IV. OBSERVATIONS OF DYNAMIC SOIL-STRUCTURE INTERACTION OF REINFORCED CONCRETE TOWER

by

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1. INTRODUCTION

It has been generally recognized that for better and more comprehensive understanding of the dynamic soil-structure interaction problem, it is necessary to accumulate observation data of the actual responses of buildings during real earthquakes. For this purpose, we have been recording continually time histories of earthquake response acceleration as well as soil pressure since August,1983. In two and half years, from August,1983 to December,1985, observation data for fifty earthquakes were recorded. Among them , records for the earthquake occured at 11:19:03 on March 6,1984 were reported in the reference [1].

This paper deals with the observation records for the earthquake occured in the southern part of Ibaragi Prefecture at 21:26:05 on October 4, 1985 (the Epicenter : Lat. 35 53'N., Long. 140 09'E., Epicentral Distance : 28 km, Focal Depth : 78 km and Magnitude : 6.0).

2. OBSERVATION SYSTEM

The observation system was constructed in Chiba Experiment Station attached to the Institute of Industrial Science, University of Tokyo. It consists of a reinforced concrete tower (Fig.1) with acceleration seismographs and soil pressure gauges, which will be referred to as 'Tower' hereafter, and Magnetic tape units to record the observed data.

The Tower is a building of five stories with a basement and is 12.5m in height as shown in Fig.2. Fig.3 gives the weight and the mass of each floor. Thirteen acceleration seismographs are set in the Tower and two at 1m and 40m underground at the position which is about 15m apart from the Tower, respectively. Their arrangement is shown in Fig.4. Each seismograph measures three components of acceleration in horizontal directions (X and Y directions) and in vertical direction (Z direction), respectively, at the same time. Fig.5 shows the arrangement of soil pressure gauges set on the walls and the floor slab. These soil pressure gauges can measure only normal soil pressures, of which values are not absolute, but relative to the average values of first ten seconds.

The magnetic tape units record the data of accelerations and soil pressures as digital signals in the sampling time interval of 0.005 second.

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The soil properties of the ground, on which the Tower is built, are given in Table 1. Fig.6 show the ratios of spectrum obtained by the acceleration records observed by acceleration seismograph No.14 (1m underground) to the spectrum of No.15 (40m underground) for five earthquakes. They indicate the vibration characteristic curves of the ground. According to Fig.6, the dominant frequencies of the horizontal vibrations of the ground are 2.5Hz, 5.5Hz and 9.0Hz.

3.TIME HISTORIES OF RESPONSE ACCELERATION AND MODE OF VIBRATION

Response accelerations were recorded for about 165 seconds from the starting time of measure (21:26:05). Figs.7 and 8 show the time histories of X and Z direction components, respectively, of the seismographs No.5, 7, 8, 13 and 14 for first 40.0 seconds. Hereafter X direction component of acceleration measured by seismograph, for example, No.5 will be refered to as '5X'.

For X direction, the accelerations are amplified as the heights of the measuring points, such that the maximum accelerations at 1m underground (14X) and the roof level of the Tower (5X) are about 80gal and 215gal, respectively. For Z direction, the height of the measuring points have no influence on the shape of wave of accelerations.

Figs.9 and 10 show the Fourier spectra of X and Z directions, respectively, which were calculated from the response accelerations for 10.0 seconds from 10.0 second to 20.0 and smoothed with the Hanning window (1 cycle).For X direction, it is understood that the dominant frequencies of 14X are 2.5Hz and 5.5Hz. By the response acceleration spectra measured on the Tower (5X, 7X, 8X and 13X), 3.3Hz is a dominant frequency except 2.5Hz and 5.5Hz. Especially, 3.3Hz is the most dominant frequency at the roof level (5X). So it can be understood that 3.3Hz is one of the natural frequencies of the Tower.

To explain the mode of vibration for each dominant frequency, the relations between the Fourier amplitudes for each dominant frequency and the height of the measuring points for X and Y directions are shown in Figs.11 and 12, respectively. As the results show the linear relations, it is understood that the Tower is rotated as a rigid body. Especially, the natural frequencies of the rocking vibrations of the Tower are 3.3Hz and 3.1Hz for X and Y directions, respectively, and the centers of the rocking are almost on the level of B1F for both directions.

4.RELATIONS OF SOIL PRESSURE AND DISPLACEMENT

Fig.13 shows the time histories of soil pressure measured by the soil pressure gauges of No.1, 4, 6, 8 and 11. Soil pressure gauges No.1 and 11 is set on the wall of the basement, and No.4, 6 and 8 the base of the Tower, respectively.

From these data, we find that firstly the negative wave crest is leveled up, this phenomenon means that the Tower separated from the ground, secondly, the values of the soil pressures, measured by the soil pressure gauges No.1 and 11, shift

positively, and those by No.4, 6 and 8 shift negatively, when the amplitude become large. This phenomenon can be explained as follows:
1) With the rocking vibration of the Tower, the ground around the Tower is thrust aside and the restraint force for the Tower by the ground falls off, 2) The friction force between the Tower and the ground decrease, too, and 3) A part of the weight of the Tower become to be supported by the normal force acted upon the base slab, which supported by the friction force since then.

And provided that the friction force between the Tower and the ground was null after shifting the soil pressures, the ground had supported about 10ton of the Tower by the friction force before shifting.

Fig.14 shows the relations between displacement and soil pressure by the soil pressure gauges of No.1 and 5. We calculated the displacements by integrating the observed acceleration twice, on the assumption that the centers of rocking vibration of the Tower is on the B1F level, and that the absolute displacement of the ground around the Tower is equal to that of the acceleration seismograph No.13. The relations of them before and after shifting of the soil pressure are expressed as full lines, and broken lines, respectively. With these figures, the apparent stiffness of the ground observed by the soil pressure gauge of No.1 decreases much after shifting the soil pressure, but the soil pressure No.5 does not show a sharp change.

Fig.15 shows the comparisons of the spectral ratios of 5X (resp. 5Y) for 14X (resp. 14Y). With these figures, it is found that the natural frequencies of the vibration of the Tower decrease a little after shifting the soil pressures. This phenomenon must be caused by the decrease of the friction force of the ground around the Tower.

5.CONCLUSION

The present paper gives an outline of the response observation of the reinforced concrete tower during the earthquake occured on October 4, 1985. And the results are summarized as follows:
1) The vibration of the Tower is mainly rocking vibration,
2) The negative wave crest of the observed soil pressure is leveled up. And this expresses the separation of the Tower from the ground, and
3) With the rocking vibration of the Tower, the ground around the Tower is thrust aside. Then, the supporting forces by the surrounding ground decrease, which results in the decrease of the natural frequency of the Tower.

ACKNOWLEDGMENTS

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REFERENCE

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2) Y.Hangai, F.Tatsuoka and N.Sato : " Observation of Soil-Structure Interaction of Towered Structure," SEISAN-KENKYU, Vol.35, NO.9, Sept. 1983, pp.35-38.

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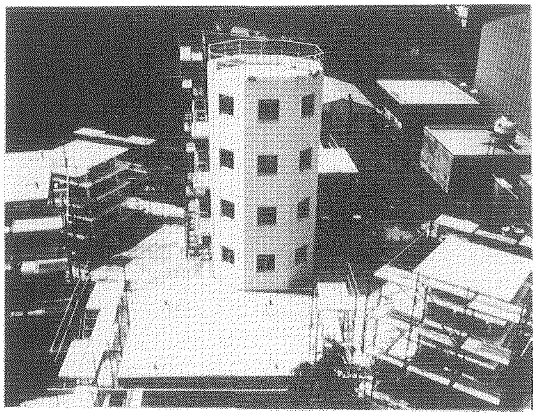


Fig.1 : Bird-View of Observation Tower

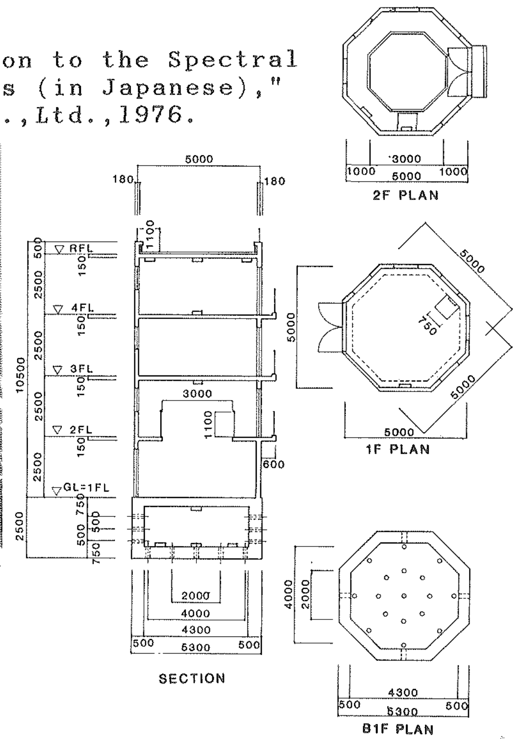


Fig.2 : Plans and Section of Observation Tower

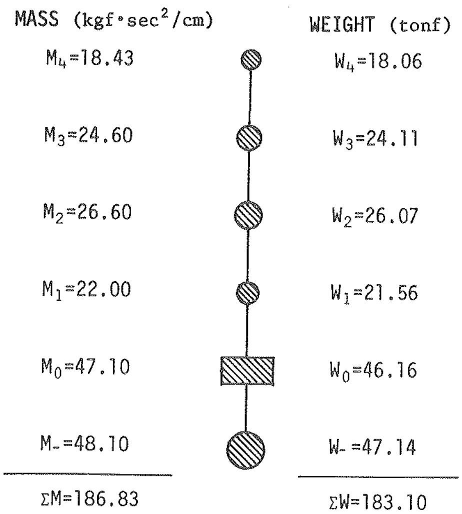


Fig.3 : Mass and Weight of Each Floor

Table 1 : Soil Properties

Depth	Name of Soil	Vs
0.0	Loam	140
	Volcanic Ash Cray	
10.0 20.0		320
30.0 40.0	Sand	420

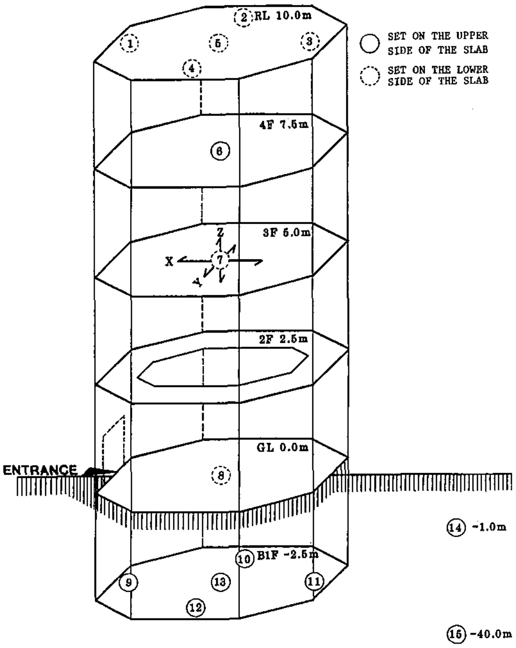


Fig.4 : Arrangement of Acceleration Seismographs

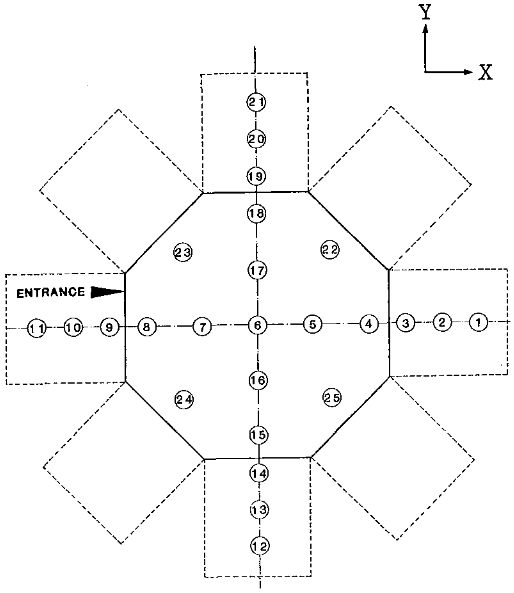


Fig.5 : Arrangement of Soil Pressure Gauges

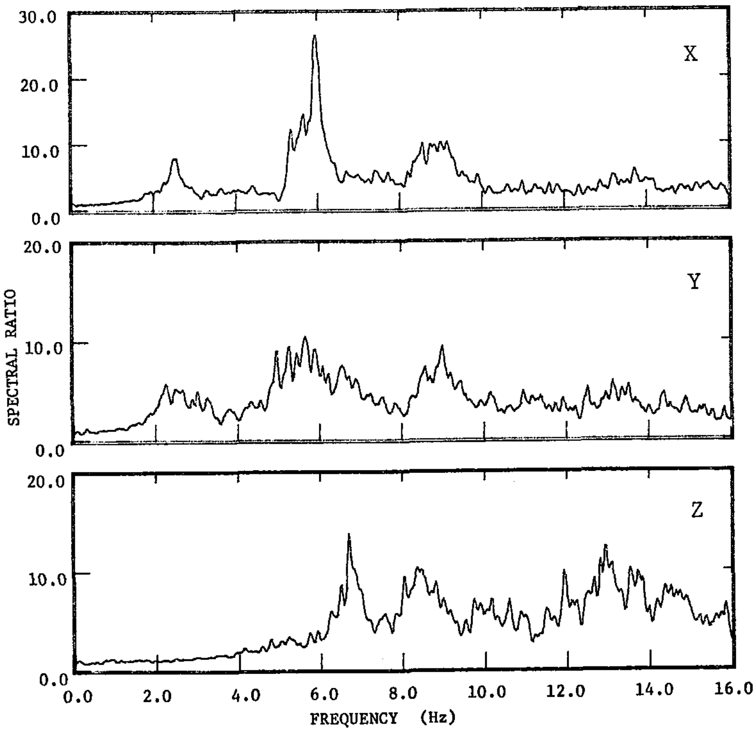


Fig.6 : Vibration Characteristic Curves of the Ground

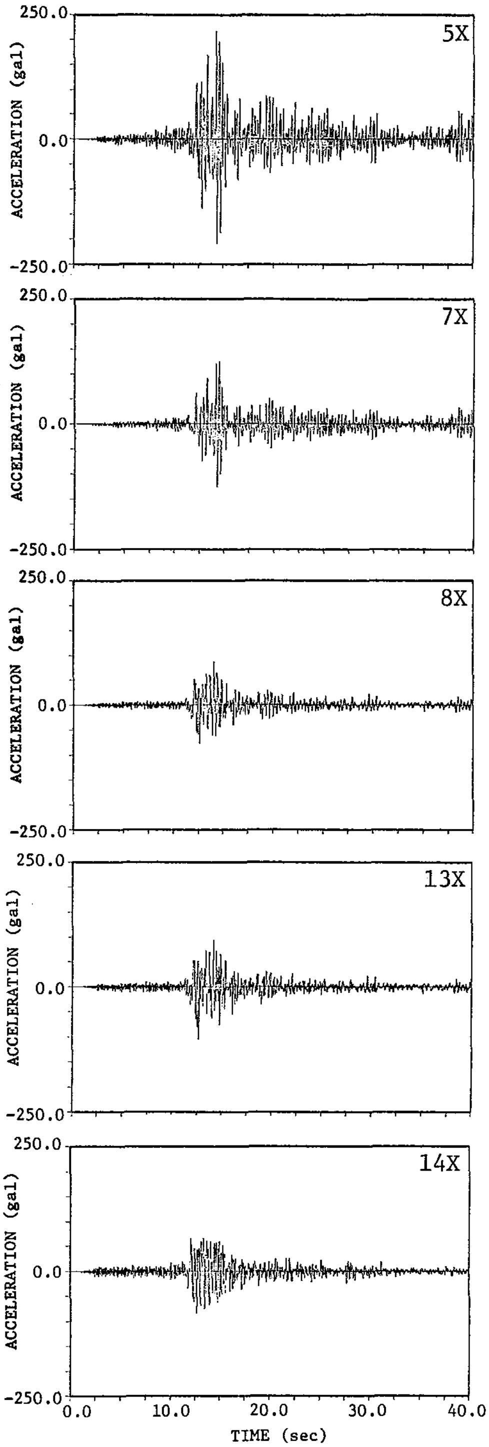


Fig.7 : Time Histories of Acceleration (X direction)

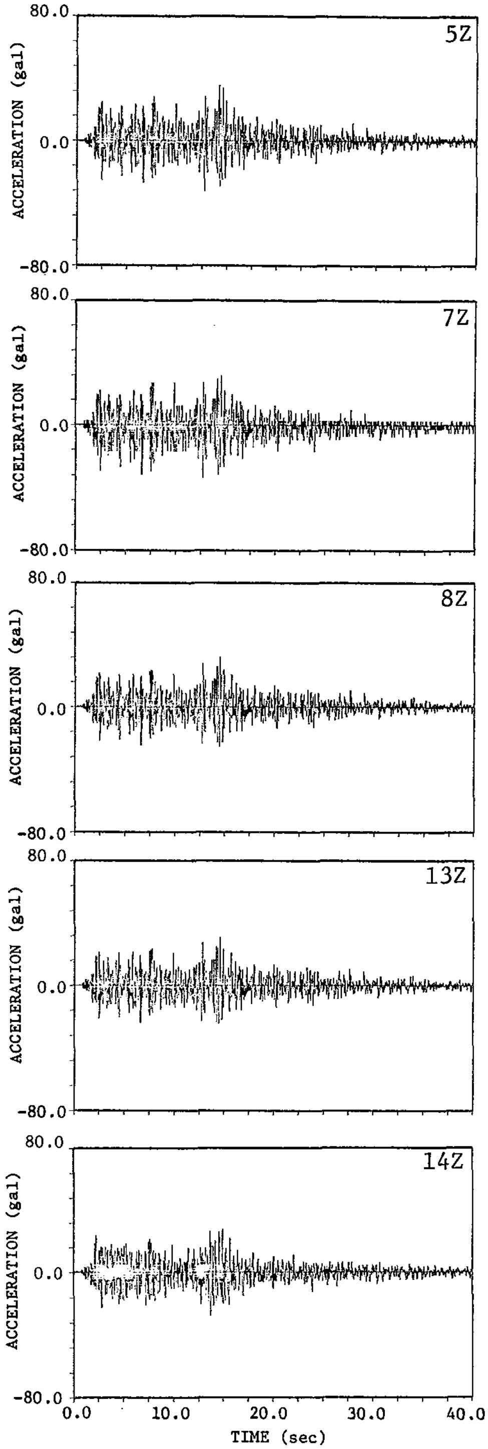


Fig.8 : Time Histories of Acceleration (Z direction)

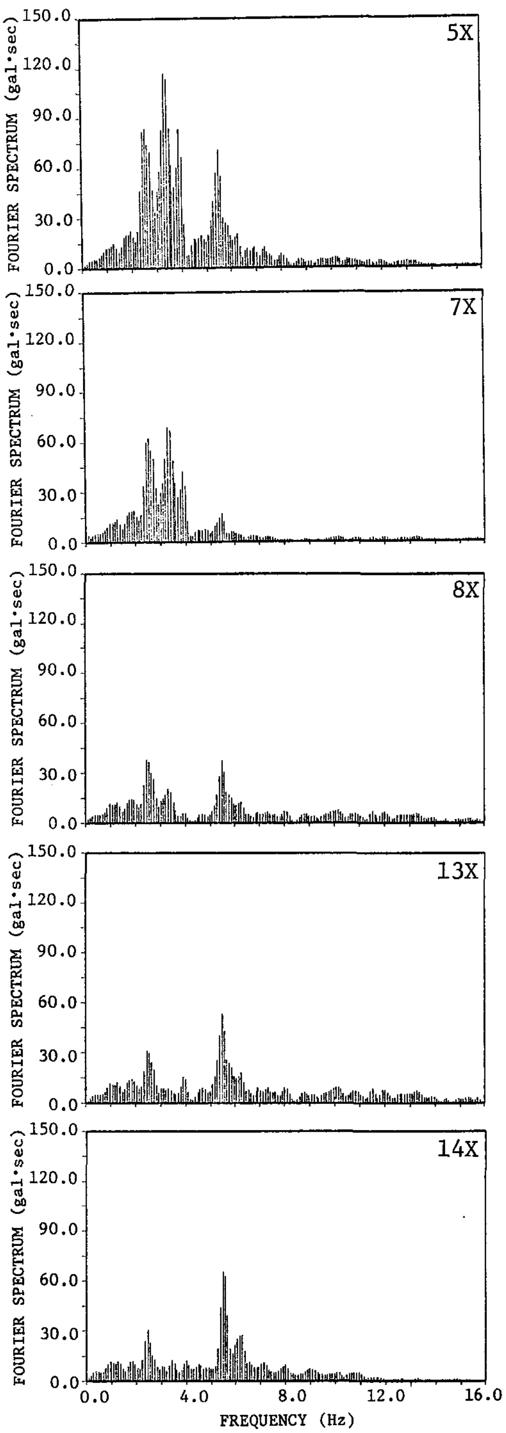


Fig.9 : Response Spectra of Acceleration (X direction)

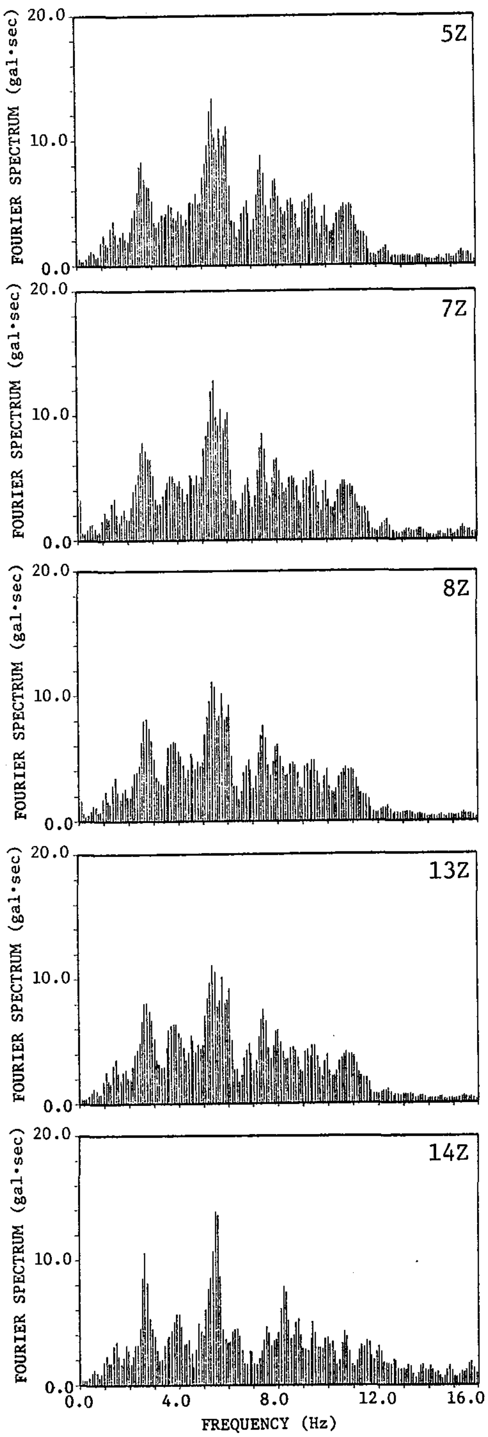


Fig.10 : Response Spectra of Acceleration (Z direction)

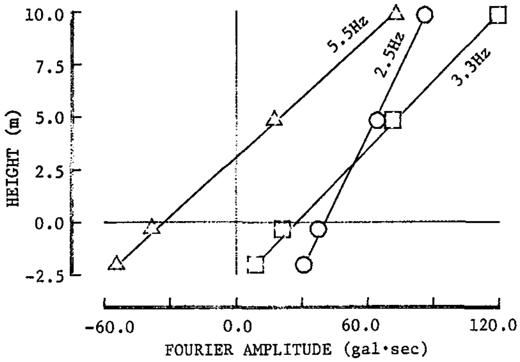


Fig.11 : Relations between Fourier Amplitudes of Dominant Frequencies and Measuring Points' Height
(X direction)

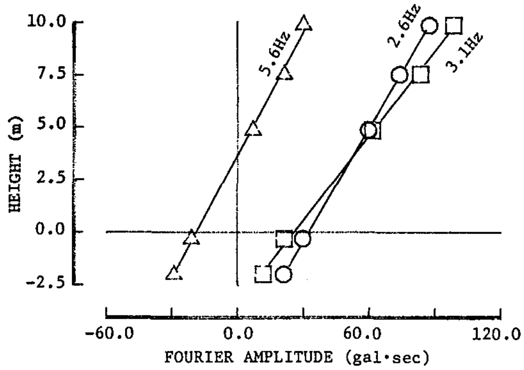
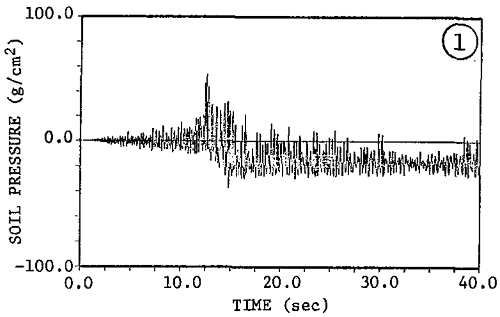
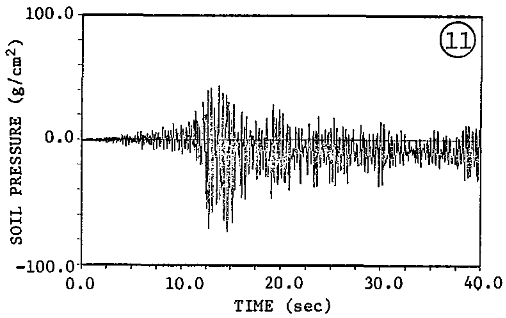
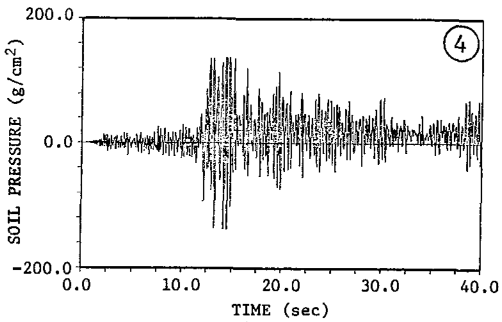
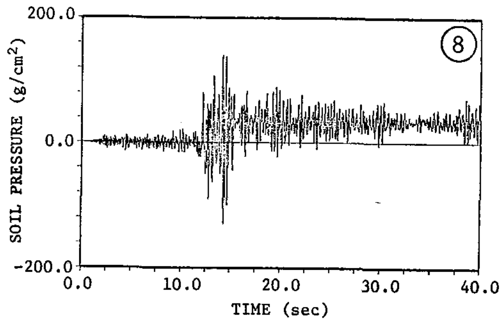


Fig.12 : Relations between Fourier Amplitudes of Dominant Frequencies and Measuring Points' Height
(Y direction)









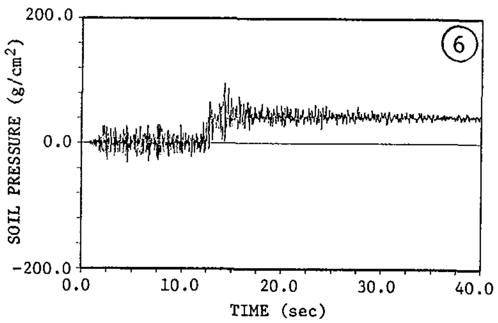


Fig.13 : Time Histories of Soil Pressure (X direction)

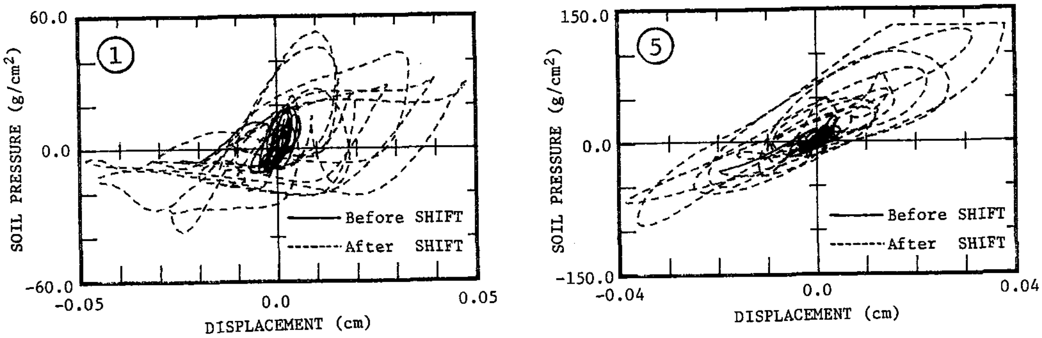


Fig.14 : Soil Pressure - Displacement Relationss

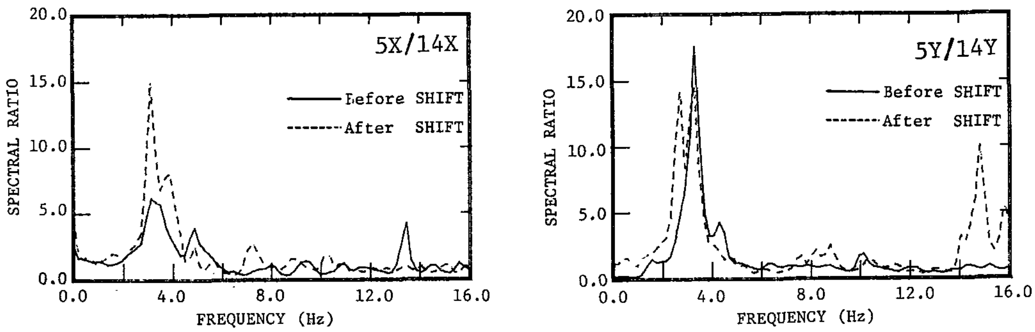


Fig.15 : Spectral Ratios before and after the Shift of Soil Pressure