EARTHQUAKE MOTION MEASUREMENT OF A PILE-SUPPORTED BUILDING ON RECLAIMED GROUND

by

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SYNOPSIS

To make clear the interaction effects between a pile-supported structure and its surrounding soft subsoil authors have been continuing earthquake motion measurement in and around 7-storied R.C.apartment-house. The earthquake motions measured are not so intense, but through their analysis amplitude and period characteristics could be clarified. Theoretical analyses were also done in the elastic range using lumped mass models, whose results were compared with the observed ones. The appropriate volume of additive soil mass and modal damping ratios of soil and structure could be estimated.

OUTLINE OF BUILDING AND SOIL

The building is 7-storied apartmenthouse made of precast light-weight concrete as shown in Figs. 1 and 2. It has no basement floor and is supported on P.C. piles driven into a dense sandy layer 12 m below ground surface. The structural components are walled frames in longitudinal (Y) direction and shear walls in transversal (X) direction. The natural periods of the building obtained from the forced vibration test are 0.19 sec in X and 0.24 sec in Y direction.

The surrounding soil consists mainly of sand and partly of silt or clay. The N-value distribution is shown in Fig.3 and it differs place by place. The thickness of reclaimed layer is as shallow as 4 - 5 m. The predominant periods observed in microtremor at the ground surface (GL) are 0.2 - 0.4 sec, 0.7 sec and 1.2 sec in the order of peak height.

MEASUREMENT SYSTEM

The location of pick-ups is shown in Fig.3. They composes two groups, building line and soil line. Building line consists of 5 points, RF and 1F in the building, GL-4 m, -12 m and -24 m just below the building. Soil line is parallel to the building line and consists of 4 points at the same level: GL, -4 m, -12 m and -24 m, each about 15 m distant from the building. Every point has three components, two in the horizontal (X,Y) and one in the vertical (Z) direction. The natural periods of the pendulum is 0.2 sec or 0.33 sec and accelerograms can be recorded.

OBSERVED EARTHQUAKES

Since the measurement was begun in 1971 more than 80 earthquakes have been observed. All of them belong to small or middle class of intensity. The distances to the epicenters are distributed in quite wide range, but more than half of them are less than 80 km. Most of the focal depths are around 50 km and 90 % of them are less than 100 km. Magnitudes are mostly below 6.0 with a few exeptions.

Fig.4 shows examples of the observed records in horizontal direction. Amplification from the lower point to the upper point is clear, but the times when maximum amplitudes occur do not always coincide. The record at RF oscilates somewhat harmonically. Comparing the records of the building line and the soil line at the same level, conspicuous difference can not

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be found at the lower two levels GL-12 m and -24 m. However at GL of the soil line shorter period elements are contained considerably and its maximum amplitude is greater compared with 1F.

AMPLITUDE CHARACTERISTICS

The average mode of maximum accelerations of 20 earthquakes in three directions are shown in Fig.5 regulating 1F to unity. In horizontal directions amplification is remarkable above GL-4 m where was the ancient sea bed and N-value is a little high, and below that point amplification is small. The difference between the building line and the soil line can be seen only between 1F and GL. Maximum amplitude of GL is about 1.5 times that of 1F. At lower levels both lines are almost equal, especially at GL-24 m and -12 m. Horizontal motion is amplified 2.52 and 2.83 times from 1F to RF each in X and Y direction. As shown in Table 2 amplification factors of horizontal motion from GL-24 m to RF are 6.19 in X and 6.64 in Y direction. In the soil line from -24 m to GL they are 3.61 in X and 3.24 in Y direction.

As shown in Fig.5 vertical amplification is not so large as horizontal. Average amplification factors are 1.48 from 1F to RF, 1.64 from -24m to 1F and 2.43 from -24m to RF. In the soil line amplitude grows 1.96 times from -24 m to GL. The ratio of the vertical motion to the horizontal ones are 0.27 - 0.34 at GL 0.45 - 0.49 at -12 m and as large as 0.61 - 0.73 at -24 m.

PERIOD CHARACTERISTICS

To know the period characteristics of the observed records Fourier analysis was made and transfer functions of the building, soil and interaction system were obtained by the spectral ratios. Figs. 6 and 7 show some examples of Fourier spectra and spectral ratios, and Table 1 represents the peak periods in transfer functions. It can be said that the longer the transfer distance is taken, the longer the first period becomes. In the building line the primary period of the spectral ratio RF/24 also dominates in RF spectrum. Compared with the periods of the building with fixed base condition, large elongation of the primary period indicates large base translation and rotation, as was recognized in forced vibration test. In the soil line short periods like 0.14 sec and 0.20 sec are predominant at GL, which are identified as the first periods of the layer above GL-4 m and -12 m respectively. Even in the transfer function from GL-24 m to GL the highest peak lies at these short periods, although the first period of the system is calculated to be 0.30 sec. On the contrary at GL-12 m and -24 m longer periods like 0.5 or 0.7 sec are predominant.

Fig.8 shows the Fourier spectral ratio between the building line and the soil line at the same level. From the ratio 1F/GL it is clear that with boundary at about 0.3 sec in longer period range both amplitudes are nearly equal but in shorter period range 1F is half of GL on an average. This means that the short period elements have large amplitudes at GL but they are reduced acting on the building. The average ratio 1.5 of maximum amplitudes can be explained by these short period elements. Such a tendency is weakened according as the depth from the ground surface increases. The ratio at GL-24 m is around unity though with some fluctuations, and it coincides with the fact that both amplitudes are nearly equal. In the ratio at GL-12 m quite large and stable fluctuation is conspicuous, though both lines were shown to have nearly equal amplitudes.

LUMPED MASS MODELS FOR BUILDING-PILE-SOIL SYSTEM

Lumped mass model was adopted to simulate the building-pile-soil interation as shown in Fig. 9. This is similar to that which Penzien et al originally used,[1] but in some points they differ. In the "Cut-out Model" used herein the surrounding soil within some area is treated as real additive masses which move together with piles, and shear -type springs are inserted between these masses. In the original model the additive mass was treated as virtual and shear-type springs between masses were not included. The pressure-type spring connecting the building line and the soil line laterally is common to both models and calculated by Mindlin"s equations.[2] In the original model the additive masses could also be evaluated using the equations on the conception of energy balance, but in the modified model they were assumed parametrically.

The appropriate volume of additive mass was obtained by changing the volume and comparing the primary period with the observed one. As shown in Fig.10 the primary period becomes shorter according to the increase of the additive mass volume. However the slope is gentle and the cross point of the calculated line and the observed one shifts sensitively if a slight error is considered. Then the additive mass ratio against the building mass should be counted with wide range as 0.7 - 2 in X and 3 - 10 in Y direction. In Fig.11 participation functions of tne coupled system are shown for the mass ratio of 1.0(X) and 3.0(Y).

MODAL DAMPING RATIO OF STRUCTURE AND SOIL

The modal damping factors of the building, soil and coupled system were calculated applying "Spectrum Fitting Method", which simulates the transfer function of the model to the observed one assuming damping ratios modally as shown in Fig.12. For the building, observed records at 1F were input to the lumped mass model with base rotation included. For the soil column, observed records at GL-12 m both of the soil line and the building line were applied to the model representing soil column above GL-12 m. The difference of both records were not influencial to the results. For the coupled system, obtained damping ratios of the soil column were used for the free soil column, and the damping ratios of the structure with additive soil masses were investigated. In this case modal synthesis is very difficult and then modal damping ratios were translated into orthogonal damping matrix.[3]

Table 3, 4 and 5 show the values obtained, each for the building with base rotation, soil column above GL-12 m and structure with additive soil masses. The average damping ratios for the first mode of each system were 5 - 6.5 % for the building, 8.5 - 9.5% for the soil column and 3.3 - 3.4 % for the structure with additive masses. For the soil column remarkable trend of decrease in higher modes can be seen. For the structure with additive masses the values for the second mode were larger than those of the first mode. As a possible reason for this the close relation of each modes for this period can be pointed out.

REFERENCES

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2) Mindlin,R.D. "Force at a Point in the Interior of a Semi-Infinite Solid" Physics, Vol.7 (1936)
3) Wilson,E.L. and Penzien,J. "Evaluation of Orthogonal Damping Matrices" International Journal of Numerical Methods in Engineering, Vol.4 (1972)

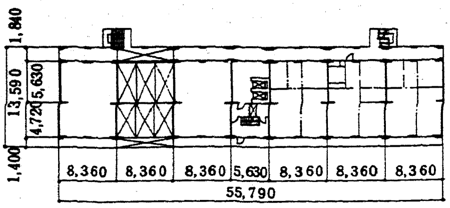

Fig.1 Plan

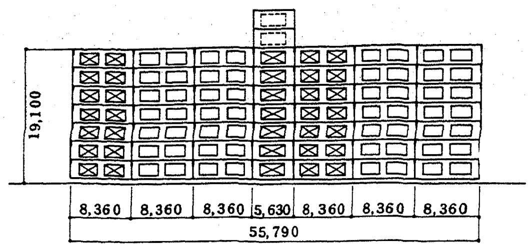

Fig.2 Section

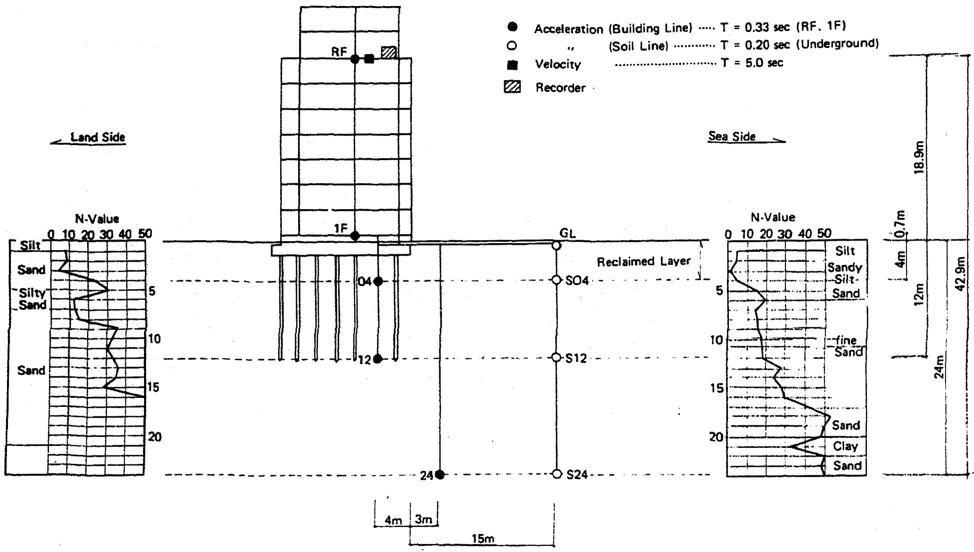

Fig.3 Pick-up Location and Soil Profile

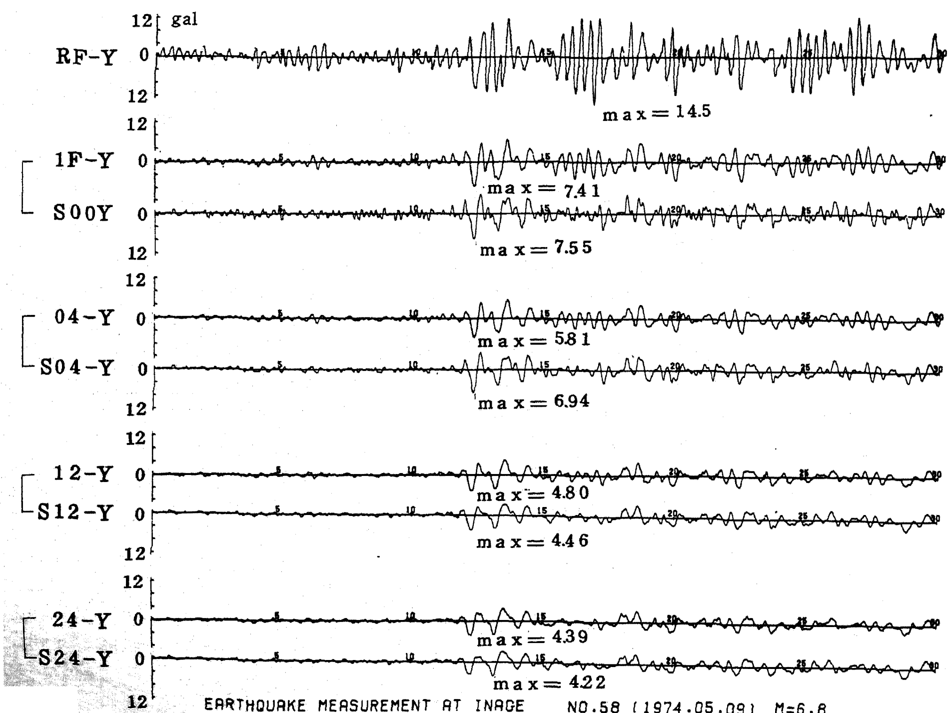

Fig.4 Observed Records No. 58-Y

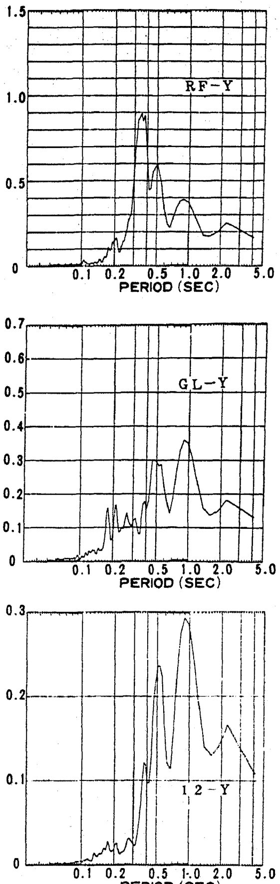

Fig.6 Fourier Spectrum

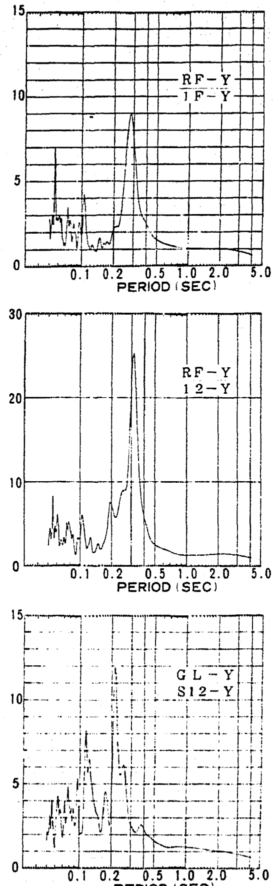

Fig.7 Transfer Function

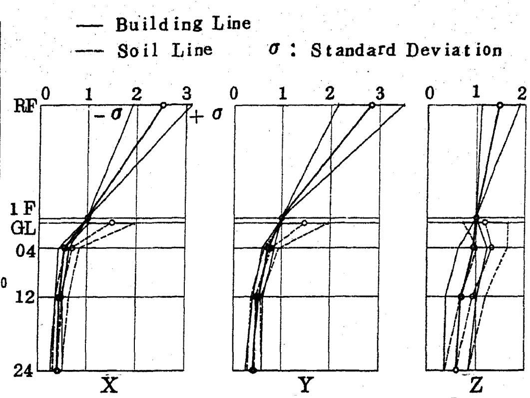

Fig.5 Maximum Acceleration Mode

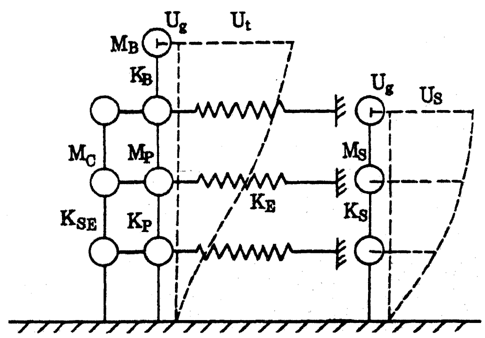

Fig.9 Model Conception

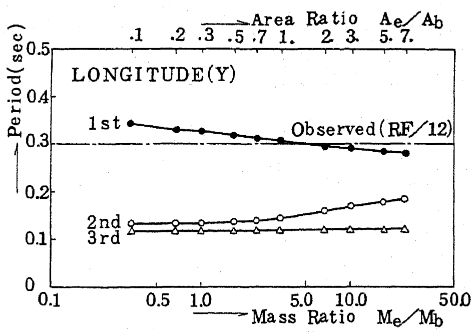

Fig.10 Additive Mass vs. Period Variation

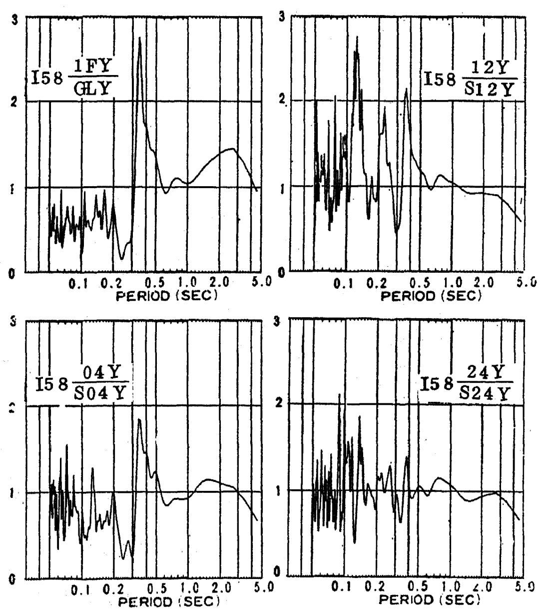

Fig.8 Fourier Spectral Ratio (Building Line / Soil Line)

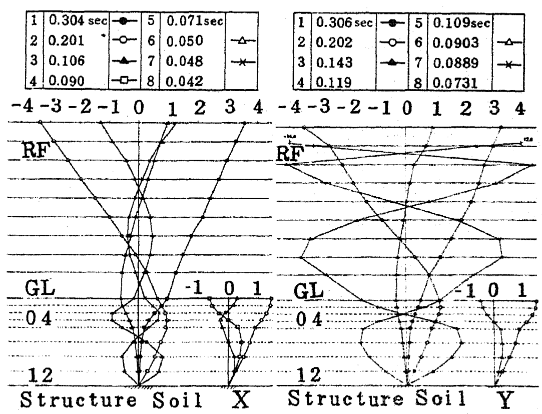

Fig.11 Participation Function of Coupled System

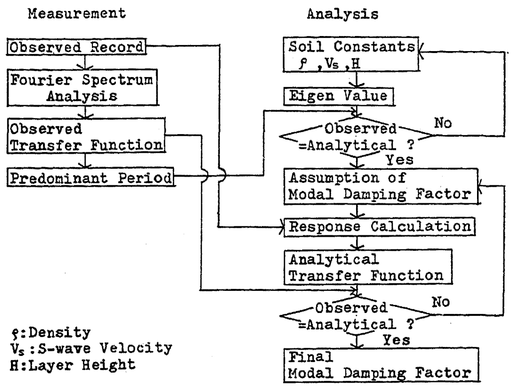

Fig.12 Spectrum Fitting Method

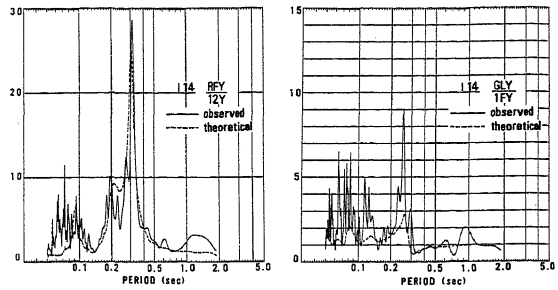

Fig.13 Fitted Spectra

Table 1. Peak Periods in Fourier Amplitude Ratio

Ratio		X			Y			Z
		1	2	3	1	2	3	1
Building Line	RF/1F	0.24	–	–	0.27	0.23	0.10	0.06
	RF/04	0.27	0.14	–	0.30	0.28	0.15	0.07
	RF/12	0.30	0.21	–	0.32	0.28	0.20	(0.07)
	RF/24	0.32	0.28	0.15	0.34	0.28	–	0.07
Soil Line	S00/S14	0.14	–	–	0.14	–	–	–
	S00/S12	0.21	0.12	–	0.22	0.12	–	–
	S00/S24	0.14	0.33	0.20	0.14	0.28	0.088	0.07

(The order is from higher to lower peak)

Table 2. Amplification Factor from GL-24m

		X	Y	Z
Building Line	RF	6.19	6.64	2.43
	1F	2.45	2.34	1.64
	04	1.32	1.70	1.55
	12	1.09	1.22	1.16
	24	1.00	1.00	1.00
Soil Line	S00	3.61	3.24	1.96
	S04	1.68	1.72	2.20
	S12	1.20	1.05	1.54
	S24	1.00	1.00	1.00

Table 3. Modal Damping Ratios of the Building (Base Rotation Included)

	Order	Period sec	Earthquakes			
			No. 07	No. 14	No. 49	No. 58
X	1st	0.237	0.018	0.073	0.064	0.057
Y	1st	0.270	0.096	0.034	0.066	0.062
	4th	0.084	0.046	0.015	0.060	0.060

Table 4. Modal Damping Ratios of the Soil Column ( ):only for No. 49, No. 58

	Order	Period sec	Earthquakes			
			No. 07	No. 14	No. 49	No. 58
X	1st	0.202 (0.228)	0.081	0.050	0.13	0.12
	2nd	0.090 (0.111)	0.050	0.048	0.057	0.086
	3rd	0.050 (0.062)	0.015	0.020	0.035	0.030
Y	1st	0.202 (0.228)	0.11	0.10	0.068	0.061
	2nd	0.090 (0.111)	0.030	0.055	0.044	0.042
	3rd	0.050 (0.062)	0.020	0.047	0.015	0.029

Table 5. Modal Damping Ratios of the Structure with Additive Mass

	Order	Period sec	Earthquakes	
			No.07	No.14
X	1st	0.303	0.026	0.042
	2nd	0.106	0.054	0.061
	3rd	0.071	0.050	0.033
Y	1st	0.306	0.027	0.039
	2nd	0.143	0.12	0.13
	6th	0.089	0.090	0.085

DISCUSSION

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The authors assumed constant damping of 6% for the soil-column. The strain dependency of the damping parameter being ignored, the response will be significantly different obviously.

Author's Closure

Not received.