(162) OBSERVATION OF SOIL-STRUCTURE INTERACTION EFFECTS BASED ON EARTHQUAKE AND MICROTREMOR RECORDS OF A REINFORCED CONCRETE TOWER

by

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1. INTRODUCTION

For observation of soil-structure interaction during earthquakes, a reinforced concrete tower is constructed in the Chiba Experiment Station of the Institute of Industrial Science, University of Tokyo[1),2)]. The seismometers, installed in it, have been in operation since August 1983 and have provided acceleration and soil pressure records from more than 200 earthquakes. In this paper, earthquake response records of the tower are compared with microtremor records in order to examine the effects of the dynamic load intensity on the soil-structure interaction.

2. DESCRIPTION OF THE OBSERVATION TOWER AND SURROUNDING SOIL CONDITIONS

The observation tower, which has an octagonal cross-section, consists of four floors and a basement, with a total height of 10 m above the ground level and 2.5 m underground as shown in Fig. 1[1),2)]. The thickness of the walls is 180 mm above the ground level and 500 mm at the basement. The thickness of all the floor slabs is 150 mm, with the exception of the basement floor slab, which is 500 mm. The slab of the second floor has an octagonal opening in the middle. A total of 13 accelerometers is attached to the floor slabs, including the

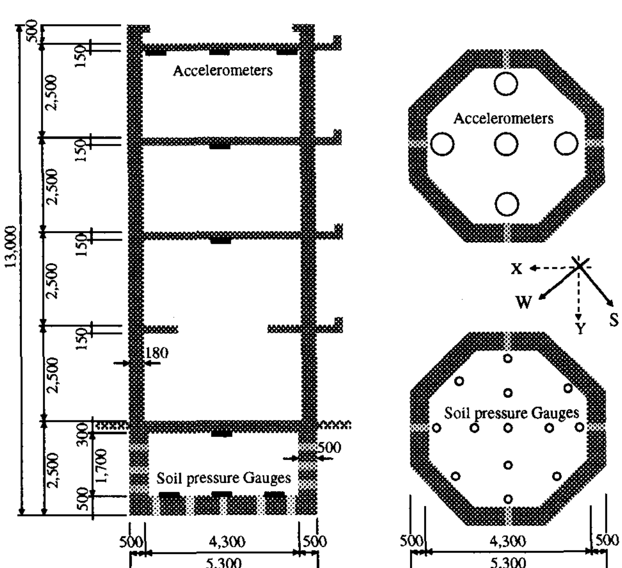

Fig.1 Plan and Vertical Cross-section of The Tower

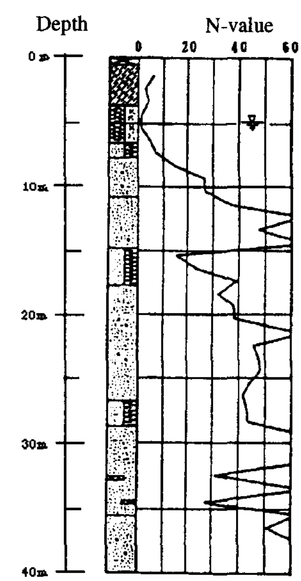

Fig.2 Soil Profile at Borehole P5

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basement floor. The comparatively high rigidity of the tower is a prerequisite for soil-structure interaction effects to be clearly manifested in the overall seismic response of the system. Borehole P5 of the Chiba seismometer array is located at an approximate distance of 15 m from the tower. The soil profile is relatively simple with rather uniform layering as shown in Figure 2.

3. PREPARATION OF THE EARTHQUAKE DATA AND MICROTREMOR RECORDS

The earthquake response records of the tower were processed in a similar manner as the records of the Chiba Array Database[3)]. A different approach was used only for determination of the starting times. The initial time step of each record was determined to be the one, at which the correlation with the corresponding record from the Chiba Array Database is the highest. Considering the properties of the gauges, the values of each soil pressure record were recalculated to obtain the relative to the averaged of the first 1 second of the record. A series of microtremor observations was conducted at daytime on November, 23, 1992 in order to study the behavior of the soil-structure system when subject to small amplitude vibrations. The weather at the time of the observations was relatively calm, with occasional wind. There was almost no disturbance from passing heavy vehicles. Each observation was carried out using simultaneously three velocity-type sensors. They were placed successively at certain points of interest in sixteen different configurations to enable evaluation of transfer functions between the free field and the structure and between different parts of the structure. All the records have a length of 60 s with a sampling interval of 0.01 s. Since the pick-ups have flat sensitivity between 1 Hz and 10 Hz, the frequency contents outside this range were eliminated by a cosine-type band-pass filter. Subsequently, for verification of the records, each one was divided into five equal parts and the Fourier spectra of each part were compared. This comparison showed satisfactory consistency of the data.

4. OBSERVATION OF SOIL-STRUCTURE INTERACTION EFFECTS

The displacements at the measuring points are obtained by integration of the acceleration data. Selecting the time instants, at which maximum displacements of the top of the tower occurred, displacement ratios at frozen times for different events are plotted in Fig. 3. They show a significant contribution of coupled rocking and sway to the horizontal motion of the structure, as well as stable trend. Figure 4 presents perspective plots of the vertical displacements of the basement floor slab at fixed time moments. The time moments are chosen such, that the difference between the displacements of two oppositely located points is the biggest. As the basement floor slab is very rigid, there is almost no bending, but a noticeable rocking effect can be observed. At the same time, the UD-motion is virtually not amplified within the structure. This can be seen in Fig 5(a),

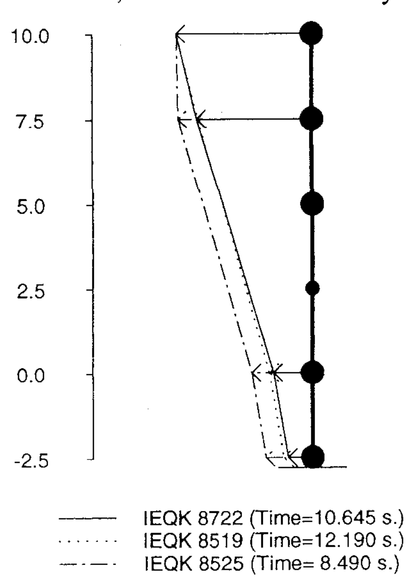


Fig.3 Displacement Ratios in NS Direction

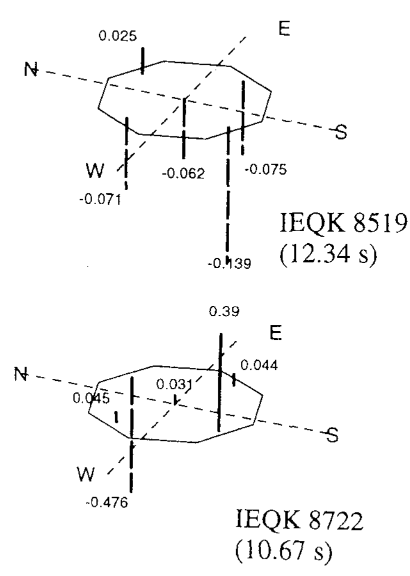
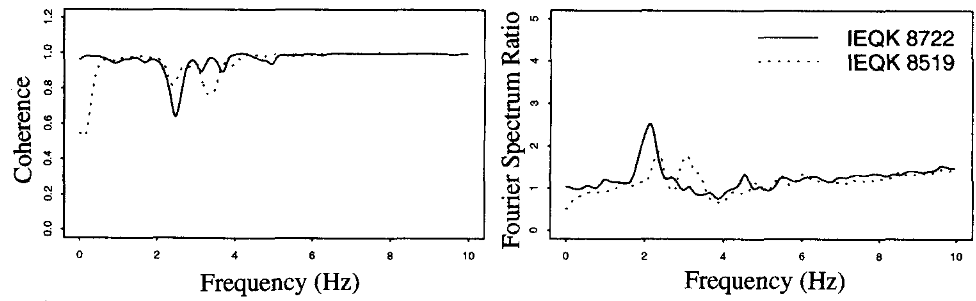
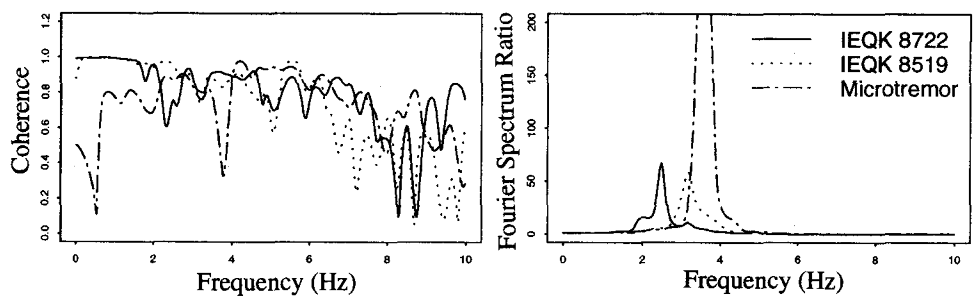


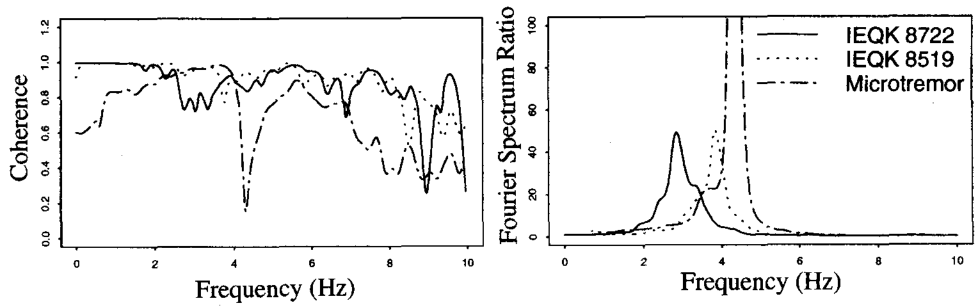
Fig.4 Vertical Displacements of the Foundation



(a) Ground Level and Fourth Floor (UD - components)



(b) Soil and Fourth Floor (EW - components)



(c) Ground Level and Fourth Floor (EW - components)

Fig.5 Coherence Functions and Fourier Spectrum Ratios

which shows high coherence and almost flat Fourier spectrum ratios between the vertical components recorded in the basement and the fourth floor. The ratios are almost equal to one in the whole range and have peaks only at the dominant frequencies, which correspond to the rocking mode. These peaks indicate that the rocking contributes to the vertical component of the acceleration. The drop of coherence and the peak-shaped Fourier spectrum ratios between the free-field motion and the tower response in Fig. 5(b) show the effect of kinematic interaction, a filtering of the high frequency contents. From the same figure it can be seen, that depending on the amplitude of the dynamic excitation, the behavior of the soil-structure system significantly changes. There is a marked shift of the dominant frequency from about 4 Hz for the microtremor through 3.5 Hz for a moderate earthquake (IEQK 8519) to 2.5 Hz for the considerably larger Chibaken-Toho-Oki Earthquake (IEQK 8722), which has peak ground acceleration above 300 Gal and peak acceleration at the roof of the tower above 700 Gal. The fundamental frequency obtained by analyzing the structure as having a foundation on elastic half-space (without considering the embedment) was 2.6 Hz . The similarity with the value, obtained from the analysis of the Chiba-Toho-Oki Earthquake data indicates small lateral soil support in this case. As it can be seen from the soil pressure time histories (Fig. 6) there is even a separation of the soil from the side wall of the structure. This is indicated by the equalizing of the negative values of the pressure, recorded by Gauge 1. The significant increase of the bottom pressure is a result not only of rocking, but also of the redistribution of stresses from the structural weight when the side wall separates from the soil. The trends

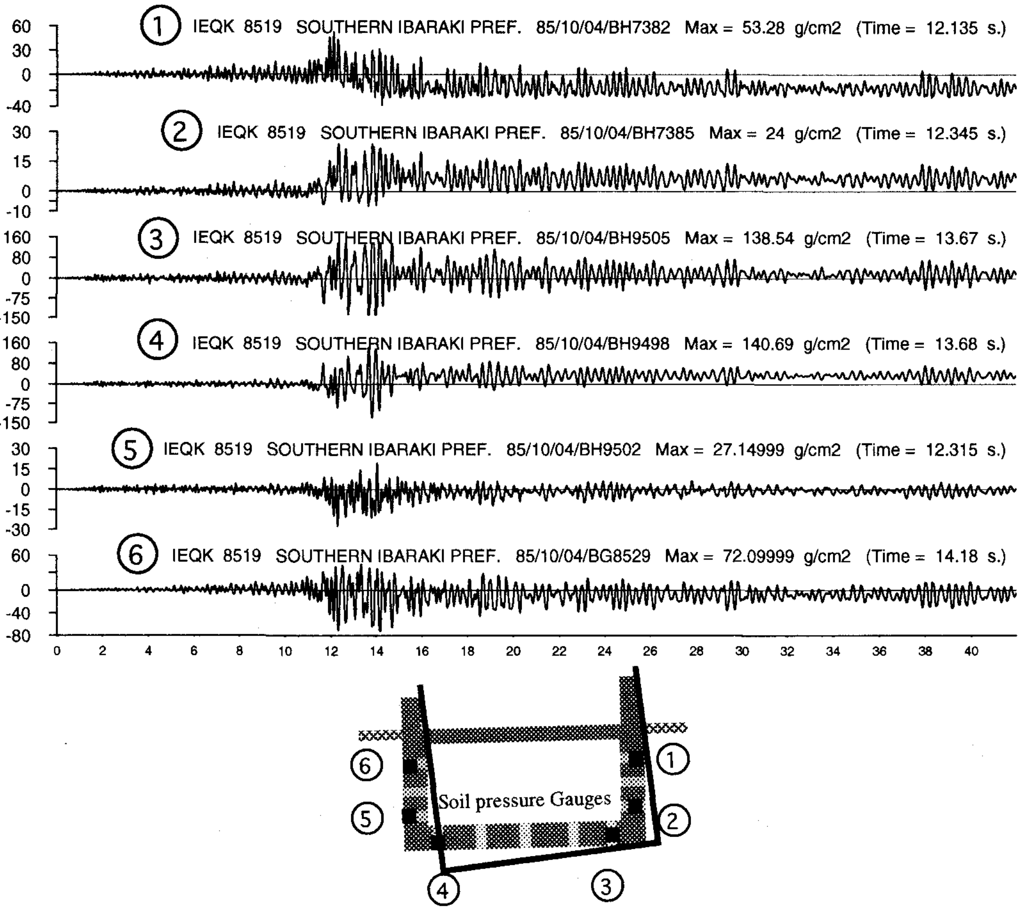


Fig.6 Time Histories of Soil Pressure (IEQK 8519)

in the baseline shifts of the soil pressure records are consistent and suggest the displacement line, shown in the same figure i.e. a combination of sway and rocking. But even though the tower experiences considerable sway and rocking, the contribution of the response of the superstructure to the overall behavior of the system can not be neglected, as show the coherence and transfer functions between the ground level and the fourth floor in Fig. 5(c).

5. CONCLUSIONS

The motion of the tower is characterized by coupled sway and rocking, including highly nonlinear elasto-plastic behavior of the soil support. Separation of the soil from the structure occurs under large dynamic loads, leading to redistribution of the stresses from structural weight over the soil. As the basement floor slab is very rigid, it experiences insignificantly small bending and moves like a solid body. There is no filtering of the high frequency contents of the vertical motion, but the vertical component is amplified only at the dominant frequencies, corresponding to the rocking mode. At the same time filtering of the high frequency contents of the horizontal motion as a result of kinematic interaction is observed. Comparative analysis of earthquake and microtremor data shows that with the increasing of the amplitude of the dynamic excitation the dominant frequency of the horizontal vibrations of the soil-structure system decreases significantly.

6. REFERENCES

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