RESPONSE OBSERVATIONS
OF
A REINFORCED CONCRETE TOWER

by

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1.INTRODUCTION

On the study of earthquake responses of structures, dynamic interaction between soil and structure has to be considered. The problem on this field is, however, so complex and so difficult that many studies have continued to explain it theoretically. And a great help in attacking the problem is to present precise data by actual measurements to be compared with analytical results and to observe behaviours of structures during real earthquakes.

For this purpose, we have been recording continually time histories of earthquake response acceleration and soil pressure since August,1983. In a year and a half, from August,1983 till January,1985, data for forty-seven earthquakes were recorded (See Table 1). Among these data, on this paper, we report on the data for a relatively intense earthquake occured at 11:19:03 on March 6th, 1984 (the Epicenter : Lat.29° 28'N., Long.138°9'E., 460km underground ; Hypocentral distance : 692km ; Magnitude : 7.9).

2.REINFORCED CONCRETE TOWER FOR RESPONSE OBSERVATIONS[1]

A reinforced concrete tower with a basement,which will be referred to as 'Tower' hereafter, was built in the Chiba Experiment Station attached to the Institute of Industrial Science, University of Tokyo in April,1983. Fig.1 shows the appearance of the Tower and Figs.2 and 3 give the plan and the section with measurement positions of soil pressure, and the weight of each floor, respectively. Fig.4 gives the soil properties and Table 2 shows the results of the plate loading test, carried out at the base level of 2.5m underground.[2]

3.TIME HISTORY AND SPECTRAL ANALYSIS OF RESPONSE ACCELERATION

Thirteen acceleration seismographs are set in the Tower, and each seismograph measures three components of acceleration (X, Y and Z direction) every 1/200 second (X and Y are the horizontal directions and Z is the vertical direction, as shown in Fig.5). Two seismographs are set at 1m and 40m underground at the position which is about 15m apart from the Tower to measure the acceleration of the ground. Fig.6 shows

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the maximum acceleration measured by the each seismograph.

Response accelerations were recorded for 304.75 seconds from the measure starting time (11:19:03) and Fig.7 shows examples of the full time histories of X direction component by seismographs No.1 and 15 (hereafter referred to as 1X, 15X and so). Figs.8 and 9 represent the time histories of X and Z direction components the seismographs No.1, 5, 9, 13 and 15, for 40 seconds from 65.0 second to 105.0 second.

With respect to X direction, 15X at 40m underground shows relatively smooth wave shape, and the amplitude is small. 9X, 13X at B1 floor level are amplified a little, and the wave shapes are disturbed, and 1X, 5X at roof level are amplified moreover. The wave shapes by seismographs on the same floor level are almost the same each other. About the Z direction, 5Z and 13Z along the center axis of the Tower are almost similar wave shapes. 1Z and 9Z are amplified and their wave shapes are different with 5Z and 13Z, respectively. This phenomenon may be caused by the vertical movement at the edge of the floor, which is due to the rocking of the Tower. This will be made sure by the spectral analysis in the following.

Acceleration response spectra were calculated by the Fourier spectral analysis for the response acceleration for 40 seconds, from 65.0 second to 105.0 second.[3] The spectrum from 0.0Hz to 100.0Hz can be obtained because measuring time interval is 1/200 second. But, in this paper, we only consider the spectrum from 0.0Hz to 10.0Hz because the important spectrum exists in this range. Figs.10 and 11 show the Fourier spectra of X direction and Z direction, respectively.

Characteristics of these spectra are as follows:

(1) X direction (Fig.10)

1X and 5X show almost similar spectra, and the spectra around 3.5Hz are predominant. When the spectra of 7X, 8X, 9X and 13X are compared with those of 1X and 5X, we can recognize that the spectra around 3.5Hz decreased as the height of the acceleration measuring points from the ground level decrease, and in other hand, the spectra for other frequencies do not change. As the results of decreasing, it cannot be recognized that the spectra around 3.5Hz are predominant for 9X and 13X. Fig.12 shows the relation between the height of measuring points and the maximum Fourier amplitudes around 3.5Hz, and this relation is almost linear, which leads to the fact that the frequency around 3.5Hz must be due to the rocking of the Tower. The computed values of frequency for the rocking of the Tower are 2.30Hz, 3.01Hz and 3.38Hz by three kinds of assumptions that (a) Disregard of the effect of the interaction between wall of the basement and soil, and the center of rocking is on B1 floor level, (b) Disregard of the effect of the interaction between wall of the basement and soil, and the center of rocking is on the ground level[4] and (c) Regard of the effect of the interaction between wall of the basement and soil, and the center of rocking is on the ground level,[5] respectively.

(2) Z direction (Fig.11)

Let us compare the spectra of 1Z and 9Z with 5Z and 13Z, respectively, because they show very different wave shapes each other. The spectra of 1Z and 9Z are predominant around

3.5Hz, which may be the natural frequency of the rocking of the Tower. In the other hand, the spectra of 5Z and 13Z are approximately obtained by deleting of the spectra around 3.5Hz from 1Z and 9Z, respectively (See Figs.13 and 14). The phases of the vertical vibrations of 1Z and 3Z around 3.5Hz have the inverse relations and the spectrum of the average wave of 1Z and 3Z are almost similar with 5Z. This is proved by comparing the spectrum of 5Z with (1Z+3Z)/2 as shown in Fig.15. Then, it is recognized that the frequency around 3.5Hz is due to the rocking of the Tower. The wave shapes and the spectra of the acceleration, measured along the center axis of the Tower, are not influenced by the height of the measuring point. Namely, it can be understood that the Tower moves vertically as a rigid body.

4.TIME HISTORY AND SPECTRAL ANALYSIS OF RESPONSE SOIL PRESSURE

Thirteen soil pressure gauges are set on the base slab, and twelve ones on the wall of the basement (See Fig.16). Fig.17 shows the time histories of the soil pressure measured at the points 1, 3, 4, 6, 8, 9 and 11. However, the values of the soil pressure in this figure are not absolute, but the relative to the average value of first ten seconds. The wave shapes of the soil pressure, measured at the points 1 and 3, are biased, by which a contact problem between structure and soil may be imagined. The waves of the soil pressure, measured at the points 4, 6 and 8 (i.e. on the base slab), are biased in the plus direction along the time history, which is well shown in Fig.18. Fig.19 show the spectra of the soil pressure, measured at the points 1, 4, 6 and 11. The soil pressure are also influenced by the rocking of the Tower, except the soil pressure on the point 6 which is the center of the Tower.

5.CONCLUSION

The present paper gives an introduction of the response observations of a reinforced concrete tower during real earthquakes, started from August,1983. Though data for forty-seven earthquakes have been obtained so far, the time histories and spectral analysis of response acceleration as well as response soil pressure for only one earthquake in March 6,1984 was described in the paper. Time histories of soil pressure indicate an important respect about the contact problem between structure and soil.

ACKNOWLEDGMENTS

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REFERENCE

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2) N.Sato and T.Katayama : " Observation of Earthquake Ground Motions and Strains," SEISAN-KENKYU, Vol.35, No.9, Sept. 1983, pp.22-26.

3) Y.Ohsaki : " An Introduction to the Spectral Analysis of Earthquake Motions (in Japanese)," Kajima Institute Publishing Co.,Ltd.,1976.

4) "Dynamic Interaction between Soil and Structure," edited by JSSMFE, 1983.

5) N.Yoshida,I.Suizu and Y.Fujitani : "Seismic Response Characteristics of Structures with a Rigid Embedded Foundation," Proc. of the Annual Convention of AIJ, Sept. 1983, pp.823-826.

Table 1 : List of Observed Earthquakes

Year	Month	Day	H	M	S	Year	Month	Day	H	M	S
1983	8	10	1	52	03	1984	6	30	2	45	52
		14	15	02	22			30	12	13	27
		17	14	00	58		9	14	8	49	33
	9	2	12	06	26			15	7	15	44
		11	0	25	23			19	2	03	32
	10	28	10	50	47		10	1	18	27	50
	11	10	13	45	44			17	17	14	09
		22	15	56	06		11	2	17	45	25
	12	17	9	11	34			3	14	02	55
		30	11	30	53		12	7	10	56	09
		30	13	59	28			11	14	58	07
1984	1	1	18	04	47			12	10	18	29
		17	20	14	16			13	13	40	53
		18	0	32	32			14	14	13	47
	2	14	1	53	18			14	15	53	49
		21	20	52	17			17	10	59	08
	3	6	11	19	03			17	23	49	59
		6	11	25	30			19	4	36	23
	4	2	4	02	31	1985	1	7	7	08	55
		24	13	13	54			12	10	31	05
	5	7	18	26	09			17	13	18	36
		23	7	38	37			17	13	28	17
		30	7	58	53			17	14	18	09
								27	10	38	32

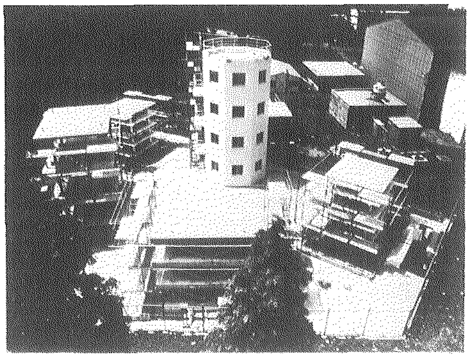


Fig.1 : Bird-View of Observation Tower

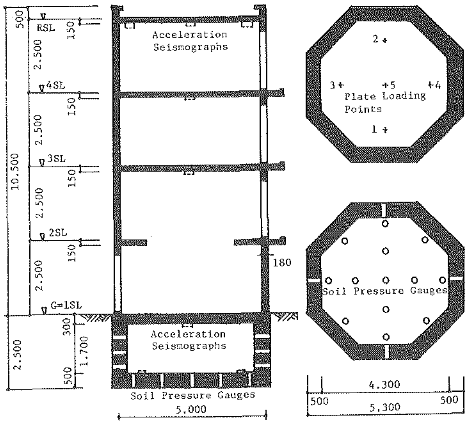


Fig.2 : Plan, Section and Points for Plate Loading Test

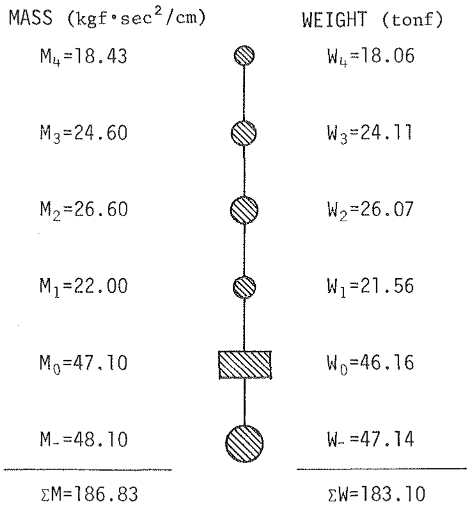


Fig.3 : Mass and Weight of Each Floor

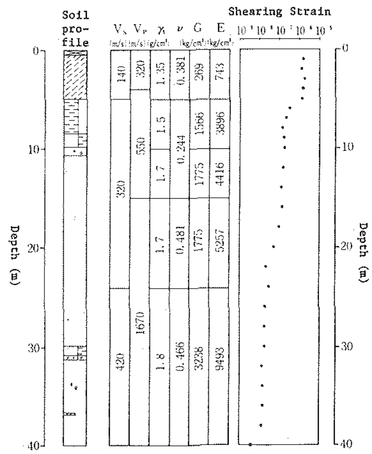


Fig.4 : Soil Properties

Table 2 : Modulus of Deformation and Modulus of Elasticity

Point	Modulus of Deformation *D* (kgf/cm²)	Tangential Modulus of Elasticity *Et* (kgf/cm²)	Secant Modulus of Elasticity *Es* (kgf/cm²)
No.1	261	300	303
No.2	163	228	206
No.3	171	244	214
No.4	209	277	236
No.5	266	288	249
Average	214	267	242

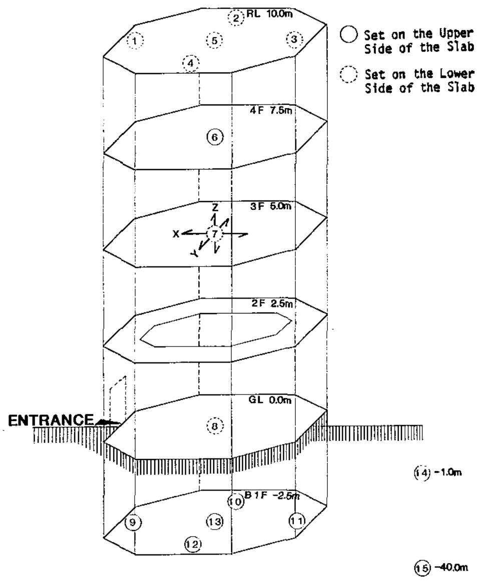


Fig.5 : Arrangement of Acceleraion Seismographs

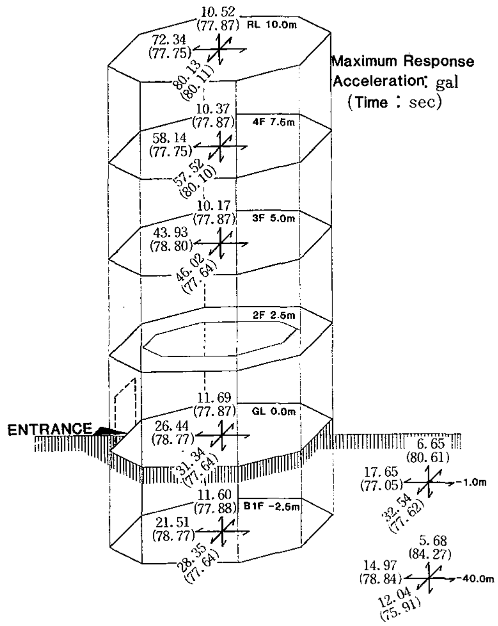
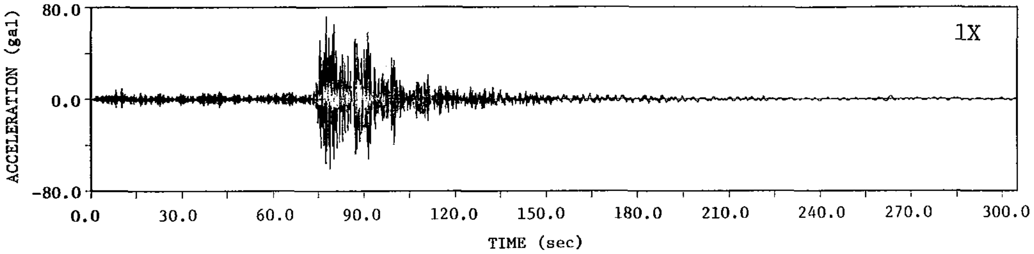


Fig.6 : Maximum Response Acceleration



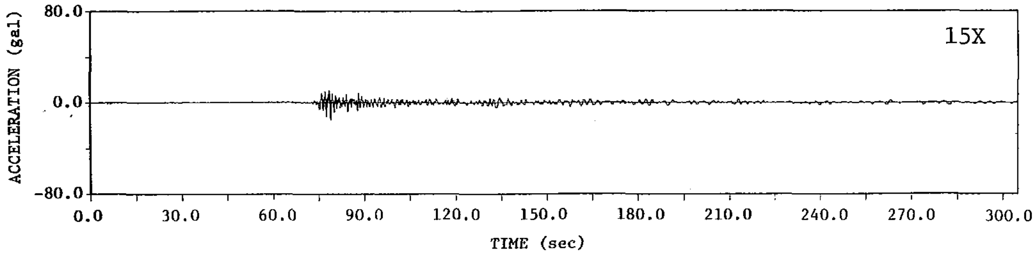


Fig.7 : Full Time Histories of Acceleration (1X,15X)

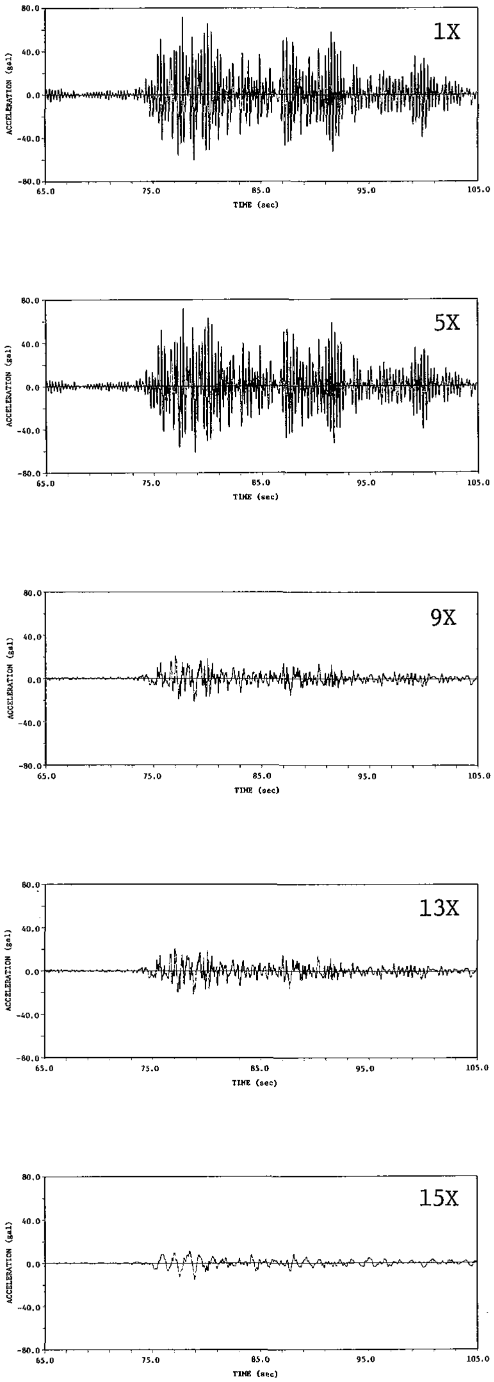


Fig.8 : Time Histories of Acceleration (X direction)

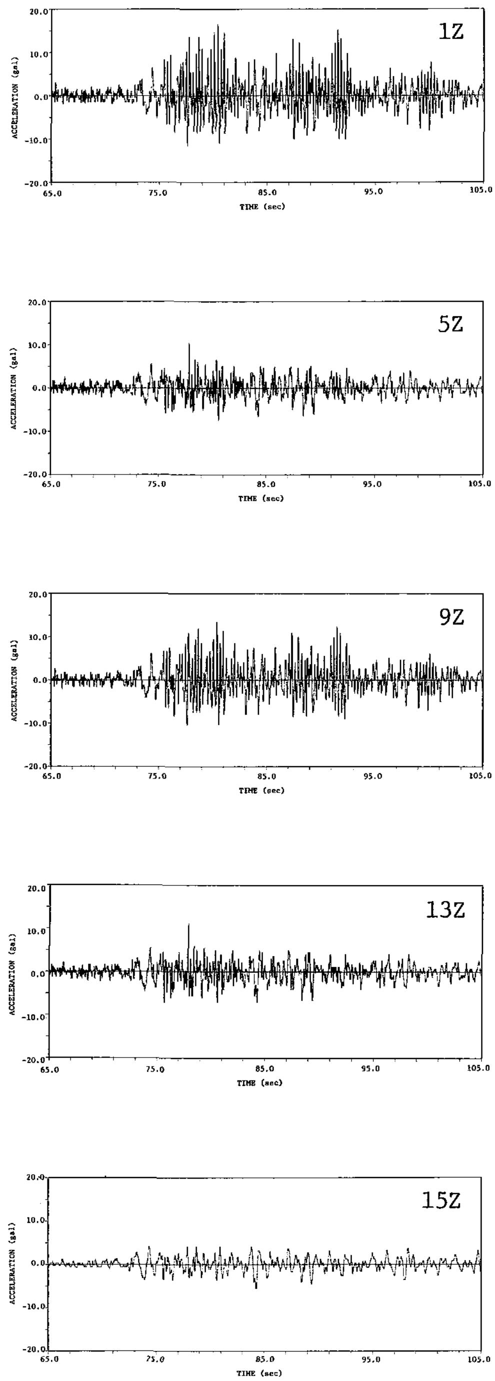
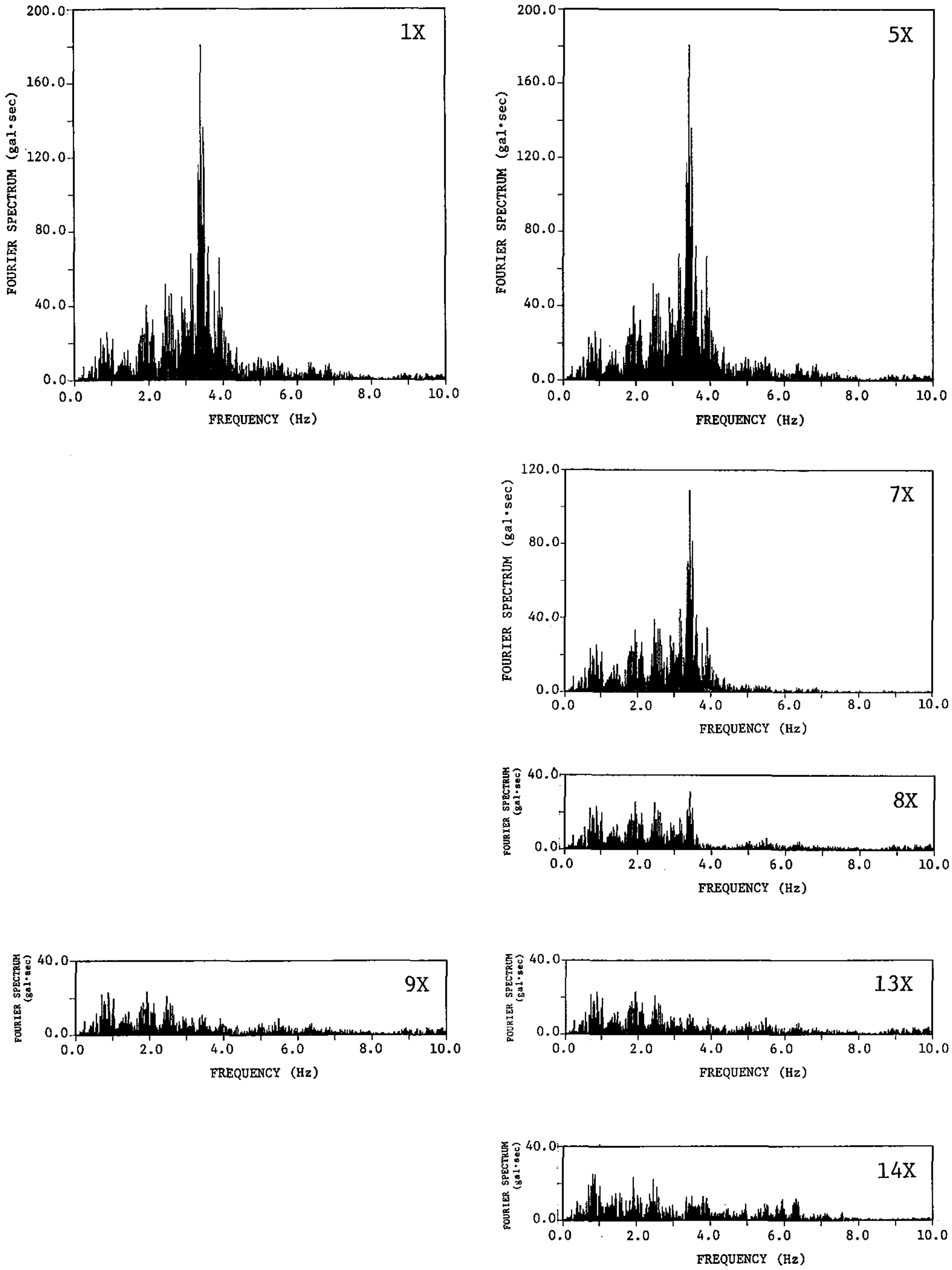


Fig.9 : Time Histories of Acceleration (Z direction)



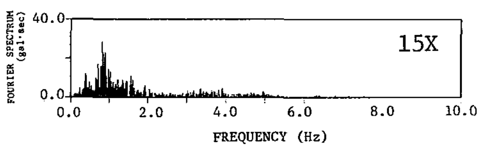


Fig.10 : Response Spectra of Acceleration (X direction)

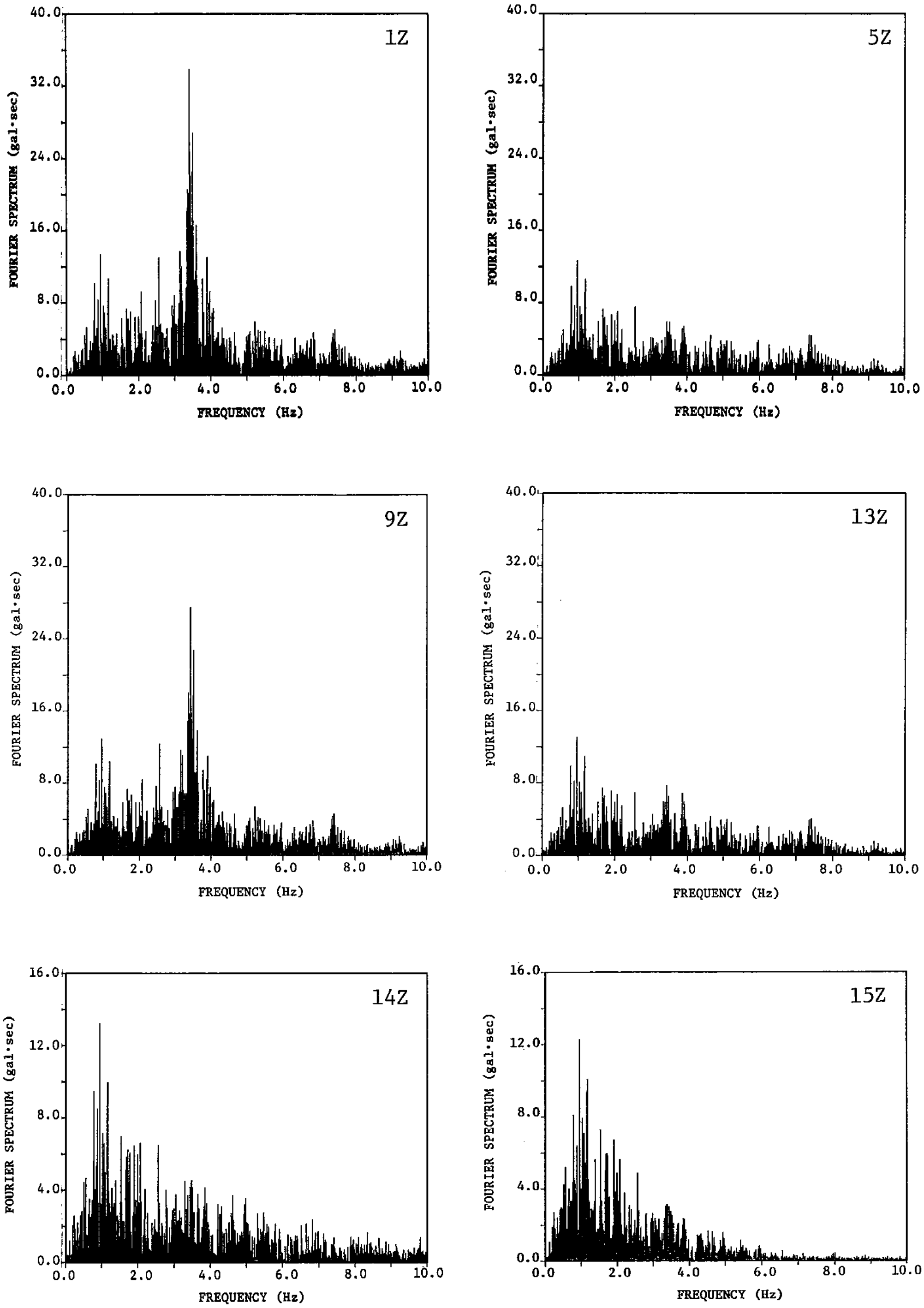


Fig.11 : Response Spectra of Acceleration (Z direction)

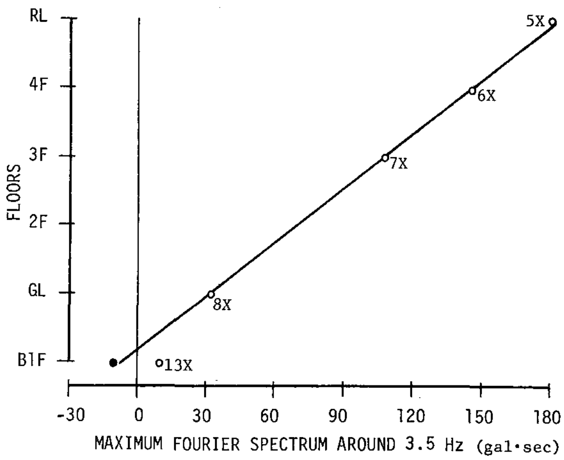


Fig.12 : Influence of Measuring Points' Height on the Maximum Fourier Amplitudes around 3.5Hz

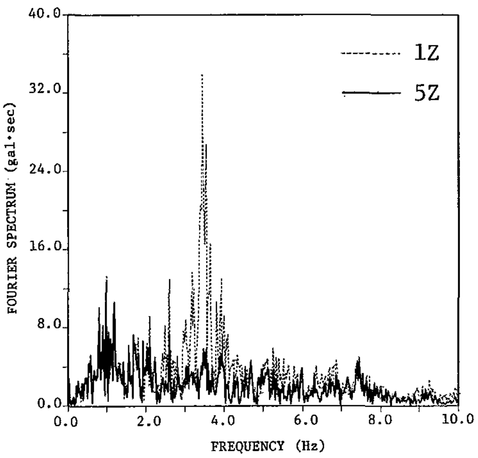


Fig.13 : Comparison of Spectra between 1Z and 5Z

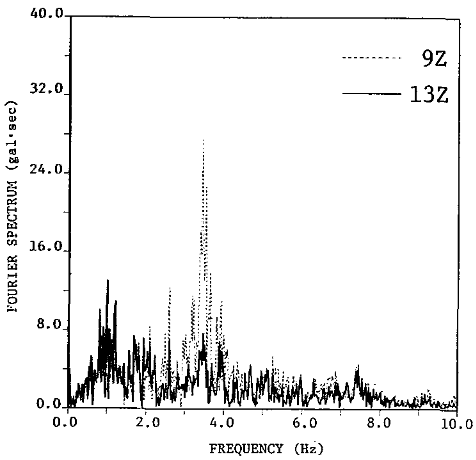
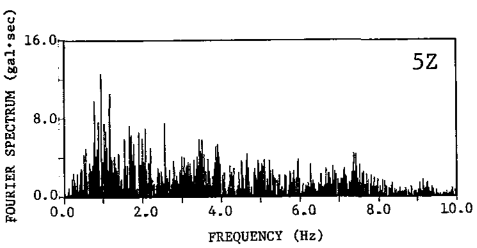


Fig.14 : Comparison of Spectra between 9Z and 13Z



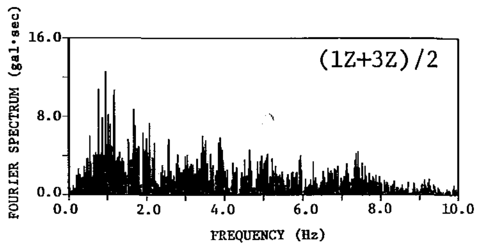


Fig.15 : Comparison of Spectra between 5Z and (1Z+3Z)/2

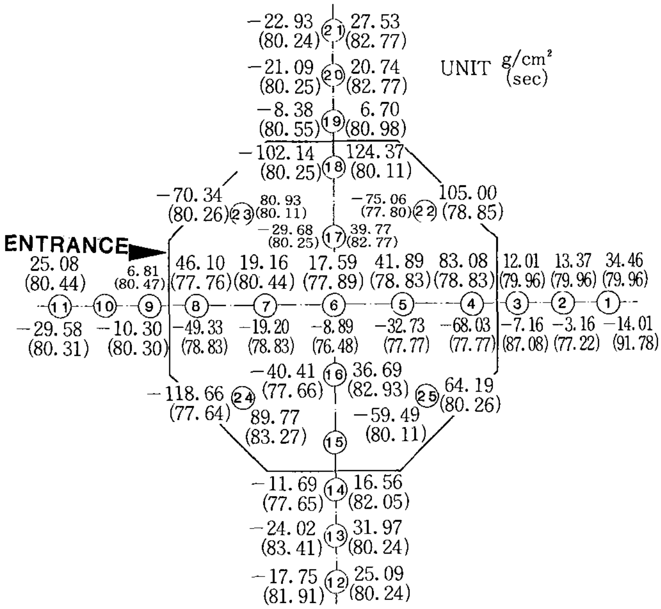


Fig.16 : Arrangement of Soil Pressure Gauges and Maximum Soil Pressure

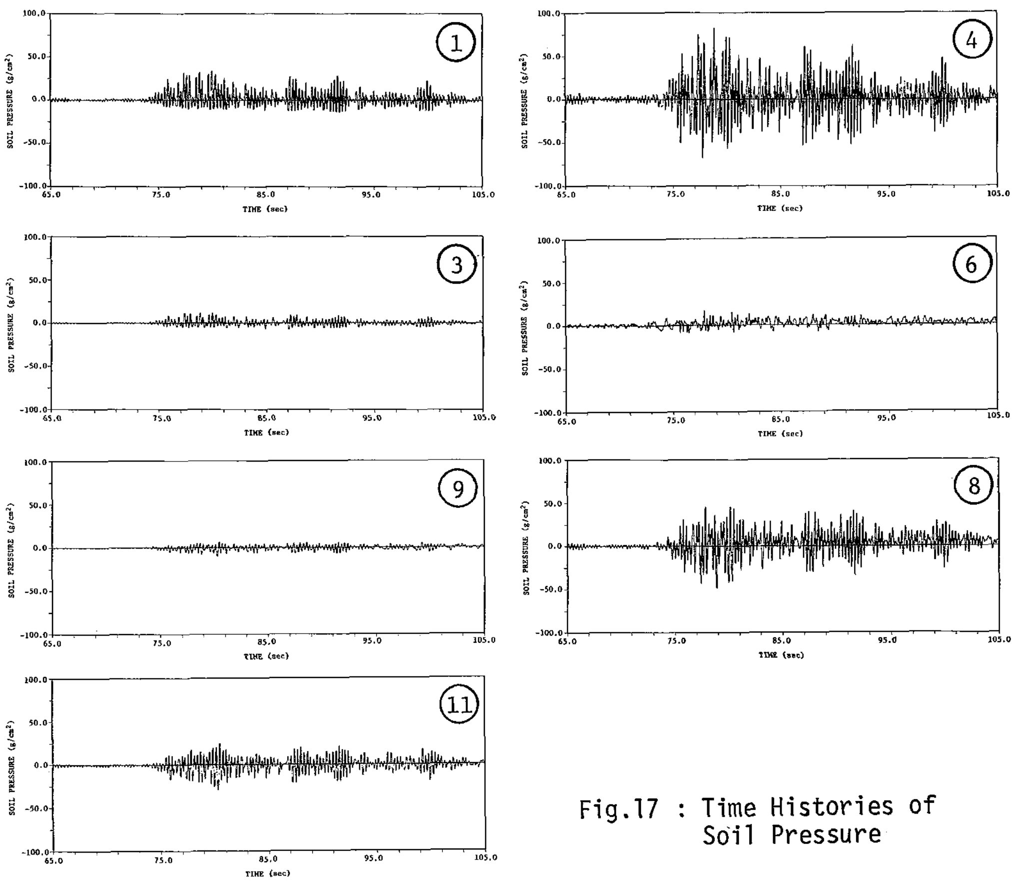


Fig.17 : Time Histories of Soil Pressure

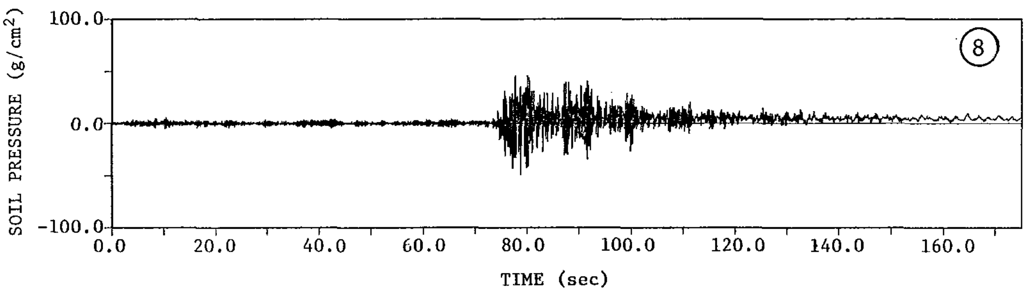


Fig.18 : Full Time History of Soil Pressure (Measuring Point No.8)

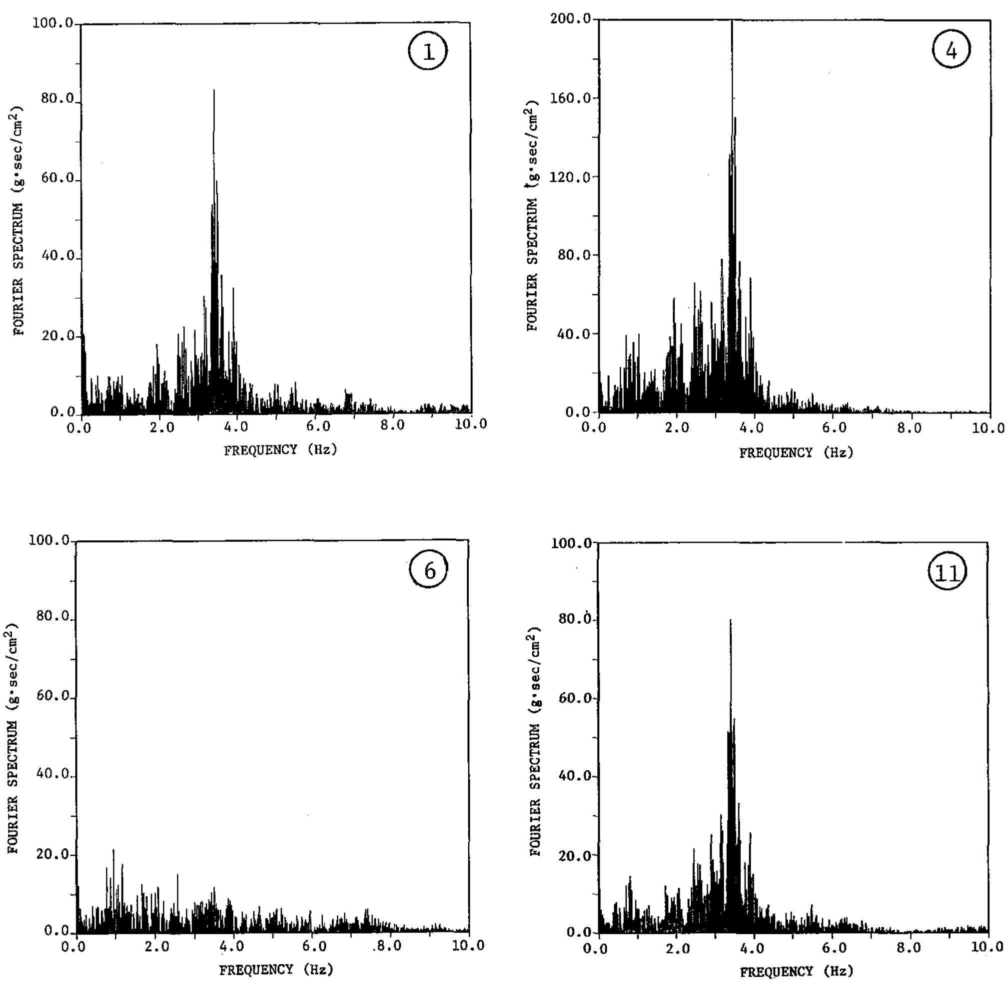


Fig.19 : Response Spectra of Soil Pressure