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WAVE TRANSMISSION CHARACTERISTICS AND LOCAL SITE EFFECTS IN SURFACE LAYER

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SUMMARY

The wave transmission characteristics in visco-elastic multi-layered surface strata are discussed from the viewpoint of an amplitude effects of incident wave from bed rock. The theoretical analysis of scattering of body wave and surface wave is investigated comparing to the actual recorded data. Especially, with regard to the measurement data , a time variant propagation characteristics of incident wave examined using by the non-stationary spectral ratio between ground surface and bed rock. It is concluded that the amplification effects by SV wave which are remarkable in the neighborhood of initial tremor change gradually to that by SH wave. Moreover, from these discussion results, the dynamic characteristics of foundation subjected to earthquake excitation is also examined, and it is shown that the analytical results and the observation results show the good agreement.

INTRODUCTION

In order to evaluate correctly an input mechanism of an earthquake excitation to large scale foundation of structural system, the following two points should be discussed on the basis of measurement data; one point is concerned to a transfer characteristics of incident wave in propagation path from bed rock to ground surface and, the other is a ground-foundation interaction effects.

In this paper, the amplitude amplification effects of body wave and surface wave of visco-elastic multi-layered model are examined on the basis of the accelerograms recorded on the large scale foundation, on the ground surface and in the underground in site. The earthquake response of large scale foundation installed on the ground surface is also discussed by a transfer characteristics between foundation and bed rock in consideration of the multi-layered strata. The earthquake accelerograms used in this paper have been observed over ten years and the large scale concrete foundation was constructed for the shaking table of seismic proving test to large components of nuclear power plant at the location of Tatotsu engineering laboratory in Kagawa prefecture in Japan.

ACCELERATION RECORDS AND EARTHQUAKE OBSERVATION SYSTEM

Dimension of the foundation and observation points of accelerometers are shown in Fig.1. Twelve observation points are installed on the foundation, ground surface, and in the underground. In Table 1, the multi-layered strata and physical parameters of ground structure are shown, which are identified from P-S investigation in site. This foundation is very large scale and has no upper-structure, so that there is not necessary to considered an interaction influence of upper-structure in the analysis.

Table 2 and Fig.2 show some parameters of earthquakes analyzed in this paper and waveforms of horizontal component of recorded accelerograms at the observation point of ground surface P.7, respectively. The earthquake record of large acceleration has not been observed, because of low seismicity in this prefecture. As to the earthquake observation system, three component accelerograms are installed at each observation points. Among the earthquakes of comparative large amplitude records, three earthquakes are selected as three cases of analysis, the epicentral distance of which are near field, intermediate and far field earthquake respectively.

WAVE PROPAGATION CHARACTERISTICS IN MULTI-LAYERED VISCO-ELASTIC MEDIUM

The transfer characteristics of propagation of body wave and surface wave are analyzed for the model of multi-layered ground structure in order to examine a propagation characteristics of an inclined incident plane wave. In the case of analysis of body wave, an amplitude amplification effect are evaluated to inclined incident plane wave from bed rock by the multi-layered reflection theory and, in the case of surface wave, the constructive interference are examined on the basis of the dispersion characteristics of Love wave.

1) BODY WAVE The propagation characteristics of body wave in visco-elastic multi-layered model are calculated by Thomson-Haskell method, on the basis of multi-layered reflection theory for the case that an incident wave with some incident angle is traveling upward from bed rock as a plane wave. A theoretical amplitude characteristics of horizontal component from bed rock to the observation points are shown in Fig.3, in which incident angles are as parameter. It is clear from this figure that there is no remarkable differences among these transfer characteristics according to the variation of incident angles and kinds of incident wave. And also, with respect to a magnification ratio of amplitude at dominant frequencies, the figure shows the decreasing tendency according to increasing frequency irrespective of an incident angle, in the case of incident P and SH wave. While, the higher predominant peaks of inclined incident SV wave shows a little decreasing tendency in the middle frequency domain of frequency range.

2) SURFACE WAVE In this site, the bed rock is almost horizontal, where shear wave velocity is distinctly different from upper strata, as shown in Table 1. If an amplitude amplification is considered to generate by a propagation of surface wave, it causes any constructive interference by Love wave, propagating from bed rock stratum to ground surface. A generation of constructive interference is caused by the propagation of Love wave if the component of Love wave is travelling with critical angle between bed rock stratum and ground surface. The dispersion curves of Love wave for the seven-layered model and two-layered model of ground structure are calculated and shown in Fig.4. From the figure, the dispersion curves for the seven layered model are well corresponding with the curves for the two-layered model in each lower frequency domain, which are considered to be important to evaluated a constructive interference practically. The frequency of constructive interference evaluated by the dispersion curves is about 1.7Hz, as indicated by black circle in Fig.4 that is determined from the cross point of curve of first mode and the horizontal line for shear wave velocity in bed rock.

ANALYTICAL RESULTS OF TRANSFER CHARACTERISTICS OF RECORDED ACCELEROGRAMS

An amplification characteristics of recorded accelerograms are analyzed numerically by the cross-spectral density functions, and two examples of calculation results of EQ.1 and 2 are shown in Fig.5 and 6, respectively. FFT method and Bartlett type window of 0.2Hz band width are used on the calculation of cross-spectral density function. From these figures, the transfer characteristics of horizontal component are almost equal in any of the three earthquakes, so that the evaluation results are considered to be stable regardless of the epicentral distance and the magnitude of earthquake. Especially, the case of horizontal component of SV wave, the incident angle of which is equal to 30 degree, shows the good agreement with the evaluation results of recorded accelerograms of EQ.2 shown in Fig.6. In order to make a more precise comparison between the theoretical analysis and the actually recorded accelerograms EQ.2, the spatial distributions in under-ground of amplification ratio for inclined incident SV wave and the amplitude ratio of P.8, P.9 and P.10 for each predominant frequencies 0.9, 2.2, 3.3 and 4,4Hz are shown in Fig.8 and Fig.9, respectively. In these figure, a horizontal axis express amplitude ratio that is average value of X and Y component. The numbers on top of figures indicates the predominant frequencies of 1st., 2nd., 3rd., and 4th. order respectively. As a general tendency in these figures, the curves of first order show the gradual amplification from bed rock to ground surface, while the curves of higher order show the remarkable amplification in first layer. From the evaluation results, the amplitude characteristics in surface layer evaluated by the actual accelerograms are regarded generally as, the amplification effects by inclined incident body wave from bed rock.

TIME VARIANT TRANSFER CHARACTERISTICS

It is expected from the intrinsic nature of seismic wave that the transfer characteristics of incident wave are varying gradually according to the lapse time from initial tremor to main shock and so that, the time variant transfer characteristics evaluated by non-stationary spectral ratio are examined. Fig.9 shows one of the example of calculation results of non-stationary spectral densities of the horizontal component of EQ.2. Each blocks in the figure are corresponded to the result for observation point P.7 of ground surface, P.10 of bed rock and the ratio of these two points respectively, from a left. In these figures, the time variation of transfer characteristics are indicated downward according to time elapse. The average spectrum and average spectral ratio of whole duration time are shown placed on the top of each figure. In these figures, Δf and t_o are the frequency width of narrow band filter and the time width of averaging time filter, respectively. From the comparison of the theoretical analysis and the calculation results of the recorded accelerograms, it is pointed out that the propagation characteristics in the underground structure can be presented initially by the incident of SV wave with incident angle of 30 degree and that, judging from the time variant feature of non-stationary spectral ratio, the characteristics of SV wave which is dominant initially shift gradually to that of SH wave. This could be confirmed by drawing the trajectory of particle orbit. As shown in Fig.10 and 11, the trajectories of X-Y and Y-Z components show the ellipsis vertically elongated, at the first phase of time from 0 to 10second, and the trajectories change gradually to thin ellipsis formed by SH wave.

DYNAMICAL BEHAVIOR OF LARGE SCALE FOUNDATION

The large scale concrete foundation subjected to the earthquake excitation is considered to behave as rigid body, because that the fundamental natural frequency for the elastic deformation mode of foundation itself is more than 50Hz. As the transfer characteristics between the ground surface and the bed rock can be formulated as the multi-layered strata model mentioned in the preceding sections, the equations of motion are introduced explicitly with regard to the ground-foundation structural system , in consideration of its interactive effect. In order to investigate quantitatively this ground-foundation interaction, the dynamical ground compliance of rigid foundation on semi-infinite elastic medium are evaluated to the horizontal component. Fig.12 shows the horizontal transfer characteristics between the foundation and bed rock of EQ.1. In this figure, the theoretical curves and the calculation results of measurement data show comparatively good correspondence in the higher frequency range, especially. But, in order to discuss more precisely the dynamic behavior of the foundation in the whole frequency range, it is necessary to examine an embedded effects for the ground-foundation interaction.

CONCLUSIONS

The wave transmission characteristics of incident wave in multi-layered visco-elastic medium are examined on the basis of analytical results of actual recorded accelerograms. From the analytical results of body wave and surface wave in site, it is concluded that the amplification effects of incident wave can be evaluated by the multiple reflection of body wave. Moreover, the time variation of transfer characteristics of incident wave evaluated by the non-stationary spectral ratio show a tendency that the amplification characteristics in the initial duration time are indicated by SV wave and that, according to the lapse of time, this characteristics shift gradually to SH wave. These tendency are well corresponded to the propagation nature of seismic wave. The dynamic behavior of the large scale foundation subjected to earthquake excitation is also discussed in comparison with the theoretical analysis of dynamical characteristics of rigid foundation on semi-infinite elastic medium. It is shown that the evaluation results are approximately well corresponded to the theoretical analysis.

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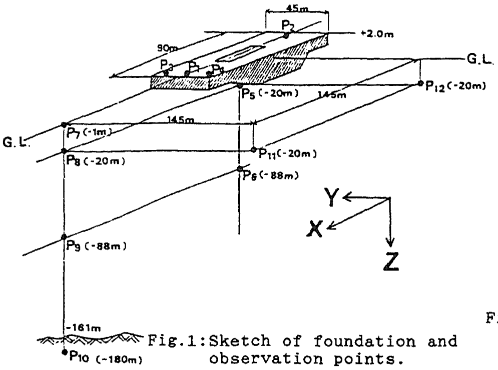

Fig.1:Sketch of foundation and observation points.

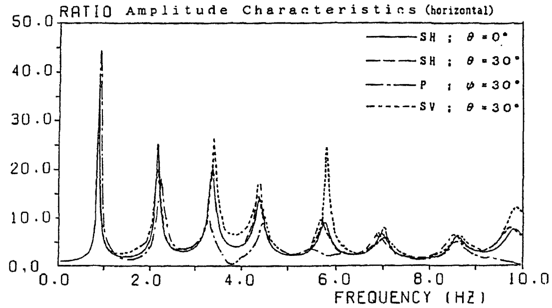

Fig.3:Amplitude characteristics between ground surface and bed rock(horizontal component;P,SV,SHwave)

Table.1:Multi-layered strata and physical parameters.

Layer	GL. (0^m)	H(m)	Vs(m/s)	Vp(m/s)	w(t/m³)	Qs	Qp
1	0	10.0	140.0	240.0	1.85	20.0	30.0
2	-10	39.0	330.0	570.0	2.00	30.0	45.0
3	-49	31.0	410.0	710.0	2.00	30.0	45.0
4	-80	34.0	515.0	890.0	2.10	30.0	45.0
5	-114	22.0	650.0	1125.0	2.10	30.0	45.0
6	-136	25.0	900.0	1560.0	2.20	30.0	45.0
7	-161	∞	1700.0	2945.0	2.50	∞	∞

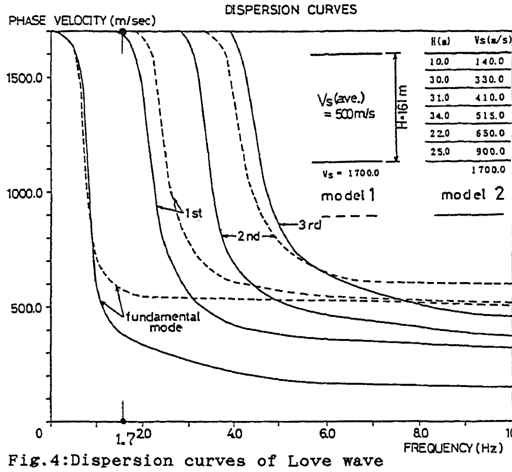

Fig.4:Dispersion curves of Love wave

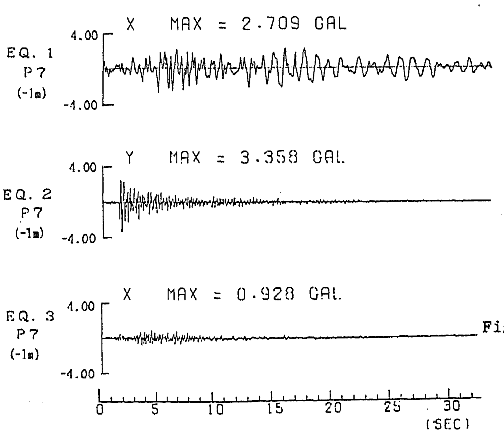

Fig.2:Horizontal component of recorded accelerograms

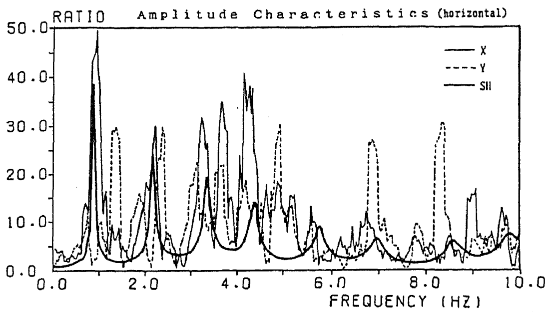

Fig.5:Amplitude characteristics between ground surface and bed rock(horizontal component;EQ.1)

Table.2:Parameters of the earthquakes

EQ No.	Time	Hypocenter LONG	Hypocenter LAT	H(km)	Hypocentral Distance(km)	M
1	1980/12/12	131°55'	32°23'	40	272.0	6.0
2	1981/01/22	133°55'	34°57'	10	77.5	4.2
3	1981/03/06	135°23'	33°49'	50	166.2	4.5

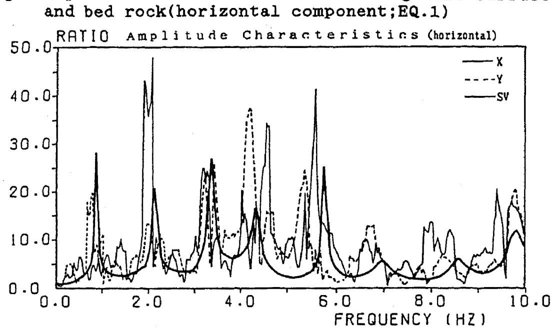

Fig.6:Amplitude characteristics between ground surface and bed rock(horizontal component;EQ.2)

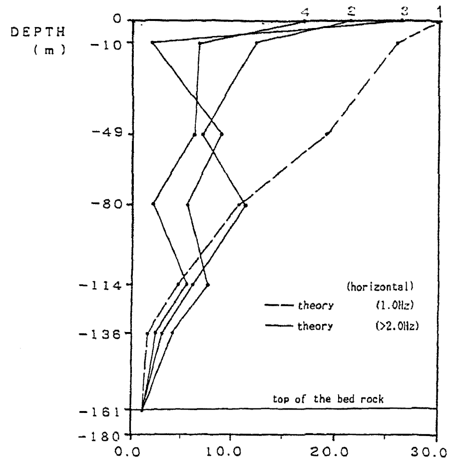

Fig.7:horizontal component;SVwave

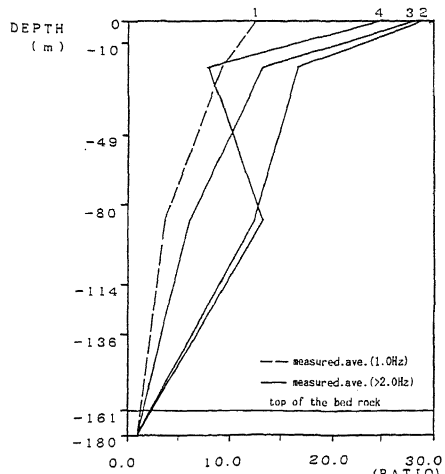

Fig.8:horizontal component;EQ.2

Fig.7,8:The spatial distributions of amplification ratio for each predominant frequencies

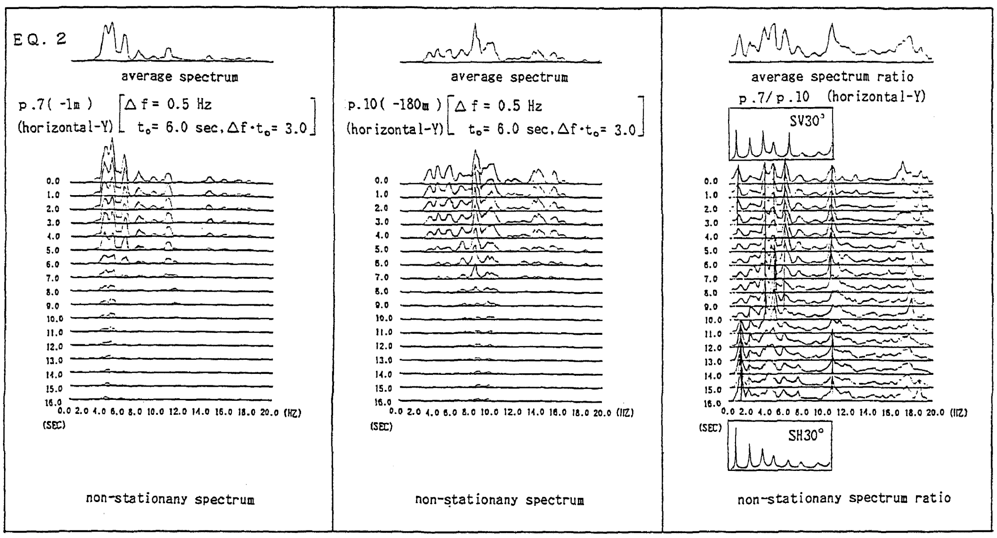

Fig.9:Non-stationary spectral density function and spectral ratio(horizontal component;EQ.2)

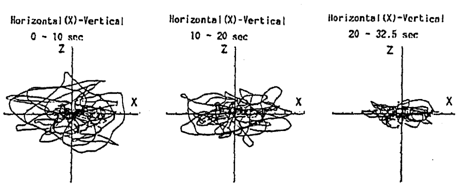

Fig.10:Particle orbits on the ground surface ;EQ.1(0-10,10-20,20-30sec.)

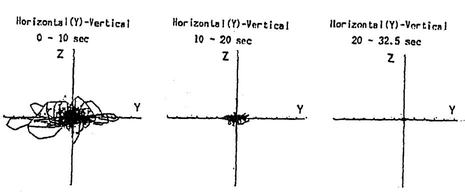

Fig.11:Particle orbits on the ground surface ;EQ.2(0-10,10-20,20-30sec.)

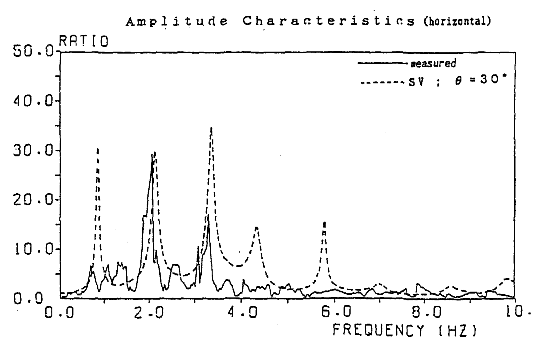

Fig.12:Amplitude characteristics between foundation and bed rock(horizontal component;EQ.2)