall structural behavior and local response. Peak accelerations and in-structure response spectra were calculated at selected nodes described in Table 2.1 and shown in Fig. 2.6. In Fig. 2.6, half of the structure has been removed to better illustrate node point locations. Wall forces and overturning moments were calculated at the roof and floor slab elevations in the major load carrying walls. Responses in the minor walls were omitted from this study. To study shear wall behavior, sections were taken in the selected walls and axial load, in-plane shear force, and overturning moment were calculated. The wall forces and moments are a summation of the elemental forces over the wall length at the section elevation. The wall sections included in this study are tabulated in Table 2.2. The wall locations in the model are illustrated in Fig. 2.7. The walls studied include the common auxiliary-turbine building wall ($X = 180.0$), a major north-south auxiliary building wall ($X = 248.0$), an end wall in the fuel-handling bldg. ($X = 462.0$), a major auxiliary building east-west wall ($Y = 43.5$), the common diesel generator auxiliary building wall ($Y = 133.0$), a diesel generator building wall ($Y = 238.0$), and two sections in major north-south walls in the auxiliary building ($X = 311.0$, and $X = 340.0$). Our data base for this study consisted of:

- Three components of peak acceleration (two horizontal and the vertical) at seven node points and six components of peak acceleration (three translational and three rotational) on the foundation - a total of twenty-seven.

- Response spectra (2% damping) at seven nodes (three components) and on the foundation (six components) - a total of twenty-seven.
- Axial load, in-plane shear, and overturning moment in eight walls - a total of thirty-five sections, and six foundation responses (three forces and three moments) - a total of 111 responses.

Table 2.1 Node Point Locations for Calculation of Peak Accelerations and Generation of In-Structure Response Spectra.

Node Number	Coordinates		
	X	Y	Z
10	229.5 ft.	0. ft.	592.0 ft
78	462.0	0.	617.0
147	222.0	197.0	617.0
188	462.0	0.	642.0
256	229.5	0.	666.0
303	222.0	197.0	666.0
672	229.5	0.	579.0

Table 2.2 Locations of Shear Wall Sections for Response Calculation.

<u>Section</u>	<u>Location</u>	<u>Elevation</u>
1	X = 180.0 ft.	666 ft.
2	"	642
3	"	630
4	"	617
5	"	592
6	"	579
7	"	560
8	X = 248.0	666
9	"	642
10	"	630
11	"	617
12	"	592
13	"	579
14	"	560
15	X = 462.0	666
16	"	642
17	"	630
18	Y = 43.5	666
19	"	642
20	"	617
21	"	592
22	"	579
23	"	560
24	Y = 133.0	666
25	"	642
26	"	630
27	"	617
28	"	592
29	"	579
30	"	560
31	Y = 238.0	642
32	"	630
33	"	617
34	X = 311.0	560
35	X = 340.0	560

Fig. 2.6 Half Section of Model Illustrating Node Points at which Peak Accelerations and In-Structure Response Spectra are Generated.

Fig. 2.7 Plan View of Model Showing Walls for which Forces and Moments were Calculated.

3.0 ELEMENTS OF THE SSI ANALYSIS

The basic elements of any SSI analysis (cast in the format of the substructure approach) are specifying the free-field ground motion, calculating the foundation input motion, calculating the foundation impedances, determining the dynamic characteristics of the structure, and performing the SSI analysis, i.e. combining the previous steps to calculate the response of the coupled soil-structure system. Each aspect is described in general below, followed by details of the present study. *Our best estimate analysis included consideration of all aspects of SSI.*

Free-field ground motion. Specification of the free-field ground motion entails specifying the control point, the frequency characteristics of the control motion (typically, time histories or response spectra), and the spatial variation of the motion.

Foundation input motion. In general, the foundation input motion differs from the free-field ground motion in all cases, except for surface foundations subjected to vertically incident waves. First, the free-field motion varies with soil depth. *Second, the soil-foundation interface scatters waves because* points on the foundation are constrained to move according to its geometry and stiffness. The foundation input motion is related to the free-field ground motion by means of a transformation defined by a scattering matrix $[S(\omega)]$, which is complex valued and frequency dependent:

$$\{U^*(\omega)\} = [S(\omega)] \{f(\omega)\} \quad (3.1)$$

The vector $\{f(\omega)\}$ is the complex Fourier transform of the free-field ground motion, which contains its complete description. For surface-founded structures subjected to vertically incident waves or for SSI analysis where embedment effects are ignored, the foundation input motion is assumed to be identical to the free-field ground motion. This latter instance is a source of conservatism which was quantified here.

Foundation impedances. Foundation impedances $[K_g(\omega)]$ describe the force-displacement characteristics of the soil. They depend on the soil configuration and material behavior, the frequency of the excitation, and the geometry of the foundation. In general, for a linear elastic or viscoelastic material and a uniform or horizontally stratified soil deposit, each element of the impedance matrix is complex-valued and frequency dependent. For a rigid foundation, the impedance matrix is a 6×6 matrix which relates a resultant set of forces and moments to the six rigid-body degrees-of-freedom. Simplifications are many times invoked; in particular, ignoring frequency dependence of the impedances and the specific non-regular geometry of the foundation.

Structure model. The dynamic characteristics of the structure to be analyzed are frequently described by its fixed-base modes. In the present study, our best estimate analyses and simplifications thereof use this form.

SSI analysis. The final step in the substructure approach is the actual SSI analysis. The results of the previous steps -- foundation input motion, foundation impedances, and structure model -- are combined to solve the equations of motion for the coupled soil-structure system.

3.2 FREE-FIELD GROUND MOTION

An ensemble of ten sets of three components of acceleration time histories (two horizontal aligned in the north-south and east-west directions and the vertical) defined the frequency characteristics of the free-field ground motion. Each set was generated to match the design response spectra of the US NRC Regulatory Guide 1.60. The three components were distinct and verified to be statistically independent. Preliminary studies showed comparable results, i.e. comparisons as presented in Sec. 4, using this RG 1.60 data set or a set of more realistically defined acceleration time histories. Ten earthquakes were used to average out the effects of a single excitation and provide stable results. Figure 3.1 shows mean and mean-plus (and minus)-one-standard-deviation response spectra for the data set.

In all of the analyses, the control point was defined on the surface of the soil and the wave propagation mechanism was assumed to be vertically propagating shear and dilatational waves -- hence, defining the spatial variation of motion when included in the SSI analysis. Specification of the control point and the spatial variation of motion in conjunction with assumptions made in the SSI analyses themselves define the relationship between the free-field ground motion and the foundation input motion. For surface-founded structures and structures with embedded foundations for which embedment effects are ignored in the SSI analysis, the foundation input motion is identical to the free-field ground motion. For structures with embedded foundations and embedment is included in the SSI analyses, foundation input motion is calculated from the free-field ground motion by applying the scattering matrices.

Fig. 3.1 Mean and Mean-Plus (and Minus)-One Standard Deviation Response Spectra for Ten Earthquakes Generated to Match RG 1.60 Design Spectra (5% Damping); (a) North-South (Y) Direction, (b) East-West (X) Direction, (c) Vertical (Z) Direction.

Fig. 3.1b (Continued).

Fig. 3.1c (Continued).

3.3 SOIL PROFILES

Two basic soil profiles were considered. The first was a uniform half-space with varying stiffness characteristics defined by shear wave velocities (V_s) of 500 fps, 1000 fps, 2000 fps, and 3500 fps. In all cases, the soil density was assumed to be 130 pcf, Poisson's ratio was 0.4, and material damping in the soil was 5% of critical.

The second basic soil profile was a single layer of soil overlying a stiff bedrock. Two layer thicknesses of 71 ft. and 110 ft. were considered. Two soil layer stiffnesses characterized by shear wave velocities of 1000 fps and 2000 fps were considered. Other properties of the soil layer remained constant, i.e. density of 130 pcf, Poisson's ratio of 0.4 and material damping of 5% of critical. The characteristics of the bedrock were a shear wave velocity of 9000 fps, density of 130 pcf, Poisson's ratio of 0.27, and material damping of 5% of critical.

One additional case was analyzed -- a fixed-base condition.

3.4 FOUNDATION IMPEDANCES

The present investigation centers on a series of analyses for various site conditions, embedment conditions, and assumptions in the SSI analysis. Modeling the soil is the key element in the studies. For our best estimate analyses, i.e. those cases which model the frequency-dependence of impedances and include scattering matrices for embedded foundations, the following general procedure was followed. For each distinct soil profile (uniform half-space, 71 ft. layer over bedrock, and 110 ft. layer over bedrock), impedances and scattering matrices were calculated explicitly for one set of material properties. The softest soil properties of interest were used in the explicit calculation to ensure adequate treatment of the frequency range of interest for stiffer soils. Using these impedances and scattering matrices as base cases, the scheme incorporated in SMACS and described in detail in Ref. 3 was used to derive the SSI parameters for differing soil material properties. For the uniform half-space case, impedances and scattering matrices were calculated for the shear wave velocity of 500 fps and the 1000 fps, 2000 fps, and 3500 fps cases were derived from it. For the 71 ft. and the 110 ft. layer cases, impedances and scattering matrices were calculated for a layer with a shear wave velocity of 1000 fps and the 2000 fps cases were derived from them.

The following sections describe the development of the impedances and present their values.

3.4.1 Surface Foundation Impedances

The foundation is idealized as a flat, T-shaped surface foundation. Figure 3.2 shows a plan view of the model's geometry, including the discretization used in computing the

impedances. This idealization retains the basic characteristics of the foundation's dynamic behavior, such as different horizontal and rocking impedances for the two horizontal directions and appropriate coupling terms. The resulting impedances are a best estimate of the foundation's behavior. The reference point location, i.e. the point about which the impedances were calculated, is shown in Fig. 3.2, and was selected to minimize the coupling impedances between horizontal and torsional motion and vertical and rocking motion. It is approximately at the center of gravity for the foundation which is somewhat coincidental.

The surface foundation impedances for the three base cases are shown in Fig. 3.3 - 3.5: uniform half-space, $V_s = 500$ fps, in Fig. 3.3; 71 ft. layer, $V_s = 1000$ fps, in Fig. 3.4; and 110 ft. layer, $V_s = 1000$ fps, in Fig. 3.5.

Fig. 3-2 Plan View of the Surface-Foundation Model Including the Discretization for Calculating Impedances.

Fig. 3.3 Impedances for the Uniform Half-Space; $V_s = 500$ fps;
Surface Foundation.

N-S Translation Term

N-S Translation/Rocking Coupling Term

N-S Rocking Term

Fig. 3.3 (Continued).

Vertical Translation Term

N-S Translation/Torsion Coupling Term

Torsional Rotation Term

Fig. 3.3 (Continued).

E-W Translation Term

E-W Translation/Rocking Coupling Term

E-W Rocking Term

Fig. 3.4 Impedances for the 71 ft. Soil Layer over Bedrock;
 $V_s = 1000$ fps; Surface Foundation.

N-S Translation Term

N-S Translation/Rocking Coupling Term

N-S Rocking Term

Fig. 3.4 (Continued).

Vertical Translation Term

N-S Translation/Torsion Coupling Term

Torsional Rotation Term

Fig. 3.4 (Continued).

E-W Translation Term

E-W Translation/Rocking Coupling Term

E-W Rocking Term

Fig. 3.5 Impedances for the 110 ft. Soil Layer over Bedrock;
 $V_s = 1000$ fps; Surface Foundation.

N-S Translation Term

N-S Translatic./Rocking Coupling Term

N-S Rocking Term

Fig. 3.5 (Continued).

Vertical Translation Term

N-S Translation/Torsion Coupling Term

Torsional Rotation Term

Fig. 3.5 (Continued).

3.4.2 Embedded Foundation Impedances

For those cases where the structure's foundation is assumed to be embedded, i.e. embedded in an identical manner to the Zion AFT complex, impedances and scattering matrices were developed. The surface-founded impedances form the basis for the embedded case, i.e. the surface-founded values were corrected for embedment. To do so, an equivalent cylinder was developed with dimensions obtained by matching the total excavated volume and the surface area of the foundations. This results in a cylinder of equivalent radius of 112 ft. and an embedment depth of 39 ft. -- and e/λ of 0.35. Scattering matrices were generated for this equivalent cylinder and used in the analyses. The procedure to obtain corrections to the impedances for embedment was to calculate impedances for the embedded cylinder and a surface-founded circular disk of equal area founded at the same elevation as the subject structure. The correction consists of computing differences in these impedances frequency-by-frequency and adding these differences to the T-shaped surface impedances. This procedure corresponds to that used in the SSMRP response calculations (Ref. 3).

Figures 3.6 and 3.7 display embedded impedances for the uniform half-space, $V_s = 500$ fps, and the 110 ft. layer, $V_s = 1000$ fps, cases, respectively.

Fig. 3.6 Impedances for the Uniform Half-Space; $V_s = 500$ fps; Embedded Foundation.

N-S Translation Term

N-S Translation/Rocking Coupling Term

N-S Rocking Term

Fig. 3.6 (Continued).

Vertical Translation Term

N-S Translation/Torsion Coupling Term

Torsional Rotation Term

Fig. 3.6 (Continued).

Fig. 3.7 Impedances for the 110 ft. Soil Layer over Bedrock;
 $V_S = 1000$ fps; Embedded Foundation.

N-S Translation Term

N-S Translation/Rocking Coupling Term

N-S Rocking Term

Fig. 3.7 (Continued).

Vertical Translation Term

N-S Translation/Torsion Coupling Term

Torsional Rotation Term

Fig. 3.7 (Continued).

3.4.3 Frequency Independent Impedances

One simplification investigated in the present study was to develop constant frequency independent soil springs which represent force displacement characteristics of the soil. The soil stiffness was represented by six spring constants, three translational and three rotational, representing the diagonal terms of the impedance matrix. The spring constants are calculated for an equivalent, rigid circular footing resting on an elastic half-space, as described in Ref. 5. For the translational springs, the circular plan was selected to yield a surface area equal to that of the actual T-shaped foundation. The circular footings for the rotational spring constants were chosen to preserve the rotational inertia of the T-shaped foundation for north-south and east-west rocking and torsion. Table 3.1 summarizes the spring constants for the six foundation degrees-of-freedom. The same four uniform half-spaces discussed earlier were treated here.

Table 3.1 Linear Frequency Independent Impedances for
Uniform Half-Spaces.

Stiffness (lb/ft) K	Shear Wave Velocity (ft/sec)			
	$V_s = 500$	1000	2000	3500
Horizontal K_{11} & K_{22}	5.67×10^8	2.27×10^9	9.06×10^9	2.78×10^{10}
Vertical K_{33}	7.48×10^8	2.99×10^9	1.20×10^{10}	3.67×10^{10}
XX Rocking K_{44}	1.59×10^{13}	6.36×10^{13}	2.54×10^{14}	7.79×10^{14}
YY Rocking K_{55}	6.57×10^{12}	2.63×10^{13}	1.05×10^{14}	3.22×10^{14}
ZZ Rocking K_{66}	1.39×10^{13}	5.55×10^{13}	2.22×10^{14}	6.81×10^{14}

3.5 THE STRUCTURE MODEL

The dynamic characteristics of the structure were represented by its fixed-base eigensystem. In all, eighty modes were extracted and used. Table 3.2 shows the eighty modes -- frequencies and percent modal masses. Table 3.3 further highlights significant modes. As noted from Table 3.2, the total mass participating in the eighty modes was 83.8% in the north-south direction, 83.8% in the east-west direction, and 71.9% in the vertical direction. To account for this non-participating mass, a "missing-mass" correction was applied.

The correction procedure involves performing a static analysis of the structure, applying load vectors consisting of the portion of the nodal masses not included in the dynamic analysis. Six load vectors are applied; one for each of the six foundation degrees-of-freedom. The resulting element stresses become influence coefficients relating element stresses to foundation acceleration. Element stress influence coefficients are combined to determine influence coefficients for axial force, in-plane shear, and overturning moment. These influence coefficients are applied to the six acceleration time histories of the foundation and then added by direct superposition to the dynamic response. All results presented here include corrections for modal truncation or "missing mass."

Table 3.2 Percent of Total Mass Participating in each Mode.

MODE	RAD/SEC	HZ	DAMPING	X-COMP	Y-COMP	Z-COMP	XX-COMP	YY-COMP	ZZ-COMP
1	11.907	1.895	0.0400	0.0	0.0	0.8	0.0	1.8	0.0
2	17.465	2.780	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
3	30.301	4.775	0.0400	0.0	0.0	0.1	0.0	0.5	0.0
4	33.819	5.382	0.0400	0.0	0.2	0.0	0.2	0.0	0.3
5	38.039	6.054	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
6	40.538	6.452	0.0400	1.2	0.0	0.0	0.0	1.0	0.0
7	43.240	6.882	0.0400	0.0	0.0	0.2	0.0	0.6	0.0
8	49.817	7.801	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
9	59.113	9.408	0.0400	1.8	0.0	0.0	0.0	1.3	0.0
10	59.549	9.493	0.0400	50.6	0.0	0.8	0.0	42.9	0.0
11	61.364	9.766	0.0400	0.2	0.0	0.0	0.0	0.2	0.0
12	63.262	10.066	0.0400	0.0	13.1	0.0	11.6	0.0	21.1
13	67.423	10.731	0.0400	0.1	0.0	0.0	0.0	0.3	0.0
14	72.570	11.550	0.0400	0.0	0.3	0.0	0.0	0.0	5.8
15	73.062	11.628	0.0400	0.0	2.3	0.0	1.1	0.0	13.6
16	74.117	11.786	0.0400	0.0	9.3	0.0	5.0	0.0	9.2
17	74.973	11.932	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
18	75.086	11.950	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
19	80.136	12.754	0.0400	0.0	0.0	0.0	0.0	0.1	0.0
20	80.616	12.830	0.0400	0.0	29.5	0.0	17.1	0.0	0.0
21	81.227	12.928	0.0400	1.7	0.0	0.1	0.0	3.2	0.0
22	82.174	13.078	0.0400	0.0	1.4	0.0	0.9	0.0	0.0
23	85.031	13.682	0.0400	0.0	0.6	0.0	0.3	0.0	0.1
24	93.373	14.851	0.0400	0.0	0.1	0.0	0.0	0.0	0.3
25	97.823	15.569	0.0400	0.0	1.1	0.0	0.9	0.0	0.2
26	98.674	15.705	0.0400	5.8	0.0	19.5	0.0	0.6	0.0
27	99.818	15.886	0.0400	0.0	0.6	0.0	0.0	0.0	0.0
28	102.412	16.299	0.0400	0.0	0.0	0.0	0.1	0.0	0.0
29	105.369	16.770	0.0400	0.8	0.0	2.1	0.0	0.6	0.0
30	110.426	17.575	0.0400	2.7	0.0	7.6	0.1	2.2	0.0
31	110.664	17.613	0.0400	0.0	0.0	0.0	0.4	0.0	1.5
32	112.662	17.835	0.0400	0.2	0.0	0.9	0.0	0.1	0.0
33	112.300	17.873	0.0400	0.0	0.2	0.0	6.4	0.0	0.3
34	114.614	18.241	0.0400	1.9	0.0	1.2	0.0	0.1	0.0
35	116.282	18.507	0.0400	0.7	0.0	0.4	0.0	0.0	0.0
36	117.548	18.708	0.0400	0.1	0.0	1.4	0.0	0.6	0.0
37	120.393	19.161	0.0400	0.0	4.2	0.0	3.0	0.0	2.8
38	121.041	19.264	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
39	125.339	19.948	0.0400	0.8	0.0	0.1	0.0	5.5	0.0
40	125.988	20.052	0.0400	0.0	0.0	0.0	2.5	0.0	0.0
41	126.658	20.158	0.0400	1.2	0.0	3.3	0.0	0.3	0.0
42	127.349	20.268	0.0400	0.0	0.7	0.0	1.7	0.0	2.9
43	130.247	20.729	0.0400	4.1	0.0	0.1	0.0	0.2	0.0
44	135.754	21.606	0.0400	0.0	0.0	0.0	0.0	0.0	0.0
45	135.577	21.737	0.0400	0.0	0.1	0.0	3.0	0.0	6.6
46	137.126	21.824	0.0400	1.4	0.0	0.3	0.0	0.2	0.0
47	139.252	22.163	0.0400	0.0	0.6	0.0	1.0	0.0	2.7
48	141.849	22.576	0.0400	1.6	0.0	0.8	0.0	1.7	0.0
49	143.052	22.769	0.0400	0.0	0.0	0.0	0.3	0.0	0.7
50	145.504	23.158	0.0400	0.0	0.5	0.0	0.1	0.0	0.3
51	146.913	23.382	0.0400	0.5	0.0	5.6	0.0	0.2	0.0
52	148.083	23.568	0.0400	0.0	0.1	0.0	5.7	0.0	0.6
53	148.433	23.624	0.0400	1.3	0.0	0.6	0.0	0.0	0.0
54	148.943	23.705	0.0400	0.0	0.3	0.0	1.2	0.0	0.6
55	151.157	24.059	0.0400	0.1	0.0	4.0	0.0	1.4	0.0

56	153.186	24.380	0.0400	0.7	0.0	0.6	0.0	0.0	0.0
57	154.716	24.624	0.0400	0.0	1.1	0.0	1.9	0.0	0.3
58	155.267	24.712	0.0400	0.0	0.2	0.0	0.2	0.0	0.7
59	155.515	24.751	0.0400	0.0	0.0	3.5	0.0	0.0	0.0
60	156.899	24.971	0.0400	1.4	0.0	0.0	0.0	0.1	0.0
61	158.451	25.218	0.0400	0.0	9.2	0.0	2.2	0.0	1.1
62	159.658	25.410	0.0400	0.0	0.5	0.0	0.0	0.0	0.0
63	160.702	25.576	0.0400	1.2	0.0	6.3	0.0	0.8	0.0
64	161.194	25.655	0.0400	0.0	2.6	0.3	5.4	0.0	0.1
65	161.432	25.683	0.0400	0.1	0.0	4.9	0.0	0.1	0.0
66	163.687	26.052	0.0400	0.0	0.3	0.0	0.2	0.0	0.0
67	165.239	26.299	0.0400	0.0	0.0	0.6	0.0	0.0	0.0
68	165.398	26.324	0.0400	0.0	0.1	0.0	0.5	0.0	1.5
69	166.380	26.480	0.0400	0.4	0.0	0.1	0.0	1.6	0.0
70	168.178	26.766	0.0400	0.0	0.5	0.0	0.9	0.0	0.6
71	169.724	26.853	0.0400	0.0	0.0	0.1	0.0	0.0	0.0
72	169.274	26.841	0.0400	0.0	0.5	0.0	4.3	0.0	0.2
73	170.337	27.110	0.0400	0.6	0.0	0.3	0.0	0.6	0.0
74	170.823	27.187	0.0400	0.0	1.9	0.0	0.1	0.0	0.4
75	171.906	27.360	0.0400	0.0	0.0	0.0	0.1	0.0	0.0
76	173.263	27.576	0.0400	0.2	0.0	0.4	0.0	0.0	0.0
77	176.602	28.107	0.0400	0.0	0.0	3.1	0.0	4.7	0.0
78	177.502	28.250	0.0400	0.0	0.0	0.0	0.9	0.0	0.9
79	178.077	28.342	0.0400	0.0	0.0	2.2	0.0	0.0	0.0
80	179.209	28.522	0.0400	0.0	1.1	0.0	1.4	0.0	0.1

TOTAL MASS PARTICIPATION OF INCLUDED MODES	83.6	83.8	71.9	77.5	73.6	79.6
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Table 3.3 Description of Significant Fixed-Base Structure Modes

<u>Mode</u>	<u>Frequency (Hz)</u>	<u>Mode Description</u>
10	9.49	E-W Lateral - Aux. and Fuel Handling Bldgs.
12	10.07	Torsion - Aux. and Fuel Handling Bldgs.
14	11.55	Torsion - Fuel Handling Bldg.
15	11.63	Torsion - Fuel Handling Bldg.
16	11.80	Torsion - Fuel Handling Bldg.
20	12.83	N-S Lateral - Aux. and Fuel Handling Bldgs.
21	12.93	N-S Rotation - Aux. and Diesel Gen. Bldgs.
26	15.71	Vertical - Aux. Bldg.
30	17.58	Vertical - Aux. Bldg.
33	17.87	E-W Rotation - Aux. Bldg.
37	19.16	N-S Lateral - Aux., Diesel Generator and Fuel Handling Bldgs.
45	21.74	Torsion - Aux. Bldg.

4.0 NUMERICAL RESULTS

4.1 GENERAL

As discussed in Sec. 1, the objectives of this study can be viewed in the context of two questions:

- How much conservatism is introduced by ignoring SSI or by approximating SSI effects by a simplified procedure?
- What effect does placing an identical structure on different sites and with different foundation conditions have on structure response?

To address these questions, a number of physical and analysis scenarios were considered. Table 4.1 itemizes 19 scenarios which form the basis for the results presented here. Cases 1-15 represent best estimate scenarios provided the analysis scenario matches the physical characteristics of the soil, structure, and foundation. Cases 16-19 represent scenarios with simplifications in the SSI analysis procedure. These latter cases are denoted half-spaces, however, the procedure is typically applied as an approximation to numerous soil profiles other than a uniform half-space, i.e. assuming equivalent soil properties. Hence, cases 16-19 represent a broader class of sites. In cases 16-19, only structure damping was applied -- no attempt to include radiation damping was made.

The responses which formed our data set were specified in Sec. 2.3 and are summarized here:

- Three components of peak acceleration (two horizontal and the vertical) at seven node points and six components of peak acceleration (three

translational and three rotational) on the foundation -- a total of twenty-seven.

- Axial load, in-plane shear, and overturning moment in eight walls, a total of thirty-five sections, and six foundation responses (three forces and three moments) -- a total of 111 responses.
- Response spectra (2% damping) at seven nodes (three components) and on the foundation (six components) -- a total of twenty-seven.

The numerical comparisons presented here are in the form of mean ratios of response and coefficients of variation (COV) for peak accelerations, peak forces, and in-structure response spectra values. The basic procedure to generate the ratios of response was to analyze the soil-structure system for each earthquake (ten earthquakes composed the data set) and calculate the ratios of response for the scenarios to be compared. A mean ratio would then be computed for each response of interest -- the mean is over the ten earthquakes. Preliminary evaluations of this data grouping like components, like directions, like locations, etc. were evaluated vs. more global groups such as all peak accelerations, all peak forces, etc. No discernible difference in the means and COVs were observed between the broader and narrower groupings. Hence, data presented here for peak accelerations and peak forces is for these two broad groups.

Peak accelerations and peak forces are scalar quantities which are amenable to comparison. In-structure response spectra are significantly more difficult to compare and interpret in the context of calibration factors. For example, consider Fig. 4.1 which shows a comparison of in-structure

response spectra at node 256 (Fig. 2.6) for surface vs. embedded foundation conditions. The effect is one of slight frequency shifts and reductions in amplitude which may be conducive to an average reduction factor. However, Fig. 4.2 shows fixed-base results vs. surface and embedded foundation conditions which demonstrate large frequency shifts and reductions in amplitude which are not well described by average ratios. Despite these problems, an attempt to summarize the data in the form of calibration factors was made by separating the frequency range of the spectra into three ranges -- 0 to 6 Hz., 6 to 12 Hz., and 12 to 20 Hz. -- and calculating mean ratios and COVs for each range. The utility of these factors is limited as discussed above. A more appropriate procedure is to estimate or calculate median spectra based on a design procedure and a best estimate calculational procedure. To aid in quantifying the effects of various soil and foundation conditions and SSI analysis assumptions, selected spectra at node 256, the top of the shear wall structure, are presented here. Additional data at all node points of interest are presented in Reference 6.

Table 4.1 Identification of Physical and Analysis Scenarios

Case No.	Soil Profile	V_s (fps)	Foundation Condition	Analysis Technique
1	Fixed-base	Fixed-base	Surface	Best estimate
2	Half-space	3500		
3		2000		
4		1000		
5		500		
6		3500	Embedded	
7		2000		
8		1000		
9		500		
10	110 ft. layer	2000	Surface	
11		1000		
12		2000	Embedded	
13		1000		
14	71 ft. layer	2000	Surface	
15		1000		
16	Half-space	3500		Soil springs
17		2000		
18		1000		
19		500		

4.2 SURFACE VS. EMBEDDED FOUNDATION

A comparison of in-structure responses for the shear wall structure founded on the soil surface vs. embedded 39 ft. ($e/r = 0.35$) pertains to both questions above. First, if one proceeds with a basic estimate analysis procedure for all aspects of SSI but the treatment of embedment, where the physical structure is embedded to the depth considered here, what is the effect on structure response? Second, in a preliminary design context, what are the effects on structure response of embedding the foundation vs. founding it on the surface.

Table 4.2 addresses these questions for peak accelerations and peak forces. The first set of data is for uniform half-spaces of varying shear wave velocities. The effect of embedment ranges from 1.17 to 1.31. Here, and for all other ratios in Table 4.2, the surface-founded structure produced higher response. The second set of data is for a 110 ft. layer of soil overlying a stiff bedrock and for two soil layer stiffnesses. The effect of embedment ranges from 1.31 to 1.38 for this case. The third set of data is a comparison of a surface-founded structure on a 71 ft. soil layer to a structure with an embedded foundation in a 110 ft. soil layer. This case corresponds to ignoring embedment in the analysis process and artificially treating the structure as being surface - founded at the 71 ft. level. For this last case, mean ratios of peak accelerations and peak forces range from 1.57 to 1.75

Table 4.3 contains comparable data for in-structure response spectra. A more informative examination of in-structure spectra is contained in Fig. 4.1 where the identical comparisons of Table 4.2 are made for node 256 at the top of the structure. The effect of embedment is, in general, to increase the predominant frequency and lower the amplitude of response as can be seen from Fig. 4.1.

Table 4.2 Mean Ratios of Forces and Peak Accelerations for Surface -- vs. Embedded Foundation Conditions (Half-Space and Layered Sites)

	Characteristic V_s (fps)	Case Comparison	Peak Accelerations		Peak Forces	
			Mean	COV	Mean	COV
Half-Space	3500	2/6	1.25	.164	1.17	.054
	2000	3/7	1.26	.146	1.22	.067
	1000	4/8	1.31	.159	1.29	.095
	500	5/9	1.28	.163	1.29	.122
110 ft. Layer	2000	10/12	1.37	.156	1.31	.110
	1000	11/13	1.38	.148	1.37	.103
71 ft. Layer Surface vs. 110 ft. Layer Embedded	2000	14/12	1.63	.138	1.57	.139
	1000	15/13	1.74	.151	1.75	.127

Table 4.3 Mean Ratios of Spectral Accelerations for Surface vs. Embedded Foundation Conditions over the Specified Frequency Range (Half-Space and Layered Sites)

Characteristic V_s (Fps)	Case Comparison	0 - 6 Hz. Mean	COV.	6 - 12 Hz. Mean	COV.	12 - 20 Hz. Mean	COV
Half-Space							
3500	2/6	1.05	.215	1.29	.182	1.28	.171
2000	3/7	1.12	.223	1.25	.186	1.26	.154
1000	4/8	1.20	.217	1.22	.133	1.21	.124
500	5/9	1.25	.197	1.11	.107	1.18	.134
110 ft. Layer							
2000	10/12	1.26	.367	1.26	.379	1.31	.135
1000	11/13	1.34	.407	1.32	.200	1.22	.134
71 ft. Layer Surface vs. 110 ft. Layer Embedded							
2000	14/12	1.27	.431	1.53	.334	1.55	.148
1000	15/13	1.40	.424	1.50	.227	1.48	.139

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz
 Translations in ft/sec²

Fig. 4.1 Comparison of In-Structure Response Spectra at Node 256;
 Surface vs. Embedded Foundation; (a) Uniform Half-space,
 $V_s = 3500$ fps, Case 2/Case 6;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————

Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz

Translations in ft/sec^2 Fig. 4.1(b) Uniform Half-space, $V_s = 2000$ fps, Case 3/Case 7;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz
 Translations in ft/sec^2

Fig. 4.1(c) Uniform Half-Space, $V_s = 1000$ fps, Case 4/Case 8;

E-W Translation

N-S Translation

Legend

Surface —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz
 Translations in ft/sec²

Vertical Translation

Fig. 4.1(d) Uniform Half-space, $V_s = 500$ fps, Case 5/Case 9;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface

Embedded

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec^2 Fig. 4.1(e) 110 ft. Layer over Bedrock, $V_s = 2000$ fps, Case 10/Case 12;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————

Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec^2

Fig. 4.1(E) 110 ft. layer over Bedrock, $V_s = 1000$ fps, Case 11/Case 13;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————

Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translation in ft/sec²

FIG. 4.1(g) 71 ft. Layer Surface vs. 110 ft. Layer Embedded, $V_s = 2000$ fps,
Case 14/Case 12;

E-W Translation

N-S Translation

Vertical Translation

Legend

Surface —————
 Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²

Fig. 4.1(h) 71 ft. Layer Surface vs. 110 ft. Layer Embedded, $v_s = 1000$ fps,
 Case 15/Case 13.

4.3 FIXED-BASE VS. (SURFACE AND EMBEDDED FOUNDATIONS)

For many older nuclear power plants, no SSI analysis was performed; a fixed-base analysis yielded accelerations and forces for design. In general, this simplification introduces significant conservatism in the calculated values of peak accelerations and forces. Table 4.4 quantifies this conservatism for cases 2-15. The first set of data in Table 4.4 is for surface-founded structures on a uniform half-space of varying stiffness characteristics. Mean ratios vary from 1.07 to 2.14. One site of interest is the uniform half-space of $V_s = 3500$ fps which is typically considered to be a rock site and in many design codes, a fixed-base analysis is permitted to be performed. Note, even in this case, accounting for the supporting media reduces design loads by a mean of $0.81 = (1/1.23)$. Peak accelerations are reduced less. The second data set presents comparable data for the structure with an embedded foundation on a uniform half-space of varying stiffness. Mean ratios range from 1.27 to 2.73. The third data set compares fixed-base response to that of a structure founded on the surface of a 110 ft. soil layer over bedrock. Two soil layer stiffnesses were considered. Mean ratios range from 1.07 to 1.39. The fourth data set compares fixed-base response to that of a structure embedded 39 ft. in the 110 ft. layer of soil. Two soil layer stiffnesses were considered. Mean ratios range from 1.39 to 1.90. Note, this case for a shear wave velocity of 1000 fps corresponds to the ratios of response likely to exist for the Zion AFT complex since the design analysis assumed a fixed-base condition. The final set of data compares the fixed-base case with the surface-founded structure on a 71 ft. soil layer. In this case, the mean ratios are near one or slightly greater and slightly less. These cases where the fixed-base results are less than the 71 ft. layer responses, the soil layer and structure are in resonance leading to higher

response at some locations especially at lower elevations. Wide scatter in all the ratios is observed.

Table 4.5 contains comparable data for in-structure response spectra. Again, however, these ratios can be misleading. A more informative approach is to examine in-structure spectra themselves for the cases of interest. Figure 4.2 displays response spectra comparisons for node 25C at the top of the structure. The general trend is a frequency shift to lower values and a reduction in amplitude.

Table 4.4 Mean Ratios of Forces and Peak Accelerations for Fixed-Base vs. (Surface and Embedded Foundations; Half-Space and Layered Sites)

Characteristic V_s (fps)	Case Comparison	Peak Accelerations		Peak Forces	
		Mean	COV	Mean	COV
Half-Space Surface Foundation					
3500	1/2	1.07	.261	1.23	.178
2000	1/3	1.25	.389	1.42	.289
1000	1/4	1.47	.500	1.64	.360
500	1/5	2.02	.601	2.14	.403
Half-Space Embedded Foundation					
3500	1/6	1.27	.231	1.44	.184
2000	1/7	1.52	.373	1.73	.288
1000	1/8	1.89	.486	2.11	.360
500	1/9	2.52	.573	2.73	.401
110 ft. Layer Surface Foundation					
2000	1/10	1.07	.421	1.23	.284
1000	1/11	1.27	.504	1.39	.342
110 ft. Layer Embedded Foundation					
2000	1/12	1.39	.393	1.60	.289
1000	1/13	1.67	.464	1.90	.353
71 ft. Layer Surface Foundation					
2000	1/14	.86	.380	1.03	.295
1000	1/15	.99	.511	1.09	.347

Table 4.5 Mean Ratios of Spectral Accelerations for Fixed-Base vs.
(Surface and Embedded Foundations; Half-Space and Layered Sites)
over the Specified Frequency Range

	Characteristic V_s (fps)	Case Comparison	0 - 6 Hz.		6 - 12 Hz.		12 - 20 Hz.	
			Mean	COV	Mean	COV	Mean	COV
Half-Space Surface Foundation	3500	1/2	.97	.056	1.08	.456	1.35	.292
	2000	1/3	.94	.091	1.55	.624	1.87	.404
	1000	1/4	.94	.188	2.70	.738	2.77	.532
	500	1/5	1.12	.510	4.67	.790	4.10	.598
Half-Space Embedded Foundation	3500	1/6	1.03	.025	1.30	.349	1.64	.264
	2000	1/7	1.04	.053	1.83	.571	2.29	.407
	1000	1/8	1.11	.206	3.31	.710	3.32	.523
	500	1/9	1.37	.523	5.29	.759	4.78	.596
110 ft. Layer Surface Founda- tion	2000	1/10	.92	.142	1.55	.747	1.77	.445
	1000	1/11	.92	.271	2.50	.643	2.57	.578
110 ft. Layer Embedded Founda- tion	2000	1/12	1.01	.038	1.69	.675	2.29	.483
	1000	1/13	1.05	.204	3.30	.642	2.96	.501
71 ft. Layer Surface Founda- tion	2000	1/14	.91	.172	1.22	.713	1.56	.544
	1000	1/15	.88	.262	2.30	.704	2.07	.553

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
Surface - - - - -

Notes

All spectra at 2% damping
Frequencies in Hz.
Translations in ft/sec²

Fig. 4.2 Comparison of In-Structure Response Spectra at Node 256; (a) Fixed-base vs. Uniform Half-space, Surface Foundation, $V_s \approx 3500$ fps, Case 1/Case 2;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————

Surface - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz. 2

Translations in ft/sec

Fig. 4.2(b) Fixed-base vs. Uniform Half-space, Surface Foundation,
 $V_s = 2000$ fps. Case 1/Case 3;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base ———
 Surface - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec^2

Fig. 4.2(c) Fixed-base vs. Uniform Half-space, Surface Foundation,
 $V_s = 1000 \text{ fps}$, Case 1/Case 4;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base _____

Surface _____

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²

Fig. 4.2(d) Fixed-base vs. Uniform Half-space, Surface Foundation,
 $V_s = 500$ fps, Case 1/Case 5;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.2(e) Fixed-base vs. Uniform Half-space, Embedded Foundation,
 $V_s \approx 3500$ fps, Case 1/Case 6;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————

Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²

Fig. 4.2(f) Fixed-base vs. Uniform Half-space, Embedded Foundation,
 $V_s = 2000$ fps, Case 1/Case 7;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
Embedded - - - - -

Notes

All spectra at 2% damping
Frequencies in Hz.
Translations in ft/sec^2

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.2(h) Fixed-base vs. Uniform Half-Space, Embedded Foundation,
 $V_s = 500$ fps, Case 1/Case 9;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
Surface - - - - -

Notes

All spectra at 2% damping
Frequencies in Hz.
Translations in ft/sec²

Fig. 4.2(i) Fixed-base vs. 110 ft. Layer over Bedrock, Surface Foundation,

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base ———
 Surface - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec^2

Fig. 4.2(j) Fixed-base vs. 110 ft. Layer over Bedrock, Surface Foundation,
 $V_s = 1000$ fps, Case 1/Case 11;

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base _____
 Embedded _____

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.2(k) Fixed-base vs. 110 ft. Tower over Redwood. Embedded Foundation

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.2(1) Fixed-base vs. 110 ft. Layer over Bedrock, Embedded Foundation,
 $V = 1000$ fps. Case 1/Case 13:

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
 Surface - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.2(m) Fixed-base vs. 71 ft. Layer over Bedrock, Surface Foundation,

E-W Translation

N-S Translation

Vertical Translation

Legend

Fixed-Base —————
 Surface - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec^2

Fig. 4.2(n) Fixed-base vs. 71ft. Layer over Bedrock, Surface Foundation,
 $V_s = 1000$ fps, Case 1/Case 1b;

4.4 SOIL SPRINGS VS. (SURFACE AND EMBEDDED FOUNDATIONS)

Simplified SSI analyses were performed for the shear wall structure and for four sets of soil springs as described in Sec. 3.4.3. These simplified analyses assumed only structure damping to act as an energy dissipation mechanism, i.e. ignoring radiation damping. These cases simulate a surface-founded structure whose SSI characteristics are treated in a simplified fashion. The first data set of Table 4.6 quantifies this effect. Mean ratios of response vary from 1.53 to 2.44. The second data set of Table 4.6 compares the simplified SSI results with responses calculated assuming the structure to be embedded 39 ft. ($e/r = 0.35$). Mean ratios of response vary from 1.84 to 3.12. Uniform half-spaces were assumed for all best estimate cases. Significant conservatisms are observed.

Table 4.7 compares comparable data for in-structure spectra. Again, a better evaluation of the effect of this simplified SSI procedure on in-structure spectra can be made by directly comparing the response spectra. Figure 4.3 compares response spectra at node 256 as before. Significant reductions are observed.

Table 4.6 Mean Ratios of Peak Accelerations for Soil Springs
vs. (Surface and Embedded Foundations; Half-Space Site)

	Characteristic V_s (fps)	Case Comparison	Peak Accelerations	
			Mean	COV
Half-Space Surface Foundation	3500	16/2	1.53	.299
	2000	17/3	1.86	.354
	1000	18/4	2.44	.432
	500	19/5	2.11	.382
Half-Space Embedded Foundation	3500	16/6	1.84	.244
	2000	17/7	2.26	.348
	1000	18/8	3.12	.429
	500	19/9	2.65	.400

Table 4.7 Mean Ratios of Spectral Accelerations for Soil Springs vs. (Surface and Embedded Foundations; Half-Space Site) over the Specified Frequency Range

Characteristic V_s (fps)	Case Comparison	Spectral Accelerations						
		0 - 6 Hz.		6 - 12 Hz.		12 - 20 Hz.		
		Mean	COV	Mean	COV	Mean	COV	
Half-Space Surface Foundation	3500	16/2	1.02	.081	1.69	.420	1.32	.308
	2000	17/3	1.20	.523	1.65	.564	1.38	.308
	1000	18/4	1.47	.712	1.67	.359	1.89	.318
	500	19/5	1.58	.693	1.81	.313	1.88	.260
Half-Space Embedded Foundation	3000	16/6	1.10	.154	2.09	.447	1.62	.332
	2000	17/7	1.39	.677	1.96	.560	1.69	.307
	1000	18/8	1.80	.813	2.05	.392	2.29	.328
	500	19/9	1.99	.770	2.05	.350	2.21	.283

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————

Surface - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²

Fig. 4.3 Comparison of In-Structure Response Spectra at Node 256; Soil Springs Vs. Uniform Half-Space; (a) $V_s = 3500$ fps, Surface Foundation, Case 16/Case 2;

E-W Translation

Vertical Translation

N-S Translation

Legend

Soil Springs —————

Surface - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translation in ft/sec^2

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs

Surface

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²Fig. 4.3(c) $V_s = 1000$ fps, Surface Foundation, Case 18/Case 4.

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————

Surface - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²Fig. 4.3(d) $V_s = 500$ fps, Surface Foundation, Case 19/Case 5.

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————
 Embedded - - - - -

Notes

All spectra at 2% damping
 Frequencies in Hz.
 Translations in ft/sec²

Fig. 4.3(e) $V_s = 3500$ fps, Embedded Foundation, Case 16/Case 6.

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————
Embedded - - - - -

Notes

All spectra at 2% damping
Frequencies in Hz.
Translations in ft/sec²

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————

Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec²Fig. 4.3(g) $V_g = 1000$ fps, Embedded Foundation, Case 18/Case 8;

E-W Translation

N-S Translation

Vertical Translation

Legend

Soil Springs —————
 Embedded - - - - -

Notes

All spectra at 2% damping

Frequencies in Hz.

Translations in ft/sec^2

Fig. 4.3(h) $V_c = 500$ fps, Embedded Foundation, Case 19/Case 9;

4.5 EFFECT OF INCREASED STRUCTURE DAMPING

The sensitivity of in-structure peak accelerations and peak forces to changes in structure damping is an important consideration. Many design procedures select conservatively biased damping values; also, as excitation levels increase and structure failure is approached, higher damping values (10% of critical or greater) can be expected. Hence, one needs to answer with increasing structure damping for soil and rock founded structures?

Table 4.8 quantifies the effect of increased structure damping on peak accelerations and peak forces for the typical shear wall structure. Fixed-base and two uniform half-spaces of shear wave velocities of 2000 fps and 1000 fps were considered. Structure damping of 4%, 7%, and 10% of critical were studied; comparisons between the three were made. The result shows structure damping to be important only for the fixed-base condition. Whenever SSI is properly modeled and the site can be characterized as soil rather than extremely stiff rock, changes in structure damping have a minimal effect on response. This is due to the fact that one must consider the soil and structure as a system and the energy dissipation characteristics of the supporting media dominate the system's behavior. Table 4.9 presents comparable data for in-structure response spectra.

Table 4.8 Mean Ratios of Forces and Peak Accelerations
for Surface Foundation Conditions at 4%, 7%, and 10%
Structure Damping (Half-Space Site).

	Characteristic V_s (fps)	Base Case	Peak Accelerations		Peak Forces	
			Mean	COV	Mean	COV
4% vs. 7%	Fixed Base	1	1.12	.102	1.18	.132
	2000	3	1.04	.063	1.02	.027
	1000	4	1.02	.046	1.01	.015
4% vs. 10%	Fixed Base	1	1.22	.172	1.32	.240
	2000	3	1.07	.108	1.03	.044
	1000	4	1.04	.071	1.01	.023
7% vs. 10%	Fixed Base	1	1.08	.070	1.11	.090
	2000	3	1.03	.041	1.01	.018
	1000	4	1.01	.024	1.00	.009

Table 4.9 Mean Ratios of Spectral Accelerations for Surface Foundation Conditions at 4%, 7%, and 10% Structure Damping over the Specified Frequency Range (Half-Space Site).

	Characteristic V_g (fps)	Base Case	Spectral Accelerations					
			0 - 6 Hz.		6 - 12 Hz.		12 - 20 Hz.	
			Mean	COV	Mean	COV	Mean	COV
4% vs. 7%	2000	3	1.00	.010	1.05	.089	1.09	.096
	1000	4	1.00	.011	1.04	.081	1.08	.091
4% vs. 10%	2000	3	1.00	.017	1.09	.164	1.17	.169
	1000	4	1.00	.019	1.06	.147	1.13	.158
7% vs. 10%	2000	3	1.00	.007	1.04	.062	1.06	.068
	1000	4	1.00	.007	1.02	.053	1.05	.060

5.0 CONCLUSIONS

The seismic analysis of a typical nuclear power plant shear wall structure was performed for a series of site and foundation conditions. Best estimate and design procedures were used. Comparisons between best estimate results allows one to quantify the effects of placing the identical structure on different sites and founding it in different manners. Comparisons between responses calculated by simplified SSI design procedures and those calculated by best estimate procedures, allows one to develop calibration factors. These factors can be used to estimate median level responses from design values accounting for SSI analysis procedures.

Results presented here emphasized in-structure responses which are scalars, i.e. peak accelerations and peak forces. These quantities can be investigated in the context of calibration factors. The difficulty of treating in-structure response spectra in the same manner has been demonstrated. Hence, in this latter case, comparison of spectra themselves is preferred.

6.0 REFERENCES

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APPENDIX A

APPENDIX A

CATEGORIZATION OF NUCLEAR POWER PLANT CHARACTERISTICS

A summary of seismic analysis and design information for the seventy-one nuclear power plants with operating licenses as of approximately April 1980 is contained here. The data was principally taken from Refs. A1 and A2. Six categories were identified and itemized in detail in Table A1:

- General Data -- Plant name, utility, A-E, NSSS manufacturer, reactor type, site classification, structures, and embedment conditions.
- Design Earthquake Definition -- Peak ground acceleration, design response spectra, etc.
- SSI analysis -- Method of analysis, structure model, soil damping, etc.
- Generation of Floor Spectra -- Method of generating spectra, structure model, number of earthquake components, etc.
- Generation of Forces in Structure -- Method of analysis, modal combination, directional combination, etc.
- Structure Damping Used -- Welded steel components, bolted steel components, reinforced concrete, prestressed concrete.

These six general categories are broken down in detail in Table A1. The resulting compilation of information has been encoded in a computer data file which permits sorting and easy compilation of summary data. To do so, numerical code numbers are identified with each attribute in a category. These code numbers are listed in Table A1.

Table A2 presents all nuclear power plants considered and the data accumulated for each. Table A2 presents the data in total with no attempt made to sort it. Tables A3 - A8 present the results of sorting the data and compiling summaries for the following categories:

Table A3 -- Distribution of Plants by Site
(Classification and Soil Model)

Table A4 -- Distribution of Plants by Method of
Generating In-Structure Forces, by
Number and Method of Combination of
Simultaneous Earthquake Components
and by Method of Combining Modal Responses

Table A5 -- Distribution of Plants by Damping Ratio
used for Welded Steel Components and by
Design Ground Response Spectrum

Table A6 -- Distribution of Plants by Damping Ratio
used for Bolted Steel Components and by
Design Ground Response Spectrum

Table A7 -- Distribution of Plants by Damping Ratio
used for Reinforced Concrete Components and
by Design Ground Response Spectrum

Table A8 -- Distribution of Plants by Damping Ratio
used for Prestressed Concrete Components
and by Design Ground Response Spectrum

References

- A1. Subudhi, M., Reich, M., Koplik, B., Lane, J., "Seismic Review Table," Brookhaven National Laboratory, NUREG/CR-1429, 1980.
- A2. Dames and Moore, "Site Parameter Study GASSAR Seismic Design for General Atomic Company," 1974.

Table A1

PLANT CLASSIFICATION

1. GENERAL DATA

- 1.1 Plant Identifier
- 1.2 Utility
- 1.3 Architect/Engineer
- 1.4 NSSS Manufacturer
- 1.5 Reactor Type
- 1.6 Site Classification
- 1.7 Structure
- 1.8 Embedment Conditions

2. DESIGN EARTHQUAKE DEFINITION

- 2.1 Number of Freefield Earthquake Components
- 2.2 Excitation Levels (OBE/SSE)
- 2.3 Horizontal SSE PGA
- 2.4 Ratio of Vertical to Horizontal SSE PGA
- 2.5 Design Response Spectrum
- 2.6 Type of Time History
- 2.7 Location of Control Point

3. SSI ANALYSIS

- 3.1 Method of Analysis
- 3.2 Structural Model
- 3.3 Number of Simultaneous Earthquake Components
- 3.4 Combination of Earthquake Components
- 3.5 Combination of Modal Response
- 3.6 Method of Modeling Soil
- 3.7 Soil Damping
- 3.8 Treatment of Embedment

4. GENERATION OF FLOOR SPECTRA

- 4.1 Method of Generating Horizontal Spectra
- 4.2 Method of Generating Vertical Spectra
- 4.3 Method of Analysis
- 4.4 Structural Model
- 4.5 Number of Simultaneous Earthquake Components
- 4.6 Combination of Earthquake Components

5. GENERATION OF FORCES IN STRUCTURE

- 5.1 Method of Analysis
- 5.2 Structural Model
- 5.3 Number of Simultaneous Earthquake Components
- 5.4 Combination of Earthquake Components
- 5.5 Combination of Modal Response

6. STRUCTURE DAMPING USED (OBE/SSE)

Welded Steel Components
Bolted Steel Components
Reinforced Concrete
Prestressed Concrete

Table A1 (Cont.)

1. GENERAL DATA

1.1 PLANT IDENTIFIER

ANO-1	Arkansas Nuclear One, Unit 1
ANO-2	Arkansas Nuclear One, Unit 2
BVPS-1	Beaver Valley Power Station, Unit 1
BRPPN	Big Rock Point Plant Nuclear
BFNPS-1,2,3	Browns Ferry Nuclear Power Station, Units 1,2 & 3
BSEP-1, 2	Brunswick Steam Electric Plant, Unit 1, 2
CCNPP-1, 2	Calvert Cliffs Nuclear Power Plant, Units 1, 2
CNS	Cooper Nuclear Station
CRNP-3	Crystal River Nuclear Plant, Unit 3
DBNPS-1	Davis-Besse Nuclear Power Station, Unit 1
DCCNPP-1, 2	Donald C. Cook Nuclear Power Plant, Units 1, 2
DNPS-1,2,3	Dresden Nuclear Power Station, Units 1,2 & 3
DAEC-1	Duane Arnold Energy Center, Unit 1
EIHNPP-1	Edwin I. Hatch Nuclear Plant, Unit 1
EIHNPP-2	Edwin I. Hatch Nuclear Plant, Unit 2
FCS-1	Fort Calhoun Station, Unit 1
FSVNGS	Fort St. Vrain Nuclear Generating Station
HNP	Haddam Neck Plant
HBRP-2	H. B. Robinson Plant, Unit 2
HBPP-3	Humboldt Bay Power Plant, Unit 3
IPS-1	Indian Point Station, Unit 1
IPS-2	Indian Point Station, Unit 2
IPS-3	Indian Point Station, Unit 3
JAFNPP	James A. Fitzpatrick Nuclear Power Plant
JMFNP-1, 2	Joseph M. Farley Nuclear Plant, Units 1 and 2
KNP	Kewaunee Nuclear Power
LCNGS	La Crosse (Genoa) Nuclear Generating Station
MYAPP	Maine Yankee Atomic Power Plant
MNPS-1	Millstone Nuclear Power Station, Unit 1
MNPS-2	Millstone Nuclear Power Station, Unit 2
MNGP	Monticello Nuclear Generating Plant
NMPNS-1	Nine Mile Point Nuclear Station, Unit 1
NAPS-1	North Anna Power Station, Unit 1
ONS-1,2,3	Oconee Nuclear Station, Units 1, 2, & 3
OCNPP-1	Oyster Creek Nuclear Power Plant, Unit 1
PNP-1	Palisades Nuclear Plant, Unit 1
PBAPS-2	Peach Bottom Atomic Power Station, Unit 2
PBAPS-3	Peach Bottom Atomic Power Station, Unit 3
PNPS-1	Pilgrim Nuclear Power Station, Unit 1
PBNP-1, 2	Point Beach Nuclear Plant, Units 1, & 2
PINGP-1, 2	Prairie Island Nuclear Generating Plant, Units 1 & 2
QCS-1, 2	Quad-Cities Station, Units 1, & 2
RSNGS-1	Rancho Seco Nuclear Generating Station, Unit 1
REGNPP-1	Robert Emmett Ginna Nuclear Power Plant, Unit 1
SNBS-1,2	Salem Nuclear Generating Station, Units 1 and 2
SONGS-1	San Onofre Nuclear Generating Station, Unit 1
SAPS	Shippingport Atomic Power Station
SLP-1	St. Lucie Plant, Unit 1

Table A1 (Cont.)

SPS-1, 2	Surry Power Station, Units 1, & 2
TMINS-1	Three Mile Island Nuclear Station, Unit 1
TMINS-2	Three Mile Island Nuclear Station, Unit 2
TNP-1	Trojan Nuclear Plant, Unit 1
TPP-3, 4	Turkey Point Plant, Units 3 & 4
VYNPS	Vermont Yankee Nuclear Power Station
YRNPS	Yankee-Rowe Nuclear Power Station
ZNP-1, 2	Zion Nuclear Plant, Units 1, & 2

Table A1 (Cont.)

1.2 UTILITIES

Arkansas Power & Light Co.....	01
Duquesne Light, Ohio Edison & Penn. Power Co.....	02
Consumer Power Co.....	03
Tennessee Valley Authority.....	04
Carolina Power & Light Co.....	05
Baltimore Gas & Electric Co.....	06
Nebraska Public Power & Iowa Powerlight Co.....	07
Florida Power Corp.....	08
Cleveland Electric Co.....	09
Indiana & Michigan Electric Co.....	10
Commonwealth Edison Co.....	11
Iowa Elec. Light & Power, Cent. Iowa Pwr. & Corn Belt Pwr.....	12
Yankee Atomic Electric Co.....	13
Georgia Power Co.....	14
Omaha Public Power.....	15
Public Service Co. of Colorado.....	16
Connecticut Yankee Atomic Power.....	17
Pacific Gas & Electric Co.....	18
Consolidated Edison Co. of New York.....	19
Power Authority of New York.....	20
Alabama Power Co.....	21
Wisconsin Public Service Co.....	22
Dairyland Power Corp.....	23
Maine Yankee Atomic Power Co.....	24
Northeast Nuclear Energy Co.....	25
Northern States Power Co.....	26
Niagara Mohawk Power Corp.....	27
Virginia Electric & Power Co.....	28
Duke Power Co.....	29
Jersey Central Power & Light Co.....	30
Philadelphia Electric Co.....	31
Boston Edison Co.....	32
Wisconsin Electric Power & Wisconsin Michigan Power Co.....	33
Commonwealth Edison & Iowa-Illinois Gas & Electric Co.....	34
Sacramento Municipal Utility Dist.....	35
Rochester Gas & Electric Co.....	36
Public Service Electric & Gas, Philadelphia Electric	
Atlantic City Electric & Delmarva Power & Light Co.....	37
Southern California Edison & San Diego Gas & Electric Co.....	38
DOE & Duquesne Light Co.....	39
Metropolitan Edison Co.....	40
Portland General Electric Co.....	41
Florida Power & Light Co.....	42
Vermont Yankee Nuclear Power Corp.....	43

Table A1 (Cont.)

1.3 ARCHITECT/ENGINEERS

Bechtel.....	01
Stone & Webster.....	02
Sargent & Lundy.....	03
UE & C.....	04
Ebasco.....	05
Burns & Roe.....	06
Gilbert.....	07
Pioneer.....	08
TVA.....	09
AEP.....	10
Gibbs & Hill.....	11

1.4 NSSS MANUFACTURERS

Westinghouse.....	1
General Electric.....	2
Babcock & Wilcox.....	3
Combustion Engineering.....	4
Gulf Atomic.....	5
AC.....	6

1.5 REACTOR TYPE

Boiling Water Reactor (BWR).....	1
Pressurized Water Reactor (PWR).....	2
High Temperature Gas Cooled Reactor (HTGR).....	3

1.6 SITE CLASSIFICATION

Rock Sites (less than 20 ft. of soil), Plutonic Bedrock...	1X
..... Sed. Bedrock.....	1S
Thin Soil Sites (20-40 ft.), Plutonic Bedrock...	2X
..... Sed. Bedrock.....	2S
Intermediate Soil Sites (50-100 ft.), Plutonic Bedrock...	3X
..... Sed. Bedrock.....	3S
Thick Soil Sites (100-400 ft.), Plutonic Bedrock...	4X
..... Sed. bedrock.....	4S
Extra Thick Soil Sites, (> 400 ft.)	

Table A1 (Cont.)

1.7 STRUCTURE

All Structures or unspecified.....	0
Reactor Building (Containment & Internal Structure).....	1
Auxiliary Building.....	2
Turbine Building.....	3
Intake Structure.....	4
Reactor Building Internal	5
Fuel Handling/Storage Building.....	6
Containment and Auxiliary Building.....	7

1.8 EMBEDMENT CONDITIONS

No Embedment.....	0
Shallow Embedment $E/R = 0.25$	1
Moderate Embedment $E/R = 0.50$	2
Deep Embedment $E/R = 0.75$	3
Foundation Mat on Piles.....	4

2. DESIGN EARTHQUAKE DEFINITION**2.1 NUMBER OF FREEFIELD EARTHQUAKE COMPONENTS**

The number of freefield earthquake components for which there is a different response spectrum or time history.

2.2 EXCITATION LEVELS (OBE/SSE)

None.....	0
SSE Only.....	1
Both SSE and OBE.....	2

2.3 HORIZONTAL SSE PGA

The peak ground acceleration defined for the horizontal component of the safe shutdown earthquake (SSE).

2.4 RATIO OF VERTICAL TO HORIZONTAL SSE PGA

The ratio of peak ground accelerations of the SSE vertical component to the SSE horizontal component.

2.5 DESIGN RESPONSE SPECTRUM

Not Available.....	00
None.....	01
NRC Regulatory Guide 1.60.....	10
Newmark.....	20
Modified Newmark.....	21
Idriss; Newmark.....	22
Housner (TID-7024).....	30
Housner; Newmark.....	31
Housner; Modified Newmark.....	32
Housner; Newmark & Hall.....	33
Housner & Estere; Rosenblueth.....	34
Housner; site specific.....	36
Housner/El Centro (1940) enveloped.....	37
Golden Gate Park (1952); Housner.....	38
El Centro (1940).....	41
Taft (1952).....	42
Helena (1935); Taft (1952).....	43
Helena (1935); San Francisco (1957).....	44
Golden Gate Park (1952)/El Centro (1940).....	45
Golden Gate Park (1952)/El Centro (1940).....	46

Table A1 (Cont.)

2.6 TYPE OF TIME HISTORY

None.....	0
Synthetic Time History.....	1
Real Earthquake Time History.....	2

2.7 LOCATION OF CONTROL POINT

Not Applicable.....	0
At Ground Surface.....	1
At Foundation Level.....	2

Table A1 (Cont.)

3. SSI ANALYSIS

3.1 METHOD OF ANALYSIS

None, Not Applicable or Indicated Elsewhere.....	0
Modal Time History Analysis.....	1
Modal Response Spectrum Analysis.....	2
Direct Integration Analysis.....	3
Fourier Analysis.....	4
Equivalent Static Analysis.....	5
Uniform Building Code.....	6

3.2 STRUCTURAL MODEL

Not Applicable.....	0
Stick Model, 2-D.....	1
Stick Model, 3-D with Floor & Wall Eccentricities Incl.	2
Finite Element Model, 2-D.....	3
Finite Element Model, 3-D.....	4
Finite Element Model, Axisymmetric.....	5

3.3 NUMBER OF SIMULTANEOUS EARTHQUAKE COMPONENTS

None.....	0
One Horizontal or One Vertical.....	1
One Horizontal & Vertical.....	2
Both Horizontals & Vertical.....	3

3.4 COMBINATION OF EARTHQUAKE COMPONENTS

No Combination.....	0
Algebraic Summation.....	1
Absolute Summation.....	2
Square-Root-Sum-of-Squares (SRSS).....	3

3.5 COMBINATION OF MODAL RESPONSE

Not Applicable.....	0
Algebraic Summation.....	1
Absolute Summation.....	2
Square-Root-Sum-of-Squares (SRSS).....	3
NRC Reg. Guide 1.92.....	4

Table A1 (Cont.)

3.6 METHOD OF MODELING SOIL

None: Fixed-Base or No Analysis Done.....	000
Spring Constants (Frequency Independent).....	100
Concentrated Springs (Rigid Foundation).....	110
Horizontal Springs Only.....	111
Rocking Springs Only.....	112
Vertical Springs Only.....	113
Horizontal & Rocking Springs.....	114
Horizontal, Rocking and Vertical Springs.....	115
Horizontal, Rocking, Vertical & Torsional Springs.....	116
Distributed Springs (Flexible or Rigid Foundation).....	120
Horizontal Springs Only.....	121
Horizontal and Vertical Springs.....	122
Vertical Springs Only.....	123
Impedance Functions (Frequency Dependent Springs).....	200
Concentrated (Rigid Foundation).....	210
Distributed (Flexible Foundation).....	220
Finite Element Model.....	300
Two-Dimensional.....	310
Axisymmetric.....	320
Three-Dimensional.....	330

3.7 SOIL DAMPING

Not Considered.....	00
Composite Modal Damping.....	10
With Limitation on Damping.....	11
Without Limitation on Damping.....	12
Accounted for Separately in Soil.....	20
Considered, but method of Inclusion not Specified.....	30
With Limitation on Damping.....	31
Without Limitation on Damping.....	32

3.8 TREATMENT OF EMBEDMENT

Not Considered.....	0
Included Only as Modified Soil Springs.....	1
Included as Modified Soil Springs and Input Motion.....	2

TABLE A1 (Cont.)

4. GENERATION OF FLOOR SPECTRA

4.1 METHOD OF GENERATING HORIZONTAL SPECTRA

None.....	0
Ground Spectra Used.....	1
Factored Ground Spectra.....	2
Dynamic Analysis.....	3

4.2 METHOD OF GENERATING VERTICAL SPECTRA

None.....	0
Ground Spectra Used.....	1
Factored Ground Spectra.....	2
Dynamic Analysis.....	3

4.3 METHOD OF ANALYSIS

None or Not Applicable.....	0
Modal Time History Analysis.....	1
Modal Response Spectrum Analysis.....	2
Direct Integration Analysis.....	3
Fourier Analysis.....	4
Equivalent Static Analysis.....	5
Uniform Building Code.....	6

4.4 STRUCTURAL MODEL

Not Applicable.....	0
Stick Model, 2-D.....	1
Stick Model, 3-D with Floor & Wall Eccentricities Incl.	2
Finite Element Model, 2-D.....	3
Finite Element Model, 3-D.....	4
Finite Element Model, Axisymmetric.....	5

4.5 NUMBER OF SIMULTANEOUS EARTHQUAKE COMPONENTS

None.....	0
One Horizontal or One Vertical.....	1
One Horizontal & Vertical.....	2
Both Horizontals & Vertical.....	3

4.6 COMBINATION OF EARTHQUAKE COMPONENTS

No Combination.....	0
Algebraic Summation.....	1
Absolute Summation.....	2
Square-Root-Sum-of-Squares (SRSS).....	3

Table A1 (Cont.)

5. GENERATION OF FORCES IN STRUCTURE

5.1 METHOD OF ANALYSIS

None or Not Applicable.....	0
Modal Time History Analysis.....	1
Modal Response Spectrum Analysis.....	2
Direct Integration Analysis.....	3
Fourier Analysis.....	4
Equivalent Static Analysis.....	5
Uniform Building Code.....	6

5.2 STRUCTURAL MODEL

Not Applicable.....	0
Stick Model, 2-D.....	1
Stick Model, 3-D with Floor & Wall Eccentricities Incl.	2
Finite Element Model, 2-D.....	3
Finite Element Model, 3-D.....	4
Finite Element Model, Axisymmetric.....	5

5.3 NUMBER OF SIMULTANEOUS EARTHQUAKE COMPONENTS

None.....	0
One Horizontal or One Vertical.....	1
One Horizontal & Vertical.....	2
Both Horizontals & Vertical.....	3

5.4 COMBINATION OF EARTHQUAKE COMPONENTS

No Combination.....	0
Algebraic Summation.....	1
Absolute Summation.....	2
Square-Root-Sum-of-Squares (SRSS).....	3

5.5 COMBINATION OF MODAL RESPONSE

Not Applicable.....	0
Algebraic Summation.....	1
Absolute Summation.....	2
Square-Root-Sum-of-Squares (SRSS).....	3
NRC Reg. Guide 1.92 or equivalent.....	4

General Data				Design Earthquake				SSI Analysis				Generation of Floor Spectra				Generation of Forces				Structural Damping Used																			
Plant Identification	Utility	Architect/Engineer	SSSI Manufacturer	Reactor Type	Site Classification	Structure	Embedment Conditions	No. of Freefield EQ Comps.	Excitation Levels	Horizontal SSI PGA	Vert/ Horiz. SSI PGA	Design Response Spectrum	Time History Type	Location of Control Pt.	Method of Analysis	Structural Model	No. of Simit. EQ. Comps.	Combination of EQ. Comps.	Method of Modeling Soil	Soil Dampeny	Treatment of Embedment	Method for Horizontal Spectra	Method for Vertical Spectra	Method of Analysis	Structural Model	No. of Simit. EQ. Comps.	Combination of EQ. Comps.	Method of Analysis	Structural Model	No. of Simit. EQ. Comps.	Combination of EQ. Comps.	Welded Steel Components		Bolted Steel Components		Reinforced Concrete		Prestressed Concrete	
																																CEE	SSS	CEE	SSS	CEE	SSS	CEE	SSS
And-1	01	01	3	2	1	0	0	0	0	0.20	0.67	30	1	0	0	0	0	0	110	00	0	0	0	1	1	0	0	0	0	0	0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
And-2	01	01	4	2	1	0	0	0	0	0.20	0.67	30	1	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	2.0	5.0	2.0	5.0	2.0	5.0
bvns-1	02	02	1	2	0	0	0	0	0	0.125	0.67	30	1	0	0	0	0	0	110	31	0	0	0	1	1	1	0	0	0	0	0	2.0	2.0	5.0	5.0	2.0	2.0	1.0	1.0
brnnn	03	01	2	1	0	0	0	0	0	0.12	0.67	30	1	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	2.0	2.0	5.0	5.0	2.0	2.0	1.0	1.0
bfnns-1,2,3	04	09	2	1	0	0	0	0	0	0.20	0.67	30	2	0	0	0	0	0	100	31	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	1.0	1.0	5.0	5.0	5.0	5.0
bseu-1,2	05	04	2	1	0	0	0	0	0	0.16	0.67	37	2	0	0	0	0	0	110	10	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	5.0	10.0	4.0	7.0	1.0	1.0
dcnnp-1,2	06	01	4	2	0	0	0	0	0	0.15	0.67	41	2	0	0	0	0	0	110	12	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.5	3.0	5.0	2.0	5.0
ens	07	06	2	1	0	0	0	0	0	0.20	0.50	42	2	0	0	0	0	0	112	30	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	7.0	1.0	1.0
ens	07	06	2	1	0	0	0	0	0	0.20	0.50	42	2	0	0	0	0	0	112	30	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	7.0	1.0	1.0
crnp-3	08	07	3	2	1	0	0	0	0	0.10	0.67	34	2	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.5	2.0	2.0	1.0	1.0
dbnps-1	09	01	3	2	1	0	0	0	0	0.15	0.67	20	2	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	5.0	10.0	2.0	7.0	1.0	1.0
dcnnp-1,2	10	10	1	2	0	0	0	0	0	0.20	0.67	41	2	0	0	0	0	0	110	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	2.0	5.0	2.0	5.0
dnps-1	11	01	2	1	1	0	0	0	0	0.20	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	5.0	1.0	1.0
dnps-2,3	11	03	2	1	1	0	0	0	0	0.20	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	5.0	1.0	1.0
dnps-2,3	11	03	2	1	1	0	0	0	0	0.20	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	5.0	1.0	1.0
dnps-2,3	11	03	2	1	1	0	0	0	0	0.20	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	5.0	1.0	1.0
dnps-2,3	11	03	2	1	1	0	0	0	0	0.20	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	5.0	5.0	1.0	1.0
daec-1	12	01	2	1	0	0	0	0	0	0.12	0.63	43	2	0	0	0	0	0	110	31	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	2.0	2.0	5.0	5.0	1.0	1.0
daec-1	12	01	2	1	0	0	0	0	0	0.18	0.67	43	2	0	0	0	0	0	110	31	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	2.0	2.0	5.0	5.0	1.0	1.0
elnnp-1	14	01	2	1	0	0	0	0	0	0.15	0.67	30	2	0	0	0	0	0	110	30	0	0	0	1	1	1	0	0	0	0	0	2.0	3.0	3.0	5.0	3.0	5.0	1.0	1.0
elnnp-2	14	01	2	1	0	0	0	0	0	0.15	0.67	21	1	0	0	0	0	0	110	00	0	0	0	1	1	1	0	0	0	0	0	2.0	3.0	3.0	5.0	3.0	5.0	1.0	1.0
fcs-1	15	11	4	2	0	0	0	0	0	0.17	0.67	31	2	0	0	0	0	0	110	31	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0
fsvns	16	03	3	0	0	0	0	0	0	0.10	0.67	30	2	0	0	0	0	0	110	00	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	2.0	10.0	2.0	5.0	2.0	5.0
hnp	17	02	1	2	0	0	0	0	0	0.17	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	0	0	0	0	0	0	1.0	1.0	2.5	2.5	5.0	5.0	1.0	1.0
hbrn-2	08	05	1	2	1	1	0	0	0	0.20	0.67	30	0	0	0	0	0	0	222	77	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.5	2.5	5.0	5.0	1.0	1.0
hbrn-3	18	01	2	1	0	0	0	0	0	0.50	0.67	10	1	0	0	0	0	0	310	20	0	0	0	1	1	1	0	0	0	0	0	2.0	4.0	4.0	7.0	4.0	7.0	1.0	1.0
ips-1	19	04	3	2	1	0	0	0	0	0.10	0.50	30	1	0	0	0	0	0	000	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	2.5	5.0	5.0	1.0	1.0
ips-2	19	04	1	2	1	0	0	0	0	0.15	0.67	30	0	0	0	0	0	0	000	00	0	0	0	1	1	0	0	0	0	0	0	1.0	1.0	2.5	2.5	2.0	2.0	1.0	1.0
ips-3	19	04	1	2	1	0	0	0	0	0.15	0.67	30	2	0	0	0	0	0	000	00	0	0	0	1	1	0	0	0	0	0	0	1.0	1.0	2.5	2.5	2.0	5.0	1.0	1.0
Jafnp	20	02	2	1	0	0	0	0	0	0.15	0.67	30	1	0	0	0	0	0	110	00	0	0	0	1	1	1	0	0	0	0	0	1.0	1.0	2.0	3.0	2.0	5.0	1.0	1.0
Jmnp-1,2	21	01	1	2	0	0	0	0	0	0.20	0.67	21	1	0	0	0	0	0	110	30	0	0	0	1	1	1	0	0	0	0	0	2.0	5.0	2.0	5.0	2.0	5.0	1.0	1.0

Table A2

[illegible]

Table A2 (cont.)

Table A2 (Cont.)

[illegible]

DISTRIBUTION OF PLANTS BY SITE CLASSIFICATION AND SOIL MODEL

Distribution of Plants by Method
of Modelling Soil

Site Classification	Number of Plants					
		None: No analysis or fixed base analysis	Soil Springs (Freq. Independent)	Impedance Functions (Freq. Dependent)	Finite Element Model	Unknown
1. Rock Sites Less than 20 ft. of soil	15	10	4	0	0	1
2. Thin Soil Sites 20-40 ft. of soil	11	3	8	0	0	0
3. Intermediate Soil Sites 50-100 ft. of soil	13	1	12	0	0	0
4. Thick Soil Sites 100-400 ft. of soil	7	0	7	0	0	0
5. Extra Thick Soil Sites More than 400 ft. of soil	5	0	3	0	2	0

Table A3

DISTRIBUTION OF PLANTS BY METHOD OF GENERATING IN-STRUCTURE FORCES,
BY NUMBER AND METHOD OF COMBINATION OF SIMULTANEOUS EARTHQUAKE COMPONENTS
AND BY METHOD OF COMBINING MODAL RESPONSE

Method of Analysis	Number of Plants	Distribution by Number of Simultaneous Earthquake Components and Method of Combination										Distribution by Combination of Modal Response					
		Three Simultaneous Components				Two Simultaneous Components				One Component No Combination	Unknown Number of Components						
		Algebraic Summation	SRSS	Absolute Summation	Unknown Method	Algebraic Summation	SRSS	Absolute Summation	Unknown Method			Algebraic Summation	Absolute Summation	SRSS	Reg. Guide 1.92 or Equivalent	None	Unknown
Modal Time History Analysis	5	0	0	0	0	1	0	3	0	1	0	5	0	0	0	0	0
Response Spectrum Analysis	53	0	2	1	3	0	0	44	2	1	0	0	7	36	7	1	2
Direct Integration Analysis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency Domain Analysis	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Equivalent Static Analysis	4	0	0	0	0	0	0	3	0	1	0	0	0	0	0	4	0
Uniform Building Code	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0
None	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Unknown	4	0	0	0	0	0	0	0	2	0	2	0	0	0	0	2	2

Table A4

DISTRIBUTION OF PLANTS BY DAMPING RATIO USED FOR
WELDED STEEL COMPONENTS AND BY DESIGN GROUND RESPONSE SPECTRUM

Damping Ratio (Percent)	Number of Plants	Distribution by Type of Design Ground Response Spectrum					
		Reg. Guide 1.60	Newmark	Housner	Real Earthquake	None	Unknown
1.0	28	0	0	24 (0.10-0.24)	4 (0.12-0.20)	0	0
2.0	17	0	2 (0.12-0.17)	13 (0.10-0.20)	2 (0.12)	0	0
2.5	1	0	0	1 (0.67)	0	0	0
3.0	2	0	1 (0.15)	1 (0.15)	0	0	0
4.0	1	1 (0.50)	0	0	0	0	0
5.0	8	1 (0.20)	2 (0.10-0.15)	2 (0.10-0.16)	3 (0.12-0.25)	0	0
7.0	1	1 (0.12)	0	0	0	0	0
Unknown	12	0	1 (0.25)	6 (0.11-0.22)	2 (0.12-0.18)	1 (0.12)	2
Total	70	3	6	47	11	1	2

Note: Numbers in parentheses give ranges of SSE peak ground accelerations in g-units.

DISTRIBUTION OF PLANTS BY DAMPING RATIO USED FOR
BOLTED STEEL COMPONENTS AND BY DESIGN GROUND RESPONSE SPECTRUM

Distribution by Type of Design Ground Response Spectrum

A-24	Damping Ratio (Percent)	Number of Plants	Reg. Guide 1.60	Newmark	Housner	Real Earthquake	None	Unknown	Table A6
	1.0	1	0	0	1 (0.20)	0	0	0	
	2.0	21	0	1 (0.12)	16 (0.10-0.24)	4 (0.12-0.20)	0	0	
	2.5	18	1 (0.20)	1 (0.17)	14 (0.10-0.20, 0.67)	2 (0.12-0.12)	0	0	
	3.0	1	0	0	1 (0.15)	0	0	0	
	5.0	8	0	1 (0.15)	7 (0.10-0.18)	0	0	0	
	7.0	4	2 (0.12-0.50)	0	0	2 (0.12-0.18)	0	0	
	10.0	4	0	1 (0.15)	2 (0.10-0.16)	1 (0.25)	0	0	
	Unknown	13	0	2 (0.10-0.25)	6 (0.11-0.22)	2 (0.12-0.18)	1	2	
	Total	70	3	6	47	11	1	2	

Note: Numbers in parentheses give ranges of SSE peak ground accelerations in g-units.

DISTRIBUTION OF PLANTS BY DAMPING RATIO USED FOR
REINFORCED CONCRETE COMPONENTS AND BY DESIGN GROUND RESPONSE SPECTRUM

Damping Ratio (Percent)	Number of Plants	Distribution by Type of Design Ground Response Spectrum					
		Reg. Guide 1.60	Newmark	Housner	Real Earthquake	None	Unknown
2.0	9	0	1 (0.12)	7 (0.10-0.20)	1 (0.12)	0	0
5.0	39	1 (0.12)	3 (0.10-0.17)	28 (0.10-0.24)	7 (0.12-0.20)	0	0
7.0	10	2 (0.12-0.50)	1 (0.13)	4 (0.10-0.16, 0.67)	3 (0.20-0.25)	0	0
7.5	3	0	0	3 (0.15-0.20)	0	0	0
10.0	1	0	0	1 (0.22)	0	0	0
Unknown	8	0	1 (0.25)	4 (0.17-0.22)	0	1 (0.12)	2
Total	70	3	6	47	11	1	2

Note: Numbers in parentheses give ranges of SSE peak ground accelerations in g-units.

DISTRIBUTION OF PLANTS BY DAMPING RATIO USED FOR
PRESTRESSED CONCRETE COMPONENTS AND BY DESIGN GROUND RESPONSE SPECTRUM

Damping Ratio (Percent)	Number of Plants	Distribution by Type of Design Ground Response Spectrum					
		Reg. Guide 1.60	Newmark	Housner	Real Earthquake	None	Unknown
2.0	4	0	0	3 (0.17-0.20)	1 (0.12)	0	0
5.0	16	2 (0.20-0.50)	3 (0.10-0.25)	8 (0.10-0.20)	3 (0.12-0.25)	0	0
7.5	1	0	0	1 (0.20)	0	0	0
Unknown	49	1 (0.12)	3 (0.12-0.15)	35 (0.10-0.24, 0.67)	7 (0.12-0.20)	1 (0.12)	2
Total	70	3	6	47	11	1	2

Note: Numbers in parentheses give ranges of SSE peak ground accelerations in g-units.