STUDY ON SEISMIC RESPONSE OF SOFT ALLUVIAL SUBSOIL LAYERS BY SIMULATION ANALYSIS

by

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SYNOPSIS

The seismic response characteristics of the soft alluvial subsoil layers in three different sites were investigated by simulation analysis based on the earthquake observations. The ground motion during an earthquake can be almost simulated by adopting the simple method, namely assuming SH wave as the incident wave and giving the same conditions to the three different sites. The procedure of this investigation and some interesting results are shown in this paper.

INTRODUCTION

A lot of apartment houses or industrial facilities have been constructed on reclaimed land such as a delta or a mersh in Japan, since it has become difficult to get a new adequate building lot in the urban environs. The earthquake response of the structures on soft grounds are much influenced by the dynamic characteristics of the soil. Therefore it is an important and urgent problem for rational and highly secured earthquake-proof design to grasp the properties of the soil during an earthquake. Several problems, especially the damping characteristics of the subsoil layers in the seismic analyses, remained unsolved in spite of the efforts by many investigators. Hence the seismic response characteristics of the soft alluvial subsoil layers in the three different sites were investigated by simulation analysis based on the earthquake observations.

OUTLINE OF THE EARTHQUAKE OBSERVATION SITES

All of these three sites, located in the environs of Tokyo, are for the apartment houses and are composed of the soft alluvial deposits 20 to 40 meters in thickness. Soil profiles are shown with N values of the standard penetration test in Fig.-1. The peculiarities of these sites are as follows:

Site A, Ohkurayama : This site was made as the building lot by piling the fill 0.5 to 1.5 meters in thickness on the paddy field of an old flood plain. This ground is composed of soft alluvial clay deposit about 20 meters in depth, thin diluvial sandy gravel deposit and the continuing tertiary silt stone deposit.

Site B, Urayasu : About five years have elapsed after reclaiming the delta with the dredged sand about 5 meters in thickness. The alluvial sandy and silty deposits underlying in this site are about 40 meters deep and the consolidated diluvial sand deposit continues underneath. The depth of the tertiary deposit is presumed to be 400 to 500 meters in this vicinity.

Site C, Ohji : This site had also been the flood plain and later was used for industrial facilities. The thickness of the alluvial silt deposit

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is about 25 meters and the diluvial sandy gravel, sand and clay deposits continue underneath alternately. The depth of the tertiary deposit is presumed to be 170 to 200 meters in this vicinity.

EARTHQUAKE OBSERVATIONS

The term of the observations, the sort of the seismographs, the method of digitizing and so on are different individually at each site. Fig.-2 shows the frequency characteristics of the seismographs and Table-1 shows the information of the sites.

The number of the observed earthquakes was different at each site as shown in Table-2. The description of the amplification factor of each deposit is given as the ratio of the maximum accelerations of the upper measuring points to the bottom measuring point which is shown in Fig.-3. Furthermore the standard deviations are computed for sites B and C which were considered to have sufficient data for statistic computations. The averages of the amplification factors at the top soil are almost the same in the three sites although there are slight discrepancies in each earthquake, in each direction of the measurement and so on. Since the predominant frequencies are similar to each other, it is presumed that the same tendency found in their amplification factors can be atributed to it, in spite of the fact that each site has different thickness of the subsoil layers of 20, 40 and 25 meters. The vertical distributions of the amplification factors increase gradually from the bottom to the ground surface, but their increasing rate is not always proportional to the depth, which is shown in Fig.-3.

The ratios of the Fourier spectrum of the top soil to the bottom were computed to obtain the frequency transfer function of the subsoil layers during an earthquake. The Fourier spectra were smoothed by using the Hanning window. The analyzed transfer functions for different earthquake records observed at each site show that the scatter of the predominant frequencies is small in comparison with that of the amplification factors of the transfer function. Hence it is not so appropriate to simply average all transfer functions in order to evaluate the typical transfer function, because it becomes, so to speak, further smoothed as a result of this procedure. For this reason, the typical transfer functions were estimated in such a way as not to lose their own features as shown in Fig.-4. Ommition was made of such transfer functions, as were much influenced by the surface waves or were not amplified at the predominant frequencies. The predominant frequencies of the subsoil layers at each site are as follows:

Site A,	1.1, 2.8, 4.9, 6.8	(Hz)
Site B,	1.0, 3.1, 4.4, 6.1	(Hz)
Site C,	1.4, 3.5, 5.7, 7.8	(Hz)

It is one of the features of the typical transfer functions that the amplification factor at site B is small compared with those at other two sites concerning the fundamental frequency. Secondly, the peak values of the amplification factors do not always decrease in proportion to the increase of frequency, which is recognized in Fig.-4.

SIMULATION ANALYSIS OF SEISMIC RESPONSE

The simulation analysis of the seismic response was performed by the modal analysis based on the wave propagation theory on which the incident wave was assumed to be SH wave. Hence this method is not enough to estimate other waves such as P, SV and the surface waves which exist in an earthquake. This analytical method, however, is of great advantage because it can easily be extended in the case of the dynamic analysis of the soil-structure system for the earthquake-proof design. Furthermore it will be practical enough to regard SH wave as the most influential factor for the structure. Thus, this method was adopted in this investigation.

This analytical model is based on the assumption that the subsoil deposit is of infinite extent in the horizontal plane with constant depth. The subsoil layers were sliced horizontally according to their sort of soils, the vertical distribution of S wave velocities, the locations of the seismographs and so on. In principle, the observed values obtained by the well-shooting method were adopted as the velocities of S wave for the analysis. However some of them were slightly amended by comparing the predominant frequencies obtained from the earthquake observations, since the well-shooting tests might contain observation errors. The dencity of soils was decided from the results of the soil tests or from the data of the similar soil when the tests were not performed.

According to the dynamic tests of soil specimen, the ratio of actual damping to its critical value is small in the range of micro strain, i.e. 3 to 4 percent for the sandy soil and 1 to 2 percent for the clayey soil, and it is independent of the frequency. On the other hand, the modal damping factors are expected not to increase but rather decrease in proportion to the increase of frequency as stated in the section of EARTHQUAKE OBSERVATIONS. Consequently the damping factor of hysteresis type was assumed as the damping property of soil, and the damping factors were presumed to be 4 for sand, 2 for sandy silt and 1 percent for clay deposit respectively.

RESULTS OF SIMULATION ANALYSIS

The analyzed transfer functions are shown in Fig.-6 and the analyzed modal damping factors are listed in Table-3. The computed transfer functions at sites A and C correspond well to the observed one, but the fundamental damping factor at site B may be underestimated. And the inclination of the modal damping at sites A and C is almost similar to that of the constant modal damping system, since the layers underlying sites A and C are composed of the cohesive soils.

The records of six earthquakes, two each at the three sites, are employed to simulate the seismic response of the subsoil layers. The vertical distribution of the maximum accelerations and the maximum strains are shown in Figs.-7 and 8 respectively. And the response spectra and the time histories are shown in Figs.-9 and 10 respectively. The acceleration level, the frequency characteristics and the time histories of the analyses are in good agreement with those observed to be enogh to justify the assumptions. Besides the computed maximum strains are scattered in the range of 10^{-3} to 10^{-2} percent and the effective strains of root mean square values are also scattered in the range of 10^{-4} to 10^{-3} percent.

CONCLUSION

The dynamic characteristics, which were grasped by the earthquake observations and their simulation analyses, of the soft alluvial subsoil layers are as follows:

a) The ratio of the maximum acceleration of the top soil to the one at the bottom is about 3. However, the vertical distributions of the amplification factors do not always increase gradually from the bottom to the surface. This is recognized in both the results of the earthquake observations at site C and the simulation analyses.

b) It is presumed from the results of the simulation analyses that the maximum strains show a tendency similar to the maximum accelerations. Namely the vertical distributions of the maximum strains are also uneven in the intermediate deposits.

c) The typical transfer function at site B is different from those at other two sites. Namely that of the former is comparatively flat at the peak values and those of the latter decrease with the increasing frequency.

d) The damping factor of the hysteresis type was adopted as the damping property of soil in this investigation, and in most cases it seems to be a suitable assumption. However, the slight difference was recognized in the fundamental or higher, i.e. fourth or fifth, oscillations. Hence it may be neccessary to apply some other damping characteristics that depend upon frequency.

It is significant that the ground motion during an earthquake can be almost simulated by adopting the simple method, namely assuming SH wave as the incident wave and giving the same conditions to the three different sites. But the observed accelerations were comparatively small in all cases, hence the further investigation pertaining to large acceleration is required.

BIBLIOGRAPHY

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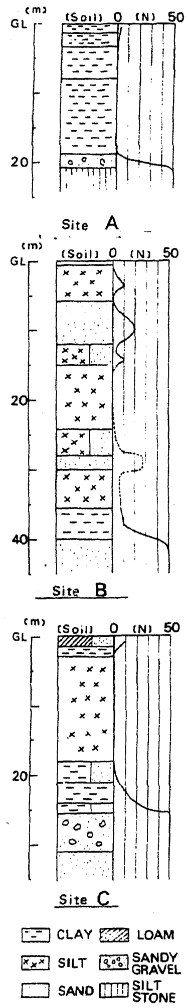

Fig.-1

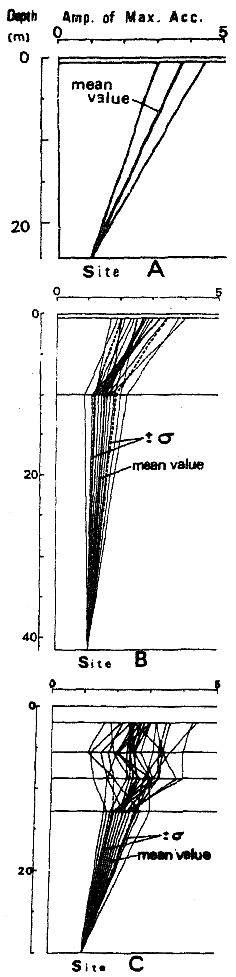

Fig.-3

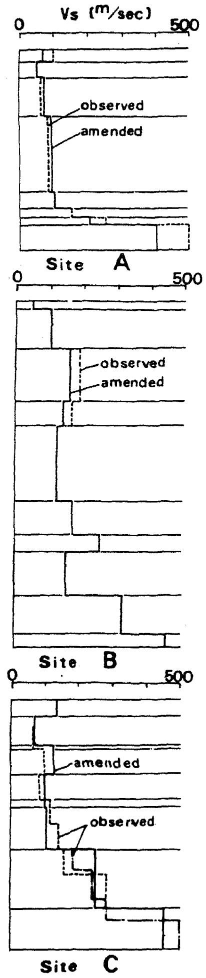

Fig.-5

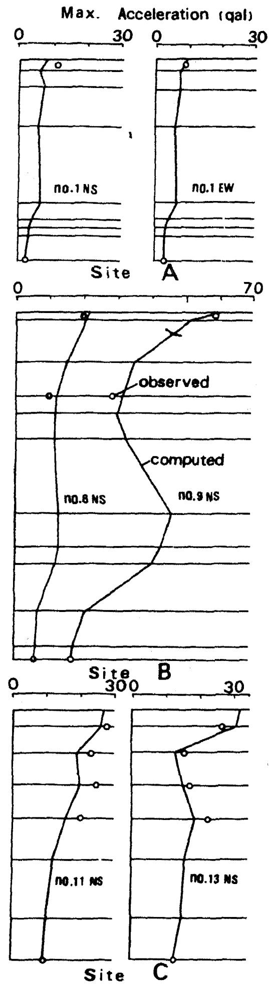

Fig.-7

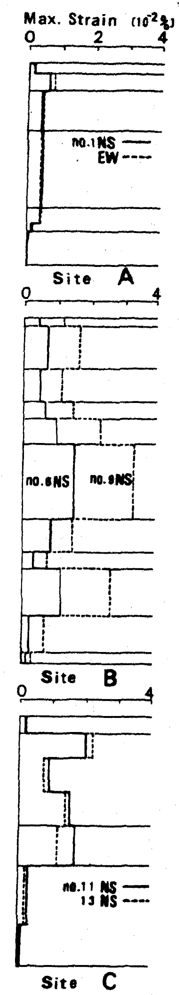

Fig.-8

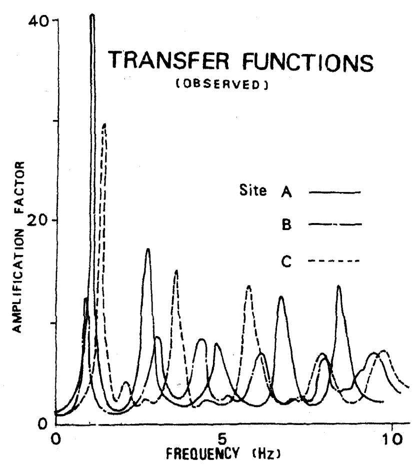

Fig.-4

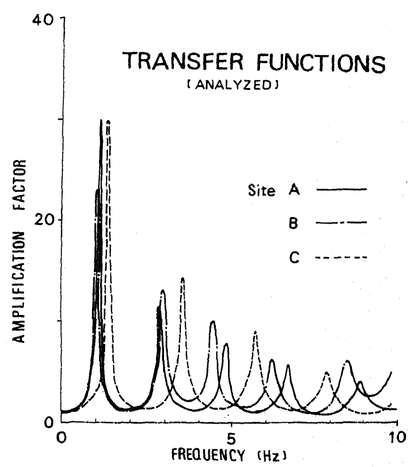

Fig.-6

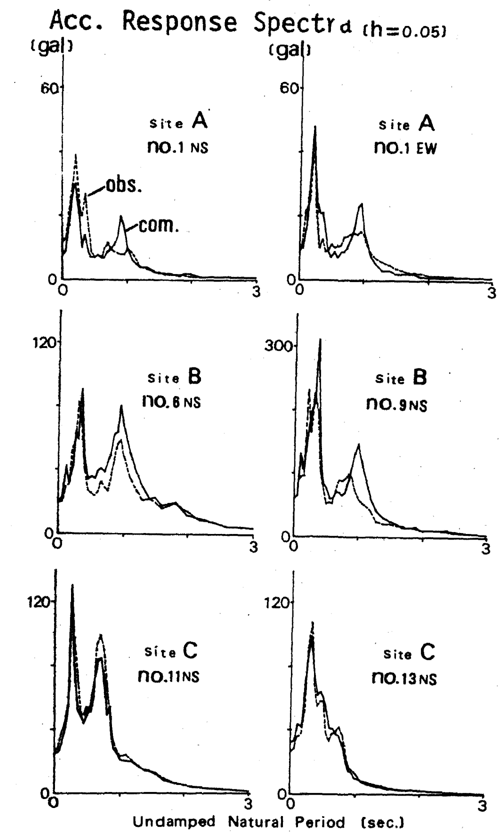

Fig.-9

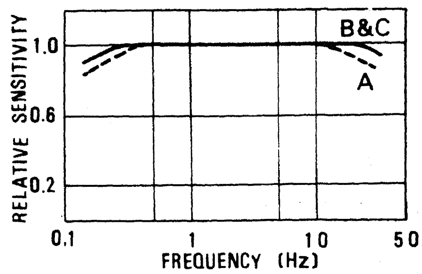

Fig.-2

Table-1

	Site A, Ohkurayama	Site B, Urayasu	Site C, Ohji
Term	Oct., 1971 to April, 1972	Nov., 1973 to Sep.,1974	Dec., 1974 to June, 1975
Seismograph	Moving Coil Type Natural Freq. 3Hz Flat Range 0.4-10Hz	Servo Type Natural Freq. 3Hz Flat Range 0.3-20Hz	
Recorder	Electro-Magnetic Oscillograph	Data Recorder	
Method of Digitization	Digitized by Tracer	Automatic Data Acquisition by A/D Converter and mini-Computer	
Correction	Corrected by Digital Filter		

Table-2

	Site	Date	Epicenter	Mag.	EPCTL. Dis. (Km)	Max.Acc. (gal)
1	A	Jan. 27,1972	Yamanashi Pref.	4.8	75	12.1
2	B	Nov. 19,1973	Off Miyagi Pref.	6.4	400	5.0
3	B	Dec. 27,1973	Off Hachijo Isl.	5.5	220	2.8
4	B	Jan. 27,1974	Off Chiba Pref.	4.9	100	6.7
5	B	Feb. 22,1974	Off Kii Pen.	6.9	370	11.8
6	B	Merch 3,1974	Off Chiba Pref.	6.1	100	19.5
7	B	May 9,1974	Off Izu Pen.	6.9	150	13.2
8	B	July 8,1974	Off Ibaraki Pref.	6.3	160	30.1
9	B	Aug. 4,1974	E. of Saitama Pref.	5.8	50	59.0
10	C	March 11,1975	Tochigi Pref.	5.1	90	7.2
11	C	March 30,1975	SW. of Ibaraki Pref.	5.4	60	31.4
12	C	April 2,1975	Near Hachijo Isl.	5.8	250	5.6
13	C	April 12,1975	SW. of Ibaraki Pref.	5.0	40	33.3
14	C	April 18,1975	ditto	5.0	40	31.4
15	C	April 21,1975	Off Ibaraki Pref.	4.8	130	4.3
16	C	May 4,1975	Off Fukushima Pref.	6.0	270	3.4
17	C	May 30,1975	S. Off Japan	6.2	370	4.2
18	C	June 12,1975	Sagami-bay	4.3	70	4.0
19	C	June 15,1975	E. Off Japan	5.9	350	3.7

Fig.-10

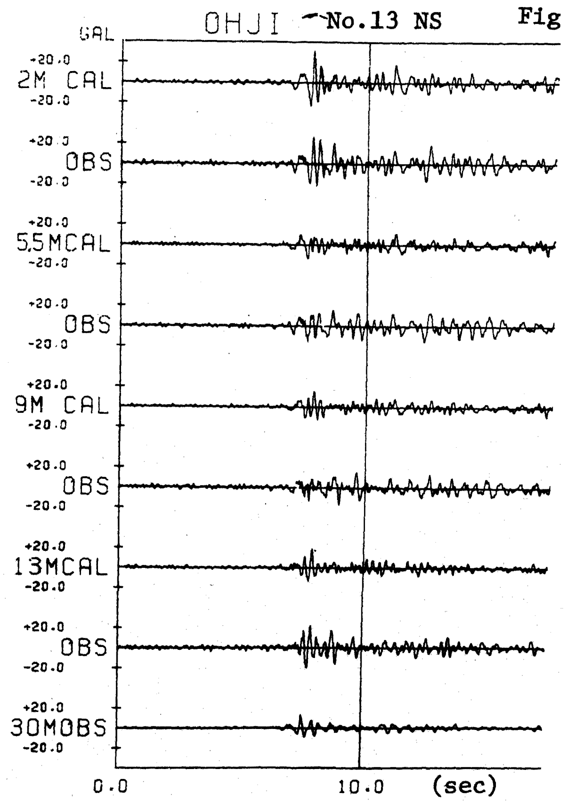

Table-3

	Fundamental	2nd	3rd	4th	5th
Site A	1.2	1.1	1.1	1.2	1.2
Site B	1.6	1.8	1.6	1.6	2.1
Site C	1.3	1.3	1.6	1.7	1.3

DISCUSSION

R. Guzman (U.S.A.)

Did you make comparisons of spectral response at various periods (other than just peak acceleration) ?

Author's Closure

With regard to the question of Mr. Guzman, we wish to state that we did not make any comparisons of spectral response other than peak acceleration.