EARTHQUAKE MOTION MEASUREMENT OF PLANT TOWERS ON SOFT SUBSOIL

Kenji HAGIO[I], Akinori SUENAGA[II]
Toshio YAMADA[I], Soichi KAWAMURA[I]

SYNOPSIS

To apprehend actually the dynamic behaviour of a rather longer period structure supported on piles and its surrounding soft subsoil and the interaction between them as well as the dynamic characteristics of a combined footing, authors has been continuing measurement of earthquake motion in and around a petrochemical plant towers built on the reclaimed ground since Dec. 1974. The measurement system, dynamic behaviour of structure and soil and analytical results are mentioned in this report.

STRUCTURE AND SOIL

The measured structures are three steel tubular towers 50m, 30m, 15m in height. They were built on a common concrete base mat supported through steel piles driven into a dense sandy layer 45m below the ground surface. They are shown in Fig.1. The weight of each towers are 130, 140 and 40 ton in the order of height and that of base mat is 690 ton.

The composition and N-value distribution of subsoil is shown in Fig.2. The soil profile is divided into four parts, the very soft reclaimed layer from GL to GL-6m, silty sand from GL-6m to GL-50m, clay from GL-50 to GL-75m and thick layer of dense sand below GL-75m.

MEASUREMENT SYSTEM

Pick-ups with two horizontal components are placed at 8 points as shown in Fig.1, top of the 30m and 50m tower, diagonal edges of base mat, GL-10m, GL-45m (pile bottom), GL-85m just below the structure and ground surface about 25m distant from the structure. Two vertical pick-ups are also placed at the same points of base mat where horizontal ones are placed. The natural period of the pick-ups is 0.2 sec and the sensitivity curve of them is flat between 0.03 sec and 3.0 sec. Though these pick-ups can be used as velocity-type, they have been working as accelero-type till now. 18 components of accelerograms for an earthquake are recorded by the measurement system consisting of the data recorder, automatic starter, automatic attenuator, filtering and delaying apparatus, and non stop power supply.

OBSERVED EARTHQUAKES

Since the measurement was begun in Dec. 1974, more than 40 earthquakes have been observed during 15 months. Their horizontal maximum amplitudes were 1-30 gal at the ground surface and all of them belong to small or middle class of intensity. Most of their epicenters were within 80 km in the distance from the observating point and focal depths were 40 km. Fig.3 shows the example of horizontal component of observed records. It occured 400 km distant, 530 km deep on Aug. 12 in 1975, and the magnitude was 6.9. This earthquake is coded as G32 in the figures of this report. It should be noted that the amplitude of the base mat was smaller than that of the

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I) Technical Development Department, Taisei Corporation, JAPAN
II) Chiba Works,Mitsui Petrochemical Industries, Ltd., JAPAN

ground surface and that the earthquake motion of the 30m tower shows beats and its amplitude was larger than 50m tower.

EIGENVALUE ANALYSIS OF STRUCTURE AND SOIL

As a simple approach of analysing the observed records, the eigenvalues of structure and soil are calculated. The natural periods and modes of lumped mass models in the fixed base condition for 30m and 50m towers are shown in Fig.4. As for the soil, two models with different thickness 45m and 85m were analysed. Their results are shown in Fig.5. The whiplash-like amplification in the reclaimeed layer is remarkable.

ANALYSIS OF OBSERVED RECORDS

Amplitude characteristics : The amplitude ratio of maximum acceleration in the horizontal direction are shown in Fig.6. They are averages of 40 earthquake records and regulated FH1X or FH1Y to unity. The pattern of the amplitude ratio are almost same in two direction X and Y except that of 30m tower, and the large amplification of soil near ground surface shoud be noted. The average magnification factor of acceleration was 2.9 from GL-85m to the base mat, 5.9 or 15 from base mat to the tower top, therefore the underground magnification was quite effective for the overall system of structure and soil. Magnification factor from GL-85m to the ground surface and to the base mat were 3.4 and 2.6 on an average, and the amplitude ratio of the base mat to the ground surface was always as small as 0.76. Vertical component of base mat motion was smaller than the horizontal one and its ratio was about 0.4 on an average. Fig.7 shows the time historical mode of the soil and structure motion in the horizontal direction Y. The overall system of structure and soil seems to move in the higher mode shape as that of 2nd or 3rd order.

Period characteristics : The common predominant periods of structure in the Fourier spectral ratios of the observed accelerograms are shown in Tab.1 and 2, comparing with the natural periods of analytical model. The Fourier spectra and their ratios of an earthquake G32 are shown in Fig.8 and 9. The predominant periods of soil above GL-85m were judged to be 1.2 - 1.3, 0.5 and 0.3 sec. Though the longest period of them corresponds to the primary period of analytical model, its peak height is lower than that of shorter period part. It indicates that the shorter period components were amplified very largely in upper layer. As a matter of fact, the growth of the shorter period components can be seen in the Fourier spectra of GL-85m, GL-45m and ground surface. The spectrum ratio of the base mat to the ground surface shows that the amplitude of them are almost same in the longer period part than about 0.5 sec and the amplitude of base mat is smaller than that of ground surface in the shorter period. The first periods of the spectral ratios between tower top and base mat were 0.46 sec and 1.0 sec each for 30m and 50m towers, and those of the ratios between the tower top and GL-45m(pile bottom) or GL-85m were just slightly longer. Hence it can be concluded that the interaction effects were not so significant to cause period elongation of structure in this case.

Two dimensional behavior of structure and soil : Fig.11 shows so called Lissajou's figures, which were obtained from the composition of a pair of the arthogonal components in the horizontal vibration as shown in Fig.10. These figures are drawn dividing the 10 sec data into 3 parts. The direction of motion at GL-85m coincides that of epcenter at first but makes right angle later. This tendency is same at the base mat. The motion of the 30m tower is different from that of base mat or GL-85m, and the later part of them forms simple elliptical shapes. That of 50m tower is rather complicated and it seems that the ratio of periods between the orthogonal components equals 3 : 1. Anyhow from these Lissajou's figures vibrational motion of structure and soil could be clearly recognized in more realistic manner, and it would be better to consider two dimensional coupled oscilation in more rigorous analysis.

Rotational motion of base mat : Two rotational motions in the horizontal and vertical plane, torsion and rocking are calculated as the difference between a pair of parallel acceleration components. Their trace and Fourier spectra are shown in Fig.12 and 13. Predominant periods of torsional motion are 0.9, 0.5, 0.4 and 0.3 sec, and those of rocking are 0.45 sec, 0.4, 0.34 and 0.3 sec.

Modal damping factor of soil : The modal damping factors of soil for the lumped mass models mentioned previously were obtained through the spectrum fitting procedure. In this procedure, the response analysis of the theoretical model are done first, assuming the damping ratio. Then spectrum ratio of the model top response to the model bottom input is compared with that of observed data. Till the analysed result fits to the observed one, this procedure are repeated varying the damping ratio. Fig.14 show the last results of the spectrum fitting. Fig.15 show the relation between the natural period and its modal damping factor for two types of soil model GL-85m, GL-45m calculated for 3 earthquakes. However they were in the range of 5-17% for the 1st mode, 2-4% for the 2nd mode and 0.7-2% for the 3rd mode, the decreasing tendency in the higher mode was very clear.

CONCLUSIONS

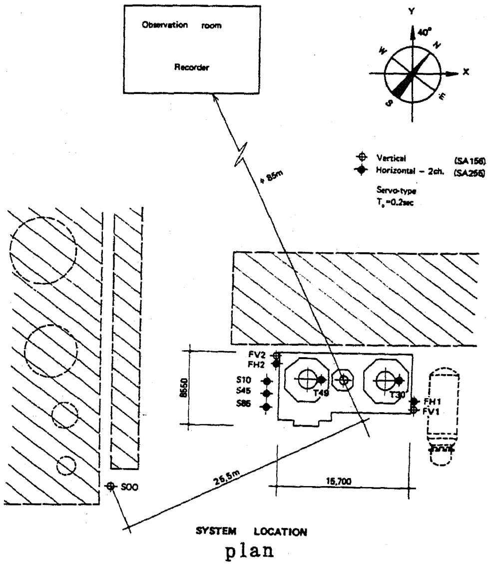
The actual dynamic behavior of rather longer period structure and its surrounding subsoil under earthquake motion, however it was limitted in the small strain level, were investigated and some facts were pointed out based upon the observed records.

1. There is a difference between the motions of ground surface and the base mat, and the latter is always smaller in the shorter period part than about 0.5sec.

2. The effects of soil deformation to the structure is slight as for the period characteristics, but significant as for the magnification factor of acceleration, which depends on the large amplification of upper layer in the short period part.

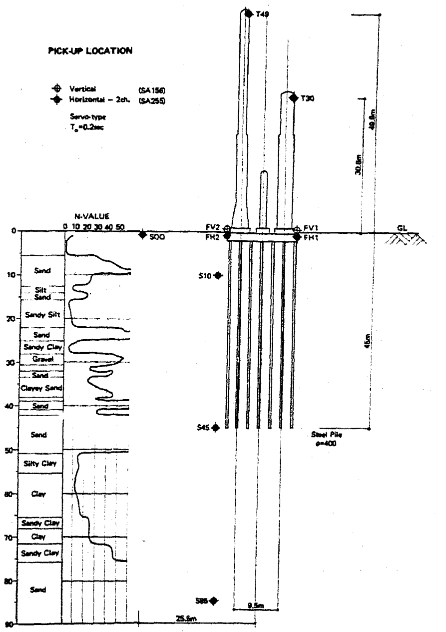
3. The modal damping factors for the lumped mass model of soil have interesting and clear tendency of decreasing in the higher mode. This fact is different from the conventional tendency of the damping factor so called frequency-proportional or constant.

As the purpose of this study, the behavior of the structure and its surrounding subsoil under strong earthquake as used in the ascismic design of structure should be clarified. But the chance to catch such a strong earthquake motion is very few, So, it would be desirous to continue the measurement to affirm the actual dynamic character even in the small strain level and to progress their result to the studies in the large strain level.



plan

Fig.1 Pick-up Location



elevation

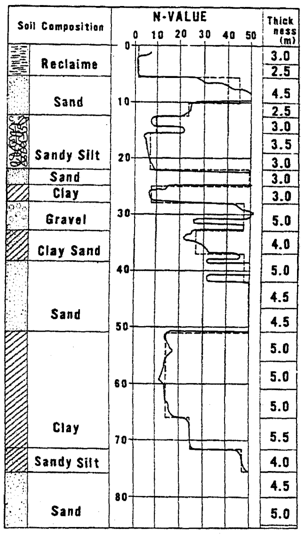


Fig.2 Soil Profile

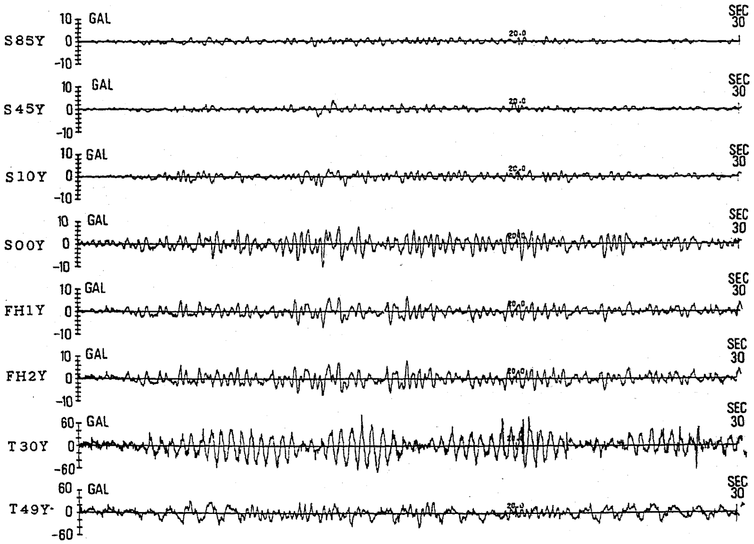
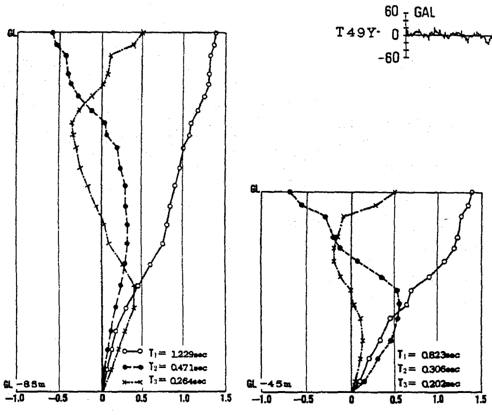
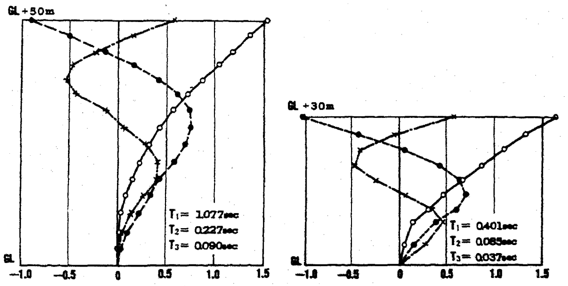


Fig.3 Observed Records G32



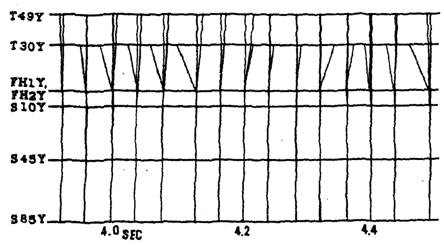
GL-85m GL-45m

Fig.5 Natural Moe of Soil

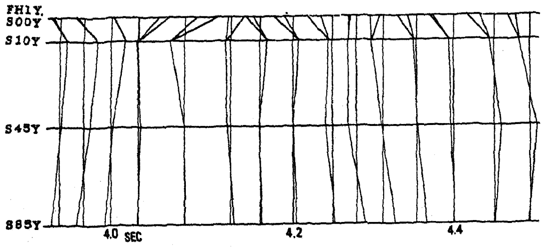


50m tower 30m tower

Fig.4 Natural Mode of Structure



overall system



soil system

Fig.7 Time Historical Mode

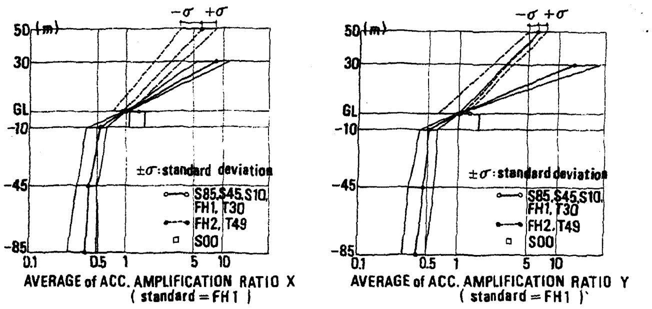


Fig.6 Maximum Acceleration Mode

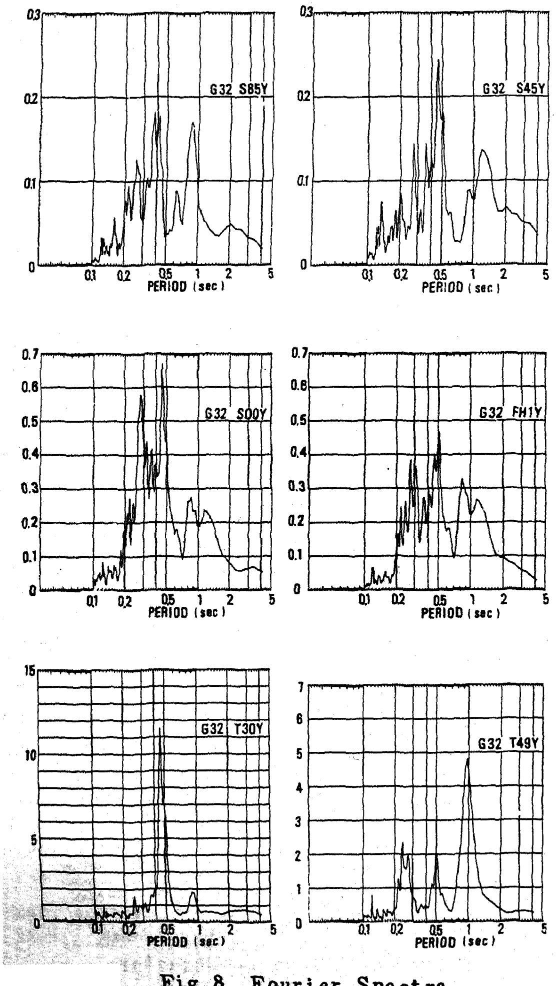


Fig.8 Fourier Spectra

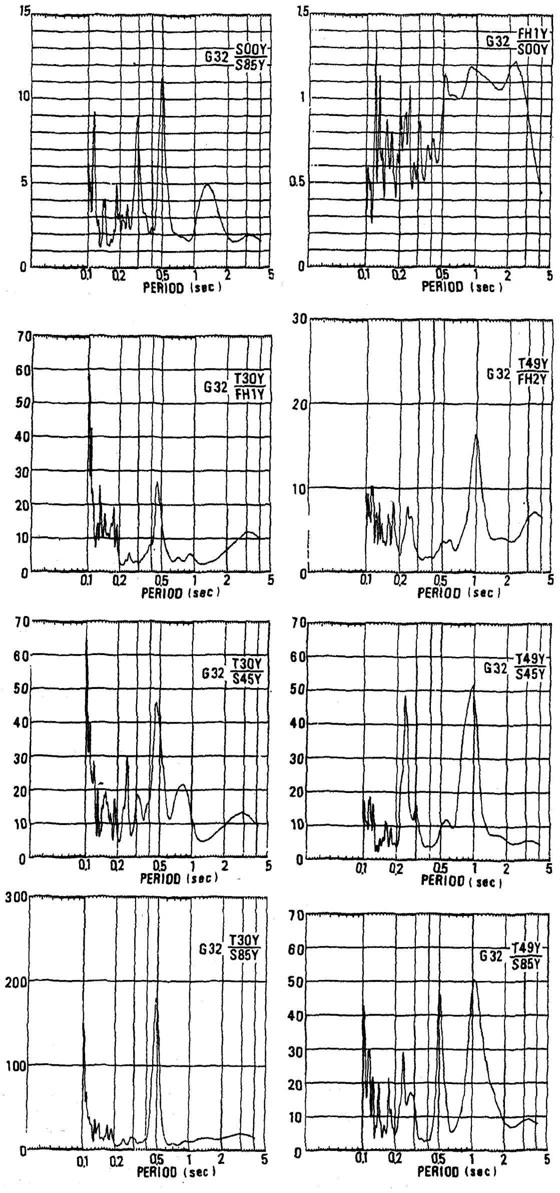


Fig.9 Spectral Ratio

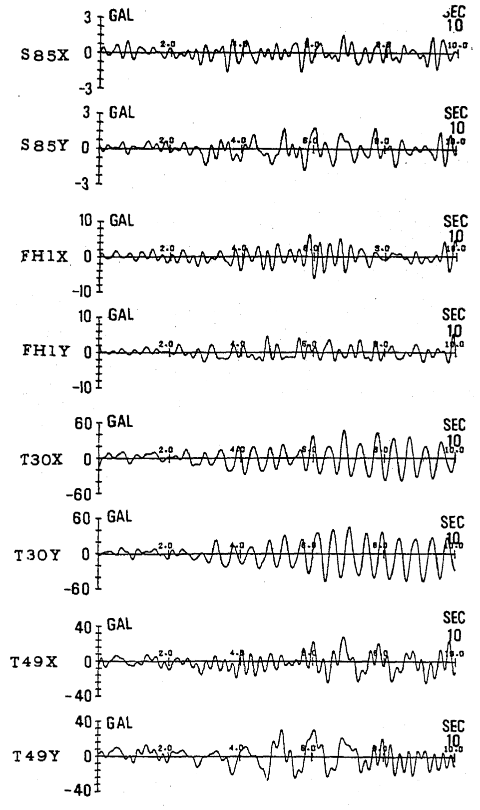
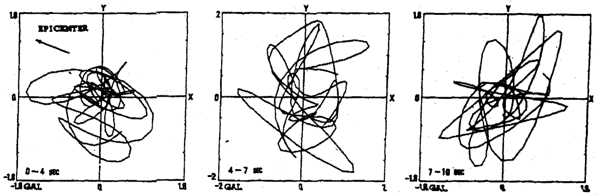
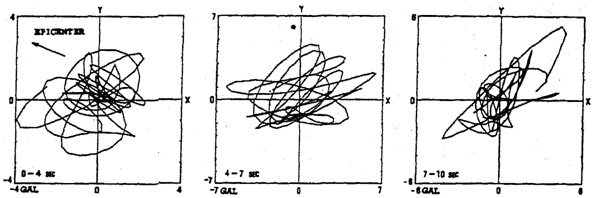


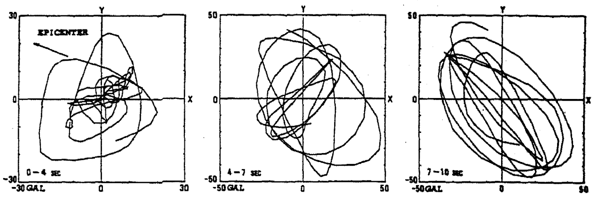
Fig.10 X,Y Component of G32



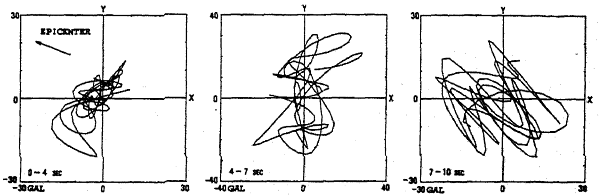
GL-85m



Basemat



30m tower



50m tower

Fig.11 Lissajou's Figure

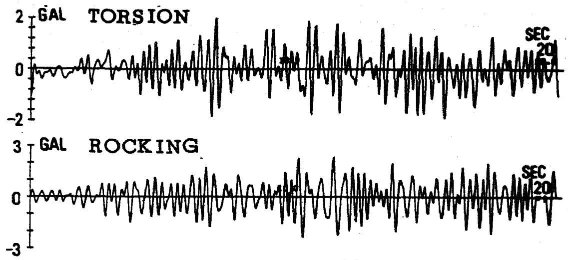


Fig.12 Rotational Motion

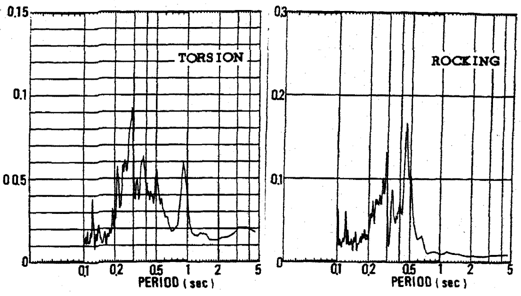


Fig.13 Fourier Spectra of Rotational Motion

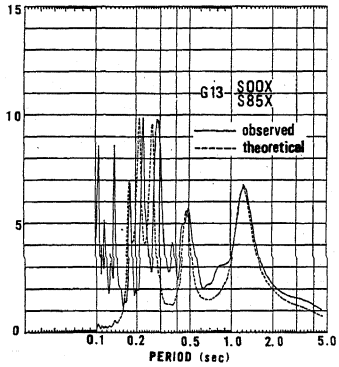


Fig.14 Spectrum Fitting

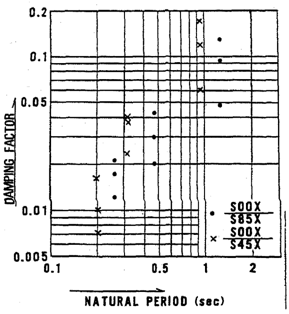


Fig.15 Damping Factor

Tab.1 Period of Structure (sec)

Mode	Tower 30*m*		Tower 50*m*	
	Analytical	Observed	Analytical	Observed
1 st	0.401	0.45~0.47	1.08	1.1~1.2
2 nd	0.085	0.11	0.227	0.26

Tab.2 Period of Soil (sec)

	GL/-85m		GL/-45m	
	Analytical	Observed	Analytical	Observed
1	1.23	1.2~1.3	0.823	0.7~0.8
2	0.471	0.50	0.306	0.32
3	0.264	0.30	0.200	0.22~0.23

DISCUSSION

B. Sarkar (U.S.A.)

The authors found out significant interaction effect in the response of the individual towers and difference in composite response from the response of a single tower. If the towers were not attached by a common base mat but their distances from each other were of the same magnitude, would the authors comment on whether the structure to structure interaction effect would be of such a significant nature ?

Author's Closure

Not received.