Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

3-5-4

EARTHQUAKE RESPONSE CHARACTERISTICS OF SOFT GROUND ON AN INCLINED HARD BASE

Kiyoshi UNO[1], Seima KOTSUBO[2] and Masaru NARITOMI[1]

[1] Department of Civil Engineering, Kyushu University, Fukuoka-shi, Fukuoka, Japan
[2] Department of Civil Engineering, Kyushu Kyoritsu University, Kitakyushu-shi, Fukuoka, Japan

SUMMARY

It is known that damage to structures and pipe-lines by earthquakes, depends on vibrational characteristics of the ground. Vibrational characteristics of parallel multi-layered grounds have been defined. However, those of soft grounds on an inclined hard base are not so clear, as in the case of reclaimed coast lines and hill slopes. So, it is important to clarify the vibrational characteristics of soft ground on an inclined hard base for the aseismic design of structures and pipe-lines.

INTRODUCTION

The vibrational characteristics and the response analysis of parallel multi-layered grounds are clarified by using multiple reflection method. But many soils are not parallel-multi-layered, and thus compose of a complex stratum. Grounds on inclined hard base are usually soft, therefore it is important to define the vibrational characteristics of soft grounds for the aseismic design. This paper shows the results of ambient vibration measurements and theoretical analysis of earthquake response on an actually reclaimed land on an inclined hard base. This ground is a site of an old, soft river bed.

The natural frequencies of the ground, were obtained by tests at several points on the ground surface at different depths. These natural frequencies and vibrational modes were calculated by using F.E.M. and multiple reflection method (M.R.M.), then the measured results and the theoretical results were compared and examined.

The earthquake response of the ground was calculated using EL-CENTRO (N-S component) earthquake wave data. Response acceleration, response displacement and shear strain of the soft ground on an inclined hard base were obtained.

TESTED GROUND AND THE POINTS MEASURED

The ambient measurements were carried out for the reclaimed land on an inclined hard base, and 16 points on the ground surface were used as shown in Fig.1. The symbols (Ac, As, Ds1, Ds2, Dc, Tm) in Fig.1 indicate the nature of the soil, where :

Ac : soft clay (N-value=0 ∿ 1)
As : slightly stiff alluvium sand (N-value=10)
Ds1: diluvium sand (N-value=15 ∿ 25)
Ds2: diluvium sand (N-value=30 ∿ 50)
Dc : diluvium clay (N-value=10)
Tm : hard base rock (N-value>50)

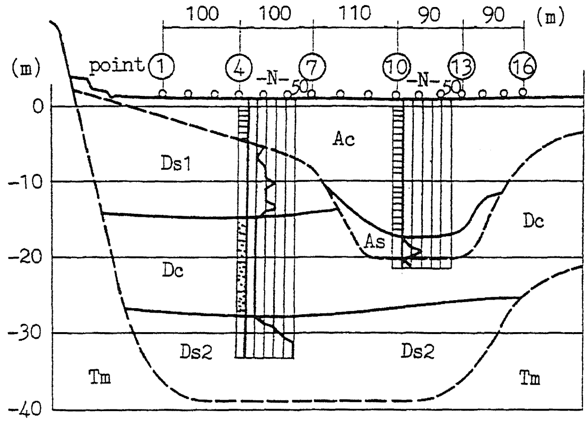

Fig.1 Cross-Sectional Diagram of Reclaimed Land

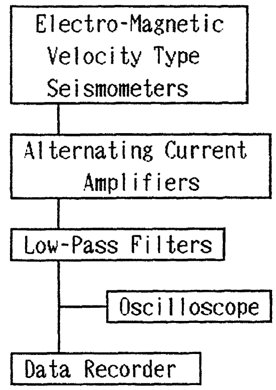

Fig.2 Couplings of Measuring Instruments

THE MEASUREMENTS AND THE RESULTS

Seismometers of the electro-magnetic velocity type of natural frequency 0.3 Hz and capacity 2 volt/kine, were used in order to measure the ground motions. The other measuring instruments were : alternating current amplifiers, low pass filters, an oscilloscope and a data recorder. Their couplings are shown in Fig.2. The seismometers were set in two horizontal directions, P-direction (measuring points line) and transverse to it (S-direction). The ambient vibrational measurements were carried out, around slight conditions of wind and vibrations, the measured time was about ten minutes at every point.

A fourier spectrum was calculated with data set N=2048 and sampling time Δt=0.02 sec. The fourier spectrum at every point was obtained with the average value of 10 above fourier spectra. The fourier velocity spectra of S-direction were obtained at the selected measuring points (2, 5 , 8, 10) shown in Fig.3. The P-direction results were the same as those of the S-direction. The natural frequencies of the ground can be easily evaluated from the outstanding peaks of those spectra. For example, at point 2 where the soft ground layer is thin, the natural frequency was 2.88 Hz, and at point 10 where it is the deepest, was 0.73 Hz.

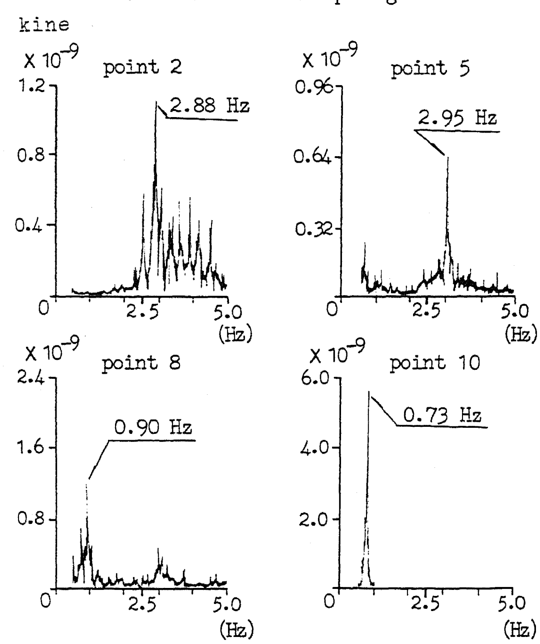

Fig.3 Fourier Spectra

THEORETICAL ANALYSIS

The dynamic characteristics of the ground were calculated by F.E.M. and M.R.M. A symmetrical model was used (Fig.4) for the multi-layered ground test, as shown in Fig.1. The left side of the model is the transmitting boundary

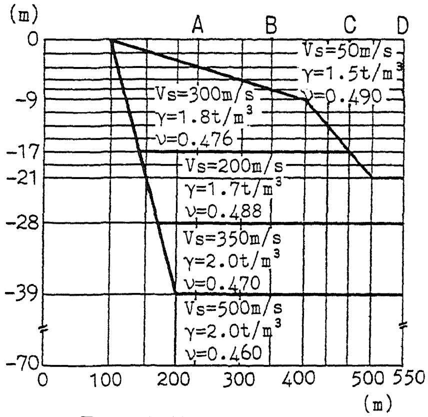

Fig.4 F.E.M. Model

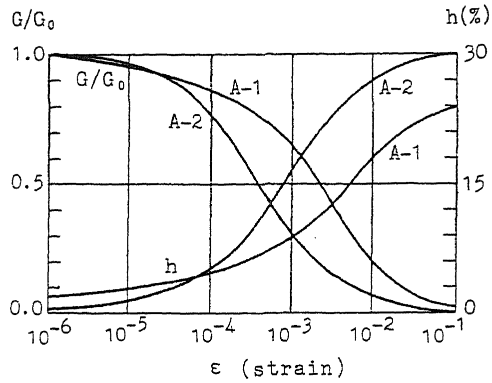

Fig.5 G/G_0 - ε and h - ε Relationships

and the right side is fixed. The marked points A, B, C and D (in Fig.4) respectively correspond to measurement points 2 , 5 , 8 and 10 (in Fig.1). The ground conditions shown in Fig.4 are as follows : Vs= Shear wave velocity (obtained from the N-value of the ground layer), γ = Unit weight of the ground layer, ν = Poisson's ratio (mean value). The damping constant for linear analysis (h) is considered equal to 0.15.

For non-linear analysis of earthquake response, equivalent linear method (E.L.M.) was used. The above calculation used the relationship of G/Go-ε and h-ε shown in Fig.5 adopted from the transportation ministry. In Fig.5, A-1 is the value of the argillaceous layer, and A-2 is of the arenaceous layer. Though the relationship of shear modulus-strain and damping constant-strain is different at each layer, the two assumed values were used.

The ground layers were assumed parallel multi-layered at the marked points (A , B , C and D in Fig.4), though the tested ground layers were inclined. The characteristics of the ground were calculated against the above model by using M.R.M..

RESULTS

Frequency-transfer-functions were calculated by F.E.M. and M.R.M.. The input earthquake wave was EL-CENTRO wave (N-S component, sampling time Δt=0.02sec) and the maximum acceleration was modified to 100 gals at bed layer. Fig.6 shows Frequency-transfer-functions that were obtained by F.E.M. and M.R.M.. The natural frequencies of the ground were derived from the outstanding peak values of the fourier spectra(Fig.3) and the Frequency-transfer-functions (Fig.6).

The above results are shown in Table 1. The theoretical results show

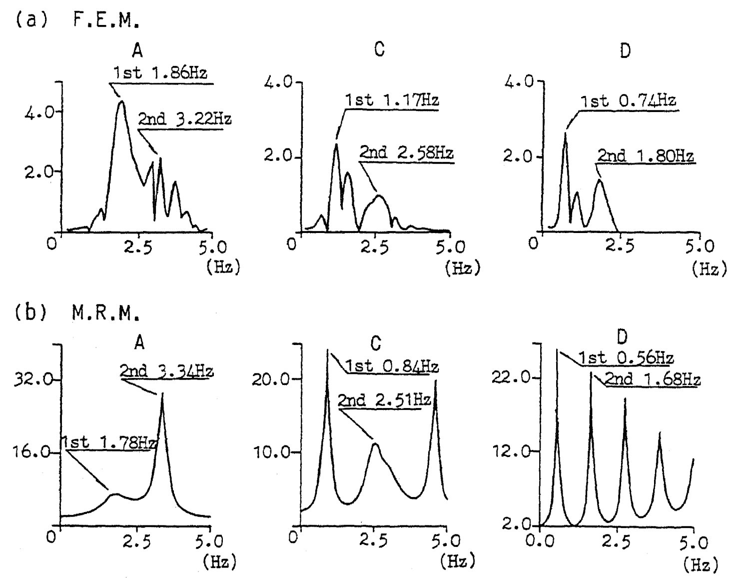

Fig.6 Frequency-Transfer-Functions

that the 1st natural frequency of the ground decreases, reciprocally to the soft ground layers depth. At points C and D , the measured 1st natural frequencies are 0.90 and 0.73 Hz respectively, and are within proximity of the theoretical results. However, the measured results at points A and B where the soft ground is of lesser depth, do not agree with the theoretical results. It is considered that the measured 1st natural frequency corresponds to the theoretical 2nd, as the measured 1st natural frequency at point A (2.88Hz) is similar to the theoretical 2nd natural frequency (3.22 Hz or 3.44 Hz). So, the 1st and 2nd vibrational modes of the ground models were calculated by inducing sine waves, with similar natural frequencies. The above results at each point are shown in Fig.7. Point C and D being at a greater depth of the soft ground, vibrate predominantly at the 1st and 2nd vibrational modes. But at the shallower soft ground (point A), the whole part of the ground vibrates at the 1st vibrational mode.

Here we are considering that the only predominant vibrations of the soft ground are obtained from the ambient vibration measurement. This measurement is an effective method, as there is a large difference between impedance ratio of the soft ground to its hard base.

Table 1 The Natural Frequencies(Hz)
(Measured Values and Theoretical Results)

Point		A(2)	B(5)	C(8)	D(10)
Measured Values		2.88	2.95	0.90	0.73
F.E.M.	1st	1.86	1.66	1.17	0.74
	2nd	3.22	----	2.58	1.80
M.R.M.	1st	1.78	1.38	0.84	0.56
	2nd	3.34	2.34	2.51	1.68

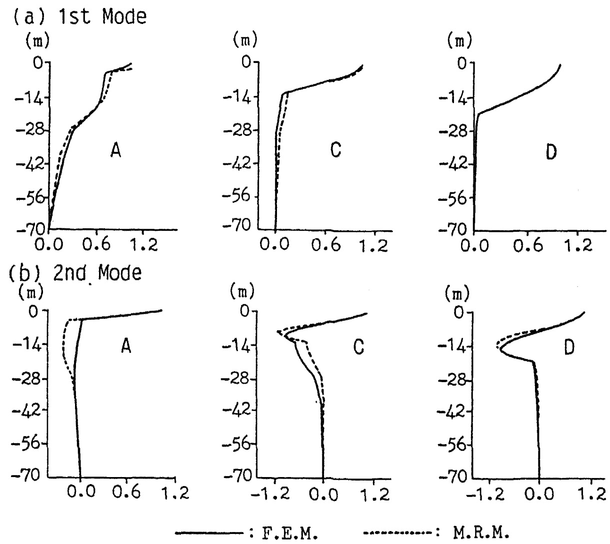

Fig.7 Vibrational Modes

The results of F.E.M. and M.R.M. in the low frequencies range agree well with both, natural frequencies and vibrational modes. The M.R.M. calculations being simpler than F.E.M., are preferred to be used for dynamic analysis of natural frequencies and vibrational modes on an inclined hard base.

The maximum response displacements, accelerations and strains were calculated at marked points on the surface ground, as shown in Fig.8. In Fig.8, the response results of linear and non-linear analysis (E.L.M.) were calculated by F.E.M.. The response results of M.R.M. were larger than that of F.E.M., it was difficult to decide the most suitable damping constants; therefore only the F.E.M. results are shown. In the case of non-linear analysis, the largest value of the response displacements occurred at the surface of deepest part of the soft ground. This value is about three times larger than that of linear analysis.

The largest value of response accelerations occured at the surface of the inclined soft ground. As the natural frequencies at these points increase from 0.7 Hz to 3.0 Hz, each point resonates with a particular earthquake frequency. Though EL-CENTRO earthquake wave was used in these calculations, if another earthquake wave was used, similar results would have been obtained. The result of the non-linear analysis shows a similar tendency as in the linear analysis.

In the case of non-linear analysis, the larger values of the response strain occurred at the surface of the inclined soft *ground's mid-point. However*, the results of the linear analysis did not change over the inclined soft ground, and was smaller than that of non-linear.

The maximum accelerations and shear strains at varied depth (point *A*, *C* and *D*) are shown in Fig.9 and 10. Both figures show that the accelerations and shear strains of the soft grounds are higher than that of harder layers, especially at the deepest point. A shear strain of a ground occurred from relative displacement of multi-layers. As the softer ground vibrates higher than the harder layers within low frequencies, it can be considered that the largest shear strain occured at the deepest part of the soft ground.

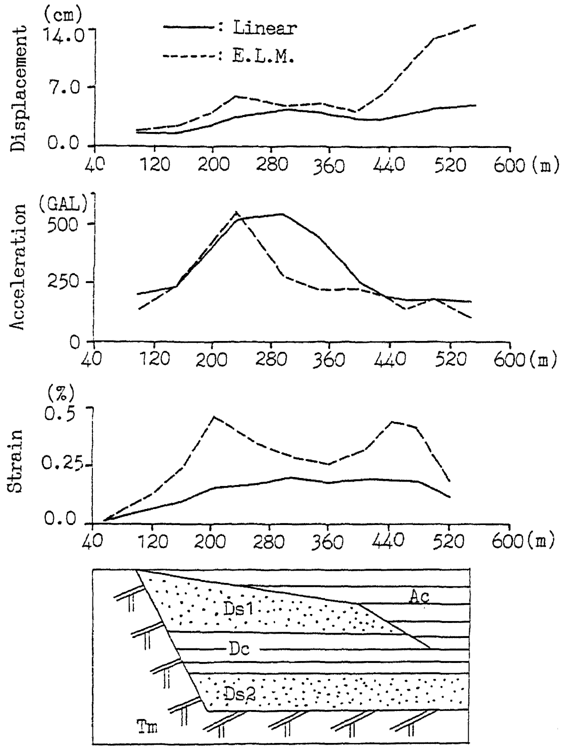

Fig.8 Maximum Response (on Ground's Surface)

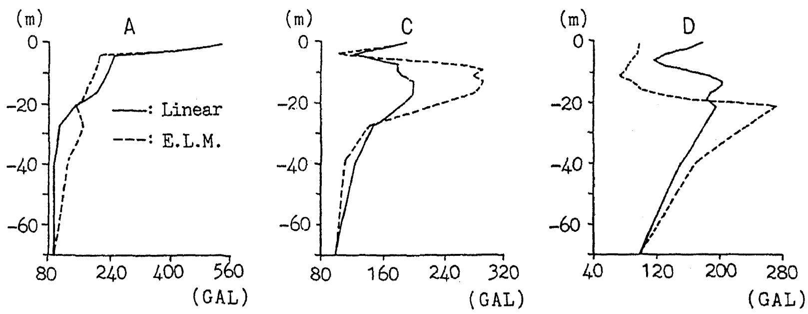

Fig.9 Maximum Accelerations (at Varied Depth)

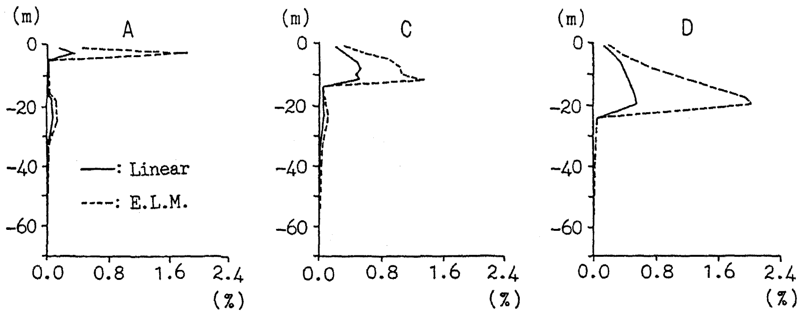

Fig.10 Maximum Shear Strains (at Varied Depth)

CONCLUSIONS

The natural frequencies of soft grounds on an inclined hard base, were obtained by ambient vibration measurements. The dynamic characteristics were calculated by the analytical methods of F.E.M. and M.R.M.. Comparing the measured values with the calculated values, the obtained results were summarized as follows :

(1) The natural frequencies of the soft ground obtained by ambient vibration measurements, were different at each depth. As impedance ratio of soft ground to hard base is largely different, these measurements are effective to obtain the natural frequencies.

(2) The results of F.E.M. and M.R.M. within low frequency range, coincide with the measured natural frequencies. The calculated vibrational mode of F.E.M. agreed with the results of M.R.M.. As the calculations using M.R.M. is simpler than F.E.M., M.R.M. is an easier method.

The earthquake response of the ground was calculated by F.E.M., against EL-CENTRO earthquake wave, and the results are as follows:

(1) The largest response displacement occurred at the surface of the deepest point of the soft ground. The largest response acceleration and strain occurred at the surface of the inclined soft ground's mid-point. These tendencies were more evident for non-linear analysis than the linear one.

(2) As the softer ground vibrated more than the harder layers within low frequency, the shear strain of the soft ground was higher than that of harder layers, especially at the deepest point.

(3) With the exception of the "acceleration", the response results calculated by the non-linear analysis were higher than that by the linear one.

REFERENCES

1. Ishii, H. and R.M.Eliis, "Multiple Reflection of Plane SH Waves by a Dipping Layer", Bull. Seism. Soc. Am., Vol.60, 1970.
2. H.L. Wong, "Effect of Surface Topography on the Diffraction of P, SV and Rayleigh Waves", Bull. Seism. Soc. Am., Vol.72, pp.1167-1183, 1982.
3. Ohtsuki, A., Yamada,H. and Harumi,K., "Effect of Topography and Surface inhomogeneities on Seismic Rayleigh Waves", Earthquake Eng. Struct. Dyn., Vol.12, pp.37-58, 1984.
4. M. Bouchon, "Effect of Topography on Surface Motions", Bull. Seism. Soc. Am., Vol.63, pp.615-632, 1973.
5. Ohtsuki, A. and Harumi, K., "Effect of Topography and Surface inhomogeneities on Seismic Waves", Earthquake Eng. Struct. Dyn., Vol.11, pp.441-462, 1983.
6. Tatsuoka, F. and Fukushima, S., "Stress-Strain Relation of Sand for Irregular Cyclic Excitation (I),(II)", Report of Institute of Industrial Science, University of Tokyo, Vol.30, Nos.9, 10, 1978.
7. Toki, K. and Sato, T., "Seismic Response Analyses of Ground with Irregular Profiles by the Boundary Element Method, Natural Disaster Science, Vol.5, No.1, pp.31-52, 1983.
8. Niwa, Y. and Hirose S., "Theoretical Analysis of Seismic Waves in a Dipping Layer, Proc. JSCE, Vol.337, pp.57-66, 1983. (in Japanese)