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DYNAMIC BEHAVIOR OF EMBANKMENT BASED ON THE OBSERVED EARTHQUAKE MOTION

Susumu NAKAMURA* and Michael O'ROUKE**

* Engineering Research Institute, SATO KOGYO CO.,LTD.,
Nihonbashi Honchyo 4-12-20, Chuo-ku, TOKYO 103, JAPAN
**Civil & Environment Engineering, Rensselaer Polytechnic Institute,
Troy, NY 12180-3950, U.S.A.

ABSTRACT

The effect of the dynamic behavior of the inhomogeneity of the ground on the earthquake motion were evaluated by use of the six seismic records which were observed in embankment at Ohtsuki City, Japan since 1988. The proposed vector spectrum technique was used to evaluate the amplification characteristics of the earthquake motion. Furthermore, quasi three dimensional dynamic response analysis was proposed to verify analytically the effect based on the observed earthquake motion. It is found that the predominant vibrating directions of the horizontal ground motion at the surface ground deflect to the particular directions which strongly relate such a inhomogeneity and that the proposed "Vector" spectrum technique and quasi three dimensional analysis method is remarkably useful to evaluate the amplification characteristics of the earthquake motion in the inhomogeneous ground.

KEYWORDS

Embankment; seismic records; inhomogeneity of surface topography; "Vector" spectrum; quasi three dimensional dynamic response analysis.

INTRODUCTION

It has been well known that the lateral inhomogeneity in surface layers, as well as soil properties, strongly influenced the ground motion (Aki, 1988). And it has been pointed out that the inhomogeneity has a high correlation to earthquake damages. Many studies with respect to the effects of the inhomogeneity on the ground motion has been carried out based on the computational approach (e.g. Kawase *et al*,, 1987) as well as the analysis of the observed seismic record (e.g.Ohtuski *et al*,1984), while, according to the effects of the surface topography on the ground motion, the computational approaches (Boore *et al*,1972,1981, Zama,1981) has been mainly performed because of the lock of the sufficient seismic observation record.

Recently, many important structures has been constructed on the cliff and embankment. However, the seismic design code has not been established expect the stability of the ground because the seismic load to the structure, in other word the dynamic behavior of such a ground has not been made clear because of the lock of the analytical results based on the observed seismic record.

Fig.1. The plane view of the created land and the contour line of original ground surface.

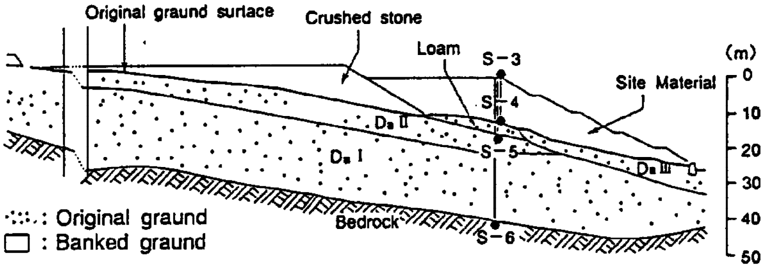


Fig.2. The seismograph arrangement and the soil profile at cross section along B-B.

The objective of this report is to evaluate the effect of the surface topography on the dynamic behavior of the banked ground by use of the seismic record which have been observed in embankment at Ohtsuki City, Japan since 1988 are used. The proposed "Vector" spectrum technique (Nakamura 1995) is used to analysis the observed earthquake motion. Furthermore, quasi three dimensional dynamic response analysis is also proposed to verify the effect analytically.

OBSERVATION DATA

Seismic array observation on the created land has been carried out since 1988 at Ohtsuki City which was located about 150km north-west of Tokyo. The land was created by banking and the cutting of the original ground. The plane view of the land and the contour line of the original ground is shown in Fig.1. The contour line in the banked area and the cut area is shown as dash line, solid line respectively and the contour interval around the land is 1.0m.

This array was equipped with sixteen seismographs which were set not only in the ground but also on the foundations of facilities. The seismograph arrangement and soil profile at the vertical section along B-B line in Fig.1 was shown in Fig.2. Seven seismographs among them were used for bore-hole array observation at two sites. One of the two site was referred to herein as S3~6 site as shown in Fig.2. The location of the subsurface seismographs which was 1,13,17 and 40m was shown by black circle in Fig.2.

Six kind of soil materials existed on the rock. Among them, three kind of soil materials originally existed on the rock and were the same soil type which was the sediment caused by an avalanche of earth and rock. The soil material used for the banking are crushed stone and the material which is generated by excavtiong the sediments. The soil properties are shown in Table.1. The shear wave velocity was expressed as the function of depth Z(m) from the ground surface. The function was determined by statistical analysis with respect to the relationship between the depth and shear wave obtained by the elastic wave test(Satoh).

Six earthquakes among the observed earthquakes were chosen. The information about the six earthquake was given in Table.2, while the location of the epicenters was shown in Fig.4. Each seismograph has observed acceleration time histories of three components with respect to north-south(NS), east-west(EW) and

Table.1 The soil properties

No	Soil Type	Unit Weight (tf/m³)	Shear Wave Velocity(m/s)	Poisson Ratio
1	Crushed stone	2.1	27.9Z+147	0.4
2	Generated material in site	2.1	22.5Z+206	0.45
3	Loam	1.3	180.	0.45
4	Sediment(Da1)	2.3	7.8Z+495	0.45
5	Sediment(Da2)	2.3	12.5Z+231	0.45
6	Sediment(Da3)	2.3	35.0Z+210	0.45
7	Rock (Weathered rock)	2.6	2000 (1250)	0.3

Table.2 Earthquake parameter

No.	Date	Epicentral Location		Magnitude (Mj)	Epicentral Distance (km)	Depth (km)
		Latitude	Longitude			
1	1991,1,26	35° 31'	138° 57'	3.3	16.0	24.0
2	1991,4,1	34° 55'	139° 46'	4.2	115.0	42.0
3	1991,4,25	35° 4'	138° 12'	4.9	80.0	32.0
4	1991,5,30	35° 53'	139° 22'	4.3	60.0	67.0
5	1991,11,24	36° 4'	139° 15'	4.1	67.0	*
6	1992,2,2	35° 14'	139° 48'	5.9	98.0	90.0

* Depth has not been still determined by Japan Meteorological Agency

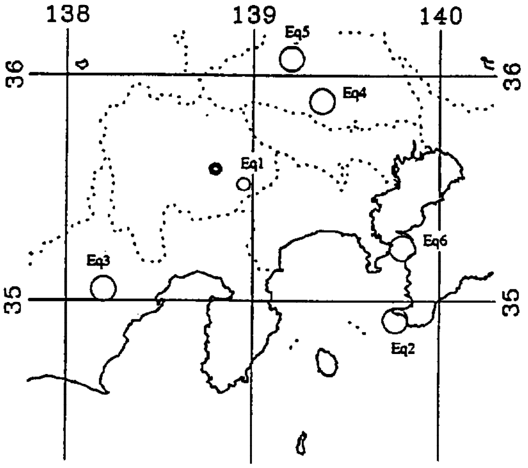


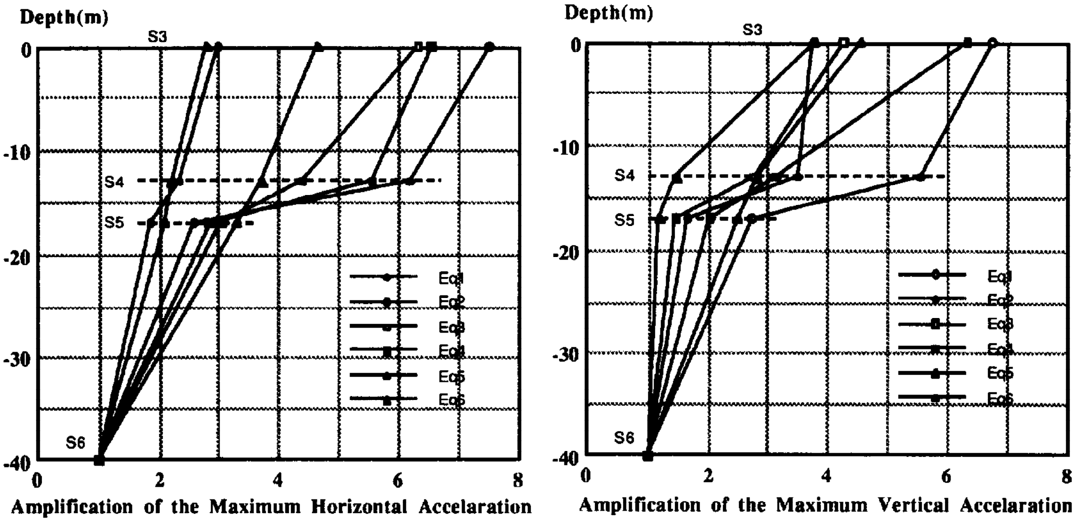
Fig.4 The location of epicenter

vertical(UD). The sample frequency was 100Hz.

AMPLIFICATION CHARACTERISTICS OF EARTHQUAKE MOTION

The distributions of the maximum horizontal and vertical acceleration with depth for all earthquakes are shown in Fig.5,6. The distribution has been usually represented by either of the maximum acceleration at NS component or that at EW component. However, the distribution is not appropriate because the effect of the surface topography and the dipping interface influences not only the maximum value but also the direction of the maximum value. And then, the maximum acceleration in horizontal plane is calculated as the maximum value of the time history $\tilde{a}(t)$ of the acceleration vector amplitude which is obtained by the root of the square summation of each horizontal component as shown equation(1). Furthermore, the maximum acceleration is normalized by that at rock point. The amplification of the horizontal and vertical maximum acceleration at the ground surface are almost the same range for each other and these ranges are for a range from 3.0 to 7.5, a range from 3.8 to 6.7 respectively. It is found that the amplification in the banked ground and the loam layer is remarkably larger than that in the origin sediment layers(Da1 and Da2).

$$\tilde{a}(t) = \sqrt{a_{NS}(t)^2 + a_{EW}(t)^2} \qquad (1)$$



a)Horizontal component b)Vertical component

Fig.5 The Distribution of the maximum horizontal and vertical acceleration

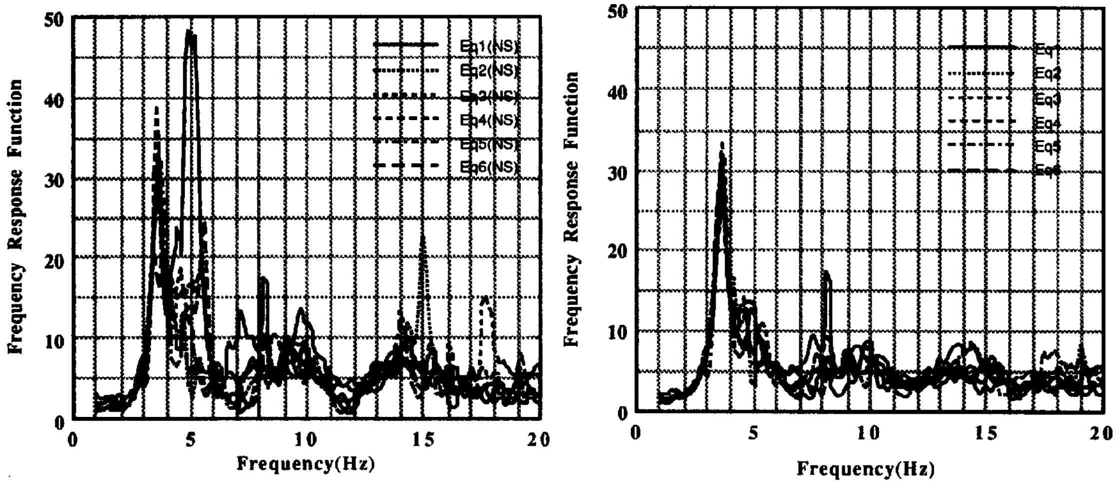
The frequency response functions with respect to horizontal component is evaluated by two kind of procedures. One is that defined as spectrum ratio which is a root of power spectrum at the other location of the same bore-hole site with respect to either of NS or EW component at the bedrock. This is referred herein as "1D" frequency response function. The other one is defined as a root of vector spectrum ratio between at the bedrock and at the other location of the same bore-hole site. This is referred herein as "vector" frequency response function. "Vector" spectrum is defined by the amplitude $S(\omega)$ and the angle $\theta(\omega)$ for the amplitude shown in equations 2 and 3. Here, $Px(\omega)$, $Py(\omega)$ and $Kxy(\omega)$ express power spectrum with respect to X and Y axis components and cospectrum. The power and vector spectrum were evaluated for the direct S wave portion of the records at each point. The sample used to evaluate the frequency response function had a 5.0 seconds starting with the arrival of the first S wave at each point.

$$S(\omega)=\frac{1}{2}\{P_x(\omega)+P_y(\omega)\}+\frac{1}{2}\sqrt{\{P_x(\omega)-P_y(\omega)\}^2+4\{K_{xy}(\omega)\}^2} \qquad (2)$$

$$\theta(\omega)=\frac{1}{2}\tan^{-1}\frac{-2K_{xy}(\omega)}{P_x(\omega)-P_y(\omega)} \qquad (3)$$

The "1D" and "vector" frequency response functions for all earthquakes were shown in Fig.6. The any "1D" frequency response function have the large defference from remarkably from that for any other events except frequency around 3.8Hz. Furthermore, the "usual" frequency response function for either of NS or EW component is also different from each other.. And then it is difficult to evaluate such a characteristics as a natural frequency and amplification factor of the ground. On the other hand, according to the "vector" frequency response function, these characteristics is very similar at any event. This tendency obviously points out that the horizontal movement of the ground has a directivity due to the deflection of the ground motion caused by such a inhomogeneity as the surface topography and dipping layer.

The average "vector" frequency response functions were shown in Fig.7 in order to evaluate such the dynamic response characteristics of the ground as natural frequency and so on. The predominant frequencies at 3.8Hz and 9.0Hz are found to be common to the any average "vector" frequency response function. The amplification at frequency 3.8Hz is remarkably predominant. At frequency less than 10Hz, the predominant frequency is not found on the average "vector" frequency response function at S4 and S5 in the original ground. However, at the average "vector" frequency response function at S6 on the bank, the predominant frequencies around 5.0Hz, 8Hz, 10Hz and around 14.0Hz are found in addition to the above frequencies and correspond to the predominant frequency of bank part obtained from the average "vector" frequency response function between S3 and S4 shown in Fig.8.



a)1D Method(NS component) b)"Vector" spectrum Method

Fig.6 Frequency response function

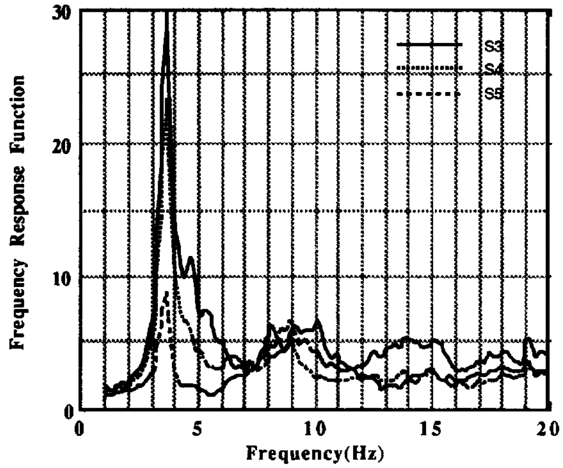


Fig.7 Average "Vector" frequency response function

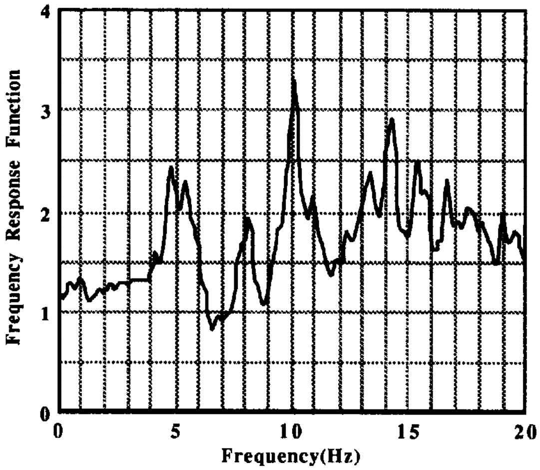
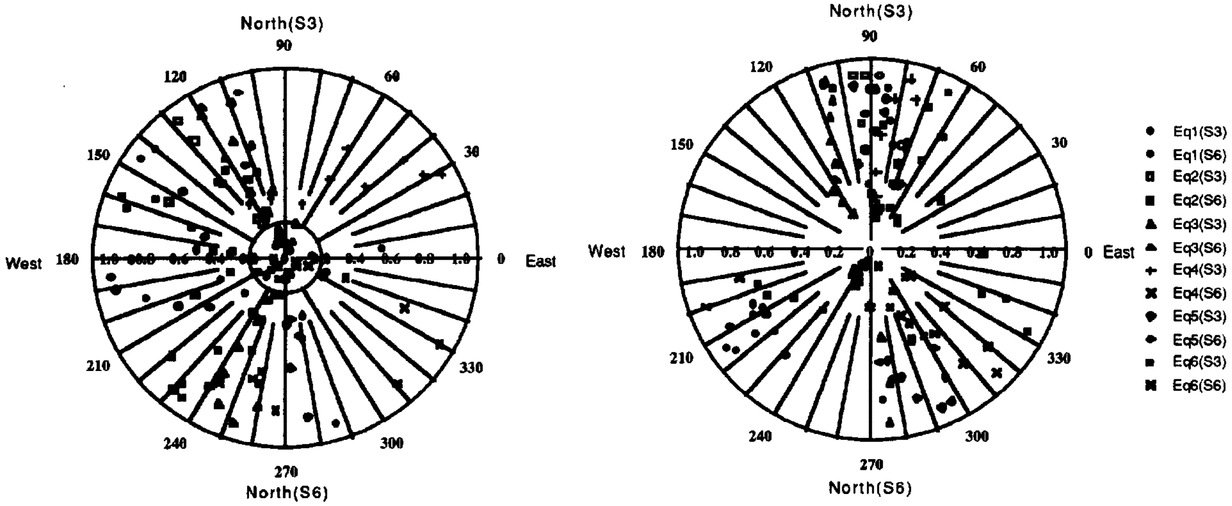


Fig.8 The "Vector" frequency response function between S3 and S4

The directivity of the horizontal ground motion in frequency domain were disccused here because it seems to be important to characterize the effect of such a inhomogeneity as the surface topography and the dipping interface on the ground motion. The directivity was evaluated by use of the relationship between the vector spectrum S(f) and the angle θ(f) from north to the direction of the vector spectrum. The relationships at the ground surface and bedrock was shown in Fig.9. These relationships were calculated for two frequency ranges: One is the range of 3.0Hz to 4.0Hz. The other one is the range of 9.5Hz to 10.5Hz. These ranges were selected by considering the predominant frequency with respect to the average "vector" frequency response function. The relationship at the ground surface was represented in the upper semicircle above the line from East(0 degree) to West(180 degree), while that at the bedrock was represented in the lower semicircle below the line by replacing the angle θ(f) with 360-θ(f). And then the direction at the bedrock was a symmetric with respect to the line. Furthermore, the vector spectrum at each frequency range was normalized by the maximum value at each frequency range. It is found that the predominant vibrating directions at the surface ground are different from those at the bedrock at any frequency range and deflect to the particular directions in spite of the predominant vibrating direction at the bedrock. The difference and deflection seem to become larger at higher frequency. That is the reason why the scattering of the "1D" frequency response functions are very large. Furthermore, the any deflected directions strongly relate such a inhomogeneity as the surface topography and the dipping interface.



a) Frequency Range of 3.0Hz to 4.0Hz   b) Frequency Range of 9.5Hz to 10.5Hz

Fig.9 The relationship between "vector" Spectrum and the angle

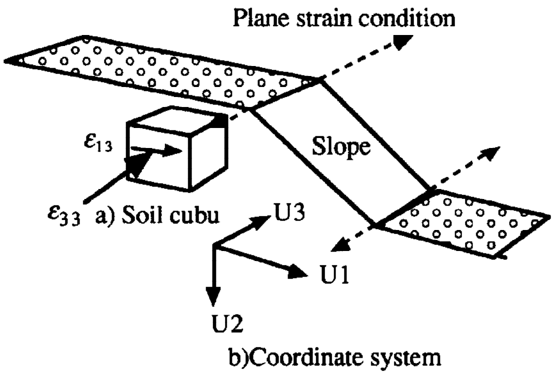


Fig.10 Schematic figure showing modelling embankment for quasi three dimensional analysis

DYNAMIC RESPONSE ANALYSIS

Three dimensional analysis is nessesary to conduct verifing analytically the effect of the inhomogeneity of the ground on the earthquake motion. However, it is hard to make the analysis according to the memory of computer and CPU time. Navior's three dimensional elastic wave equation is able to separate into following two equations with respect to in-plane state and out-plane state under the assumption that the axial strain along the direction perpendicular to slope(the plane strain condition) and shear strain in horizontal plane shown in Fig.10 are zero respectively. Therefore, quasi three dimensional analytical method combined the usual two dimensional in-plane analysis with the two dimensional out-plain was proposed. Analytical code 'Super-Flush' and 'Super-flush/SH' based on finite element method were used for in-plane and out-plane analysis respectively.

$$\rho\frac{\partial^2 U_i}{\partial t^2} = G \cdot U_{i,jj} + (\lambda + G)U_{j,ji}(i,j = 1,2) \quad \text{in plain state} \qquad (4)$$

$$\rho\frac{\partial^2 U_i}{\partial t^2} = G \cdot U_{i,jj}(i = 3, j = 1,2) \qquad \text{out plain state} \qquad (5)$$

Two dimensional in-plain analysis and quasi three dimensional analysis were carried out. The analytical model based on Fig.2 was shown in Fig.11. Horizontal and vertical component of earthquake motion observed at

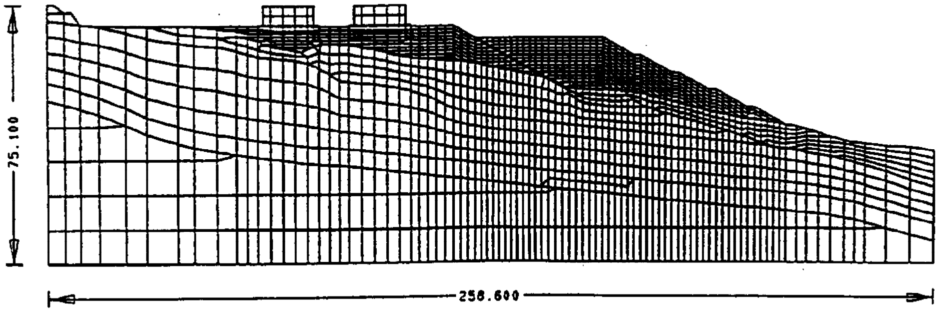
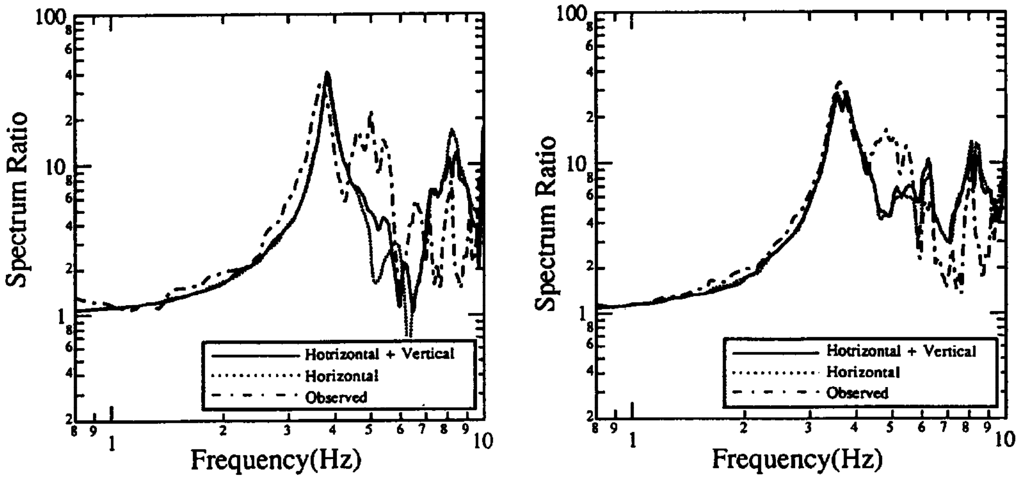
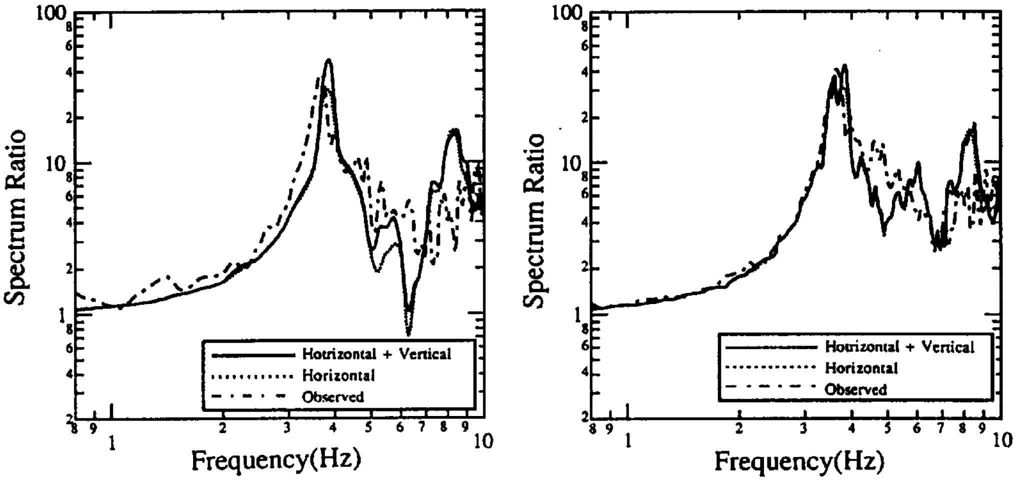


Fig.11 The analytical model



a)In plane analysis b)Quasi three dimensional analysis

Fig.12 Comparison of frequency response function based on quasi three dimentional analysis to that based on in plane analysis for earthquake No.3



a)In plane analysis b)Quasi three dimensional analysis

Fig.13 Comparison of frequency response function based on quasi three dimentional analysis to that based on in plane analysis for earthquake No.6

rock for earthqake no. 3 and 6 were used as input motion. Here, Horizontal component was transformed for the component along B-B section in Fig.1 based on the observed two horizontal components. Two cases were considered as input motion: One case is that only horizontal component was used as input motion. The other case was that Both horizontal and vertical component were used. The comparison of the frequency response function calculated by the observed earthquake motion to that calculated by the analytical results are shown in Figs.12 and 13. The frequency response function for quasi three dimensional analysis was defined as the vector spectrum ratio of the horizontal response at the seismic observed point S3 to the input motion and is refered herein as the Q frequency response function. The other frequency response function by the in-plane analysis is refered herein as the P frequency response function.

The frequencies at the peak value of the P frequency response function are observed at 3.8Hz and 8.0Hz and correspond with those of the Q frequency response function. According to the characteristics of the frequency response function at the range of 5.0Hz to 6.0Hz, which correspond to the predominant frequency at first mode of the banked ground between S3 and S4, the Q frequency response functio correspond to the frequency response function calculated by the observed earthquake motion. On the other hand, the P frequency response function is different from that calculated by the observed earthquake motion. The difference of input condition didn't reconginized.

CONCLUSION

The six seismic records were observed in embankment at Ohtsuki City, Japan since 1988. The embankent has a imhomegenity of the ground with respect to the surface topography and the dipping interface between adjacent layers. The effect of the dynamic behavior of such a inhomogeneity of the ground on the earthquake motion were evaluated. In order to evaluate the amplification characteristics of the earthquake motion, The proposed vector spectrum technique was used. Furthermore, quasi three dimensional dynamic response analysis was proposed to verify analytically the effect based on the observed earthquake motion. The following results are obtained by this study;

(1)The predominant vibrating directions of the horizontal ground motion at the surface ground deflect to the particular directions which strongly relate the inhomogeneity of the ground.
(2)The proposed "Vector Spectrum" technique and quasi three dimensional analysis method is remarkably useful to evaluate the amplification characteristics of the earthquake motion in the imhomogenious ground.

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