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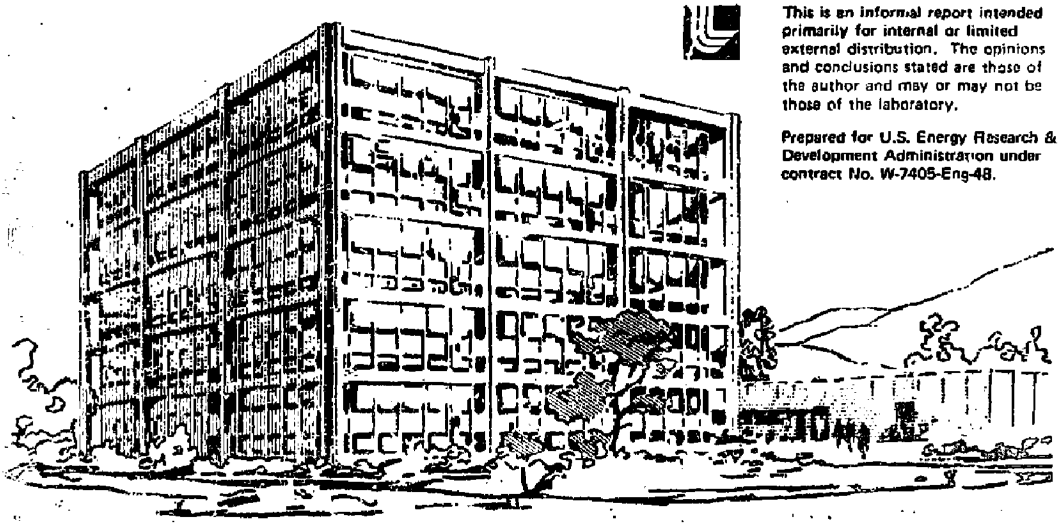
LLL/DOR SEISMIC CONSERVATISM OF OPERATING PLANTS PROJECT
INTERM REPORT ON TASK II.1.3: SOIL-STRUCTURE INTERACTION

MASTER

DECONVOLUTION OF THE JUNE 7, 1975, FERNDALE EARTHQUAKE AT THE HUMBOLDT BAY POWER PLANT

O. R. MASLENIKOV and P. D. SMITH

MARCH 28, 1978



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LLL/DOR SEISMIC CONSERVATISMS OF OPERATING PLANTS PROJECT
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DECONVOLUTION OF THE JUNE 7, 1975, FERNDALE EARTHQUAKE*
AT THE HUMBOLDT BAY POWER PLANT

by

D. R. Maslenikov

P. D. Smith

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* "Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48."

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DECONVOLUTION OF THE JUNE 7, 1975, FERNDALE EARTHQUAKE AT THE HUMBOLDT BAY POWER PLANT

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1.0 INTRODUCTION

The Ferndale Earthquake of June 7, 1975, provides a unique opportunity to study the accuracy of seismic soil-structure interaction methods used in the nuclear industry because, other than this event, there have been no cases of significant earthquakes for which moderate motions of nuclear plants have been recorded. The major objective of Task II.1.3 of the LLL/DOR Seismic Conservatisms of Operating Plants project is to use the Ferndale earthquake data to evaluate these methods, recognizing the limitations imposed by the earthquake event and data, atypical nuclear structure, available analytical methods, and present knowledge of soil behavior. Future studies are planned which will evaluate the soil-structure interaction methodology further, using increasingly complex methods as required.

The first step in this task is to perform deconvolution and soil-structure interaction analyses for the effects of the Ferndale earthquake at the Humboldt Bay Power Plant site. The purpose of these analyses is to attempt to duplicate the analyses performed by Valera, Seed, et al., as closely as possible, given the available information, in order to benchmark the analytical models and procedures to be used in subsequent steps of this task.

This interim report discusses the deconvolution analyses performed in the course of this benchmarking process. The discussion covers the principal deconvolution analyses that were compared with those of Valera and Seed as well as additional studies for analytical sensitivity.

2.0 SUMMARY OF ANALYSES AND RESULTS

Four principal deconvolution analyses were performed using the computer code SHAKE2 (Reference 2) to obtain "bedrock" motion for the June 7, 1975, Ferndale earthquake at the Humboldt Bay Plant site. These deconvoluted motions were obtained for use in the soil-structure interaction analyses of the Refueling Building. The deconvolutions performed were:

Case 1: Deconvolution of the Ferndale earthquake North-South (longitudinal) accelerogram at the Storage Building, through Storage Building Soil Profile A (Figure 3).

Case 2: Deconvolution of the Ferndale earthquake North-South accelerogram at the Storage Building, through Storage Building Soil Profile B (Figure 4).

Case 3: Deconvolution of the Ferndale earthquake East-West (transverse) accelerogram at the Storage Building, through Storage Building Soil Profile A.

Case 4: Deconvolution of the Ferndale earthquake East-West accelerogram at the Storage Building, through Storage Building Soil Profile B.

The values of the input parameters used for these analyses are discussed in Section 5 and the analyses in Section 6. Additional analyses were performed to investigate the sensitivity of the solutions to changes in some of the input parameters. These are discussed in Section 7.

The analyses described in this report produced reasonable deconvoluted "bedrock" motions which will be used for the soil-structure interaction analyses for the Ferndale earthquake at the Humboldt plant site. Reasonably good agreement was obtained between these results and those of Valera, and Seed, (Reference 1). Some differences exist near the model bases but the sensitivity studies performed indicate that no single parameter investigated caused these differences. Further sensitivity studies are being performed to determine the effects of variations of additional parameters in an attempt to determine the source of the discrepancies.

3.0 ANALYTICAL METHODS AND PROCEDURES

The deconvolution process is used as the first step in the general procedure for performing a soil-structure interaction analysis by the finite element method. It is used to obtain a bedrock motion, or a motion at a given depth in a soil deposit, which, when used to excite the deposit, will cause a specified "free-field" motion (control motion) to occur at a control elevation. The control elevation is usually at the ground surface or at the elevation of the foundation of the structure. Soil strata are assumed to be horizontal and motions at any given soil depth are assumed to be uniform at all horizontal locations in the free-field. This is equivalent to the assumption of vertically propagating shear waves and reduces the deconvolution problem to a one-dimensional one.

The deconvolution analyses for this task are performed using the computer code SHAKE2 (Reference 1), which calculates the deconvolved motion in the frequency domain. Reference 1 contains a detailed description of the theory on which the code is based. The Fourier spectrum of the control motion is obtained with the Fourier Transform and the frequency-dependent transfer function of the soil deposit between the control depth and the bedrock depth is computed using assumed dynamic properties for each layer. The bedrock motion can then be calculated by application of the transfer function to the control motion Fourier spectrum and applying the inverse Fourier transform to this result. The algorithm used in SHAKE2 performs this process directly without any filtering to suppress any deleterious effects of noise in the control motion.

This deconvolution calculation is iterated using what is called the "equivalent linear method" to obtain strain-compatible soil properties in the deposit. For each calculation of bedrock motion, "equivalent-linear" soil shear strains, which, typically, are equal to 65% of the maximum shear strains, are calculated for each soil layer. New strain-dependent properties are then computed based on soil test results which relate soil shear moduli and damping to strain, mean effective stress and undrained shear strength, and the deconvolution calculation is repeated using the new assumed properties. This process is repeated until the soil properties calculated from the results from the analysis are within a certain tolerance (typically 10%) of those assumed for the analysis. At this point, the procedure is considered to have converged and the resulting bedrock motion is ready for use in the interaction calculation.

The theory used in SHAKE2 is an "exact" one, given the basic assumptions. That is, the spatially one-dimensional ordinary differential equations which result from the application of the basic assumptions are solved exactly. Sometimes, the sense in which this solution is "exact" has been misinterpreted. For example, a basic assumption in SHAKE2 is that the soil properties are constant over each layer or sub-layer. It should be noted that this results in a spatial discretization of the assumed continua not unlike that resulting from the use of the finite element method. Thus, the sense in which solutions obtained using SHAKE2 are "exact" should always be carefully described.

4.0 FREE-FIELD ACCELERATION RECORDS

Nine digitized acceleration records of the Ferndale earthquake accelerograms recorded at the Humboldt Bay Power Plant Refueling Building and Storage Building were obtained from the NRC for use in the analyses. The records used as control motions for deconvolution are:

STOR12NS	-	North-South (longitudinal) component at the Storage Building, elevation + 12 feet.
STOR12EW	-	East-West (transverse) component at the Storage Building, elevation + 12 feet.

These names correspond to the file names on the LLL mass storage device. The additional records included the vertical component at the Storage Building and three components at each of the two accelerograph locations in the Refueling Building. The locations of the strong motion recorders at the Humboldt Bay plant are shown in Figures 1 and 2. The precise plan location of Sensor 2 could not be determined from the information presently available. The significance of this uncertainty will be discussed in a future report on the soil-structure interaction analyses.

Each of the digitized records consisted of 4000 acceleration points at intervals of 0.005 seconds (20 second duration). All values were in g-units calculated to 10^{-6} g. These records are assumed to be the same as those described in Appendix 6 of Reference 4, and the checks which could be performed support this assumption.

The number of acceleration points in the time histories as received was too great for direct use with a standard version of SHAKE2. Therefore, the number of points was reduced by omitting alternate acceleration points, creating time histories of 2000 points each, at a time interval of 0.01 seconds.

This modification will not have a significant effect on the analyses, which will be made for frequencies below 12.5 Hz, since the Nyquist frequency for a 0.01 second interval is 50 Hz. Comparison of the peak accelerations of the original time histories and their abridged versions show that the N-S component peak acceleration of 0.255 g occurred at a point which was among those elminated and consequently the resulting abridged time history had a peak acceleration of 0.251 g, approximately 2% below the original value. The E-W component peak acceleration of 0.351 g was included in its corresponding abridged time history. In the deconvolution analyses, where a cutoff frequency of 12.5 Hz was used, peak accelerations at the control point were further degraded, by approximately 1% to 2% below those values in the abridged histories. Thus, an error of approximately 4% reduction can be expected in the peak acceleration results of the deconvolution analyses, provided these analyses are sufficiently well behaved.

5.0 SOIL PROFILES AND ANALYTICAL MODELS

Two soil profiles were used for the four principal deconvolution analyses. These are shown in Figures 3 and 4 as Storage Building Soil Profiles A and B and are the same as those used by Valera (Ref. 1) for his deconvolution analyses. The soil properties which were used for the analyses are shown in Figures 3 through 6. These properties were obtained from Reference 3 and are LLL's best estimates of the actual properties used by Valera.

The two profiles consist of 30 feet of clay of varying stiffness underlain successively by 26 feet of medium to dense sand, 6 feet of very stiff clay, and a bed of dense to very dense sand extending to bedrock at a depth of about 400 feet. This stratification agrees with that described in Reference 1 except for the deep clay layer for which there appears to be some ambiguity. The text of Reference 1 and Plate 4 of Reference 3 describe this layer as being 10 feet thick. However, in Figures 3 and 5 of Reference 1 and in Plate 11 of Reference 3, this layer is shown as being 6 feet thick. The sensitivity of the analysis to this uncertainty will be the subject of future investigation.

Figure 7 shows the soil profile at the Refueling Building. This stratification will be used for the finite element soil-structure interaction analyses. By comparing this profile with Figure 3, one can see that, except for an additional 5 foot layer of soft clay at the top of the profile at the Storage Building, the stratification at both locations is almost identical.

Because of limitations of the standard version of SHAKE¹, all deconvolution models discussed herein consisted of 19 soil layers. The selection of layer thicknesses for the models was based on the thicknesses of the different strata and on expected variations of shear modulus in each profile. The sensitivity of the deconvolution models to layer refinement will be studied later.

6.0 DECONVOLUTION ANALYSES AND RESULTS

The deconvolution analyses summarized above were performed using the computer code SHAKE2. For all analyses, 4096 Fourier terms and a cutoff frequency of 12.5 Hz were used. Calculation of new soil properties was accomplished assuming "equivalent linear shear strains" equal to 65% of the peak soil shear strains, determined in the time domain. Iteration was terminated after successive sets of soil layer shear moduli and damping ratios were within 10% of each other. The Coefficient of Earth Pressure at Rest for sand layers was taken at 1.0.

Peak accelerations as well as final soil properties and stresses were obtained throughout the profiles. Response spectra at 5% damping were calculated at several layers in the profiles. Comparisons were made with Valera's results where possible. The results are discussed below.

6.1 Acceleration Profiles

Figures 8 and 9 show a comparison of maximum accelerations at different depth in Soil Profiles A and B for the deconvolution analyses of the Storage Building N-S and E-W accelerograms. The comparisons are made on enlarged reproductions of the appropriate figures from Reference 1 and provide direct comparisons between the results of the LLL analyses, described herein, and those obtained by Valera. It can be seen from the figures that generally good agreement was obtained between the two investigations. The sets of results deviate the most from each other in Soil Profile B at soil depths of 40 to 50 feet and below about 100 feet. This is especially evident for the E-W (transverse) component where the LLL results fall below Valera's result by up to 15% at depths below 100 feet. Sensitivity studies of the analyses conducted to date indicate that, of the parameters studied, changes in the Coefficient of Earth Pressure at Rest (K_0) used for the analysis had the most significant effect and that K_0 less than 1.0 might give better agreement. However, based on the information available to LLL, values of K_0 less than unity, which was assumed for the analysis, could not be justified.

6.2 Response Spectra

Response Spectra were calculated from acceleration time histories obtained from each deconvolution, at grade, at a soil depth of 87 feet (the depth of the reactor caisson base), and at a depth of 150 feet (the base of the model). All spectra were calculated at 5% damping.

Figures 10 and 11 show the spectra of the time histories at grade, the control motions for the deconvolutions. Spectral points from the LLL analysis are identified by circles and are compared with the 5% damping spectrum obtained from Reference 4. As expected, good agreement was obtained.

Figure 12 shows a comparison of response spectra at a soil depth of 87 feet. The figure shows data points from the LLL analyses, shown as circles or triangles, plotted on reproductions of appropriate figures from Reference 1. As can be seen from the figure, the results from the two sets of analyses compare well except at frequencies above 8 Hz, where the LLL results for Soil Profile B were somewhat lower than those obtained by Valera. This deviation may be connected with that observed in the comparison of maximum accelerations. However, at this time, the causes of these deviations have not yet been determined.

Figures 13 and 14 show the response spectra of the deconvolution model base motions (at soil depth 150 feet) obtained from the four analyses. These motions will be used as input for soil-structure interaction analyses which will be performed on site models of the Refueling Building. As no data was available from Valera's investigation (Ref. 1), no comparison could be made. Comparison of these figures with Figure 12 indicates that almost no amplification occurs in the N-S direction below about 87 feet depth of soil. In the E-W direction, some de-amplification from the base (150 feet) to depth 87 feet occurs at about 3 Hz. However, this is the only frequency where significant differences in spectral values occur. The absence of amplification of accelerations in the bottom layers of the soil profiles is also seen in Figures 8 and 9.

7.0 SENSITIVITY STUDIES

Sensitivity studies were performed using variations of the four principal deconvolution analyses discussed above to determine the effects of changes in certain parameters on the results of the analyses. The parameters that have been investigated to date include the Coefficient of Earth Pressure at Rest, the number of Fourier terms used, the effect of the soil existing beneath the model base, and the maximum allowable error between soil properties of successive iterations. These studies are discussed below. Additional deconvolution analyses will also be performed to study the effect of soil layer refinement and model depth on soil-structure interaction.

7.1 Effect of Coefficient of Earth Pressure at Rest

Deconvolution of the Ferndale earthquake, longitudinal (N-S) component, through the Storage Building Soil Profile A was performed for three different values of K_0: 0.45, 1.0 and 3.0. All other parameters were held constant and equal to those values used for the principal deconvolution analyses, for which a K_0 of 1.0 was used.

Comparison of results showed that the use of lower values of K_0 gave higher shear strains, higher damping, lower moduli and higher accelerations in the sand layers. Maximum shear strains from the analysis with K_0 = .45 averaged about 1.3 times those from the control analysis (K_0 = 1.0) while strains from the analysis with K_0 = 3.0 averaged about 0.7 times the control analysis results. As might be expected, shear modulus behavior varied inversely with the shear strains, the averages varying from about 0.75 to 1.6 of the control analysis values, respectively. Average damping ratios varied from about 1.1 to 0.9. Maximum acceleration ratios (Figure 15) varied from about 1.15 to 0.85.

The variation of each variable with K_o appeared to plot fairly well on a semi-log plot. It was also noted that variation of results up to about 1% could be attributed to truncation of the iterative process.

Comparison of spectral values showed that the softer sites yielded higher peak spectral accelerations and velocities. However, there was no consistent shifting of the frequencies of these peak values as might be expected. This inconsistency might possibly be explained as the result of irregularities (non-uniformity) in the control motion across the frequency spectrum.

Deconvolution analyses identical to those described above were performed for the Ferndale earthquake, transverse (E-W) component for both soil profiles (Figures 16 and 17). The comparisons of these analyses generally gave the same results as discussed above although the differences found in the Profile B analyses were more pronounced.

From this study it was concluded that uncertainties in the values of the coefficient of Earth Pressure at Rest (K_o) for the sand layers can introduce significant variations in estimates of effective (average through time) dynamic soil properties. However, it appears that maximum accelerations and velocities are relatively insensitive to these large variations and that the uncertainty in these values is on the order of about 10%.

As no specific value of K_o used for the previous investigation of the Ferndale earthquake at the Humboldt Bay plant (Ref. 1) was available, a value of K_o = 1.0 was assumed. The effects of the uncertainties in this value on the ultimate response of the Refueling Building obtained from soil structure interaction analyses have not yet been investigated.

7.2 Effect of Number of Fourier Terms Used in Analysis

An evaluation of the sensitivity of the deconvolution analyses to the number of Fourier terms used was made by comparing the results, using 2048 and 4096 terms, of deconvolutions of the Ferndale, transverse (E-W) component, through Storage Building Soil Profile B. Other than the number of Fourier terms used in the calculations, input to the two analyses was identical.

Comparison of the results of the two deconvolutions showed that this analysis is not significantly affected by the difference in refinement of frequency points. Maximum accelerations differed by less than 0.2%. Peak spectral accelerations differed by less than 0.04% and soil shear strains, moduli and damping varied by similar percentages. Shear strains for the coarse analysis (2048 terms) were smaller, with correspondingly increased moduli and decreased damping.

From the comparison of acceleration and strain results of the two deconvolutions it was concluded that the use of 2048 Fourier terms could produce accurate results for the deconvolution of the Ferndale earthquake through soil profiles at the Humboldt plant site. However, the duration of the quiet zone, which follows the input earthquake record as a set of trailing zeros, was less than 0.5 seconds for 2048 term analysis. Therefore, the analyses were performed with 4096 Fourier terms. This gave ratios of quiet zone peak accelerations to earthquake peak accelerations that were less than 0.002 for all layers in the soil profile.

7.3 Effect of Half-Space Soil Properties

The input data to program SHAKE2 which defines the soil profile requires that properties for the elastic half-space beneath the deposit be included,and all deconvolution analyses performed for this study have assumed that bedrock exists below the model base (at a depth of 150 feet). However, according to the theory which serves as the basis for the SHAKE2 algorithm, the properties that exist below the model base should have no influence on the motion of the base, because this motion is entirely defined by the properties and motions above it. To check the algorithm, the deconvolution of the Ferndale earthquake, transverse (E-W) component, through the Storage Building Soil Profile A, was re-analyzed using half-space properties similar to those in the lower sand layers of the model instead of rock. All other parameters were the same as previously used.

The results of this re-analysis proved to be identical to those of the previous one, confirming that the selection of half-space properties has no effect on the analysis and is unnecessary for deconvolution using program SHAKE2.

7.4 Effect of Soil Property Convergence Criteria

All deconvolution analyses in the studies previously discussed used a convergence criterion that allowed a 10% maximum error between soil layer shear moduli and damping ratios from successive iterations. A preliminary study was made to investigate the effect of convergence accuracy by performing deconvolution analyses of the Ferndale earthquake transverse (E-W) component through two models of Storage Building Profile B. One model had initial shear moduli that were upper bound estimates of the converged values; the second model had lower bound initial moduli. Both models had the same initial lower bound damping ratio estimates. The results of the two analyses showed differences in final moduli and maximum accelerations of about 5%. However, there appeared to be no consistent relationship between the two sets of results in that the "upper bound" analysis did not converge to modulus values that were higher in all layers than the converged "lower bound" moduli. Further studies would be necessary to determine if any consistent convergence patterns exist. However, the results from the analyses discussed above provide typical errors that could be expected from commonly used convergence criteria.

8.0 CONCLUSIONS

Based on the deconvolution analyses performed to date, the following conclusions are made.

The principal analyses produced reasonable deconvoluted bedrock motions which can be used for the soil-structure interaction analyses of the Humboldt site. Reasonably good agreement with the results reported in Reference 1 was obtained as is seen from Figures 8, 9, and 12; the greatest differences found were on the order of 15%. The reasons for these differences have not been determined, but the possible sources studied in Section 7 can be eliminated. The only parameter to which the analyses were at all sensitive is the Coefficient of Earth Pressure at Rest (K_0), used to compute the mean effective stress in sands, upon which the shear modulus is dependent. However, variations in K_0 produced changes in results which were generally independent of the soil profiles studied, in contrast to the differences seen in Figures 8 and 9.

Further deconvolution analyses of the Ferndale earthquake at the Humboldt Bay Power Plant will be performed in the near future to investigate other potential areas of sensitivity. These include analyses to obtain soil motions at depths greater than 150 feet for use in soil-structure interaction depth studies, and analyses of models having greater layer refinement.

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4. "Report on June 7, 1975, Ferndale Earthquake," Pacific Gas & Electric Co., San Francisco, California, August 2, 1975.

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6. Private communications between Drs. Richard G. Dong, LLL, and Julio E. Valera, Dames and Moore.

7. R. G. Dong, "Qualification of Seismic Conservatism of Operating Plants: Humboldt Nuclear Power Plant FLUSH Model Reconstruction," LLL internal report UCIR-01145, July 29, 1977.

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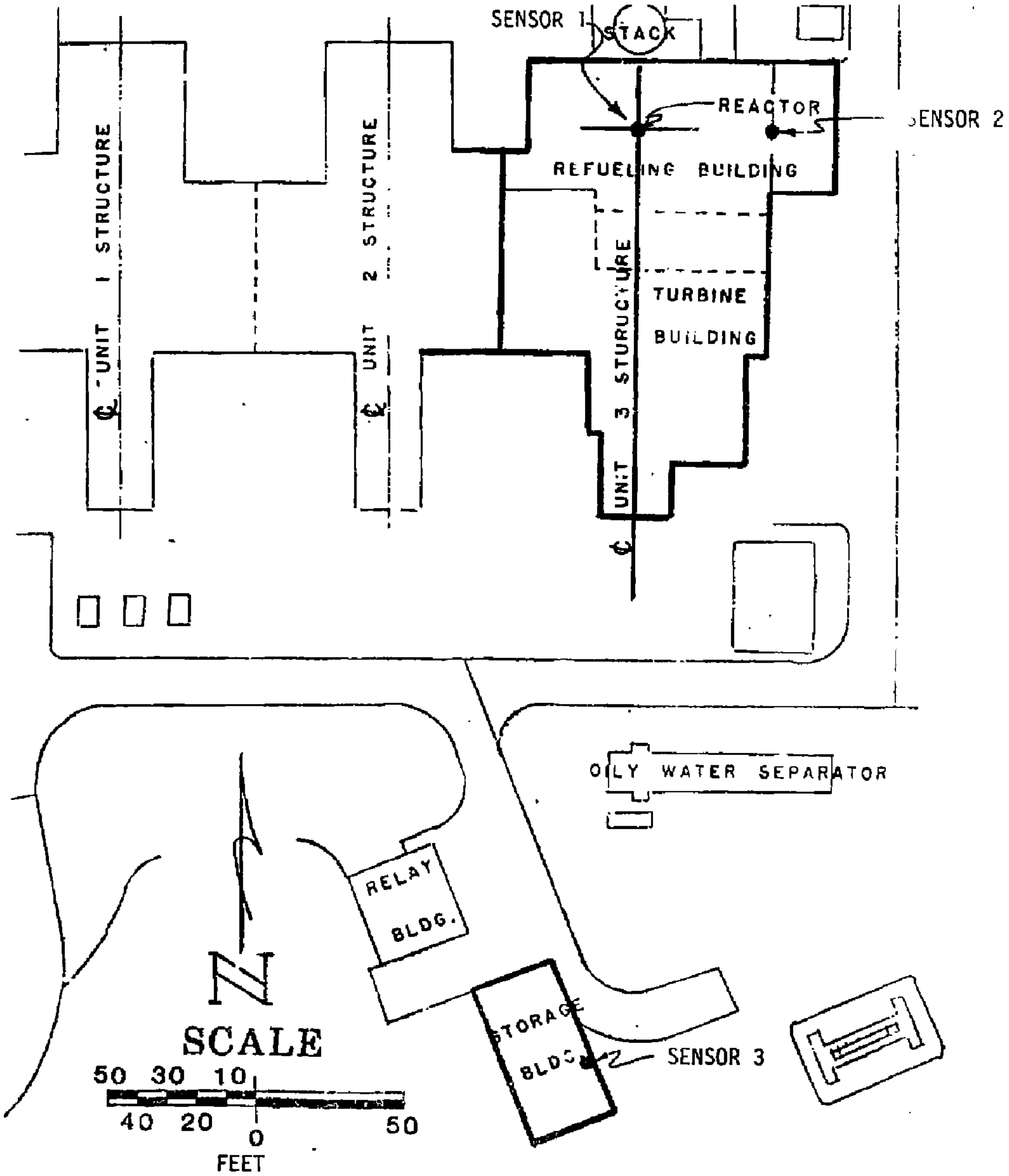

FIGURE 1. PLAN VIEW OF HUMBOLDT BAY POWER PLANT SHOWING LOCATION OF STRONG MOTION ACCELEROGRAPHS. (FROM REFERENCE 4)

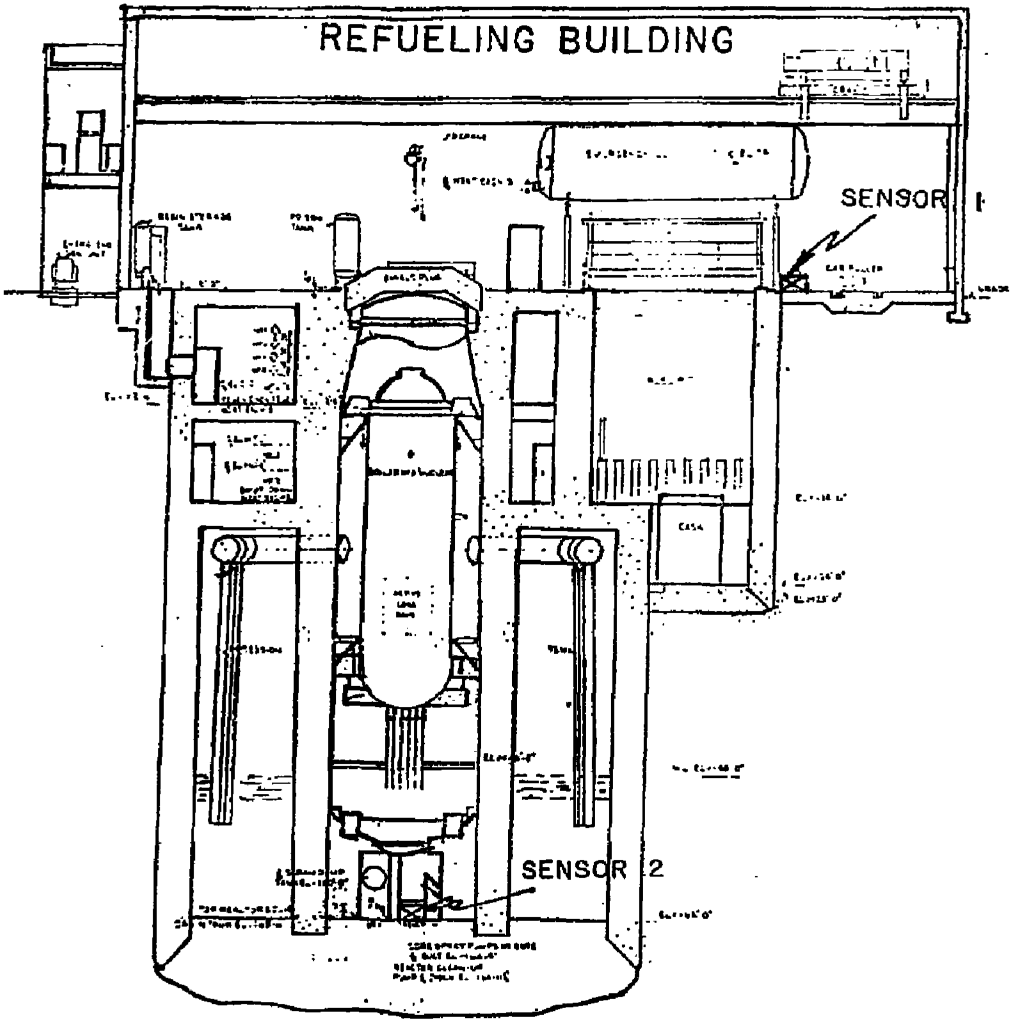

FIGURE 2. ELEVATION VIEW OF REFUELING BUILDING, FACING NORTH, SHOWING LOCATION OF STRONG MOTION ACCELEROGRAPHS (FROM REFERENCE 4)

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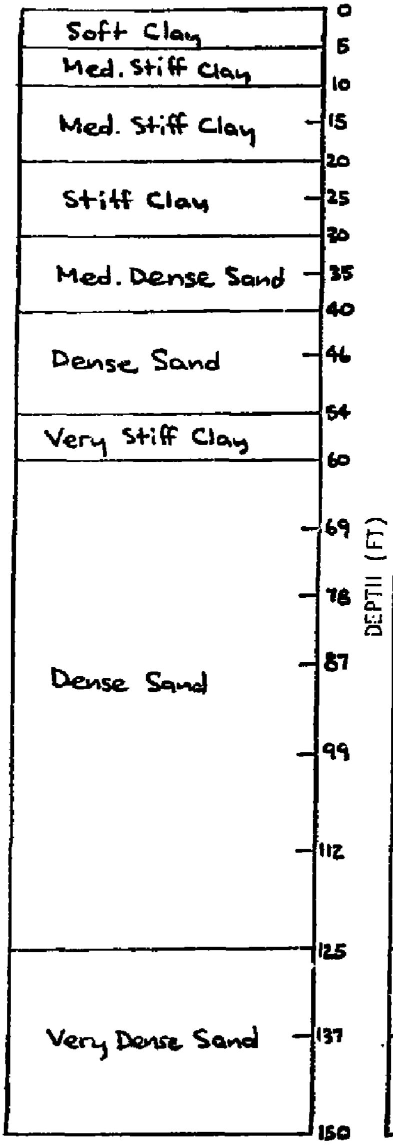
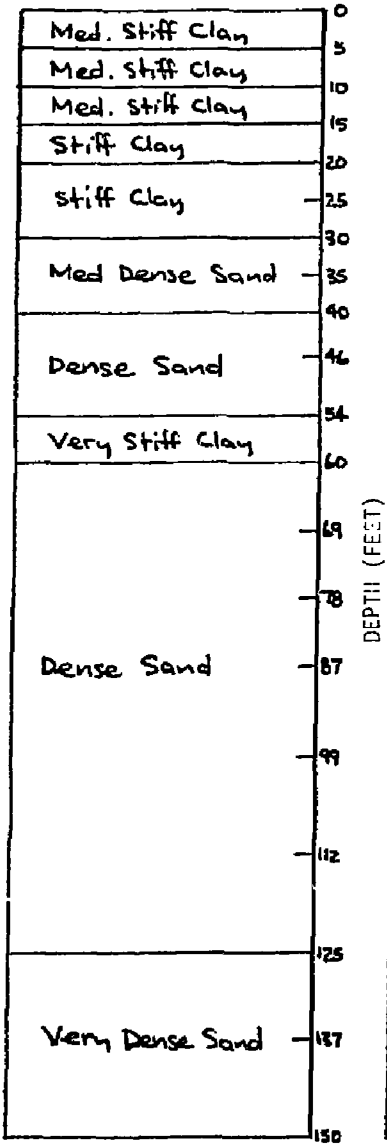


LAYER NO.	THICKNESS (FT)	TOTAL UNIT WT (PCF)	S_u (PSF)	FACTORS ON STD CURVES	
				MODULUS	DAMPING
1	5	125	500		1.0
2	5	125	800		1.0
3	5	125	1500		1.0
4	5	125	1500		1.0
5	5	125	3000		1.0
6	5	125	3000		1.0
7	5	130		0.65	1.15
8	5	130		0.65	1.15
9	6	130		1.0	1.0
10	8	130		1.0	1.0
11	6	130	6000		1.0
12	9	130		1.0	1.0
13	9	130		1.0	1.0
14	9	130		1.0	1.0
15	12	130		1.0	1.0
16	13	130		1.0	1.0
17	13	130		1.0	1.0
18	12	135		1.25	0.8
19	13	135		1.25	0.8

FIGURE 3. STORAGE BUILDING SOIL PROFILE A



LAYER NO.	THICKNESS (FT)	TOTAL UNIT WT (PCF)	S_u (PSF)	FACTORS ON STD CURVES	
				MODULUS	DAMPING
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2	5	125	800		1.0
3	5	125	1000		1.0
4	5	125	2000		1.0
5	5	125	3000		1.0
6	5	125	3000		1.0
7	5	130		0.65	1.15
8	5	130		0.65	1.15
9	6	130		1.0	1.0
10	8	130		1.0	1.0
11	6	130	6000		1.0
12	9	130		1.0	1.0
13	9	130		1.0	1.0
14	9	130		1.0	1.0
15	12	130		1.0	1.0
16	13	130		1.0	1.0
17	13	130		1.0	1.0
18	12	135		1.25	0.8
19	13	135		1.25	0.8

FIGURE 4. STORAGE BUILDING SOIL PROFILE B

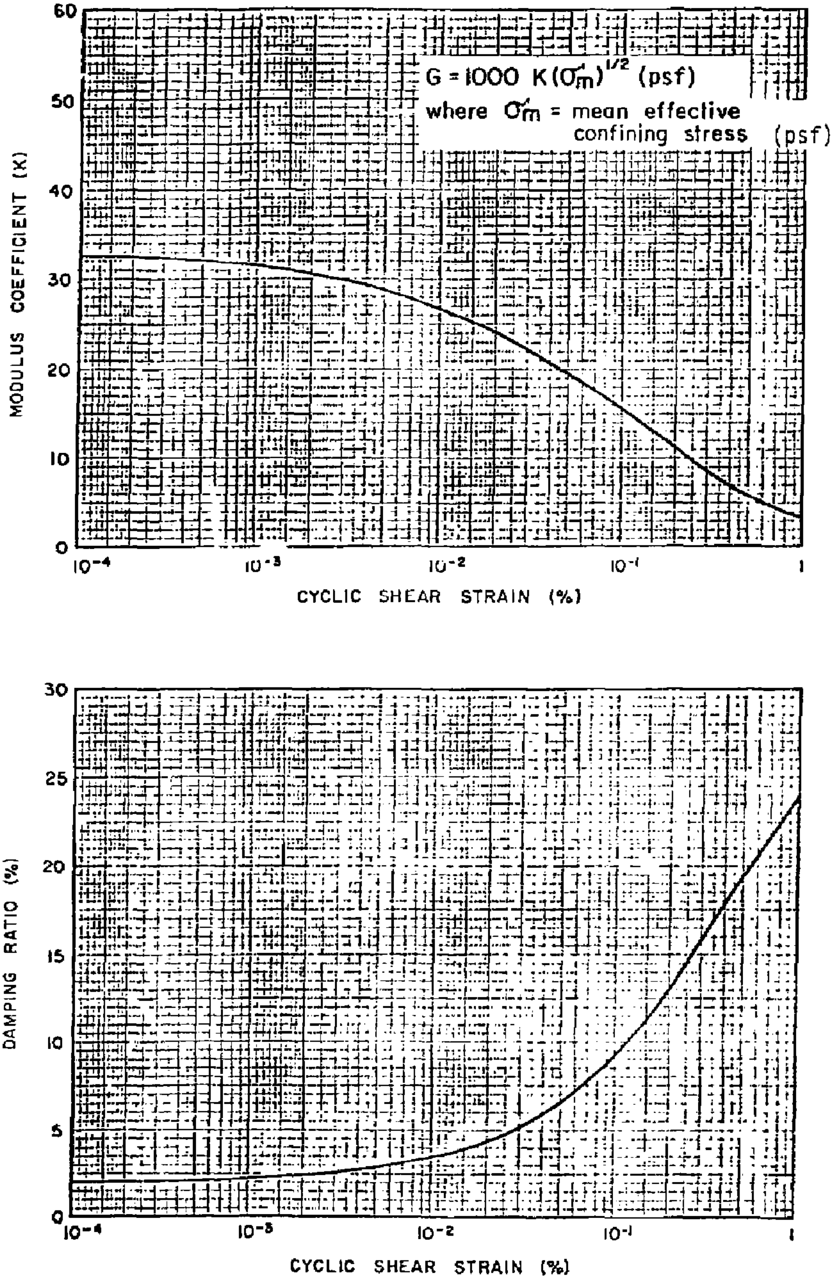

FIGURE 5

AVERAGE DYNAMIC SOIL PROPERTIES - COHESIONLESS SOILS
(FROM REFERENCE 3)

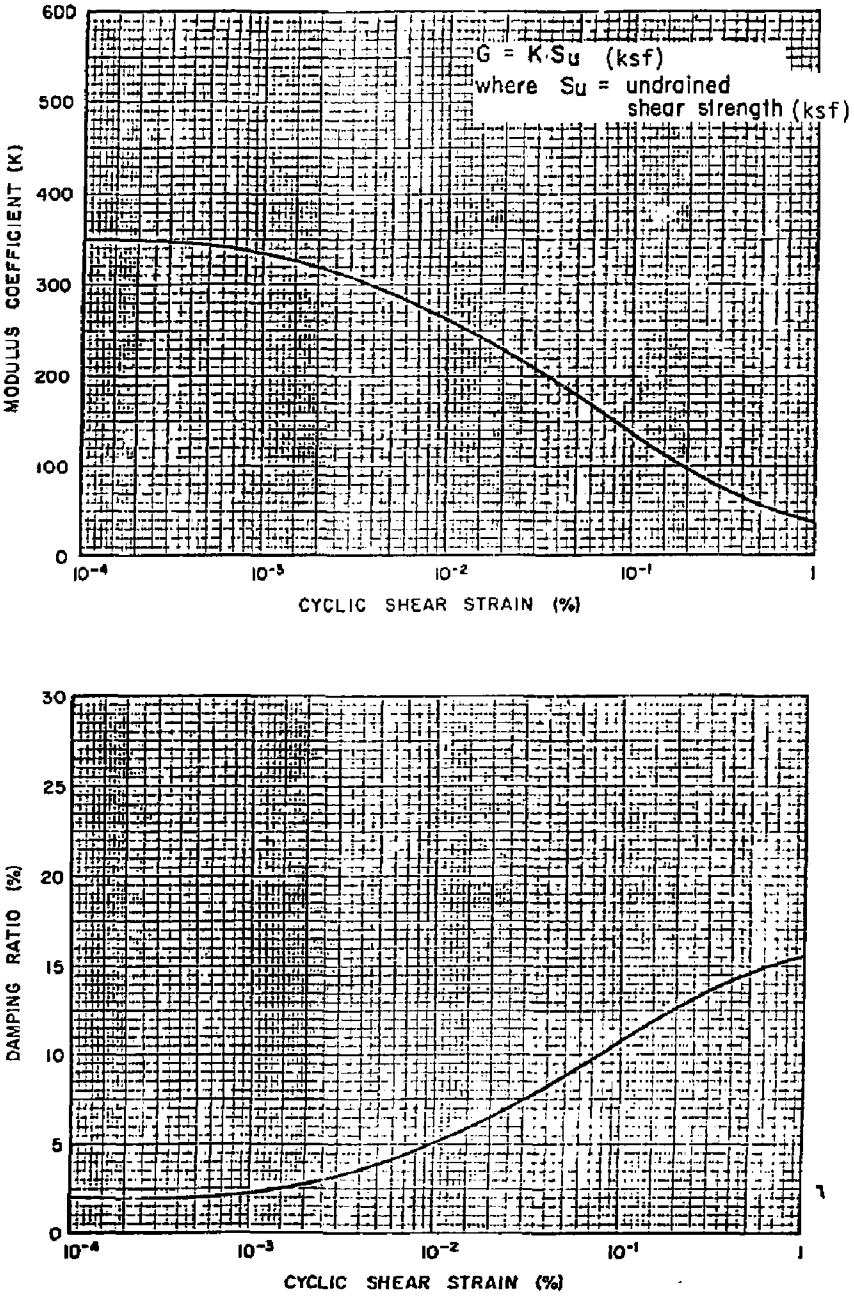

FIGURE 6

AVERAGE DYNAMIC SOIL PROPERTIES - COHESIVE SOILS
(FROM REFERENCE 3)

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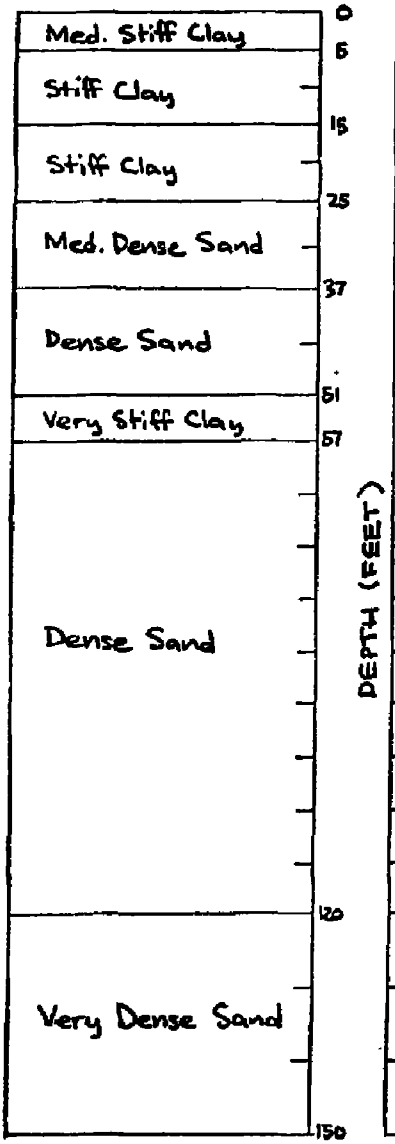

LAYER NO	THICKNESS (FT)	TOTAL UNIT WT (PCF)	S_u (PSF)	FACTORS ON STD CURVES	
				MODULUS	DAMPING
1	5	125	800		1.0
2	5	125	1600		1.0
3	5	125	1500		1.0
4	5	125	3000		1.0
5	5	125	3000		1.0
6	6	130		0.65	1.15
7	6	130		0.65	1.15
8	7	130		1.0	1.0
9	7	130		1.0	1.0
10	6	130	6000		1.0
11	7	130		1.0	1.0
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16	7	130		1.0	1.0
17	7	130		1.0	1.0
18	7	130		1.0	1.0
19	7	130		1.0	1.0
20	10	135		1.25	0.8
21	10	135		1.25	0.8
22	10	135		1.25	0.8

FIGURE 7. SOIL PROFILE AT REFUELING BUILDING

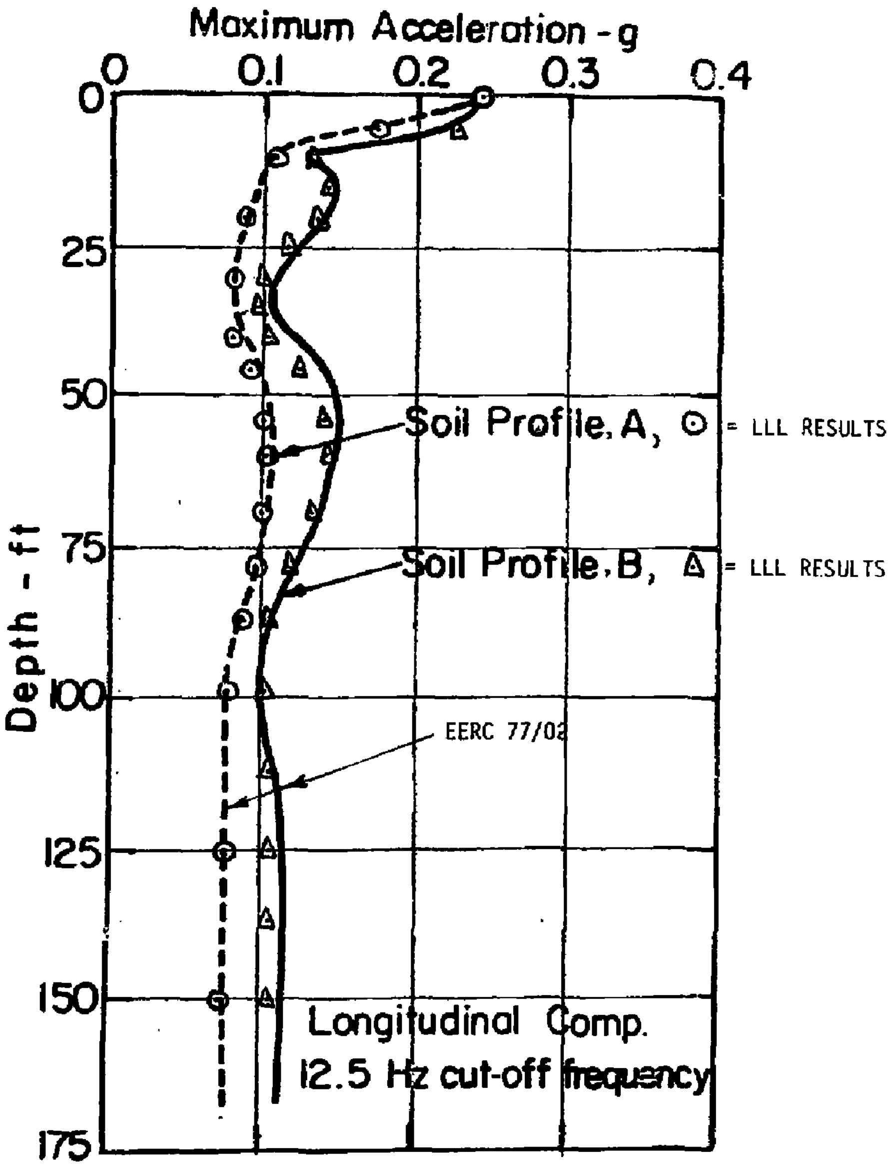

FIGURE 8. VARIATION OF MAXIMUM ACCELERATION WITH DEPTH, STORAGE BUILDING N-S COMPONENT DECONVOLUTION ANALYSIS, COMPARISON OF LLL RESULTS WITH EERC 77/02.

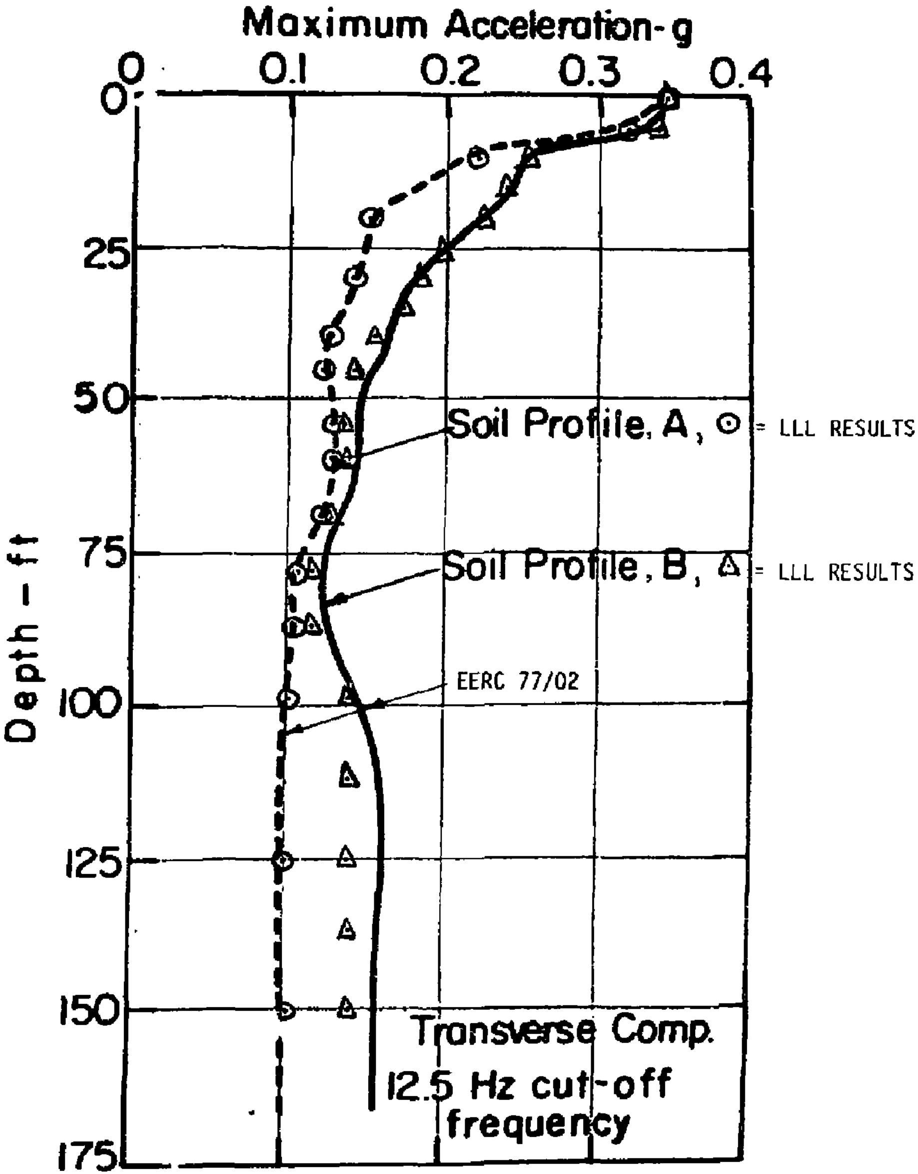

FIGURE 9. VARIATION OF MAXIMUM ACCELERATION WITH DEPTH, STORAGE BUILDING E-W COMPONENT DECONVOLUTION ANALYSIS, COMPARISON OF LLL RESULTS WITH EERC 77/02.

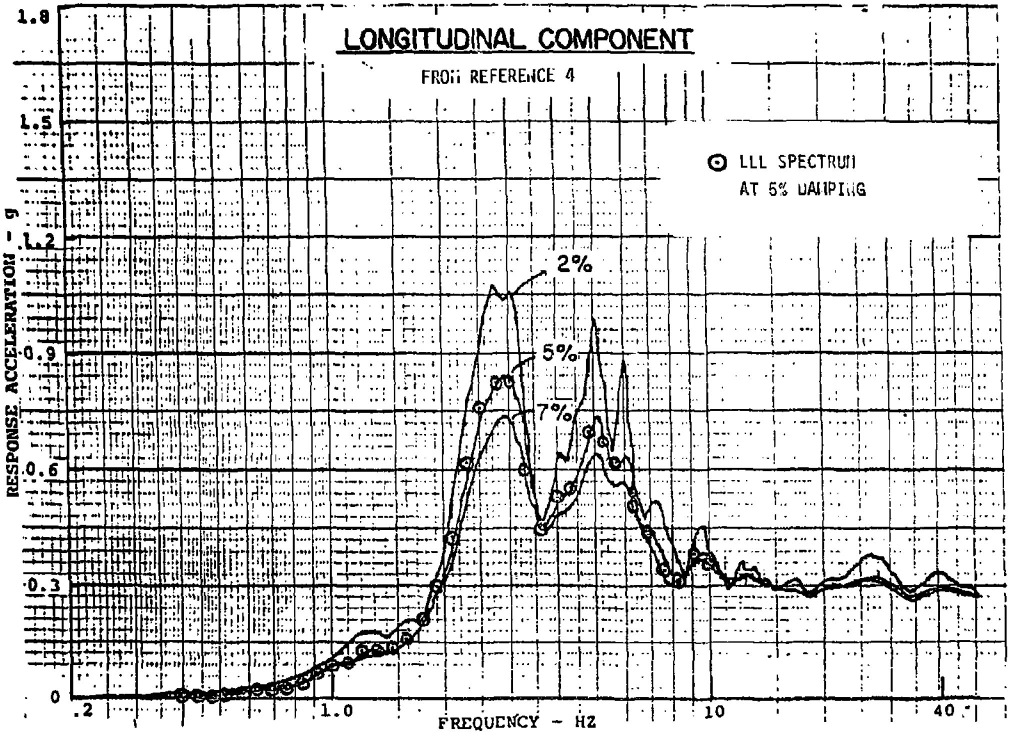

FIGURE 10. RESPONSE SPECTRA, STORAGE BUILDING N-S COMPONENT, COMPARISON OF LLL SPECTRUM WITH SPECTRUM OF ORIGINAL DIGITIZED ACCELEROGRAM.

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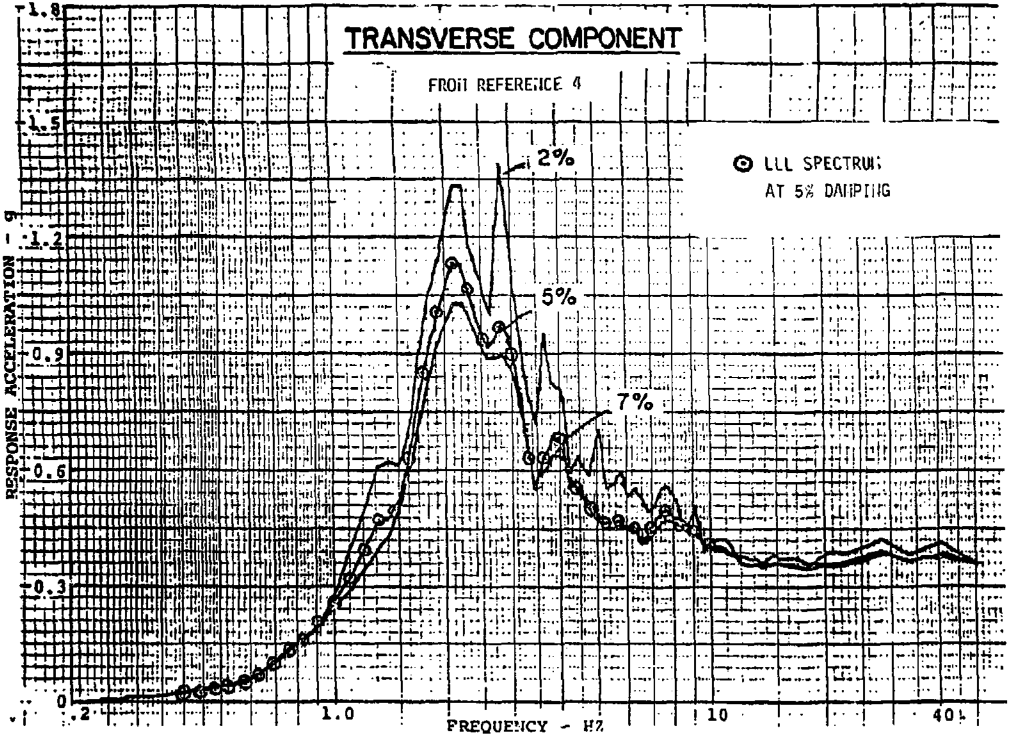

FIGURE 11. RESPONSE SPECTRA, STORAGE BUILDING E-W COMPONENT. COMPARISON OF LLL SPECTRUM WITH SPECTRUM OF ORIGINAL DIGITIZED ACCELEROGRAM.

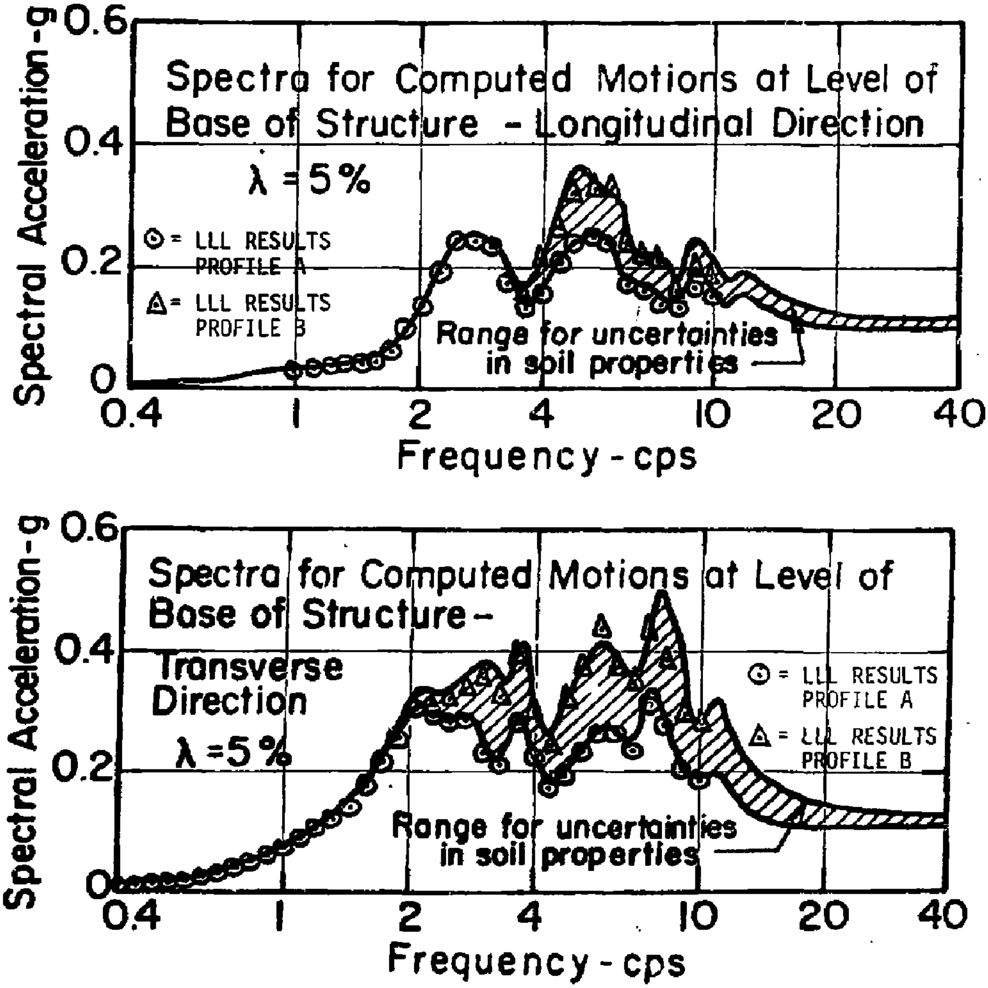

FIGURE 12. RESPONSE SPECTRA AT 87 FOOT SOIL DEPTH, STORAGE BUILDING N-S AND E-W DECONVOLUTION ANALYSES, COMPARISON OF LLL RESULTS WITH EERC 77/02

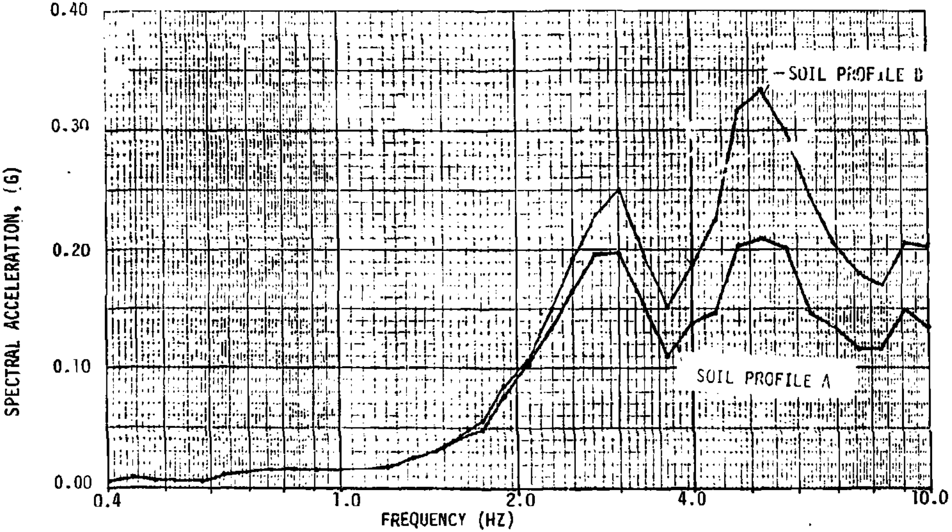

FIGURE 13. RESPONSE SPECTRA AT 150 FOOT SOIL DEPTH STORAGE BUILDING N-S DECONVOLUTION ANALYSIS

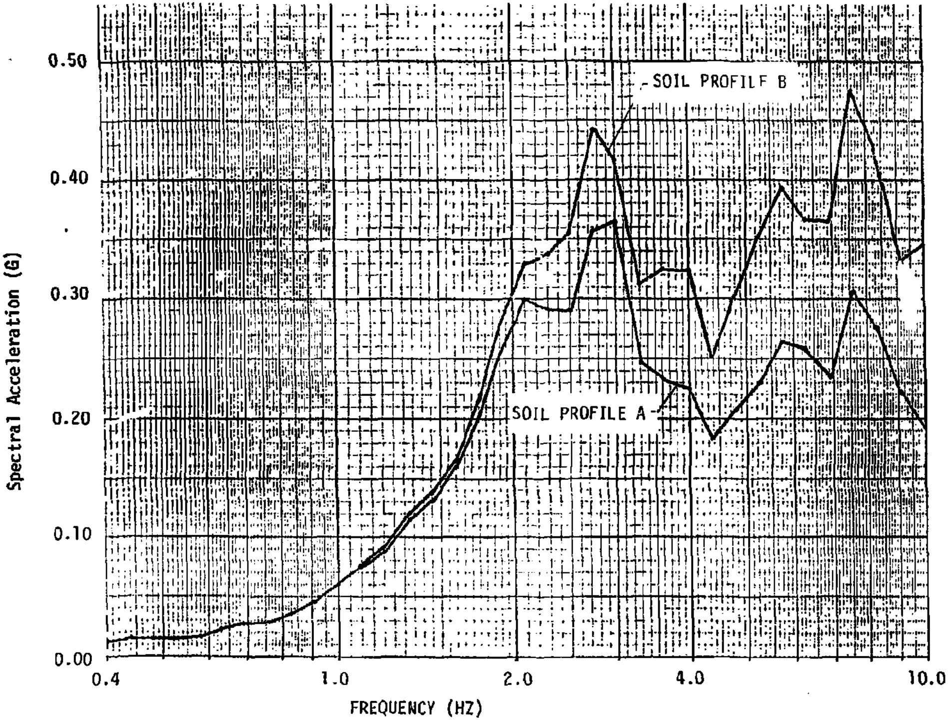

FIGURE 14. RESPONSE SPECTRA AT 150 FOOT SOIL DEPTH.
STORAGE BUILDING E-W DECONVOLUTION ANALYSIS

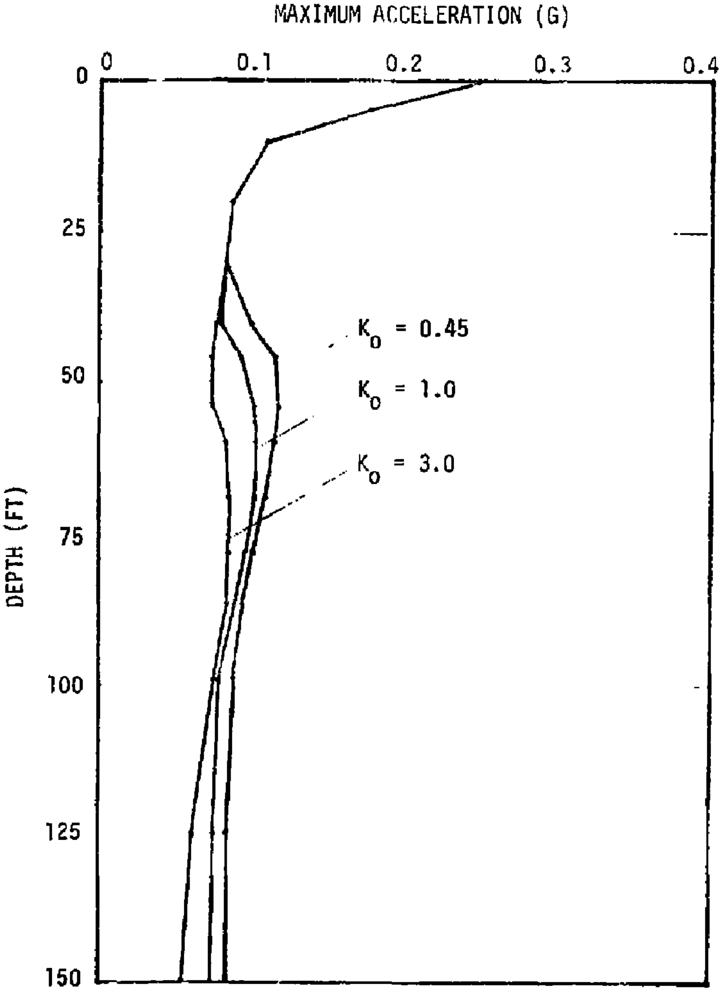

FIGURE 15. VARIATION OF MAXIMUM ACCELERATION WITH DEPTH
STORAGE BUILDING SOIL PROFILE A
FERNDALE N-S COMPONENT DECONVOLUTION ANALYSIS
EFFECT OF COEFFICIENT OF EARTH PRESSURE AT REST (K_0)

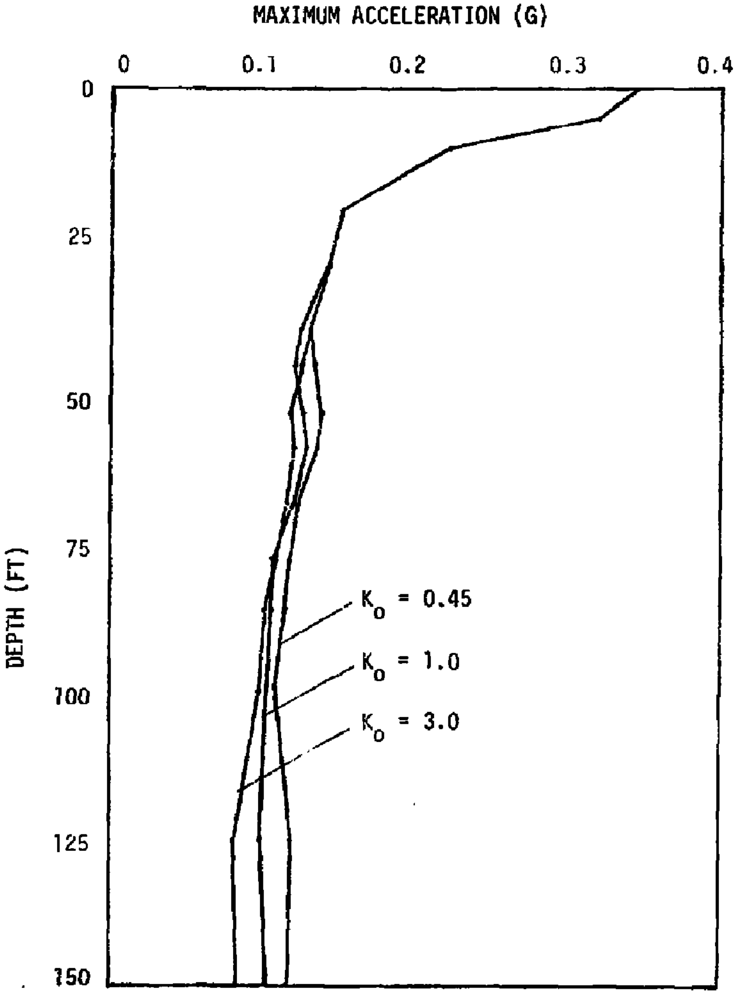

FIGURE 16. VARIATION OF MAXIMUM ACCELERATION WITH DEPTH
STORAGE BUILDING SOIL PROFILE A
FERNDALE E-W COMPONENT DECONVOLUTION ANALYSIS
EFFECT OF COEFFICIENT OF EARTH PRESSURE AT REST (K_o)

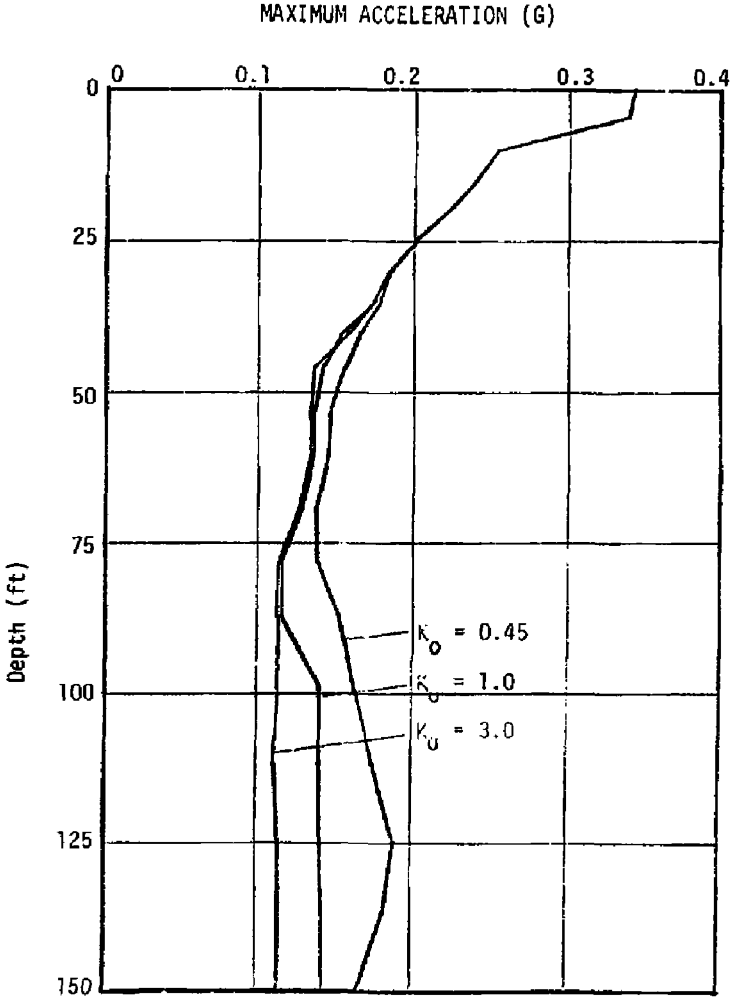

FIGURE 17. VARIATION OF MAXIMUM ACCELERATION WITH DEPTH
STORAGE BUILDING SOIL PROFILE B
FERNDALE E-W COMPONENT DECONVOLUTION ANALYSIS
EFFECT OF COEFFICIENT OF EARTH PRESSURE AT REST (K_o)

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