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VERTICAL DISTRIBUTION OF PEAK SUBSURFACE HORIZONTAL EARTHQUAKE ACCELERATIONS

by

P. C. Chen

Report to the
National Science Foundation

Interpacific Technology, Incorporated
Oakland, California

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ABSTRACT

A total of 192 sets of Japanese free-field peak horizontal accelerations of subsurface earthquake motions recorded at 20 sites were studied to determine the vertical distribution with depth of peak subsurface horizontal accelerations. The 20 sites are classified as either soft or medium, depending on the blow count number, N, near the ground surface and the average blow count number, $\overline{N}$, of the soil layers between the ground surface and the depth at which N first reaches a value of 50.

The 192 sets of peak horizontal accelerations were divided into five groups according to their various peak ground-surface horizontal accelerations. The mean values of the peak horizontal accelerations at various depths for five acceleration groups were computed for both soft and medium sites. The amplification factors of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches a value of 50 and that between the ground surface and depths at which N is less than 50 were studied. Finally, the amplification factors for soft and medium sites of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches 50 were compared with the calculated site amplifications using average normalized horizontal acceleration response spectra.

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1. INTRODUCTION

1.1 Background

Engineering characteristics such as the design accelerations and response spectra of earthquake ground surface motions have been studied intensively in the past several decades. Because of these intensive studies, the seismic design criteria for ground-supported structures can now be developed with confidence. However, comparatively little is known of the engineering characteristics of free-field earthquake motions below the ground surface, hereinafter referred to as subsurface earthquake motions. This is because it has been less urgent in the past to understand subsurface earthquake motions as few deeply embedded and buried structural facilities have been built.

With the current trend of constructing more deeply embedded and buried structures, the need increases for better knowledge of the engineering characteristics of subsurface earthquake motions. Many sites have been instrumented to record subsurface earthquake motions either to develop seismic design criteria for structural facilities at these sites or to observe the patterns of these motions. However, while some subsurface earthquake motions at these sites have been reported, no study has used recorded subsurface earthquake motions at various sites to investigate their general engineering characteristics. A comprehensive and systematic study was therefore initiated using as many as possible of the recorded subsurface earthquake motions at various sites to investigate the vertical distributions of horizontal subsurface earthquake accelerations and the effects of site geological conditions on these distributions. The results of this study will provide valuable information for developing seismic design criteria for deeply embedded and buried structure facilities.

1.2 Studies of Subsurface Earthquake Motions

The study of subsurface earthquake motions was initiated by Nasu (1) and Inouye (2).* Kanai and his colleagues subsequently performed a series of studies of subsurface earthquake motions using recorded earthquake motions data (3-7). They also developed the multiple reflections theory of waves in a layered medium to estimate subsurface earthquake motions when ground surface earthquake motions were known. Shima (8) used recorded ground surface and subsurface earthquake motions at the same site to study the seismic waves in a layered soil medium.

With increasing construction of high-rise buildings, tunnels, long-span bridges, underground facilities, and nuclear power plants in Japan in recent years, many projects have been initiated there to instrument various sites to obtain the seismic design information needed for these facilities. Downhole arrays have been installed to various depths at these sites, and subsurface earthquake motions have been recorded from many earthquake events. The recorded motions have been analyzed to develop seismic design criteria for specific facilities on or below the ground. As a result, numerous publications have appeared in the public domain as well as many unpublished reports on the subject of subsurface earthquake motions. Some of the recent case studies written in English are discussed briefly below. Of the numerous reports written in Japanese, some are discussed in Section 2 of this report, Data Base.

Tanaka et al. (9, 10, 11) summarized the observations of subsurface earthquake motions in Japan and analyzed some of

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* - refers to reference number.

the subsurface earthquake motions recorded at Hachinohe site and at the Earthquake Research Institute of the University of Tokyo. They studied the amplification of Fourier spectra of ground surface and subsurface earthquake motions as well as the multiple reflections theory of linear viscoelastic layers with vertically propagating plane and shear waves to predict subsurface earthquake motions. Osawa et al. (12) performed statistical studies of the maximum accelerations and Fourier spectral ratios of subsurface earthquake motions recorded at four sites as part of soil-building response amplification studies. Iwasaki et al. (13, 14) studied the vertical distributions of accelerations and response spectra of subsurface earthquake motions recorded at four sites around Tokyo Bay. Tsuchida et al. (15), Arai et al. (16), and Noda et al. (17) studied the subsurface earthquake motions recorded in ports and harbors, focusing on the Fourier amplitude spectra of motions recorded at the ground surface and below ground. Kobayashi et al. (18) studied the amplification of response spectra of subsurface earthquake motions recorded at Shinjuku, Tokyo. Recently, Omote et al. (19) studied the subsurface earthquake motions recorded at deep boreholes.

These studies indicate:

- Earthquake motion amplitudes change with depth. Changes in the vertical direction are smaller than those in the horizontal directions. The amount of change in soil sites is larger than that in rock sites.
- At some sites, frequency characteristics of ground surface and subsurface earthquake motions at different depths are similar for the same earthquake event.
- Earthquake characteristics (e.g. small and near vs. large and distant) and local geology (e.g. soil vs. rock) affect the amplitude distributions and

frequency characteristics of ground surface and subsurface earthquake motions.

These observations from site-specific case studies are qualitative and do not provide enough information to establish the seismic design criteria of subsurface facilities at sites with different geological properties.

The study of subsurface earthquake motions in the U.S. has been limited, largely due to the limited amount of available recorded subsurface earthquake motions data. Only three downhole arrays have recorded subsurface earthquake motions from microtremors. Those at Union Bay in Seattle and at San Francisco Bay are no longer in operation. Only the downhole array at Richmond Field Station, University of California, is still operating. The study of subsurface earthquake motions at Union Bay was performed by Seed and Idriss (20), at San Francisco Bay by Joyner et al. (21) and Seed and Lysmer (22), and at Richmond Field Station by Johnson and Silva (23). These studies emphasize the validity of an analytical model assuming vertical wave propagation. A state-of-the-art review of the studies of subsurface earthquake motions has been conducted by Chen (24). He has also studied some Japanese subsurface strong earthquake motions data (25) and the vertical distribution with depth of peak horizontal earthquake accelerations (26, 27).

2. DATA BASE

This study uses subsurface horizontal earthquake acceleration data with peak horizontal accelerations at or near the ground surface equal to or larger than 10 gals. All data were recorded at 20 Japanese sites (References 28 to 43). No U.S. subsurface horizontal earthquake acceleration data were used in this study, as their recorded peak horizontal accelerations at or near the ground surface were less than 10 gals.

Descriptions of the site locations, site geological information, instruments used for recording subsurface earthquake motion data, earthquake characteristics (date of occurrence, magnitude, etc.), and the peak horizontal accelerations at different depths of each site caused by different earthquakes are given in References 28 to 43. The site geological information, expressed in profiles of blow count number, N, shear and compressional wave velocity for all sites is given in Figure 1. As only the shear wave velocity profiles were originally given for Sites 4 and 13, the profiles of blow count numbers of these two sites as shown in Figure 1 are estimated. The estimate is an average of the blow count numbers obtained by the methods of Imai and Shibata (45), which relate shear wave velocity to the exponential of the blow count number.

The depths of instruments used to record subsurface earthquake motions and the number of earthquake data sets used in the study are summarized in Table 1. The earthquake data sets of each site are divided into five groups according to the peak horizontal acceleration values at or near the ground surface. Group (a) contains those data sets for which the peak ground or near-ground surface horizontal acceleration values are between 10 and 20 gals. The range of peak ground or near-ground surface horizontal acceleration values for Groups (b) to (e) are, respectively, 20-40, 40-60, 60-80, and 80-130 gals.

One data set for each site contains all the peak horizontal accelerations recorded for an earthquake event at different instrument depths at this site. For each site, the total number of data sets used in the study is the sum of data sets in each group. For example, for Site 1, there are 11 data sets in Group (a) and 5 data sets in Group (b) (a total of 16 data sets) recorded at depths of 3m, 21m, 50m, and 90m below the ground surface.

3. DATA ANALYSIS

3.1 Site Classification

Each of the 20 sites was classified as either soft or medium, depending upon the blow count number, N, near the ground surface and the average blow count number, $\overline{N}$, of the soil layers between the ground surface and the depth at which N first reaches a value of 50. The average blow count number, $\overline{N}$, of each site is the sum of the product of the blow count number of each soil layer and the corresponding soil layer length divided by the sum of the lengths of all soil layers.

If N is less than or equal to 5, and $\overline{N}$ is less than or equal to 10, the site is considered as soft. A site is classified as medium when N is less than 50 but larger than 5, and $\overline{N}$ is larger than 10. Because the depth at which N first reaches 50 varies from site to site, each site is further classified as either shallow or deep. If this depth is less than 15m, the site is considered shallow; if it is equal to or greater than 15m, the site is considered deep. The value of N is used to classify the sites for two reasons: In Japan, the depth at which N first reaches a value of 50 is generally considered the base rock for design purposes. In addition, Japanese bore-hole data normally stop at a depth when N reaches a value of 50.

Table 1 gives the site classifications of all 20 sites, as well as the layer thickness of each site, defined as the distance from the ground surface to the depth at which N first reaches a value of 50.

3.2 Data Analysis

The mean values of the peak horizontal accelerations at different depths for each acceleration group of each site were computed. In order to have a common base, the mean peak horizontal accelerations of some sites were extrapolated to the ground surface (0m). This is because not all sites have instruments located at the ground surface. For example, one of the instruments at Site 1 is at -3m. The extrapolation is achieved by assuming a linear relation between 0m and -3m. Also, for many sites, the instruments are not located at a depth when N first reaches 50; the mean peak horizontal acceleration at this depth is computed from the mean peak horizontal accelerations at the neighboring instrument locations by assuming a linear relation.

The ratios of the mean peak horizontal accelerations at different depths of the same site are the peak horizontal acceleration amplification factors (amplifications factors) calculated for this site. These amplification factors are derived from recorded data and are also referred to as observed amplification factors to distinguish them from calculated site amplifications. The amplification factors were studied for two cases: (1) amplification factors between the ground surface and the depth at which N first reaches a value of 50; and (2) normalized amplification factors between the ground surface and depths at which N is less than 50. Once the amplification factors for each site were examined, they were grouped by site classification to determine the amplification factors for soft vs. medium and shallow vs. deep sites.

4. AMPLIFICATION FACTORS BETWEEN GROUND SURFACE AND THE DEPTH AT WHICH N FIRST REACHES 50

The amplification factors of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches 50 for both the soft and medium sites are shown respectively in Figures 2 and 3. The amplification factors are the ratios of the mean peak horizontal accelerations at the ground surface to that at which N first reaches a value of 50. Various acceleration groups at each site are identified together with the site's average blow count number, $\overline{N}$. For example, the amplification factors of various acceleration groups at Site 6 as seen in Figure 2 are identified with different symbols and the site number. The average blow count number $\overline{N}$ for this site is given in parentheses.

The amplification factors for soft and medium sites are discussed below.

4.1 Soft Sites

4.1.1 Observations of Amplification Factors

- Amplification factors are not necessarily larger for acceleration groups with larger mean peak accelerations at the ground surface (Sites 1, 6, 14, 16 and 17). This is because when the peak horizontal accelerations at the ground surface are larger, the peak horizontal accelerations at depths also are larger. The resulting amplification factors between the ground surface and the depth at which N first reaches 50 can therefore be smaller compared with cases where the peak horizontal accelerations at the ground surface are smaller.

- In Figure 2, a weighted solid line is drawn through the amplification factors of various sites. This line is drawn by weighting the number of data sets in each acceleration group and is extended by a dash line to the ground surface. At the ground surface, the amplification factor is 1.0. It is seen from the solid line that the amplification factors for all soft sites fluctuate about a value of 2.5.
- The average blow count number, $\overline{N}$, of all soft sites, except for Site 11, are less than or equal to 10. The top 25m of Site 11 has a N value less than 5, a N value of 10 between the depths of 25m and 37m, and an average value of N equal to 30 between 37m and 56m at which N first reaches a value of 50 (Figure 1). Although the overall average value of N is larger than 10 for Site 11, it is classified as a deep soft site because the N value of the top 25m is less than 5.

4.1.2 Comparison of Observed Amplification Factors and Calculated Site Amplifications

The average normalized horizontal acceleration response spectra at given sites can be considered site amplifications that are affected by the depths and the material properties of the soil layers between the ground surface and base rock and by earthquake parameters. The observed amplification factors are the amplifications of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches 50. Because these two amplifications are similar, a comparison was made of their amplification values. Ideally, site horizontal acceleration response spectra and site geological data would be used to determine site amplifications. However, except for Sites 1 and 9, site horizontal acceleration response spectra were not available. The average normalized horizontal acceleration response spectra for soft sites (44) were therefore used for calculating site amplifications.

The period of each site was calculated using the shear wave velocities of soil layers between the ground surface and the depth at which N first reaches 50, assuming that earthquake waves propagate vertically. The calculated periods of all the soft sites are shown in Figure 2. They range from 0.268 second for Site 6 to 1.17 second for Site 11. In general, the period increases as the depth increases. However, there are variations: At Sites 1 and 11, the period becomes smaller when the depth increases and $\overline{N}$ is larger.

Once the site periods were calculated, the site amplifications were obtained from the average normalized horizontal acceleration response spectrum with a 5% damping for soft sites (Figure 4). They are marked by small circles in Figure 2, and are connected by a dash-dot line. The portion of the dash-dot line from the site amplification of Site 6 to that of 1.0 (ground surface) was extended.

The calculated site amplifications (dash-dot line of Figure 2) fluctuate about a value of 2.5. The observed amplification factors (solid line) and the calculated site amplifications are seen to be very close. The reasons that the calculated site amplifications fluctuate about 2.5 are because the average normalized horizontal acceleration response spectrum with a 5% damping for soft sites (Figure 4) has an amplification factor of 2.5 in the period range of 0.25 to 1.0 second and that the periods of the sites studied are mostly in this range.

It should be noted that the data base for developing the average normalized horizontal acceleration response spectra for soft sites (44) is different from that used to obtain the observed amplification factors of mean peak horizontal accelerations. The value of N is unknown for the sites used to develop the average normalized horizontal acceleration response spectra. In spite of different data bases, the comparison between the two amplifications is good. This suggests that the average normalized horizontal acceleration response spectrum, with a 5% damping for soft sites may be used to estimate the amplification factors for these sites of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches 50.

4.2 Medium Sites

4.2.1 Observations of Amplification Factors

- Amplification factors are not necessarily larger for acceleration groups with larger mean peak horizontal accelerations at the ground surface.
- In Figure 3, a weighted solid line is drawn through the amplification factors of various sites. This line is drawn by weighting the number of data sets in each acceleration group and is extended by a dash line to the ground surface. The amplification factors of medium sites start at 1.0, gradually increase to about 2.5, and then fluctuate about 2.5.

4.2.2 Comparison of Observed Amplification Factors and Calculated Site Amplifications

The observed amplification factors were compared with the calculated site amplifications, using the same approaches as were used for soft sites. The calculated periods of medium sites are shown in Figure 3. The site amplifications obtained from the average normalized horizontal acceleration response spectrum with a 5% damping for medium sites (Figure 5) using the calculated site periods are shown in Figure 3 by small circles connected by a dash-dot line. The portion of the dash-dot line from the site amplification of Site 15 to that of 1.0 (ground surface) was extended.

An examination of the observed amplification factors (solid line) and the calculated site amplifications (dash-dot line) indicate that for deep medium sites, the observed and calculated amplifications are close. However, large differences exist between the observed amplification factors and the calculated site amplifications for shallow medium sites.

The calculated site amplifications were obtained using the thickness and soil properties of the soil layer, measured from the ground surface to the depth at which N first reaches 50, and the average normalized horizontal response spectra, assuming that earthquake waves propagate vertically. The above soil layer thickness for shallow medium Sites 15, 10, 13, and 4 is less than 15m. The periods of these sites are 0.175 second, 0.179 second, 0.269 second, and 0.295 second, respectively. Because these periods fall in the range at which large site amplifications occur (Figure 5), the calculated site amplifications are therefore large.

However, the average blow count number, $\overline{N}$, for Sites 15, 10, 13, and 4 varies from 20 to 35 (Figure 3). These large $\overline{N}$, together with the small thickness of the soil layer (less than 15m for these four sites), would suggest that the site amplification factors for these sites would be small when the earthquake waves are assumed to propagate vertically. The differences between the observed amplification factors and the calculated site amplifcations for shallow medium sites are probably due to the different data bases used to obtain the observed amplification factors and that used to develop the average normalized horizontal acceleration response spectra for medium sites. Further investigation of the data base, including the N values of sites used to develop the average normalized horizintal response spectra, will clarify the above differences.

5. AMPLIFICATION FACTORS BETWEEN GROUND SURFACE AND DEPTHS AT WHICH N IS LESS THAN 50

The normalized amplification factors of the mean peak horizontal accelerations between the ground surface and depths at which N is less than 50 for both soft and medium sites are given in Figures 6 to 9, respectively. The normalized amplification factors are the ratios of the mean peak horizontal accelerations at the ground surface to that at different depths, and are normalized with respect to the mean peak horizontal accelerations at the ground surface. The ratios of normalized amplification factors at the ground surface to those at the deepest depth for each site in Figures 6 to 9 are the amplification factors for the same sites as given in Figures 2 to 3.

The normalized amplification factors for various acceleration groups at each site are identified with different symbols, and their average blow count number $\overline{N}$ is given. For example, the normalized amplification factors of various acceleration groups at Site 6 as seen in Figure 6 are identified with different symbols and the site number. The average blow count numbers $\overline{N}$ for the sites are given in parentheses.

5.1 <u>Soft Sites</u>

A comparison of Figures 6 and 7 indicates that:

- The slopes of the normalized amplification factors, defined as the angles measured from the horizontal axis at the depth when N first reaches 50 (the lowest point in these figures) to the line connecting this depth to the ground surface, for shallow sites are smaller than those for deep sites. The mean peak horizontal acceleration values of shallow sites decrease therefore faster as a function of depth than those of deep sites.

- There is a wide spread in normalized amplification factors for deep soft sites. For example, Sites 1 and 11 are different in normalized amplification factors between the ground surface and a depth of 50m. Between the ground surface and a depth of 21m, the normalized amplification factors for Site 1 are small, while those between the depths of 21m and 50m are large. This is because there are large variations in N values at Site 1 (Figure 1): the average N value, $\overline{N}$, for the first 12m is 10, decreases to about 3 between the depths of 12m and 40m, and gradually increases to 50 at 56m. The soft layer with $\overline{N}$ equal to 3 causes large normalized amplification factors between the depths of 21m and 50m. At Site 11 (Figure 1), in contrast, the $\overline{N}$ value for the first 35m is about 4, and gradually increases to 50 at 57m. The soft top layer with $\overline{N}$ equal to 4 results in larger normalized amplification factors compared with other depths. This indicates that although the amplification factors of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches 50 may be similar for two sites (Sites 1 and 11, Figure 2), the normalized amplification factors between the ground surface and depths at which N is less than 50 may be different because of the different distributions of the N values of each site.

- Although large variations exist in normalized amplification factors for deep soft sites between the ground surface and depths at which N is less than 50, it is conservative to state that, for both shallow and deep soft sites, the normalized amplification factors of the mean peak horizontal accelerations vary linearly within the ground surface and the depth at which N first reaches 50.

5.2 Medium Sites

It is seen from Figures 8 and 9 that:

- The slopes of the normalized amplification factors for shallow medium sites are larger than those for deep medium sites. This indicates that the mean peak horizontal acceleration values of shallow medium sites decrease more slowly as a function of depth than those of deep medium sites.

- The spread in normalized amplification factors at deep medium sites is small compared with that at deep soft sites. This is because there are no large variations in N values at deep medium sites in that there exist no layers with relatively small $\overline{N}$ values.

- It is conservative to state that, for medium sites, the normalized amplification factors of the mean peak horizontal accelerations vary linearly between the ground surface and depths at which N is less than 50.

6. CONCLUSIONS

Observed amplification factors were obtained for both soft and medium sites of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches a value of 50. For soft sites, the amplification factors between the ground surface and the depth at which N first reaches a value of 50 fluctuate about a value of 2.5. For deep medium sites, the amplification factors are also about 2.5. For shallow medium sites, the amplification factors are less than 1.5.

These observed amplification factors for both soft and medium sites were compared with the site amplifications calculated using previously published average normalized horizontal acceleration response spectra with a 5% damping for soft and medium sites. Although different data bases were used to obtain observed amplification factors and calculated site amplifications, the comparisons are good for soft sites and deep medium sites.

Because of the above observations, it appears that the average normalized horizontal acceleration response spectrum with a 5% damping for soft sites may be used to estimate the amplification factors for these sites of the mean peak horizontal accelerations between the ground surface and the depth at which N first reaches a value of 50. The average normalized horizontal acceleration response spectrum with a 5% damping for medium sites can also be used for this estimate, provided the differences between the observed amplification factors and the calculated site amplifications for shallow medium sites are accounted for.

The distribution of the N values of a site is seen to affect the normalized amplification factors of the mean peak horizontal accelerations between the ground surface and depths at which N is less than 50. Care should be taken to account for the local variation of N values if one is interested in the normalized amplification factors of mean peak horizontal accelerations at particular depths. However, it is conservative to assume that the normalized amplification factors of the mean peak horizontal accelerations for both the soft and medium sites vary linearly within the ground surface and the depth at which N first reaches 50.

The observed amplification and the normalized amplification factors provide insight into the vertical distribution of mean peak subsurface horizontal earthquake accelerations, and will be of assistance in realistically establishing seismic design criteria for deeply embedded and buried structural facilities.

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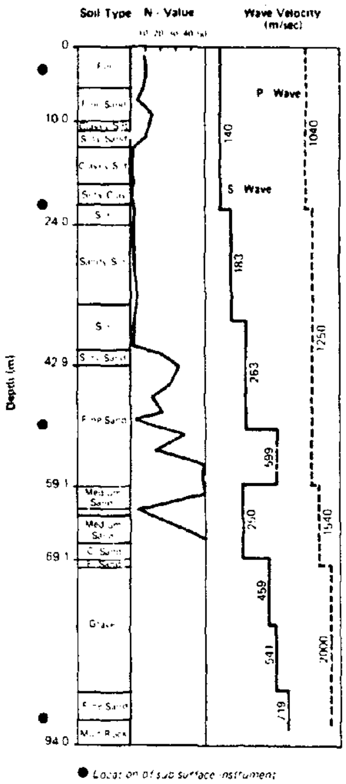
45. Hayashi, S., Tsuchida, H., and Uwabe, T., "Characteristics of Base Rock Motions Calculated from Strong Motion Accelerograms," Proceedings of Fifth Joint Meeting, U.S.-Japan Panel on Wind and Seismic Effects, UJNR, Tokyo, May 14-16, 1973.

Table 1. Site and Subsurface Earthquake Data Information

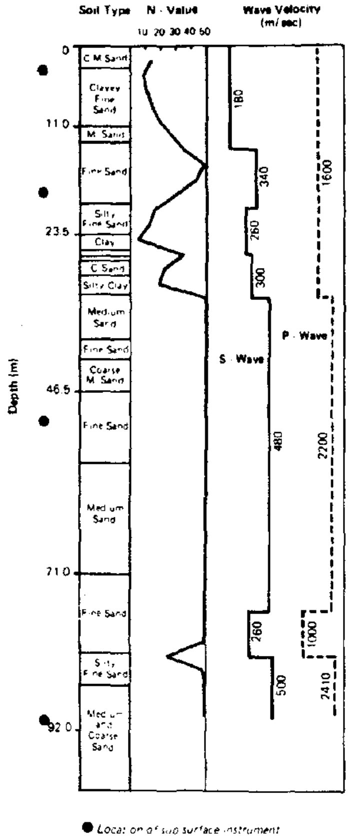
Site	Layer thickness		Site Classification				Subsurface Instrument Locations (m)	No. of EQ Data Set Used in Analysis				
			Soft^{x}		Medium^{xx}							
	h^{+}(m)	hh^{++}(m)	Shallow^{x+}	Deep^{ox}	Shallow^{x+}	Deep^{ox}		(a)	(b)	(c)	(d)	(e)
1	56			X			-3,-21,-50,-90	11	5			
2		34				X	-3,-20,-50,-91	9	3	1		
3		20			X		-3,-20,-50,-90	5				
4		13			X		0,-20,-60	2	2			
5	22			X			-1,-25,-50	10				
6	7		X				-1,-5,-8, -22,-55	2	4			2
7		25				X	-2,-33,-85	6	2	2		
9	53			X			0,-27,-67, -127	24				2
10		10			X		0,-70,-110	25	7	4	1	
11	57			X			-5,-15,-38, -160	3		2		
13		12			X		0,-41	8	3	1		
14	45			X			-3.5,-11.2, -44.4	1	1			
15		7			X		0,-30,-50				1	1
16	13		X				0,-18,-26.5	4	4	3	2	
17	30			X			-7,-14,-21, -30,-43,-60	1	1			
18	50			X			0,-20,-30,-60	2				
19		25				X	-1,-14,-25	2				
20	38			X			-2,-18,-38, -71	1				
21		15			X		-1,-17,-67 -123	10	8			2
22	25			X			-2,-5.5,-9, -13,-30,-100				2	

+ - layer thickness to N first equals 50 for soft site. x = for $N \leq 5$. xx - for $5 < N \leq 50$.
++ - layer thickness to N first equals 50 for medium site. x+ - for depth up to 15m, ox for depth larger than 15m.
(a) 10-20 gals*, (b) 20-40 gals*, (c) 40-60 gals*, (d) 60-80 gals*, (e) 80-130 gals*
*Peak ground surface acceleration.



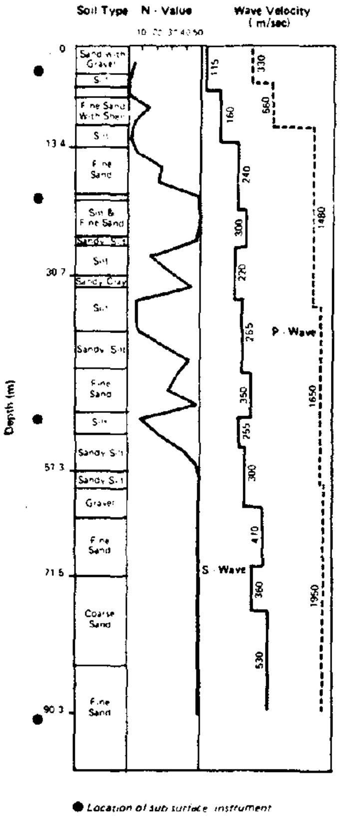
● Location of sub-surface instrument

Site No. 1



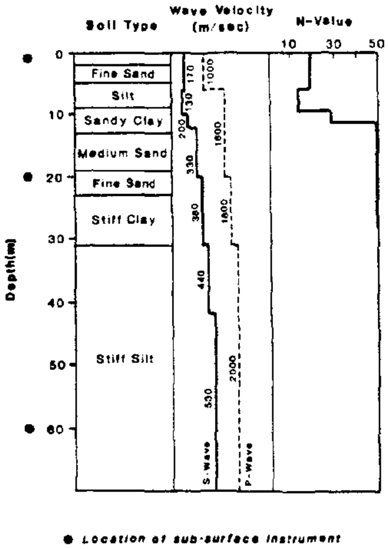
● Location of sub-surface instrument

Site No. 2



● Location of sub-surface instrument

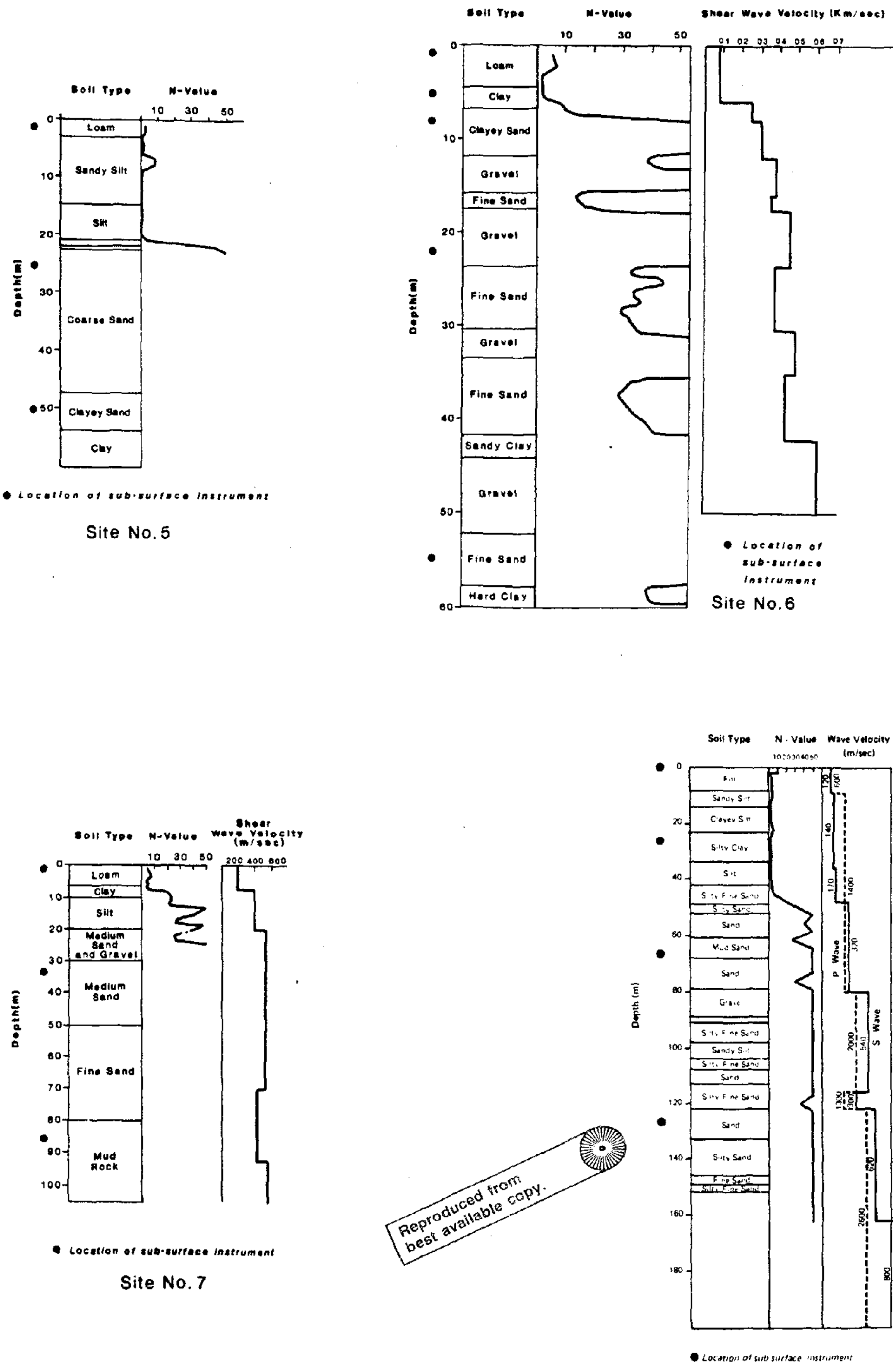
Site No. 3



● Location of sub-surface instrument

Site No. 4

Figure 1. N - Value, Shear, and Compressional Wave Velocity Profiles at Various Sites



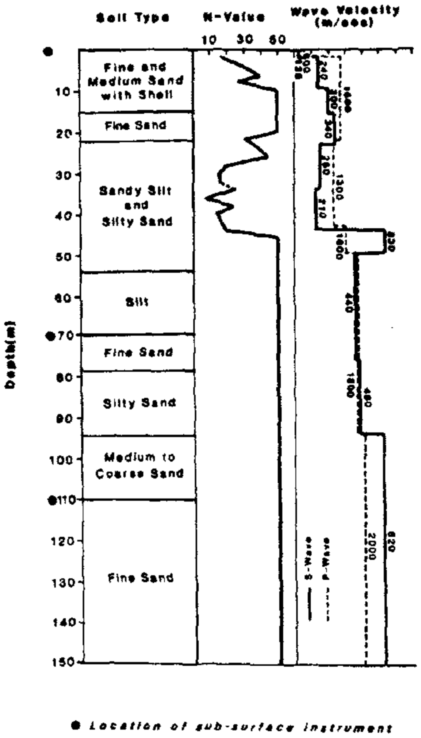
Site No. 5

Site No. 6

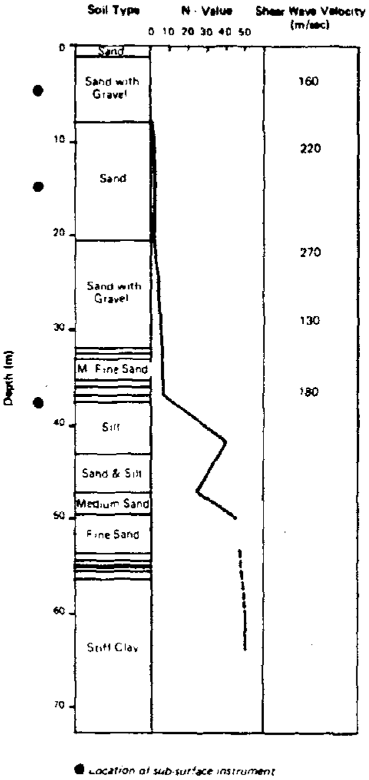
Site No. 7

Site No. 9

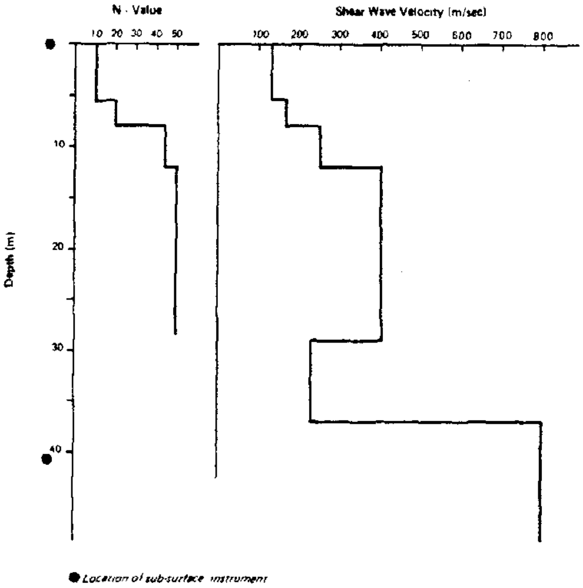
Figure 1. N - Value, Shear, and Compressional Wave Velocity Profiles at Various Sites



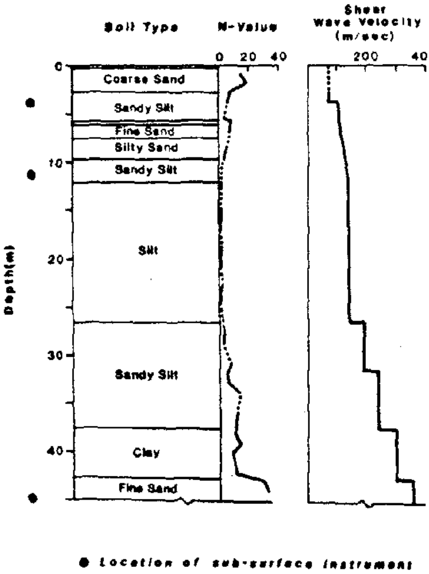
Site No.10



Site No. 11

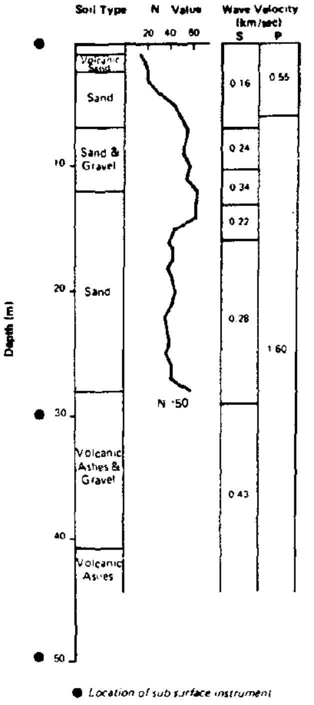


Site No. 13

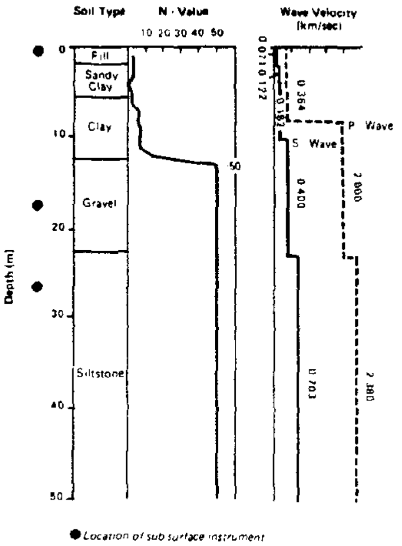


Site No.14

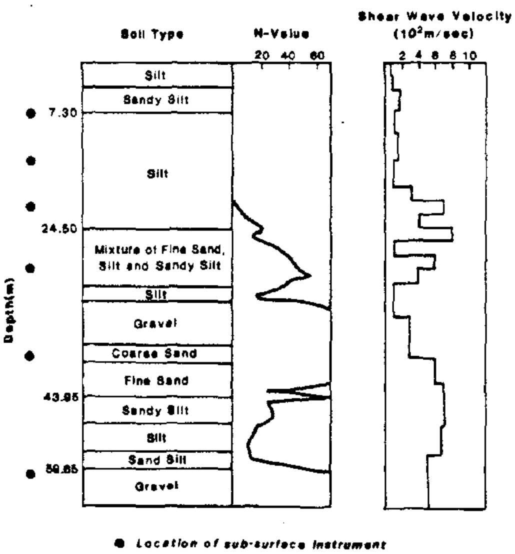
Figure 1. N - Value, Shear, and Compressional Wave Velocity Profiles at Various Sites



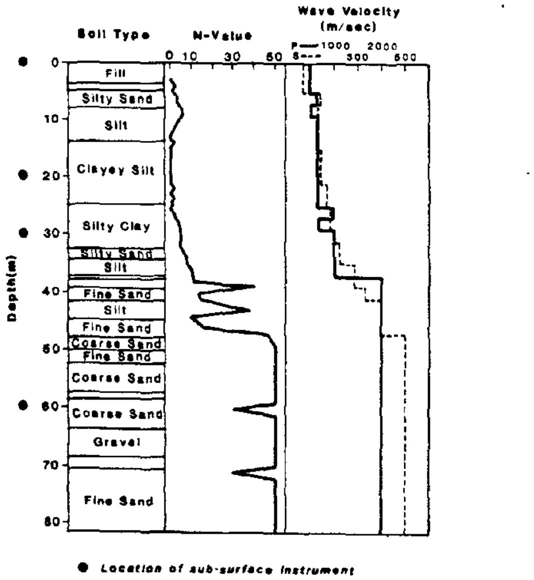
Site No. 15



Site No. 16

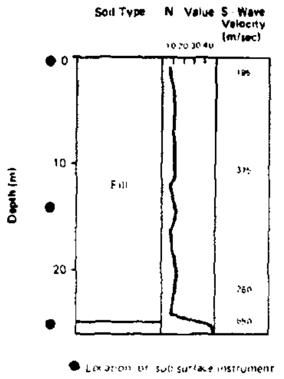


Site No.17

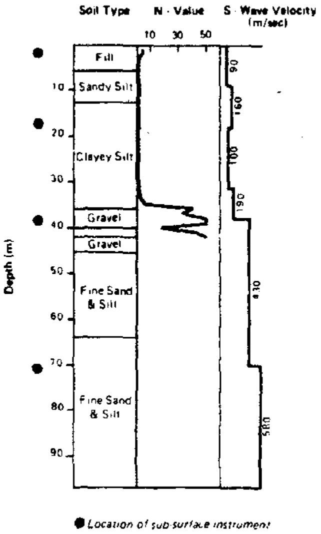


Site No.18

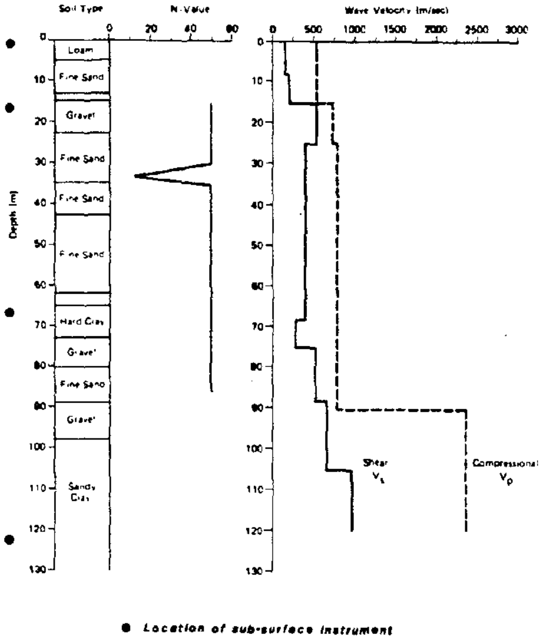
Figure 1. N - Value, Shear, and Compressional Wave Velocity Profiles at Various Sites



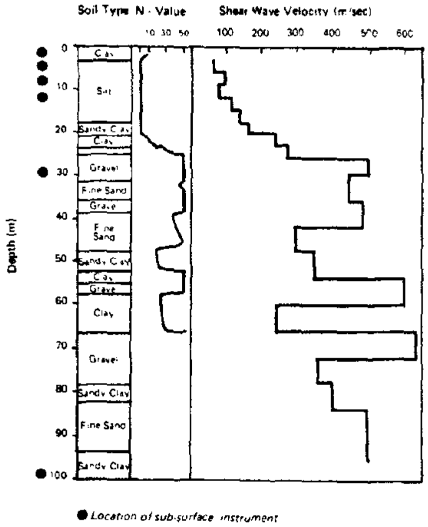
Site No. 19



Site No. 20



Site No. 21



Site No. 22

Figure 1. N - Value, Shear, and Compressional Wave Velocity Profiles at Various Sites

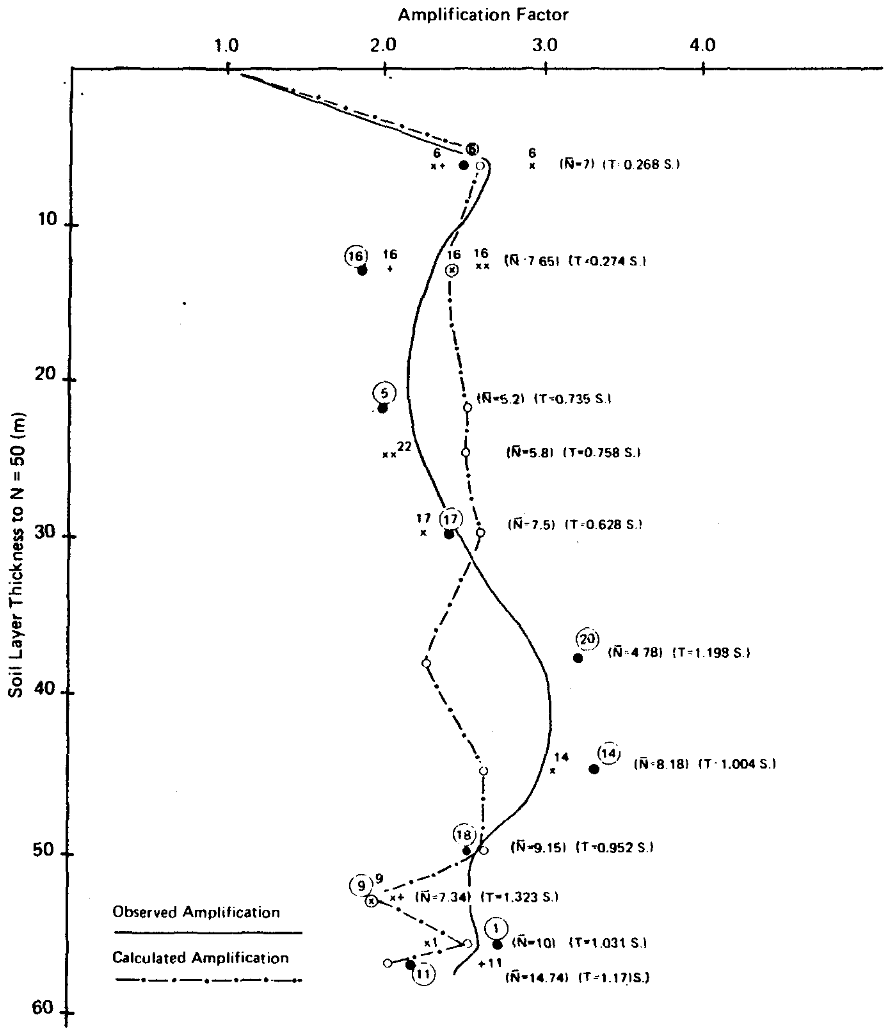


Figure 2. Amplification Factors Between Om/ Depth with N =50, Soft Sites

Legend:

● · 10-20, x · 20-40, + · 40-60, xx · 60-80, x+ – 80-130 gals
peak ground surface acceleration of various groups.

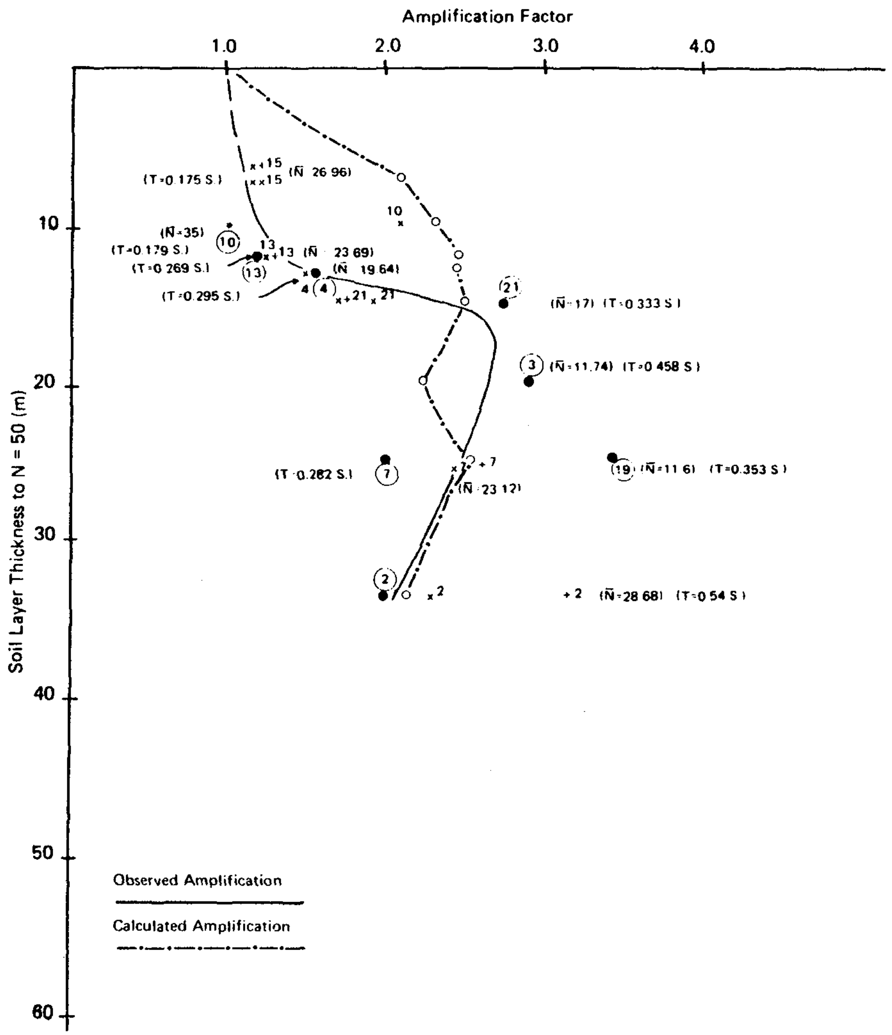


Figure 3. Amplification Factors Between Om/Depth with N = 50, Medium Sites

Legend:

● · 10-20, x · 20-40, + · 40-60, xx · 60-80, x+ – 80-130 gals
peak ground surface acceleration of various groups.

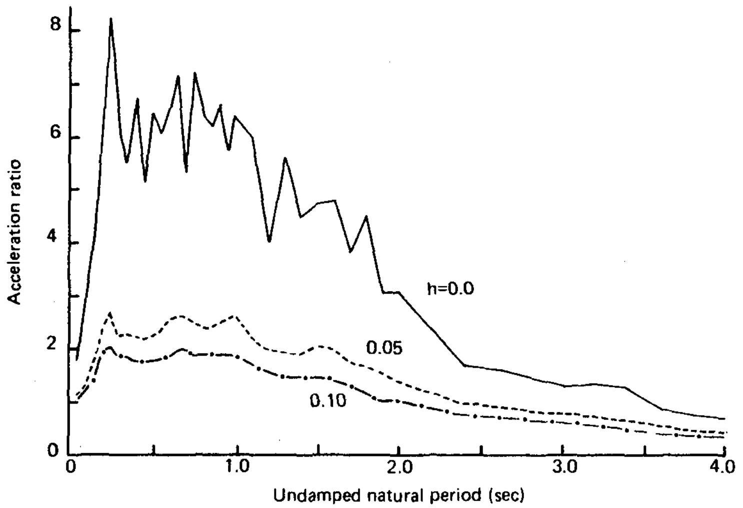


Figure 4. Average Response Spectra for Soft Sites
(Reference 44)

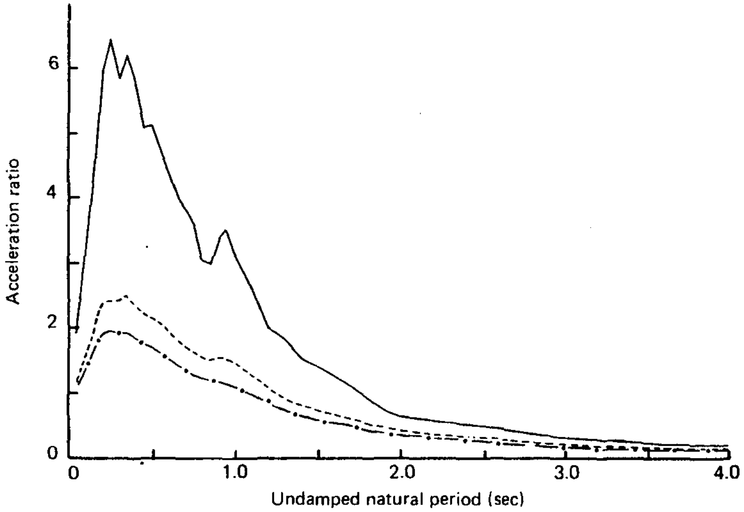


Figure 5. Average Response Spectra for Medium Sites
(Reference 44)

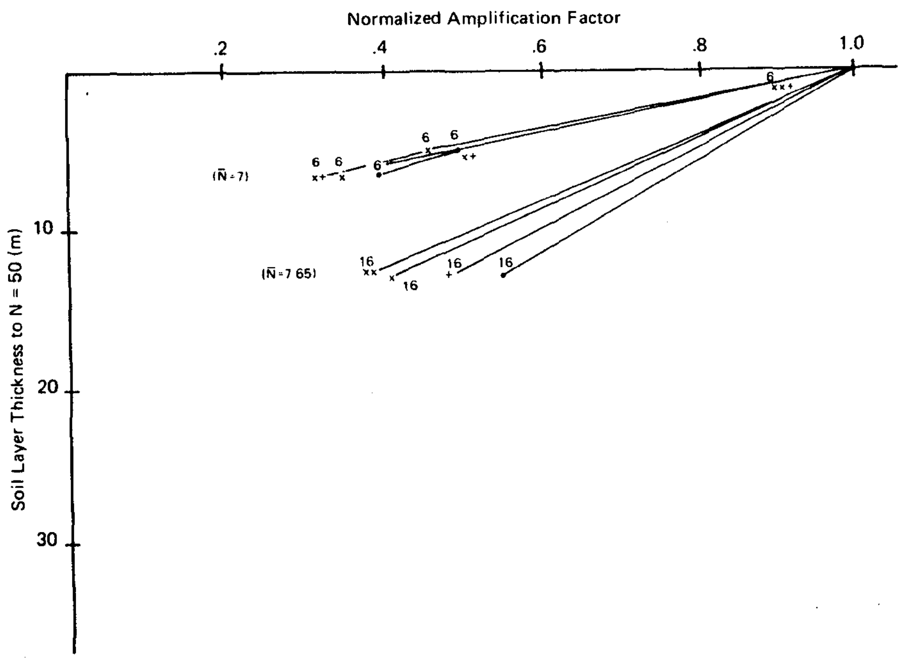


Figure 6. Normalized Amplification Factors Between Om/Depth with N≤50, Shallow-Soft Sites

Legend:

● - 10-20, x - 20-40, + - 40-60, xx - 60-80, x+ – 80-130 gals peak ground surface acceleration of various groups.

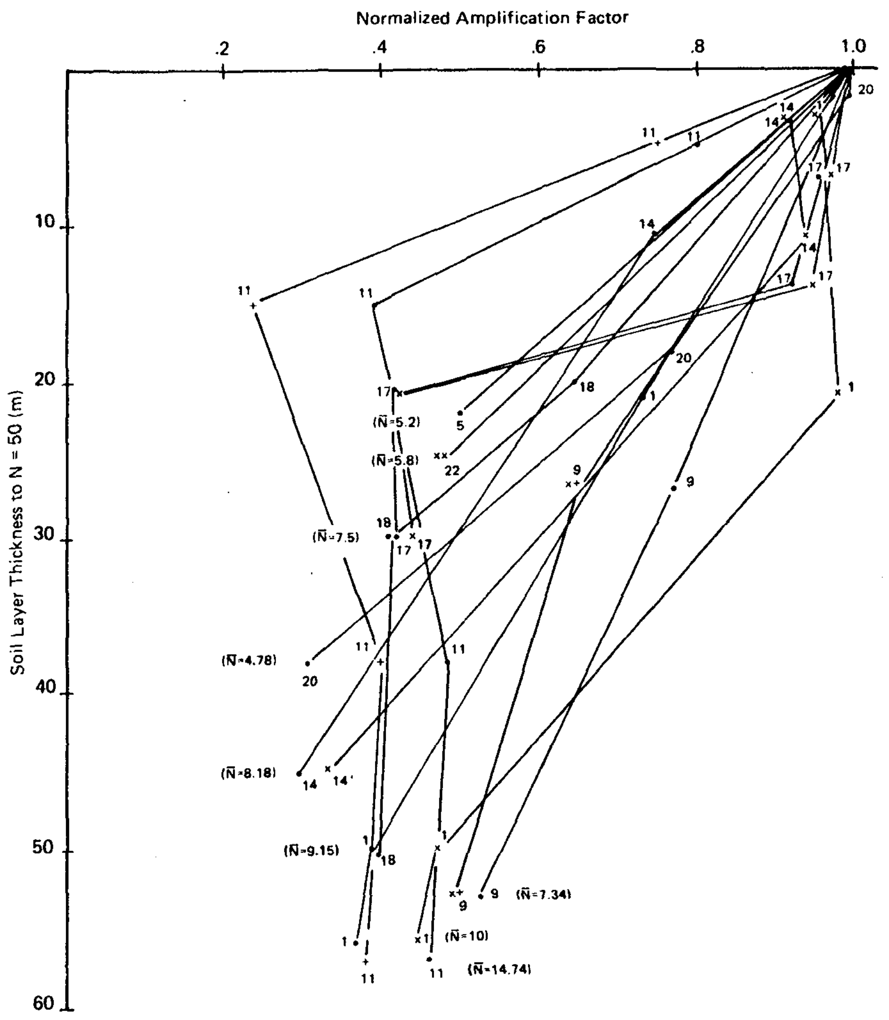


Figure 7. Normalized Amplification Factors Between Om/Depth with N≤ 50, Deep-Soft Sites

Legend:

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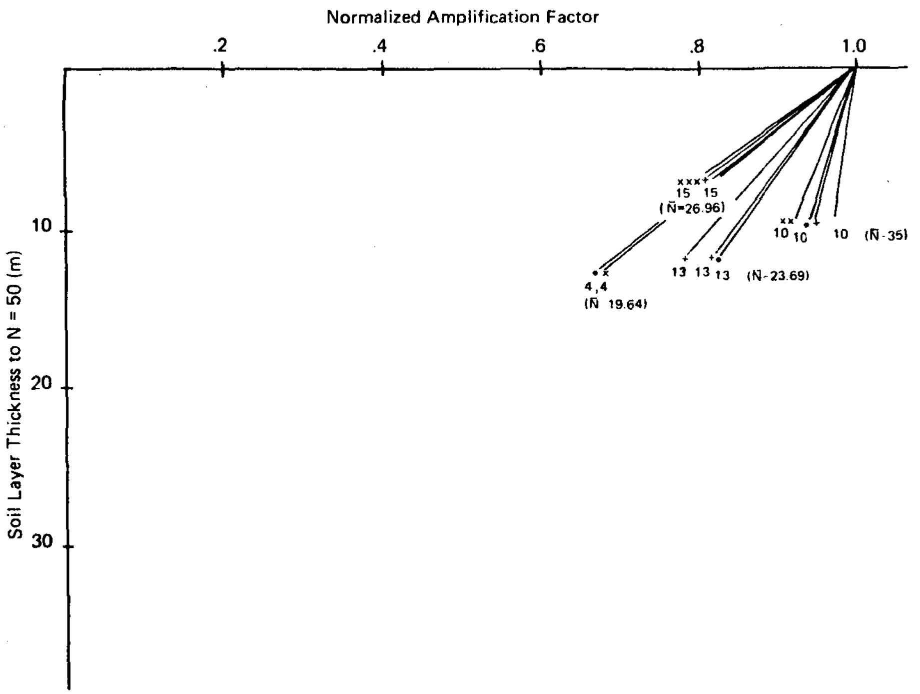

Figure 8. Normalized Amplification Factors Between Om/Depth with N ≤ 50, Shallow-Medium Sites

Legend:

● - 10-20, x - 20-40, + - 40-60, xx - 60-80, x+ – 80-130 gals peak ground surface acceleration of various groups.

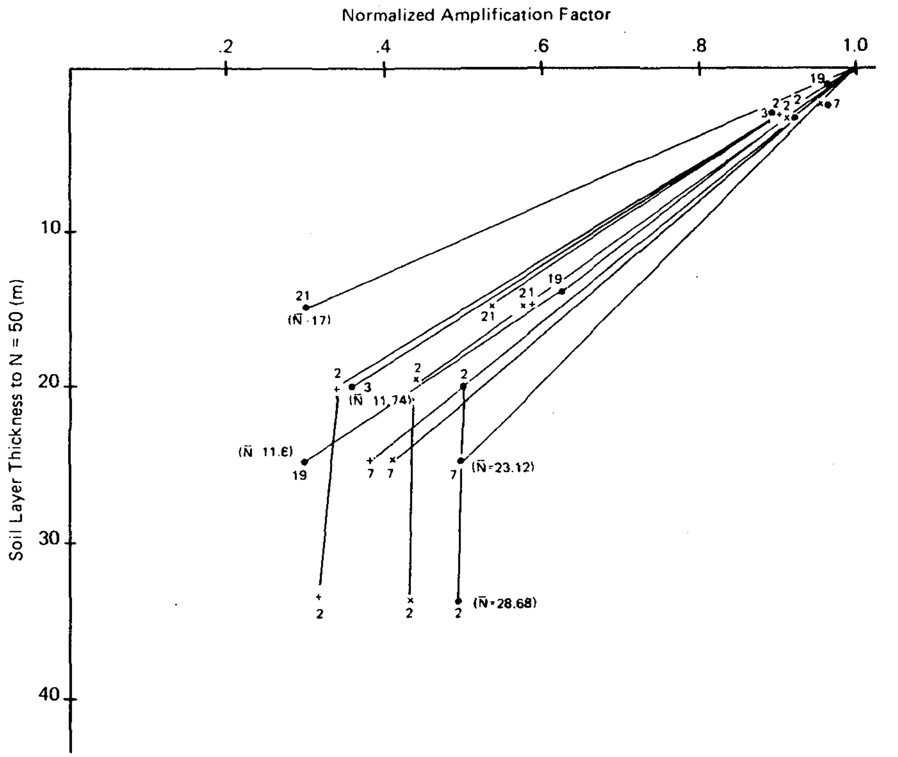

Figure 9. Normalized Amplification Factors Between Om/Depth with N ≤ 50, Deep-Medium Sites

Legend

● - 10-20, x - 20-40, + - 40-60, xx - 60-80, x+ – 80-130 gals peak ground surface acceleration of various groups.