EARTHQUAKE OBSERVATION IN AND AROUND A STEEL FRAME APARTMENT HOUSE WITH PRECAST CONCRETE PANEL

by

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SUMMARY

The behaviour of buildings and soil under actual earthquakes is a significant concern in the field of earthquake engineering. Since 1970 has been carried out the long term earthquake observation in an existing building and its surrounding subsoil. More than seventy sets of acceleration records have been stored up until 1979. In this investigation, the behaviour and characteristics of the soil-structure system under earthquakes were examined in statistic terms and were compared with the results of the forced vibration tests and with the results of two analytical models idealized by a dynamical ground compliance theory and a finite element method.

INTRODUCTION

Recently in Japan steel frame apartment houses with precast concrete wall panels have been constructed. Authors have continued a series of experimental and analytical investigations on the seismic capacities of this type of buildings [1,2,3]. As a part of them, the forced vibration tests and microtremors observation were carried out on the existing sample building located at Kimitsu-city in Chiba Prefecture on the coast of Tokyo Bay. The earthquake observation in the building and its surrounding subsoil followed them to reexamine the interesting behaviour of the building observed on the tests.

More than seventy sets of acceleration records have been stored up on the 1970-1979 observation. Twenty-five sets of accelerograms have been digitized by reason of relatively large amplitude and complete or nearly complete sets. The number of these data encouraged authors to examine the behaviour of the building and soil and to evaluate the characteristics of soil-structure system, especially in statistic terms.

The main purpose of the present paper is firstly to make clear the dynamic behaviour of the building and its surrounding subsoil under actual earthquakes, secondly to evaluate the dynamic characteristics of the building, subsoil and soil-structure system by obtaining transfer functions, thirdly to compare the characteristics obtained with the forced vibration test results, and finally to pursue an analytically appropriate model.

OUTLINE OF BUILDING, SUBSOIL AND MEASUREMENT SYSTEM

Building and Subsoil

The biulding is an eleven-story steel frame structure with fireproof covering of concrete, and is 8.5m x 92.7m in plan and 29.6m high as shown in

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Fig.1. The subsoil profile and penetration test results are shown also in Fig.1. The building is supported by steel piles reaching the sand layer with the penetration resistance of N-value > 50 about 12m below the ground level.

Results of Forced Vibration Tests

The results of the forced vibration tests are tabulated in Table 1. In the transverse direction the rocking and swaying displacement components, the torsional mode and the mode associated with the horizontal slab deformation (the slab deformation mode) are measured. In the longitudinal direction the swaying displacement component is measured while the rocking component is very small.

Measurement System

Sixteen sets of the electro-magnetic seismometers are installed to measure the earthquake accelerations under, around and inside the building as shown in Fig.1. In this paper the location and direction of earthquake records are denoted by the corresponding notations in Fig.1. The location of the instruments inside the building is designed to measure the torsional and slab deformation modes, earthquake input modes at the base and rocking displacements as well as translational vibration.

OBSERVED EARTHQUAKES

During 10 years from 1970 to 1979, more than seventy sets of earthquake records have been obtained. The epicenters of fifty earthquakes observed until 1976 are shown in Fig.2(a) and (b). Digitized sixteen sets of accelerograms are used for analyses in this investigation and tabulated in Table 2.

Although obtained at same site, considerable amount of variation is seen in the ground motion spectra as shown in Fig.3(a). Fig.3(b) represents the average spectrum and its standard deviation for these spectra, where each spectra are normarized by their R.M.S. values so as to remove the difference in amplitude level among earthquake records. Smaller variation is seen in the spectral ratios shown in Fig.3(c).

RESULTS OF OBSERVATION

Behaviour and Characteristics of System

Fig.4(a) shows NE11, NC11 and NW11 denoting the average spectra of the N-S direction and the east, central and west location in eleventh floor, respectively, and Fig.4(b) shows UDR denoting the average spectrum of rocking displacement component of the eleventh floor converted from the vertical displacements at the north and south locations of the base. It is seen in these figures that in the transverse direction the rocking component, the torsional mode and the slab deformation mode are apparently observed during actual earthquakes as well as on the forced vibration tests. The dynamic characteristics of a system are evaluated from spectral ratios, i.e. transfer functions, between corresponding two observation points. The dynamic characteristics of each system are tabulated in Table 1 using the average spectral ratios shown in Fig.5.

Dynamic Interaction Effect

The influence of the building on the dynamic behaviour of the subsoil under earthquakes decreases with the depth below the ground level and is scarcely observed at 30m below as shown in spectral ratios shown in Fig.5(f) and (g). The spectral ratios between the base of the building and the surface of the ground, NC1/NG0 and EC1/EG0 in Fig.5(b) and (c), show the tendency that the frequencies of their peaks are lower than those of valley, the former representing the fundamental frequency of a soil-structure system and the latter representing that of the superstructure. In the transverse direction, the ratio between the rocking component spectrum of the eleventh floor and that of the ground surface, UDR/NG0 shown in Fig.5(e), has a peak at the fundamental frequency of the interaction system. In both directions, the spectra of the eleventh floor, NC11 and EC11 shown in Fig.4(b), and the spectral ratios between the eleventh floor and 30m below the ground level, NC11/NB30 and EC11/EB30 shown in Fig.5(b) and (c), have peaks at the fundamental frequency of the interaction sytem. This fact supports that the swaying displacement occurs at the layer near the surface of the ground as mentioned above.

By comparing both directions each other, followings are derived.
(1) The ratio of the swaying component to the total displacement of the eleventh floor in the longitudinal direction is larger than that in the transverse direction. And the rate of reduction of the fundamental frequency of the soil-structure interaction system to that of the structure system is larger in the longitudinal direction than in the transverse direction.
(2) The amplification of the eleventh floor to the ground surface in the transverse direction, which has large amount of rocking component, is greater than that in the longitudinal direction. And as a consequence the fraction of critical damping in the transverse direction is smaller than that in the longitudinal direction.

COMPARISON WITH FORCED VIBRATION TESTS

The fundamental frequency of the soil-structure system obtained by the observation is about 20% lower in the longitudinal direction and about 10% lower in the transverse direction than that of the forced vibration test results. The reason is supposed to be the change of elasticity in the overall system due to amplitude level, and/or the change of the mass and stiffness of the building. Each ratio of swaying and rocking components to the total displacement of the eleventh floor is in good agreement with the test results. The fractions of critical damping are larger than that of the test results in both directions.

ANALYTICAL MODELS

Description

Since it is the intent of this examination to concentrate on the interaction of the soil-structure system, two elastic models for the soil-structure system are employed, of which the horizontal stiffness of each slab are assumed infinite. One, denoted by "F.E.M. Model", represents the transfer characteristics between the eleventh floor and 30m below the ground level where the piles are idearized as bars and the soil stiffness is evaluated by the finite element method of the plane strain state as shown in Fig.6(a). The superstructure and subsoil are given the different amount of damping respectively. The other, denoted by "D.G.C. Model", represents the transfer characteristics between the eleventh floor and the surface of the ground where the stiffness and damping of the soil are evaluated by the dynamical ground compliance of a rectangular footing on an elastic half space [5]. This is a simple model as shown in Fig.6(b). The shear wave velocities in soil for the two models are assumed with reference to the experimental formula giving the relation between N-values and shear wave velocities and also with reference to the fundamental frequency of the surface layer.

Results of Analysis

Two models have several parameters of shear wave velocity in soil and so on. Fig.7(a) and (b) show examples of the transfer functions. These results are different from the obvervational ones in detail but indicate that, if the system parameters were suitably assumed, these two models could be powerful tools to simulate the characteristics of the soil and structure system in the vicinity of the fundamental frequency.

CONCLUDING REMARKS

The main results of this study can be summarized as follows:

(1) Although observed at the same site, the ground motions show a considerable variation in the frequency contents.

(2) In the transverse direction, the torsional mode of the building and the slab deformation mode are apparently observed during actual earthquakes as well as on the forced vibration tests.

(3) In the transverse direction, the rocking displacement component is dominantly observed and its ratio to the total displacement of the eleventh floor coincides with that of the forced vibration test results. In both directions, the swaying ratio to the total displacement of the eleventh floor is also in agreement with the test results.

(4) The fundamental frequencies in the soil-structure system obtained by the observation are 10-20% lower than those of the forced vibration tests.

(5) The dynamic soil-structure interaction is apparently seen in observation records and the influence decreases with the depth below the ground level and is scarcely observed at 30m below the ground level.

(6) Two analytical models of which the subsoil is estimated by the finite element method and the dynamical ground compliance theory, respectively, can simulate the observation results in the range of amplitude level of the records used in this study. These two models can be considered to be the powerful tools to simulate the dynamic characteristics of the soil and structure.

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Table 1 Dynamic Characteristics Estimated by Forced Vibration Tests and Earthquake Observations

		Predominant Freq. of the Top of the Building (HZ)	Soil-Structure Interaction System						Structure System	Surface Layer System
			f_0 (HZ)	Dr	Ds	h_0	fs_1 (HZ)	fs_2 (HZ)	fu (HZ)	fg (HZ)
Forced Vibration Test	Transverse direction	-	2.1	0.42	0.10	0.03	2.4	4.0	-	-
	Longitudinal direction	-	3.2	0.	0.18	0.04	-	-	-	-
Earthquake Obser-vation	Transverse direction	1.9	1.9	0.47	0.12	0.05	2.4	3.4	2.1	3.3
	Longitudinal direction	2.5	2.6	0.	0.21	0.09	-	-	2.9	

Notation : f_0,fu,fg = natural frequency of the fundamental mode
fs_1,fs_2 = natural frequency of the torsional mode and the mode associated with slab deformation
Dr,Ds = swaying and rocking ratio of the fundamental mode
h_0 = fraction of critical damping

Table 2 Observed Earthquakes Used for the Analyses

NO.	DATE	TIME	EPICENTER		DEPTH (km)	EPICENTRAL DISTANCE (km)	MAGNITUDE	INTENSITY (J.M.A.) CHIBA	MAX. REGION	AMP. LEVEL** (gal)
1	'70. 5.17.	23:52	34°36'N	141°06'E	60	140	-	I	II:TATEYAMA	3.8
2	'70.12. 8.	6:36	29°32'N	140°36'E	180	660	-	II	-: -	4.4
3	'72. 2.29.	18:23	33°11'N	141°16'E	70	280	7.0	IV	V:HACHIJOHJIMA	7.1
10	'72.10. 6.	20:31	34°24'N	138°31'E	30	160	5.5	*II	IV:OMAEZAKI	2.3
12	'72.10.18.	10:48	35°44'N	140°07'E	80	50	-	III	III:CHIBA	13.6
16	'73.12.22.	10:20	35°13'N	140°17'E	70	40	-	II	III:TATEYAMA	8.2
19	'74. 2.22.	9:37	33°08'N	137°07'E	400	370	6.9	II	III:TATEYAMA	6.3
20	'74. 3. 3.	13:50	35°34'N	140°53'E	60	90	6.1	III	IV:CHOHSHI	6.5
21	'74. 4. 3.	10:52	35°01'N	140°11'E	50	40	4.3	*I	II:TOKYO	10.4
27	'74.11.30.	7:06	30°36'N	138°46'E	420	540	7.6	II	IV:TATEYAMA	11.4
30	'75. 3.30.	4:57	36°10'N	140°06'E	70	90	5.4	II	III:TOKYO	4.9
31	'75. 4. 2.	17:44	33°42'N	140°47'E	40	200	5.8	I	IV:HACHIJOHJIMA	5.2
34	'75. 4.18.	3:41	36°08'N	139°51'E	50	90	5.0	*I	III:MITO	4.2
41	'75. 8.12.	23:22	31°57'N	138°12'E	400	410	6.9	II	III:TOKYO	6.7
48	'76. 6.16.	7:36	35°30'N	139°00'E	20	80	5.5	*III	IV:TOKYO	12.0
50	'76.12.29.	23:37	36°38'N	139°10'E	130	160	5.8	*I	IV:TOKYO	7.8

* at TATEYAMA

** AMP. LEVEL = $\sqrt{NG0max^2+EG0max^2}$

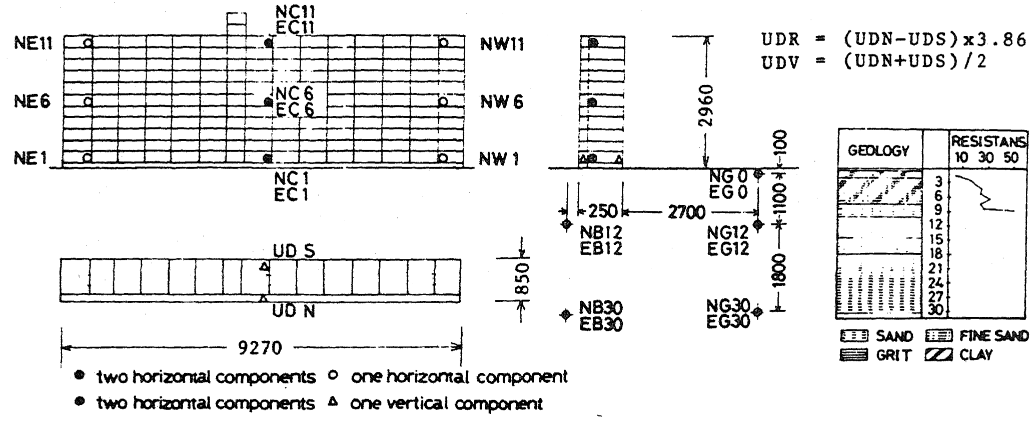


Fig.1 Outline of Building, Soil Profile and Location of Instruments

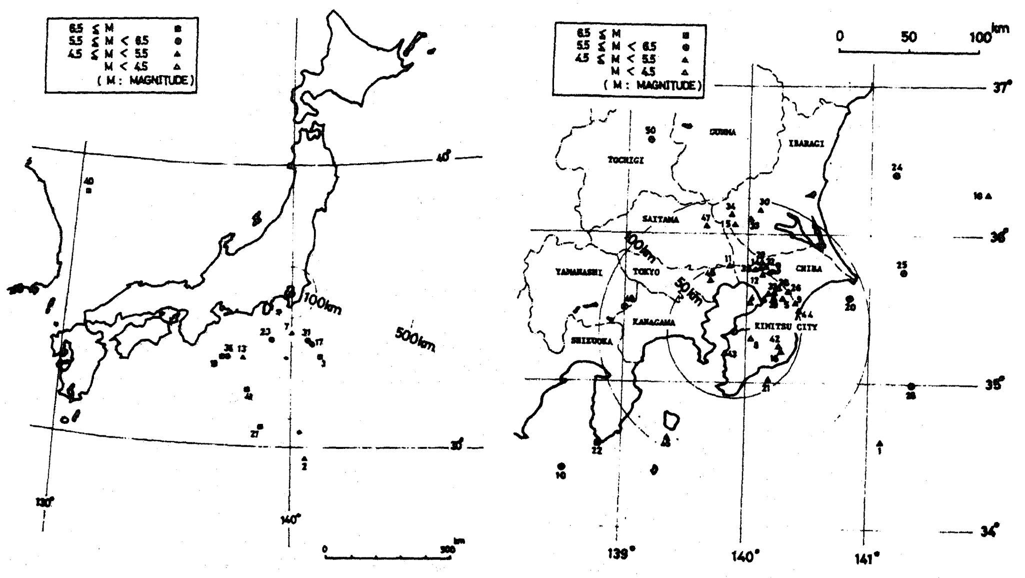
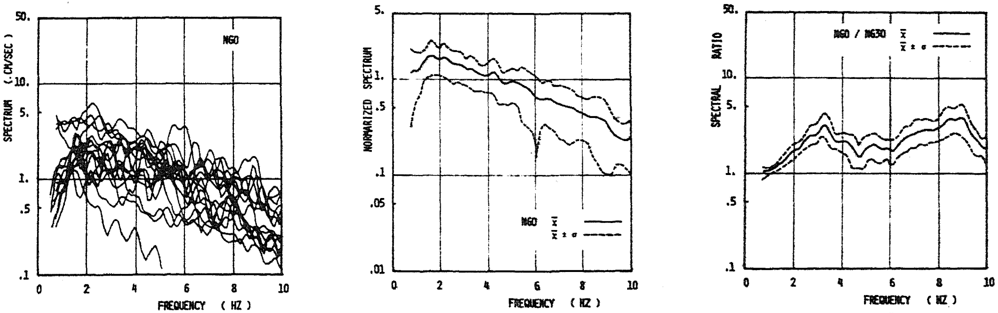
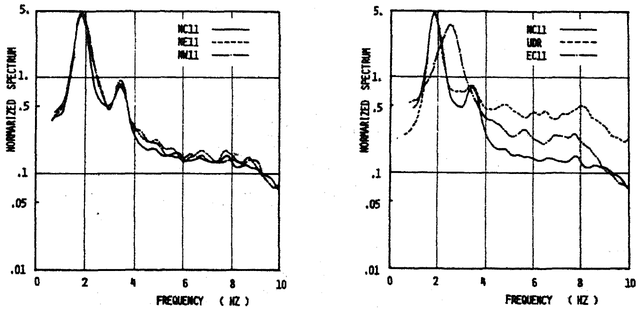


Fig.2 Epicenters of Observed Earthquakes

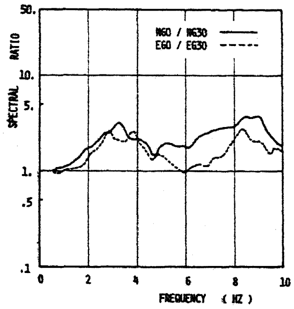


(a) (b) (c)

Fig.3 Variation in Spectra and Spectral Ratios

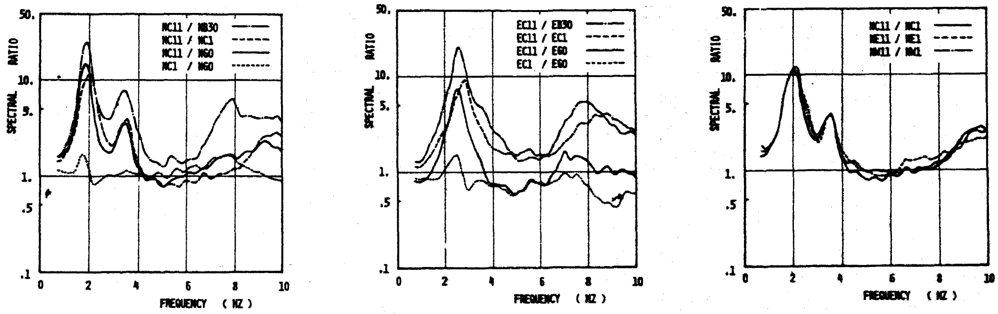


(a) (b)



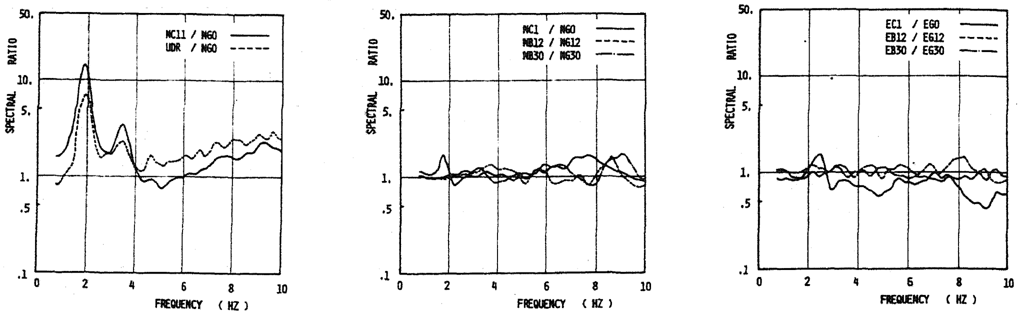
(a)

Fig.4 Average Spectra



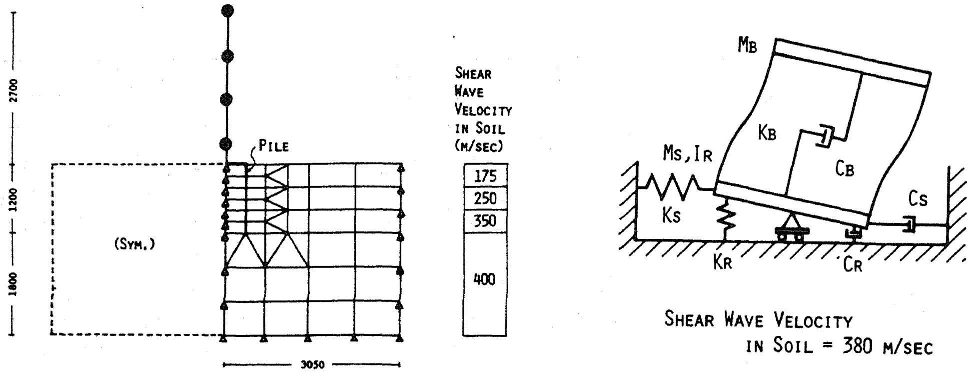
(b) (c) (d)

Fig.5 Average Spectral Ratios



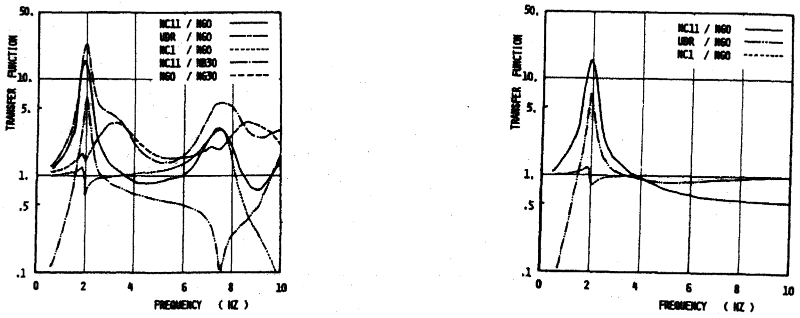
(e) (f) (g)

Fig.5 Average Spectral Ratios (continued)



(a) "F.E.M. Model" (b) "D.G.C. Model"

Fig.6 Analytical Models



(a) "F.E.M. Model" (b) "D.G.C. Model"

Fig.7 Transfer Functions