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THREE DIMENSIONAL VIBRATION OF A THREE STORY R/C RAHMEN STRUCTURE

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SUMMARY

Presented in this paper is a special three dimensional vibration mode of a low rise R/C rhamen building of Hachinohe Institute of Technology. The special mode is the deformation "V" which intersects the longitudinal axis of the building. The natural frequency of the special mode is evaluated as 5.2 Hz from the study. The special mode is clarified by the three dimensional modal analysis. The numerical model for the modal analysis, is decided from the result of the crack distribution research.

INTRODUCTION

In many cases, complex buildings, high rise buildings, and special types of buildings are carefully designed, including the behavior of the ground by the three dimensional analyses. On the other hand, low rise buildings such as school buildings are often simply or experimentally designed by the two dimensional analyses. The earthquakes, for example, 1968 Off-Tokachi Earthquake and 1978 Off-Miyagi Prefecture Earthquake, gave structural damage to the low rise R/C rhamen buildings built on soft ground. The damages showed the effect of the three dimensional vibration of the building, caused by the eccentricity of stiffness, irregular mass concentration and so on. To improve the aseismatic-proof of low rise R/C rhamen buildings, it is important to clarify the three dimensional characteristics of vibration of the building, foundation (especially pile foundation), soil layer, and soil-structure coupling system.

The authors started the earthquake observation with a low rise R/C rhamen building of Hachinohe Institute of Technology in April 1987 to clarify the three dimensional characteristic vibrations of the building. In the preceding studies, the special three dimensional vibration mode of the building is found. The special mode shows the building's deformation "V" under the earthquakes. The objects of this paper are to study the special three dimensional vibration mode by the three dimensional modal analysis and to evaluate the natural frequency of this special mode.

OUTLINE OF EARTHQUAKE OBSERVATION

Fig.1 shows the site location for earthquake observation and the epicenters of the observed earthquakes. The site is in Hachinohe, Aomori, Japan. The array system was set as shown in Fig.2. The earthquake motions are observed on 21

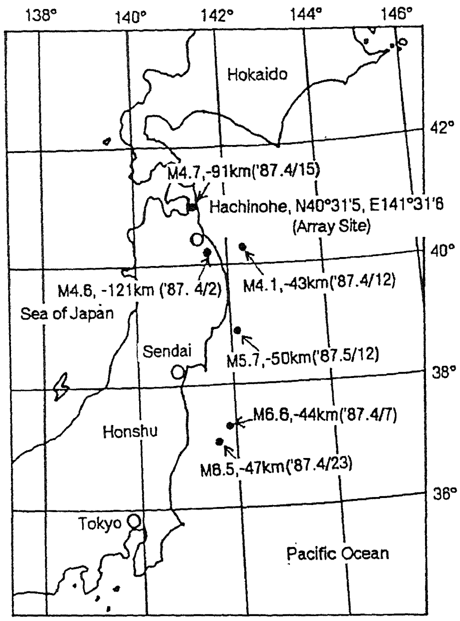
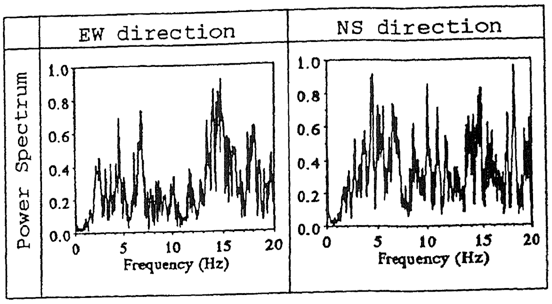
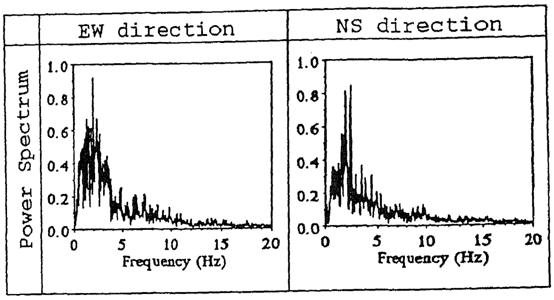


Fig.1 Site Location and Epicenters



(a) Earthquake No.1 (4/2, 1987)



(b) Earthquake No.2 (4/7, 1987)

Fig.3 Sample Power Spectra of Observed Earthquakes

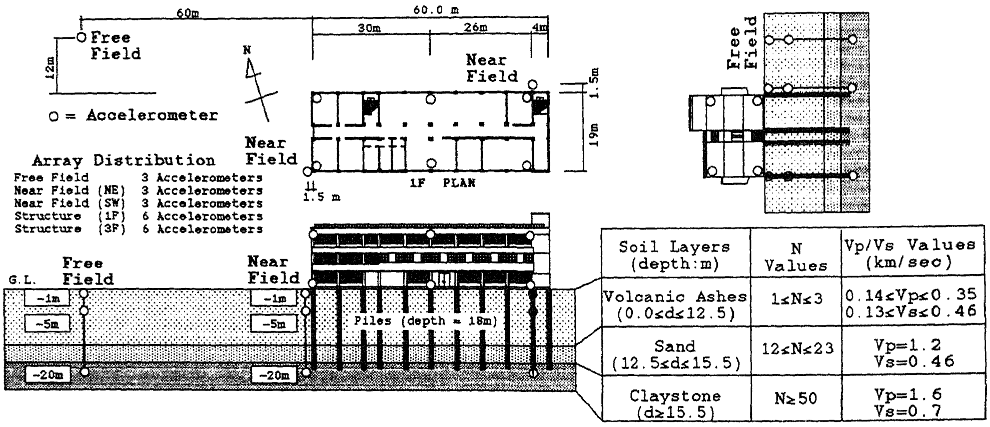


Fig.2 Outline of the Array System

Table 1 Summary of the Observed Earthquakes

No	Observed Time (JST)	Lat. (N)	Lon. (E)	Depth (km)	Mag.	Max. Intensity	Max. Acce. (observed)	Delta (km)	Azimuth (degree)
1	'87 4/02 22:13:53	40°20.6	141°40.0	121	4.6	2	17.2 gal	23.4	330
2	'87 4/07 09:41:36	37°18.0	141°52.0	44	6.6	5	33.7 gal	359.3	355
3	'87 4/12 23:16:06	40°22.6	142°12.7	43	4.1	2	5.2 gal	60.4	286
4	'87 4/15 11:44:00	40°57.9	141°20.5	91	4.7	3	14.4 gal	51.3	162
5	'87 4/23 05:14:19	37°05.3	141°37.6	47	6.5	5	16.4 gal	381.6	359
6	'87 5/12 05:52:11	38°51.6	142°08.2	50	5.7	4	32.2 gal	192.2	344

points of the array system. Each point, the accelerations to the EW, NS and vertical directions are recorded. The observed accelerations are recorded on magnetic tape as digital data in 16 bits length.

The accelerometers are separated into three groups. The first group records the three dimensional motions of the building. On the first floor and at the top of the building, 6 accelerometers are set. The second group records the near field motion. This group is separated in two sets of three accelerometers. Each set is 1.5 m apart from the building and records the near field motion at the points under 1 m, 5 m and 20 m from the ground level (GL). The third group records the free field motion. This group has 3 accelerometers and they are set at the same level points of the near field group. The soil layers of the ground are separated by Volcanic Ashes, Sand, and Claystone from the top.

Table 1 is a summary of observed earthquakes (Refs. 1,2). The maximum acceleration is 33.7 gal at the top of the building. In Table 1, latitude, longitude, and depth are the values of epicenter location. Delta and azimuth are the relative distance and angle of the epicenter to the site. Fig.3 shows the typical power spectra calculated from the records observed at the free field point under 20 m from the GL. These spectra are normalized and smoothed. The spectra of earthquake No.3 and No.4 are similar to them of Fig.3 (a). The spectra of earthquake No.5 and No.6 are similar to them of Fig.3 (b).

OBSERVED CHARACTERISTICS OF VIBRATION

Fig.4 shows the frequency transfer functions of the structure system, the near field system, the free field system, and the soil-structure coupling system. These transfer functions are calculated from the waves made by ensemble of the observed records shown on Table 1. The input wave and output wave in each system are selected as follows: In the structure system, the input is at the first floor of the building and the output is at the top of the building. The ensemble waves are made by 36 records. In the near field system, the input is the point under 20 m from the GL and the output is the point under 1 m from the GL. The ensemble waves for input and output are made by 12 records in each other. In the free field system, the input is the point under 20 m from the GL and the output is at the point under 1 m from the GL. The ensemble waves are made by 6 records. And in the soil-structure coupling system, the input is the near field point under 20 m from the GL and the output is at the top of the building.

From the peak frequencies of the transfer functions in Fig.4, the characteristics of vibration are estimated as follows: Namely, the free field system and the near field system have the same natural frequencies to the EW and to the NS. In the free field system, the first natural frequency is 3.0 Hz and the second frequency is 7.7 Hz. In the near field system, the first natural frequency is 2.7 Hz and the second frequency is 7.6 Hz. Here, it is considered that the slight difference of the first natural frequencies between the free field system and the near field system is caused by the vibration of the building and the vibration of the piles. In the structure system, the first natural frequency is 4.0 Hz for the EW and the second frequency is 5.2 Hz for the NS. In the soil-structure coupling system, the natural frequencies from the first to the fourth are 2.5 Hz, 2.8 Hz, 7.6 Hz, and 7.7 Hz. The first and the second natural frequencies of the coupling system are considered the coupling vibration of the first modes of the structure system and the soil system.

Fig.5 presents the relative displacement modes of the building observed in the earthquake No.2 (Table 1). In Fig.5, the original location, the modal shape on the first floor and the modal shape at the top of the building are plotted. The values of the figure are timed from the trigger for recording the start. In this earthquake, the maximum acceleration is recorded at 60.0 sec after the

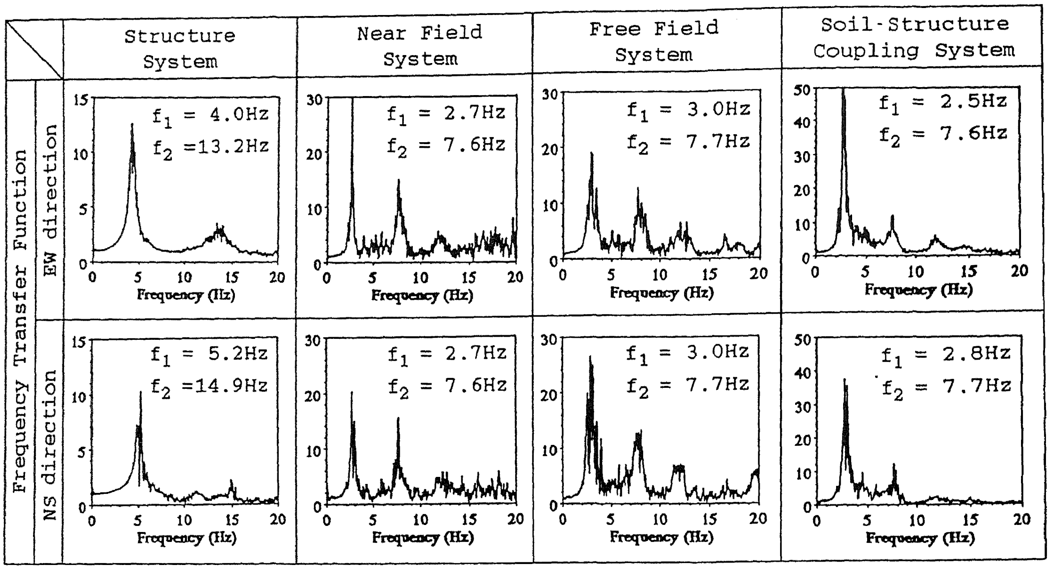


Fig.4 Frequency Transfer Functions

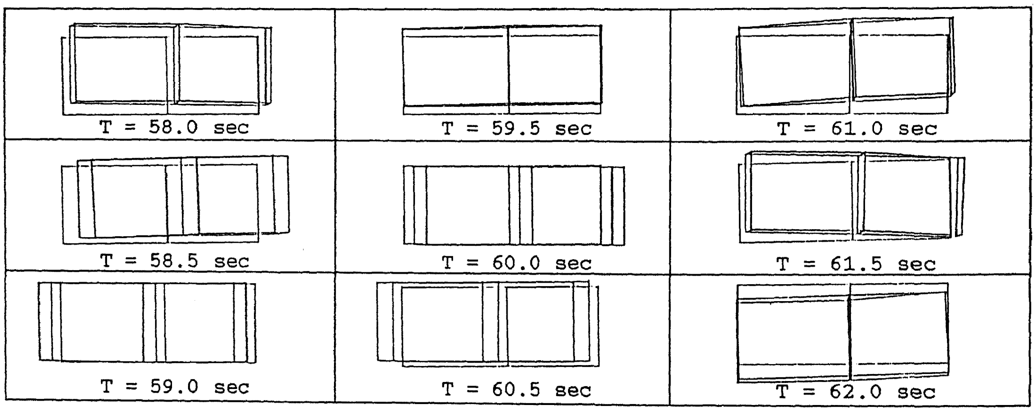


Fig.5 Observed Vibration Modes of the Building (Earthquake No.2)

trigger. From the modes at 58.0 sec, 58.5 sec, 61.0 sec, 61.5 sec, and 62.0 sec, it is clear that the sway mode, the torsional mode, and the special mode are highly coupling. The special mode shows the building's deformation "V" which intersects the longitudinal axis of the building. The existence of the special mode is very important, because it is very difficult to evaluate this kind of three dimensional mode by the two dimensional structural analysis.

MODAL ANALYSIS OF THE STRUCTURE

Fig.6 shows the modal analysis model of the building. In this figure, squares, thin solid lines, and thick solid lines mean columns, beams, and walls. The material constants are selected as follows: The unit weight is 2.4 ton/m^3. Young's modulus of each element is defined by αE. The standard Young's modulus E is 210 kg/cm^2. The constant α is decided by the result of the crack distribution research -- 0.9 for columns, 0.8 for beams, the values presented in Fig.6 for walls and slabs. The live load, penthouse, and overhangs on the second story, are evaluated as the additional weight on the nodal points of the model. The total weight of the first story, the second story, and the third story are respectively 1,647 ton, 1,505 ton and 1,450 ton.

Fig.7 shows the three dimensional natural modes are analyzed by the Subspace Iteration Method. The obtained first and second natural frequencies are nearly equal to the peak frequencies of the transfer functions presented in Fig.4. It is clear that the observed special mode is the second natural mode. Furthermore, this structure has local mode as the fourth natural mode.

Fig.8 shows the story modes and the natural frequencies of the model. These story modes are analyzed by the Component Mode Method (Ref.3). From these story modes, the modal characteristics of the building presented in Fig.7 are described as follows: The first natural mode, Fig.7 (a), of the building is caused by the coupling

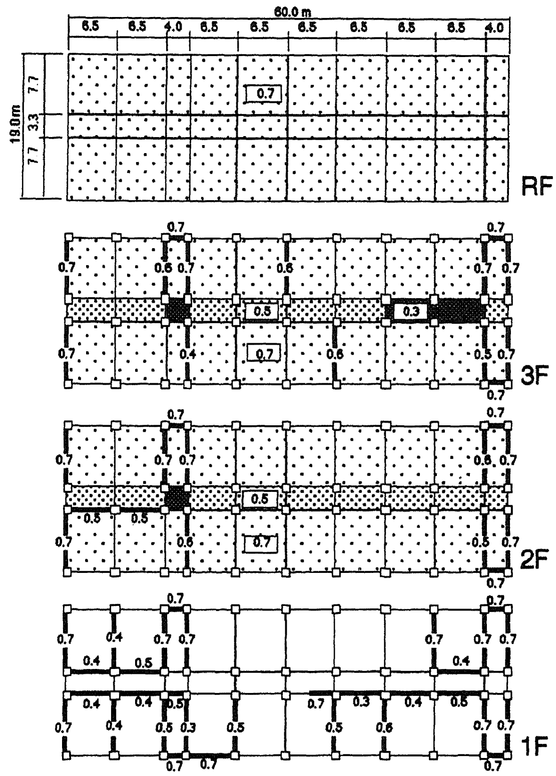


Fig.6 Modal Analysis Model

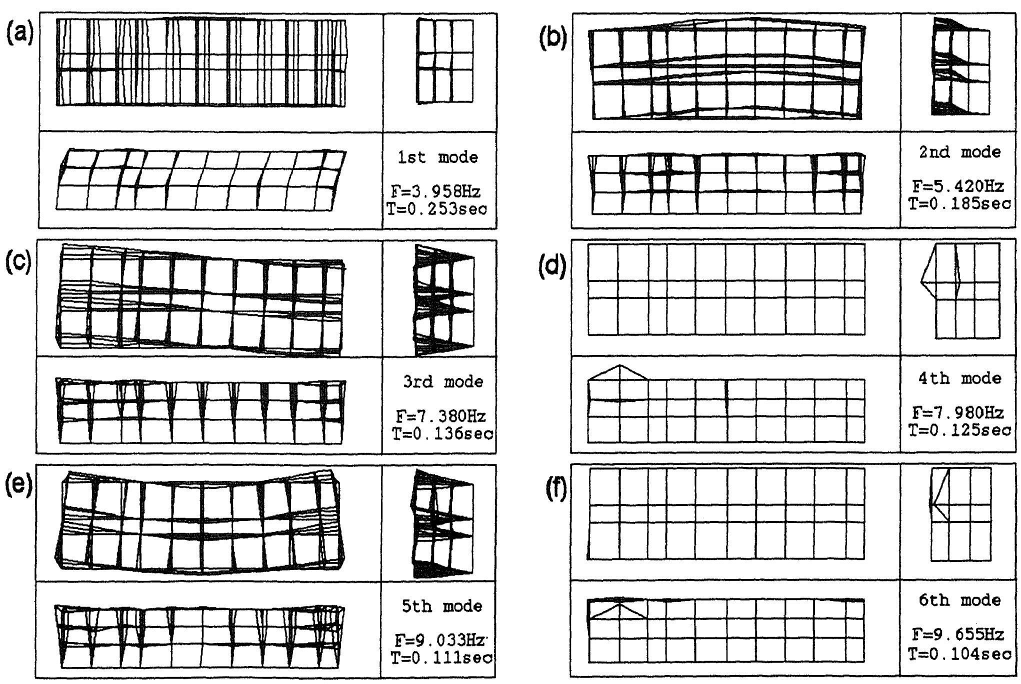


Fig.7 Three Dimensional Natural Modes of the Building

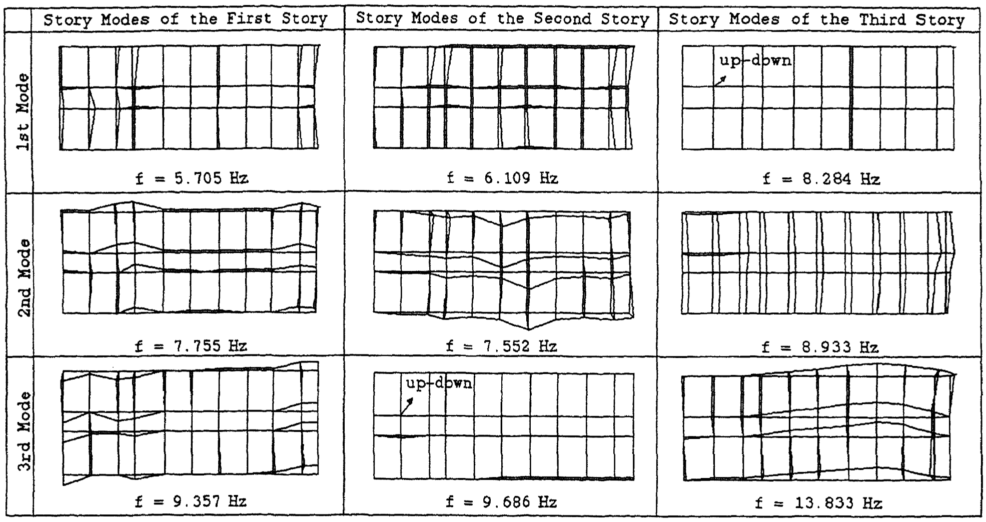


Fig.8 Story Modes by the Component Mode Method

of the first story mode of the first and the second stories, and the second story mode of the third story (Fig.8). The second mode, Fig.7 (b), of the building, presented as the special mode, is caused by the coupling of the second story modes of the first and the second stories and the third story mode of the third story (Fig.8).

CONCLUSIONS

From the analyses of the observed earthquake records and the three dimensional modal analysis of a pile-supported three story R/C rhamen building of Hachinohe Institute of Technology, it is clarified that the special three dimensional vibration mode is the second natural mode of the building and the natural frequency of the mode is 5.2 Hz. Also, it is very difficult to evaluate this kind of three dimensional vibration mode of the building by the two dimensional analyses. On the design of low rise R/C rhamen buildings, especially the buildings similar to the objective building of this study, it is important to carefully analyze the three dimensional characteristics of vibration.

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REFERENCES

1. The Seismological Bulletin of the Japan Meteorological Agency for April 1987, The Japan Meteorological Agency, Tokyo, (1988).
2. The Seismological Bulletin of the Japan Meteorological Agency for May 1987, The Japan Meteorological Agency, Tokyo, (1988).
3. Takita,M., Izumi,M., Ito,K. and Katsukura, H., "A Study on Modal Coupling Analysis of Structures by the Component Mode Method", Proceedings of the Eighth World Conference on Earthquake Engineering, 4, 411-418, (1984).