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RESPONSE OBSERVATION OF A REINFORCED CONCRETE TOWER

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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 actual responses of structures during real earthquakes. For this purpose, the authors have been recording continually time histories of acceleration and those of soil pressure since August, 1983. And in four years and nine months by April, 1988, observation data for about one hundred and twenty earthquakes were recorded. This paper deals with the observed records for the earthquakes occurred on March 6, 1984 and December 17, 1987 (Table 1) in order to examine the response behaviors of the structure due to different input earthquakes. These results show the geometrical non-linear phenomenon caused by the separation of the structure from the ground, and also show the material non-linear one. In the latter part of this paper, the effect of each non-linearity to the behavior of the structure will be discussed.

OBSERVATION SYSTEM

The observation system was constructed in Chiba Experiment Station attached to the Institute of Industrial Science, University of Tokyo. It consists of an embedded reinforced concrete tower (photo 1) with accelerometers 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 height as shown in Fig.1. Fig.2 gives the weight and the mass of each floor. Thirteen accelerometers are set in the Tower, and two ones at 1m and 40m underground (Fig.3). Each accelerometer can measure three components of acceleration in horizontal directions (X and Y directions) and vertical direction (Z direction) at the same time. Fig.4 shows the arrangement of soil pressure gauges set on the side walls and floor slab of the basement. These soil pressure gauges can measure only normal soil pressure. The values of soil pressure measured by them are not absolute, but relative to the soil pressure when the recording begins. The magnetic tape units can record the data of accelerations and soil pressures as digital signals in the sampling time interval of 0.005 second.

The soil properties of the ground, on which the Tower is built, are given in Fig.5. The vibration characteristic curves of the ground are shown in Fig.6. In the figure, the dotted line is calculated without damping by the theory of multireflection using physical values in Fig.5. And two solid lines (X and Y direction) are ratios of spectra obtained by the acceleration records observed by the accelerometer No.14 (1m underground) to those by No.15 (40m underground) for nine earthquakes. According to Fig.6, the dominant frequencies of the horizontal vibrations of the ground are about 2.5Hz, 5.5Hz and 9.0Hz.

OBSERVED RECORDS

Response Acceleration The time histories of response acceleration to the earthquake occurred on March 6, 1984 and December 17, 1987 are shown in Fig.7 and Fig.8, respectively. The maximum response acceleration of the earthquake on March 6 is about 72gal, and that of the earthquake on December 17 is about 783gal. The Fourier amplitude spectra of the time histories shown in Figs.7 and 8 are given in Figs.9 and 10, respectively. From Fig.9, the dominant frequency of the response acceleration measured on the roof of the earthquake on March 6 is about 3.4Hz, and that at 1m underground, which is approximately considered as spectrum of input motion, is about 0.8Hz or 2.0Hz. On the other hand, in the case of the earthquake on December 17, the dominant frequency on the roof is about 2.5Hz or 3.0Hz, and that at 1m underground is about 5.5Hz or 6.0Hz. So, the Tower vibrates in higher frequency than the ground motion during the earthquake on March 6. But, during the earthquake on December 17, the behavior of the Tower is contrary.

Soil Pressure The time histories of normal soil pressure, observed on the side wall of the basement and on the floor slab, are shown in Fig.11 for both earthquakes on March6 and December 17. The soil pressure on side wall observed on March 6 seems to have negative limit value, and it expresses that the Tower separated from the ground. The soil pressure, observed on December 17, shifts positively when the amplitude becomes large, on the side wall and floor slab. Figs.12 and 13 show the correlations between the soil pressures and the deformations of the ground at the points which the soil pressure gauges are set. From Fig.12, the correlation between the soil pressure and the deformation on the floor slab is almost linear. And that on the side wall shows the geometrical non-linearity caused by the separation of the Tower and the ground, but the material non-linearity is not found. In the case of the earthquake on December 17 (Fig.13), geometrical non-linearity is not found, but after the soil pressure becomes large, the inclination becomes small. This fact expresses the material non-linearity of the soil caused by the shifting of the soil pressure.

The Wigner Distribution From the data of earthquake on December 17, it is found that the character of the soil made a change during the earthquake. So, the observed waves cannot think of stationary waves. So, we try to analyze the behavior of the Tower during the earthquake by the Wigner distribution, a kind of a non-stationary spectrum.

The auto-Wigner distribution of a signal is defined as following (Ref.2):

$$W(t,\omega) = \int_{-\infty}^{\infty} e^{-i\omega\tau} f(t+\tau/2) f^{*}(t-\tau/2) d\tau \quad (1)$$

And for a finite discrete time signal, the Wigner distribution can be obtained approximately as following (Ref.3):

$$W(n,m\frac{\pi}{M}) = 2 \sum_{k=-N+1}^{N-1} e^{-ikm(2\pi/M)} f(n+k) f^{*}(n-k) \quad (2)$$

where, $M = 2N-1$

This is called the pseudo-Wigner distribution. And we can calculate it using the algorithm for FFT.

Figs.14 and 15 show the pseudo-Wigner distribution of the X-direction response acceleration on the roof of the earthquake occurred on March 6 and December 17, respectively. In the case of the earthquake on March 6, the dominant frequency changes from 3.4Hz to 3.3Hz during vibration, but it is very little. And in the case on December 17, we find that the dominant frequency is reduced from 3.3Hz to 2.4Hz. Especially, when the amplitude of the response acceleration becomes large, the reduction of the dominant frequency occurs instantaneously.

CONCLUSIONS

In this paper, the behaviors of the Tower for two earthquakes, occurred on March 6, 1984 and on December 17, 1987, which have difference in their dominant frequencies of vibrations, are compared. And the results are summarized as follows:

(1) Two kinds of non-linear phenomena are observed. One is geometrical non-linear phenomenon caused by the separation of the Tower from the ground, the other is material non-linear one caused by the increase of the soil pressure. And the material non-linearity is more effective to the behavior of the structure than geometrical non-linearity.

(2) It seems that the separation of the side wall of the basement from the ground of an embedded structure like the Tower is not affected by the strength of the earthquake. And it is expected that the phenomenon is affected the correlation between the frequencies of input motion and structure own.

(3) The Wigner distribution, a kind of non-stationary spectrum, can find out the change of behaviors of the structure during the earthquake in detail.

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3. Claasen, T.A.C.M. and Mecklenbrauker, W.F.G., "The Wigner distribution - A tool for time-frequency signal analysis, Part II : Discrete time signals," Philips journal of research, Vol.35, Nos.4/5, pp.276-300, (1980).

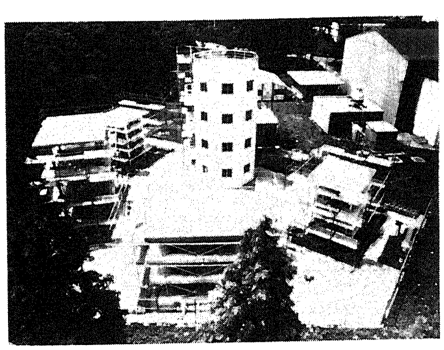


Photo 1 : Bird-View of Observation Tower

Table 1 : Analized Earthquakes

Date	6 Mar.,1984	17 Dec.,1987
Time	11:19:03	11:08:27
Epicenter		
North Lat.	29°20.4'	35°21'
East Long.	139°12.3'	140°29'
Distance (km)	705	46
Focal Depth(km)	452	58
Magnitude	7.9	6.7

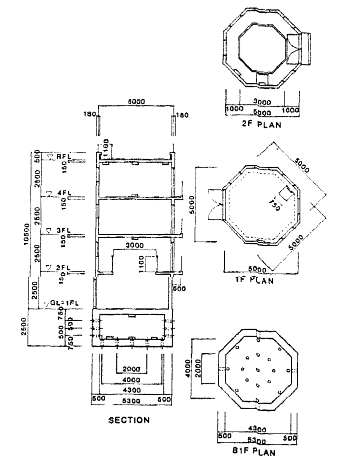


Fig. 1 : Plans and Section of the Observation Tower

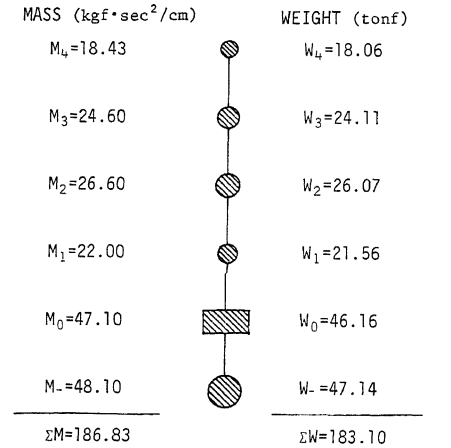


Fig. 2 : Mass and Weight of Each Floor

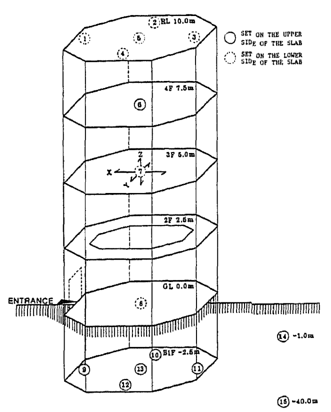


Fig. 3 : Arrangement of Accelerometers

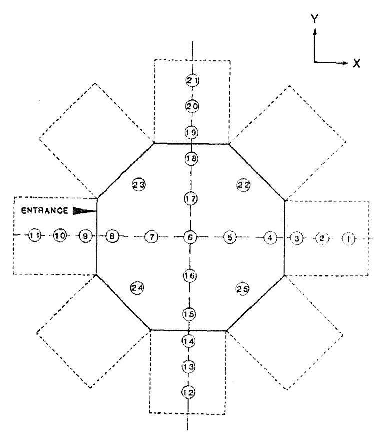


Fig. 4 : Arrangement of Soil Pressure Gauges

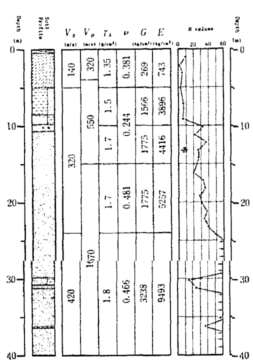


Fig. 5 : Soil Properties of the Ground

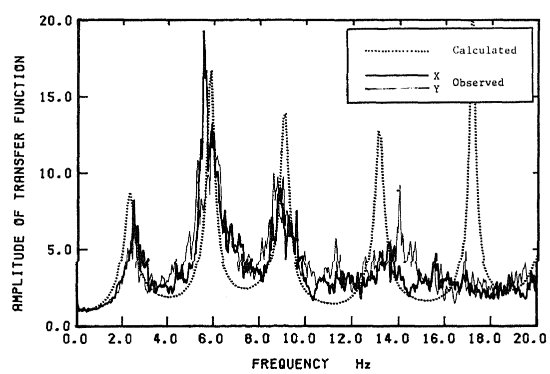


Fig. 6 : Vibration charcteristic Curves of the Ground

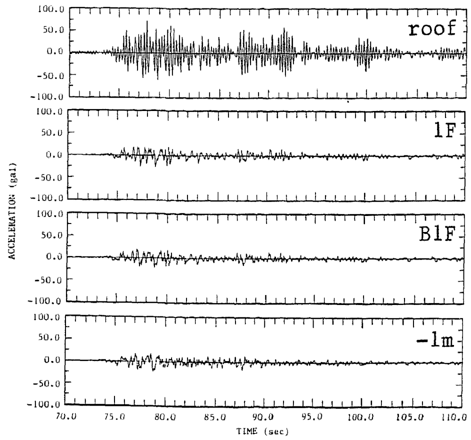


Fig. 7 : Time Histories of Response Acceleration (March 6, 1984)

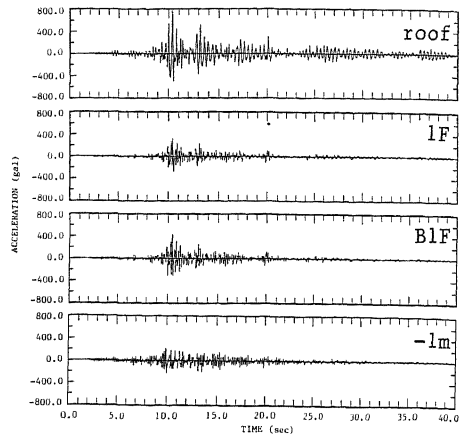


Fig. 8 : Time Histories of Response Acceleration (Dec. 17, 1987)

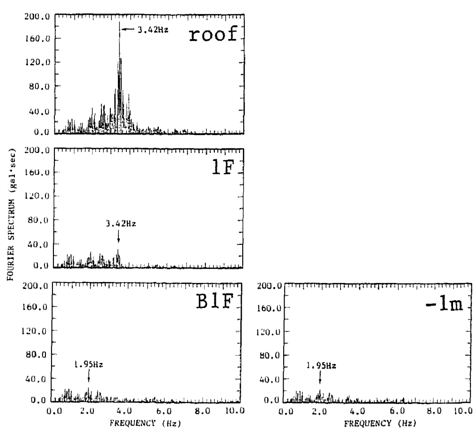


Fig. 9 : Response Spectra of Acceleration (March 6, 1984)

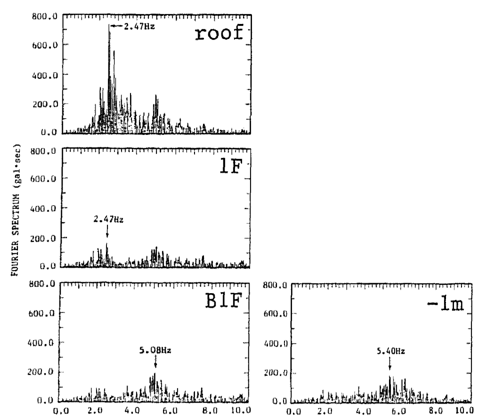
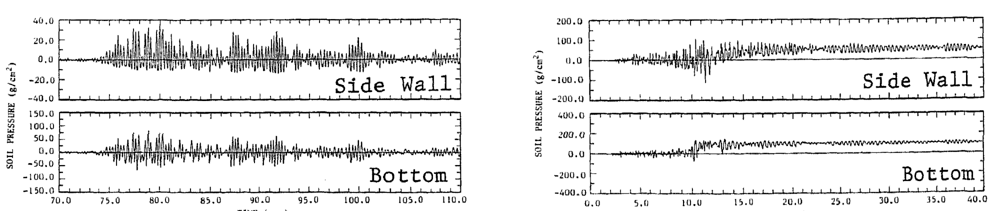


Fig. 10 : Response Spectra of Acceleration (Dec. 17, 1987)



March 6, 1984

Dec. 17, 1987

Fig. 11 : Time Histories of Soil Pressure

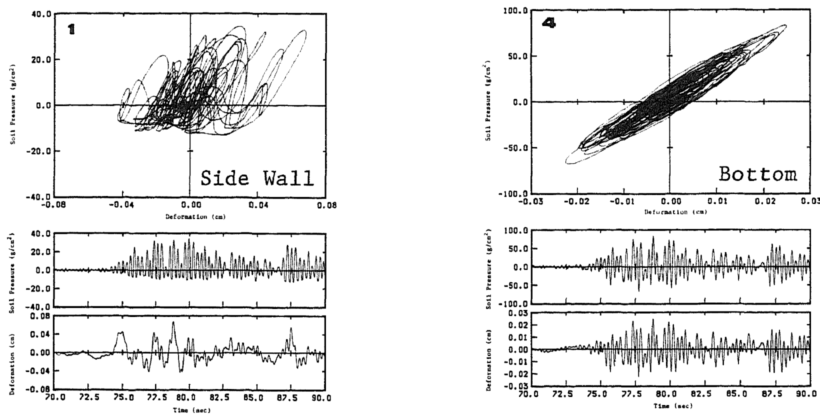


Fig. 12 : Relationship linking Soil Pressure and Deformation (March 6, 1984)

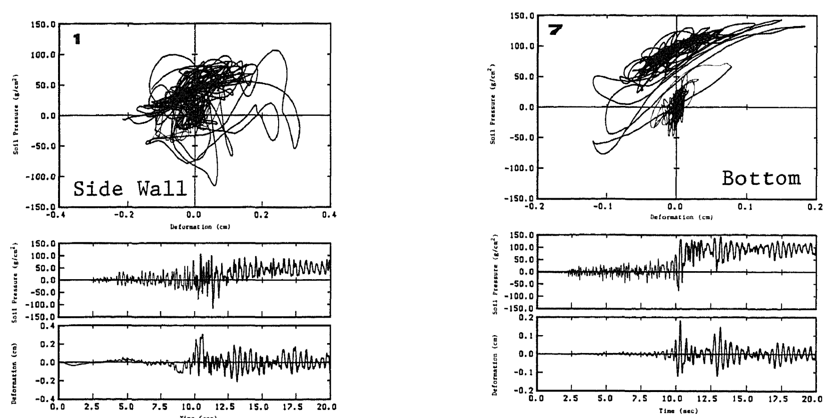


Fig. 13 : Relationship linking Soil Pressure and Deformation (Dec. 17, 1987)

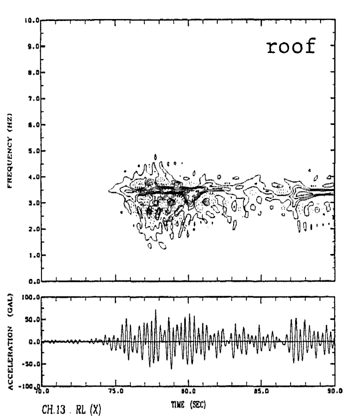


Fig. 14 : The Wigner Distribution of Response Acceleration (March 6, 1984)

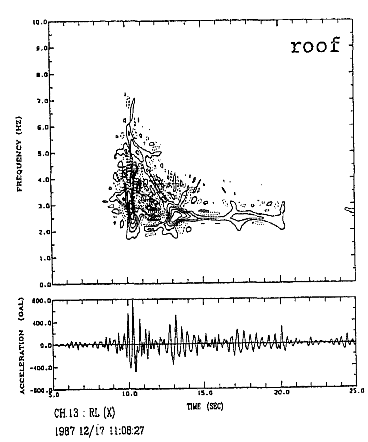


Fig. 15 : The Wigner Distribution of Response Acceleration (Dec. 17, 1987)