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OBSERVED EFFECTS OF SITE GEOLOGICAL CONDITIONS ON FREQUENCY CONTENTS OF SUBSURFACE EARTHQUAKE MOTIONS

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SUMMARY

Subsurface earthquake motions at two sites (one deep medium site and one deep soft site) recorded simultaneously from four earthquakes were studied to determine the effects of site geological conditions on the frequency contents of subsurface earthquake motions. It was observed that for the deep soft site, the predominant periods of the subsurface earthquake motions at depths are the characteristics of site geological conditions. For the deep medium site, the predominant periods, besides site characteristics, are also affected by earthquake parameters such as epicentral distance, focal depth, and the azimuthal angle between the site and the epicenter.

INTRODUCTION

Engineering characteristics such as the design accelerations and response spectra of free-field ground surface earthquake motions have been studied extensively in the past several decades. These extensive studies have provided insight into free-field ground surface earthquake motions. However, little is known of the engineering characteristics of the free-field earthquake motions below ground surface (subsurface earthquake motions). This is because it was less urgent in the past to understand the subsurface earthquake motions, as comparatively few deeply embedded and buried structural facilities were built. However, with the trend of building more deeply embedded and buried structures in recent years, the need is increasing for a better knowledge of subsurface earthquake motions.

The Port and Harbour Research Institute (PHRI) of the Ministry of Transport, Japan, has recognized the importance of studying subsurface earthquake motions for many years, and has instrumented many sites around its harbours to obtain subsurface earthquake motions data. Many studies of these motions (Refs. 1 to 6) have been performed to investigate the engineering characteristics of these recorded motions. This study is a continuation of the previous studies by the PHRI to further investigate the engineering characteristics of the subsurface earthquake motions recorded at Funabahi (Site A) and Tokyo-Tatsumi (Site B). The vertical distribution of the peak accelerations of these two sites has been studied (Refs. 1 and 2). This study emphasizes the effects of site geological conditions on the vertical distribution with depth of horizontal earthquake acceleration response spectra.

DATA BASE

The N-S components of subsurface earthquake motions with a peak horizontal ground surface acceleration equal to or larger than 10 gals recorded simultaneously from four earthquakes at Sites A and B were studied. Site A had a downhole array of accelerometers at -3m, -20m, -50m, and -91m, while Site B had a downhole array of accelerometers at -3m, -21m, -50m, and -90m. The site locations and epicenters of the four earthquakes are given in Figure 1. Figures 2 and 3 are the site geological information.

Site A is classified as a deep medium site, while Site B is a deep soft site. The site classification is based upon the blow count number, N, near the ground surface and the average blow count number, $\bar{N}$, 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, $\bar{N}$, of a site is the sum of the product of the blow count number of each soil layer and the corresponding length of the soil layer divided by the sum of the lengths of all soil layers. If N is less than or equal to 5, and $\bar{N}$ 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 $\bar{N}$ is larger than 10. If the depth at which N first reaches 50 is greater than 15m, the site is considered deep (Ref.7).

The information on instrumentation used to record the earthquake motions is described in Refs. 1 and 2. The information on the four earthquakes, such as the date of occurrence, magnitude, etc., is given in Table 1. The peak accelerations at different accelerometer levels of the two sites are given in Tables 2 and 3.

VERTICAL DISTRIBUTION WITH DEPTH OF ACCELERATION RESPONSE SPECTRA

<u>Site A</u> The acceleration response spectra at different depths of Site A for the N-S components of Earthquakes 1, 2, 3, and 4 are respectively shown in Figures 4 to 7. It is observed from these figures that:

- at -3m, the acceleration response spectra are narrow-band, while those at -91m in general are broad-band.
- the predominant periods of the acceleration response spectra at depths agree well with those at -3m.
- the predominant periods of the acceleration response spectra at -3m for Earthquakes 1, 2, 3, and 4 are respectively 0.435, 0.278, 0.217, and 0.385 seconds.
- the amplifications between the peak spectral accelerations at -3m and -91m for Earthquakes 1, 2, 3, and 4 are respectively 3.07, 2.6, 1.97, and 2.19. However, at -20m and -50m, the spectral accelerations are not always larger than those at -91m (Figures 4 and 7).
- the calculated fundamental period using vertically propagating shear wave approach is 0.29 seconds between -3m and -20m, and 0.91 seconds between 0m and -82m. These periods do not appear as predominant periods in acceleration response spectra.

<u>Site B</u> The acceleration response spectra at different depths of Site B

for the N-S components of Earthquakes 1, 2, 3, and 4 are respectively shown in Figures 8 to 11. It is seen from these figures that:

- the predominant periods of the acceleration response spectra at -3m for Earthquake 1 are 0.208 and 0.4 seconds, for Earthquake 2, 0.208 seconds, and for Earthquakes 3 and 4, 0.227 seconds. The acceleration response spectra at -3m, -21m, and -50m are narrow-band, while those at -90m are broad-band. The shapes of acceleration spectra at different depths are in general similar.

- the amplifications between the peak spectral accelerations at -3m and -90m for Earthquakes 1, 2, 3, and 4 are respectively 5.73, 3.44, 3.79, and 5.46. The spectral accelerations at -3m are in general larger than those at -20m, those at -20m are larger than at -50m, and those at -50m are larger than at -90m.

- the calculated fundamental periods using vertically propagating shear wave approach for depths between 0m and -21m, 0m and -51m, and 0m and -87m are respectively 0.61 seconds, 1.09 seconds, and 1.18 seconds. None of these periods appears as predominant period in acceleration response spectra.

OBSERVATIONS

Site A (deep medium site) and Site B (deep soft site) had almost identical downhole arrays but with different geological conditions, and simultaneously recorded subsurface earthquake motions from four earthquakes. These recorded earthquake motions provide insight into the effects of geological conditions on the frequency contents of subsurface earthquake motions. It is observed from the vertical distribution with depth of acceleration response spectra of these two sites that:

- the predominant periods of acceleration response spectra near the ground surface (-3m) and at depths are nearly the same for the four earthquakes recorded at Site B. However, for Site A the predominant periods of the acceleration response spectra near the ground surface and at depths vary from one earthquake to another. It appears that for a deep soft site, the predominant periods of subsurface earthquake motions at depths are the characteristics of site geological conditions. For a deep medium site, the predominant periods, besides site characteristics, are also affected by earthquake parameters such as epicentral distance, focal depth, and the azimuthal angle between the site and the epicenter.

- the predominant periods of the two sites calculated using vertically propagating shear wave approach do not agree with observed predominant periods of acceleration response spectra. It appears that a site has many periods. The predominant period in an acceleration response spectrum is one of the site periods that is amplified by earthquake waves.

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Table 1. Earthquake Event information

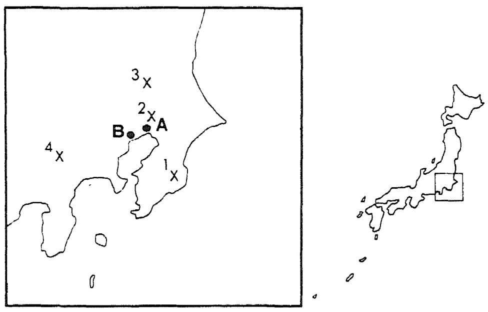
Earthquake	Date of Occurrence	Magnitude	Depth (km)	Distance (km) to Site A	Site B
1	12/22/73	-	70	58	64
2	2/8/75	5.4	60	19	34
3	4/12/75	5.0	50	47	54
4	6/16/76	5.5	20	92	75

Table 2. Peak Acceleration of Earthquake Events, Site A (Gals)

Downhole	Earthquake 1			Earthquake 2			Earthquake 3			Earthquake 4		
Array (m)	NS	EW	UD	NS	EW	UD	NS	EW	UD	NS	EW	UD
-3	10.76	12.01	1.45	38.91	57.97	7.60	18.91	20.47	4.62	11.07	9.98	1.30
-20	3.25	3.37	1.74	21.39	21.77	6.65	14.04	9.21	3.96	5.65	4.26	2.92
-50	3.00	1.01	1.14	21.31	18.38	4.81	9.52	9.10	2.90	2.84	4.32	1.04
-91	3.83	2.91	2.15	18.83	0.66	7.92	8.75	8.43	5.24	4.13	2.48	2.39

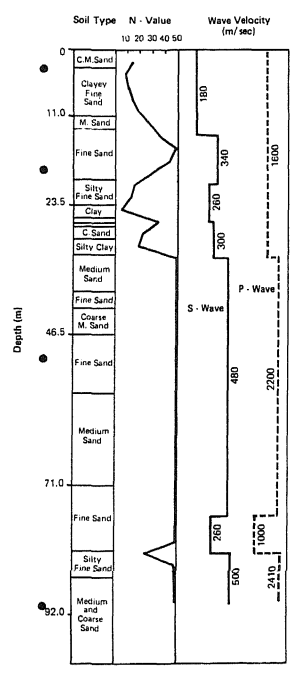
Table 3. Peak Acceleration of Earthquake Events, Site B (Gals)

Downhole Array (m)	Earthquake 1 NS	Earthquake 1 EW	Earthquake 1 UD	Earthquake 2 NS	Earthquake 2 EW	Earthquake 2 UD	Earthquake 3 NS	Earthquake 3 EW	Earthquake 3 UD	Earthquake 4 NS	Earthquake 4 EW	Earthquake 4 UD
-3	12.83	18.00	2.98	20.61	25.51	8.93	10.81	11.61	2.07	19.42	18.62	2.53
-21	6.93	12.91	2.19	18.16	34.14	3.83	13.33	11.44	2.59	12.19	17.43	4.35
-50	5.80	7.05	1.58	10.80	11.48	3.41	3.83	4.55	1.34	6.91	5.75	3.82
-90	1.94	3.30	0.68	8.24	7.88	2.02	3.84	3.14	0.75	5.08	3.39	1.50



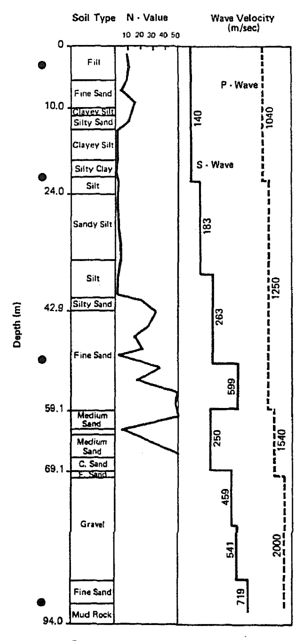
Site	Downhole Arrays (m)			
A	−3 m	−20 m	−50 m	−91 m
B	−3 m	−21 m	−50 m	−90 m

Figure 1. Site locations, Downhole Arrays and Earthquake Epicenters



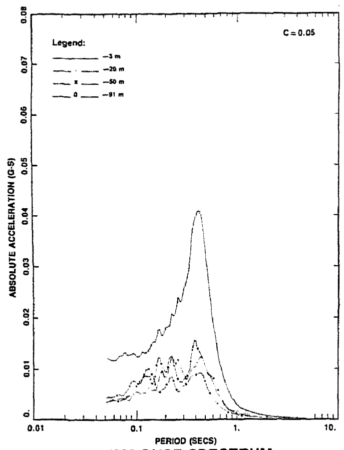
● Location of sub-surface accelerometer

Figure 2 Geological Information, Site A.



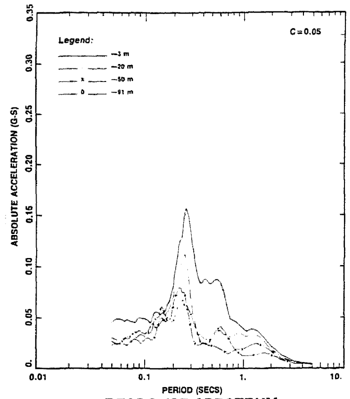
● Location of sub-surface accelerometer

Figure 3 Geological Information, Site B.



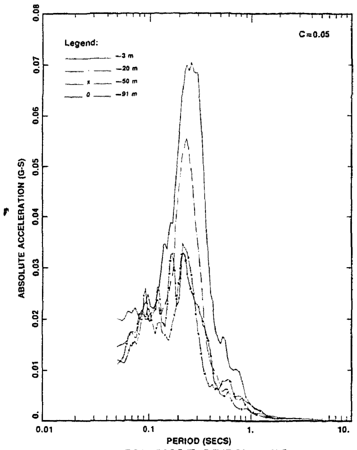
RESPONSE SPECTRUM

Figure 4 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site A, Earthquake 1



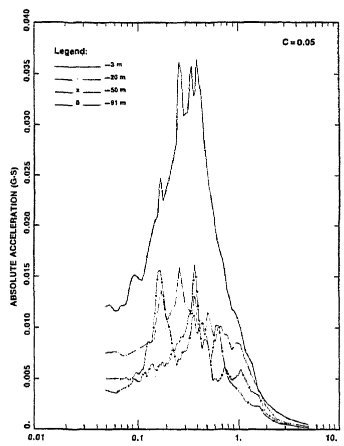
RESPONSE SPECTRUM

Figure 5 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site A, Earthquake 2



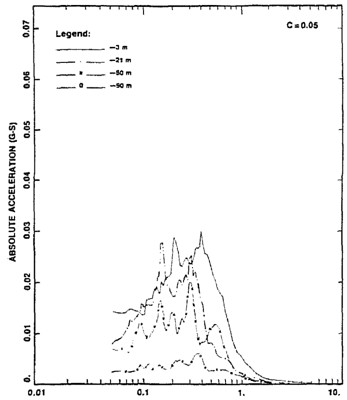
RESPONSE SPECTRUM

Figure 6 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site A, Earthquake 3



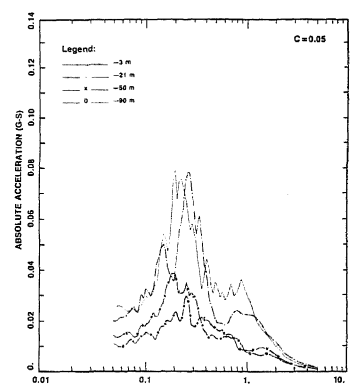
RESPONSE SPECTRUM

Figure 7 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site A, Earthquake 4



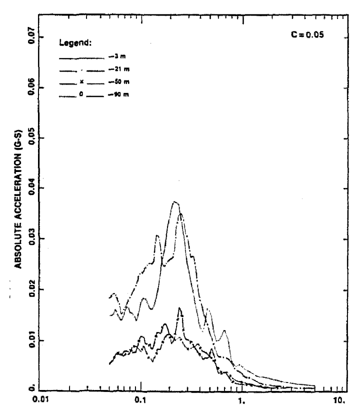
RESPONSE SPECTRUM

Figure 8 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site B, Earthquake 1



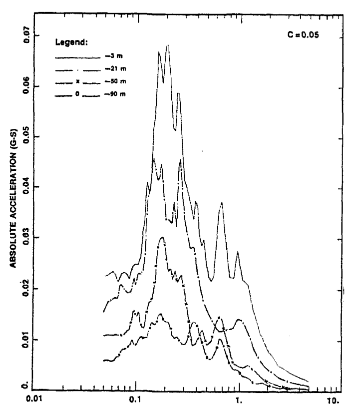
RESPONSE SPECTRUM

Figure 9 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site B, Earthquake 2



RESPONSE SPECTRUM

Figure 10 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site B, Earthquake 3



RESPONSE SPECTRUM

Figure 11 Vertical Distribution with Depth of Acceleration Response Spectra, N-S Component, Site B, Earthquake 4