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SHAKING TABLE TESTS AND EARTHQUAKE OBSERVATIONS OF AN ACTUAL SIZE STEEL FRAME

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SUMMARY

Dynamic characteristics of an actual size steel frame was mesured in the shaking table tests and impulse-hummer tests. The impulse-hummer tests are useful the estimation of natural frequencies. The computer simulation program was developed for shaking table tests, including the control systems. The computer simulation of shaking table tests is necessary to conduct the shaking table test of the structure accurately. The eartquake observations, using six components seismograph, shows that the tortional vibrations have been observed even for a synmetric sturucture.

INTRODUCTION

The dynamic analysis methods have become to be often used for the earthquake-resistant design of the structure in resent years. Static experiments on earthquake-resistant performance of structural elements, dynamic experiments of structures using a shaking table and observation of earthquake response of structures are performed to verify the validity of analysis methods.

However, the studies that one structure was tested on the shaking table and ground surface, are a few.

In recent years the shaking table with three-dimensional six degree freedom is developed, but rotational motion is rarely used as a input of the shaking table exitation. It is one reason that observation of rotional motion has not been recorded directly. Therefore, we developed the seismograph with six mesurament components(three dimentional six freedom) and we used it to observation of eartquake response of the structure.

In the shaking table tests of the structure, interaction effects between shaking table and structure is rarely considered. In the analysis of the shaking table data, it may be necessary to consider the shaking table systems. In this reason, the dynamic test structure simulations including the shaking table control system, were tried.

MATERIAL AND METHOD

Outline of Actual Size Steel Frame Photo 1 and Fig.1 show the actual size steel frame model used in the test (herein-after called the test frame). Moreover, the members size of the test frame is shown in Table 1. The test frame had a span and two stories, which were forced with a single brace of L-shaped steel bar (L-75*7*5*2) in the direction of excitation (herein-after called the X direction). In the direction perpendicular to excitation (herein-after called the Y direction), double braces were equipped: L-90*90*10 for the first story and L-75*75*6 for the second story. The braces in the X direction could be detached both of the two stories. Eight concrete blocks (1.6 * 1.6 * 1.6 (m)) were placed on each story. The test frame was constructed with bolted joint. So this frame would be easily reconstructed.

To install the test frame on the shaking table, the pedestals were bolted on the cross-shaped steel base, which was bolted on the shaking table. This frame was installed on the reinforced concrete foundation on the ground surface by fixing anchor bolt set.

Table 1 Member size of test frame

Story	Element	Direction	Structual steel
1	Colmun	—	BH-300×200×12×19
	Beam	X	H-588×300×12×20
		Y	H-450×200×9×14
	Brace	X	L-75×75×6
		Y	L-90×90×10
2	Column	—	BH-300×160×9×12
	Beam	X	H-488×300×11×18
		Y	H-400×200×8×13
	Brace	X	L-75×75×6
		Y	L-75×75×6

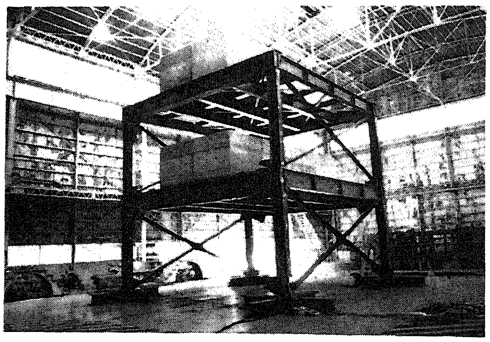
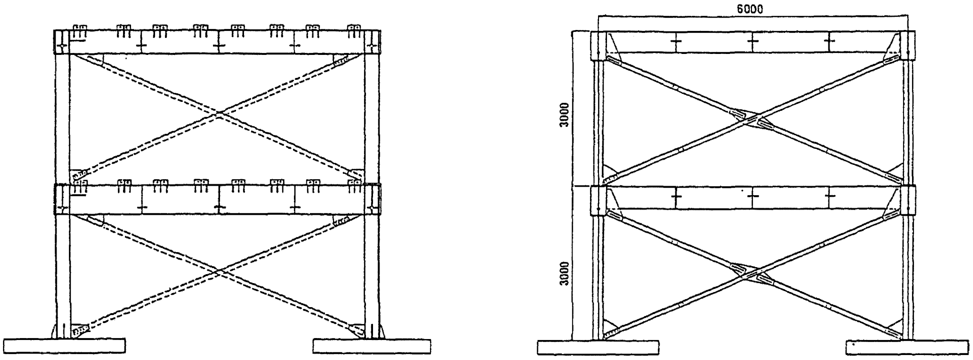


Photo 1 Acutual size steel frame



(a) X direction (b) Y direction

Fig.1 Actual size steel frame

<u>Test Method</u>

A. Test on large shaking table

a. Shaking table excitation test

Three types of the test frames, with double side ,with single side and without braces in the X direction, were tested by exciting the shaking table with sinusoidal vibration (1 - 10 Hz). The test frame without braces in the X direction was tested with pulse excitation.

b. Impulse-hammer test

Three types of the tests frame wrer tested by exciting at the junction of the column and beam with a hammer (approx. 5.9 kg). The shaking table was stopped and settled during the tests.

B. Test on the foundation of the ground surface

a. Test using the ground vibration excited by shaking table

The ground vibration by exciting the large shaking table was used as input motion to the test frame without braces in the X direction. Fig. 2 shows the position of the large shaking table and the test frame. Fig. 3 shows the boring log near the installation site of the test frame, and Fig. 4 shows the foundation for the test frame. The foundation, 5.6m*5.6m*0.35m, is equipped with the foundation beam of 1.2 meters in height and 0.4 meters in width on the periphery, totally weighing about 60 ton.

b. Impulse-hammer test

The test frame installed on the reinforced concrete foundation on the grand surface was tested by the same test method as in the impulse-hammer test on the shaking table.

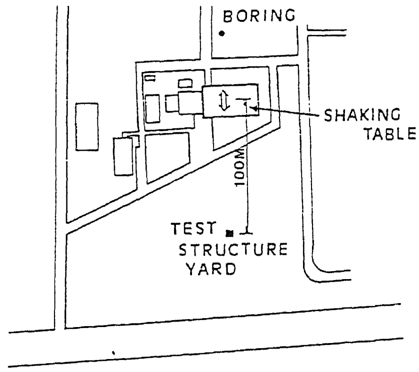


Fig.2 Test yard

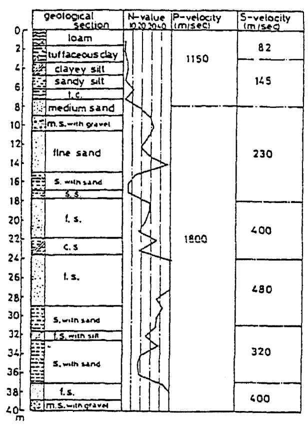


Fig.3 Boring log

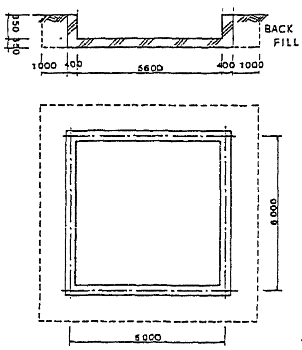


Fig.4 Foundation of test frame

C. Seismic observation

The seismic observation is conducted by installing the seismograph on the test frame and the the reinforced concrete based on the ground surface. Fig. 5 shows the installation position of the seismograph, and the direction of the seismic observation.

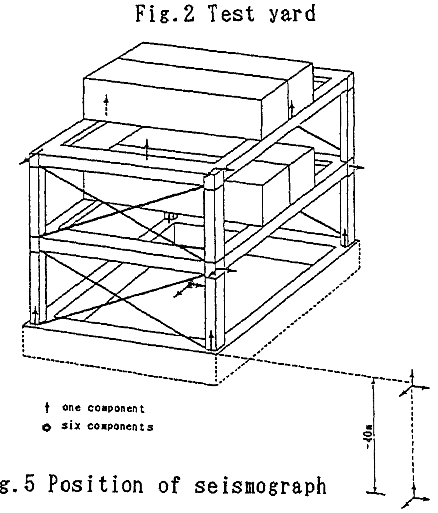


Fig.5 Position of seismograph

RESULTS

Results of Test on Large Shaking Table Table 2 shows the first natural frequency and the damping ratio of the test frame obtained by the shaking table excitation test and the impulse-hammer method on the large shaking table. The frequency in the X direction was 2.0 Hz in the shaking table excitation and 2.12 Hz in the impulse-hammer method, showing similar values. The damping ratio was 1.94% in the shaking table excitation and 0.29% in the impulse-hammer method, 75% less than the value of the shaking table excitation. The frequency of the test frame of the Y and tortion directions in the shaking table excitation and in the impulse-hammer method show similar values as in the test of the X direction. Since the direction of excitation was the X direction alone in the shaking table excitation, the damping ratio of the Y and tortion direction could not accurately obtained.

Table 2 Results (on the shaking table)

Test method		X direction		Y direction		Tortion	
Brace (X)	Input	Frequency Hz	Damping %	Frequency Hz	Damping %	Frequency Hz	Dampin %
Double side	Impulse hummer	3.88	0.39	4.48	0.53	11.1	1.13
	sinusoidal wave	2.8	3.57	4.3	—	9.4	—
Single side	Impulse hummer	2.88	0.38	4.44	0.47	—	—
	sinusoidal wave	2.4	5.21	4.34	—	8.2	—
Without	Impulse hummer	2.12	0.29	4.37	1.33	8.76	0.69
	sinusoidal wave	2.0	1.94	4.38	—	8.0	—
Design (without brace)	Pin	1.47	—	4.70	—	—	—
	Fix	2.70	—	4.81	—	—	—

Fig. 6 shows the resonance curve of the test frame obtained by shaking table excitation.

The acceleration of the shaking table at the shaking table excitation was 20 gal,and the acceleration of the test frame at resonance point was 300 gal on the second story.

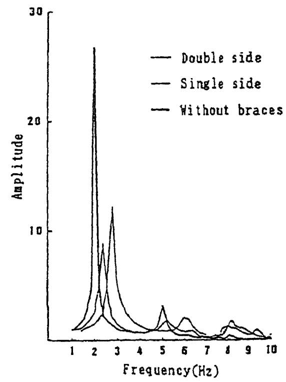


Fig.6 Resonance curve

Results of Test on Foundation Table 3 shows results of the ground vibration test generated by the shaking table excitation. It also shows results of the test by the impulse-hammer method. The natural frequencies the test frame in the X, Y and tortion directions show almost the same results in both tests. However, the damping ratio of the test frame was 1.90% inthe X direction and 4.10% in the Y direction in the ground vibration test, while the respective figures in the impulse-hammer method became 0.64%and 1.88%, 50 or 60% less than those in the ground vibration test.

The multi-degree of freedom model, taking rocking and sway into consideration for ground vibration test of the test frame on foundation, was used to conduct simulation with a computer. The ground was assumed to be a semi-finite elastic body with Poisson 's ratio of 0.45, unit volume weight of 1.54 t/m**3, and shear wave speed of 145 m/s, and rigidity, additional mass, and damping for the foundation were taken into consideration. Fig. 7 shows resonance curves of the test frame obtained by the ground vibraion test and by the simulation.

The acceleration of the ground near the test frame in the ground vibration test was 0.1 gal at the excitation frequency of 2 Hz.

Table 3 Results (on the ground)

Direction / Input	X direction		Y direction		Tortion	
	Frequency Hz	Damping %	Frequency Hz	Damping %	Frequency Hz	Damping %
Impulse hummer	2.08	0.64	3.54	1.88	6.92	1.42
sinusoidal wave	2.08	1.90	3.55	4.10	6.90	—
Theory	2.13	1.48	—	—	—	—

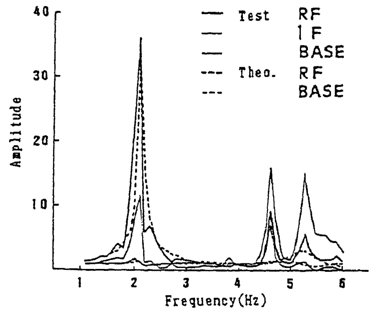


Fig.7 Resonance curve

Seismic Observation Results The system outline of six components seismograph is shown in Fig. 8. The each component of this seismograph was made up by adding or subtracting the outputs of six sensors by the electric amplifier.

Several significant waves were observed as of now. Fig. 9 shows the comparisons of six components seismograph records and the waves obtained by one component seismogrphs. The rocking motions about X,Y axis and the up-down motion which were synthesized from the up-down waves of one component seismographs. To verify adjustment of synthetic waves and waves observed by the six components seismograph, both waveforms were checked for correlation. The correlation in the angles of rotation were 0.85 in the N-S and 0.89 in the E-W. The correlation of vertical waveforms was 0.64. Tortion(1F)comp. in Fig 9 was synthsized from the first floor recods. Fig 10 shows a spectrum of the tortion component of the test frame recorded by the six components seismograph. There was a major peak at 6 Hz, and this frequency is thought the the first natural frequency of the tortion of the test frame.

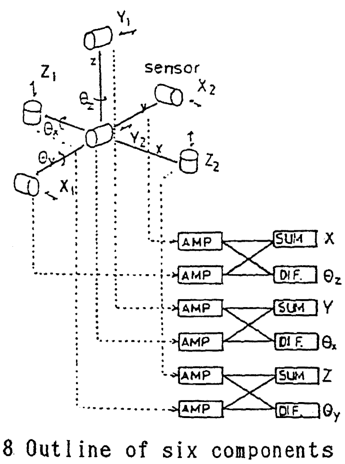


Fig.8 Outline of six components seismograph

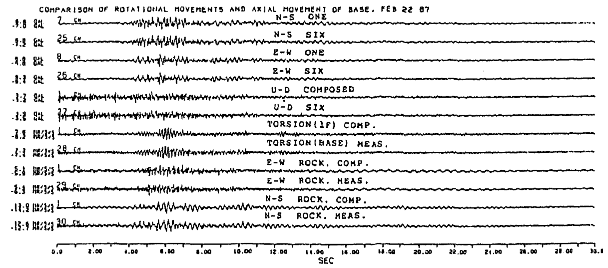


Fig.9 Comparisons of two kinds waves

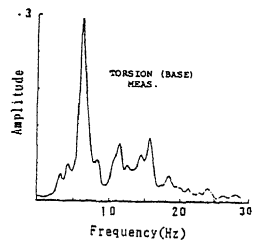


Fig.10 Fourier spectrum of torsion comp.

A two-direction model of the test frame, taking rocking and sway into consideration was used, and waveforms in the E-W and N-S were used as input of the model for responce analysis. Fig. 11 shows the results. The rigidity of the test frame was obtained from the above-mentioned test results, and that of the ground spring was obtained parametrically. The difference of the center of gravity and the center of rigidity was assumed to be 60cm in N-S on each floor and to be 0 cm in E-W on each floor.

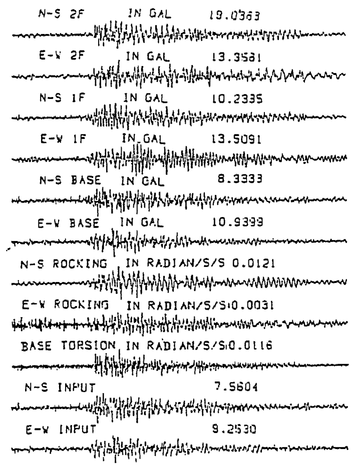


Fig.11 Results of two-direction model

<u>Results of Computer Simulations Considering the Mechanism of Shaking Table</u> The shaking table has displacement-controlled system. The displacement command signal in this test was the displacement wave of EL Centro, 1940, N-S. The computer simulation model of a shaking table test that has hydraulic actuators with servo control systems, is shown in Fig. 12. In this model, the non-linearities of oil flow in servo valves, and of oil column rigidities in actuators are considered.

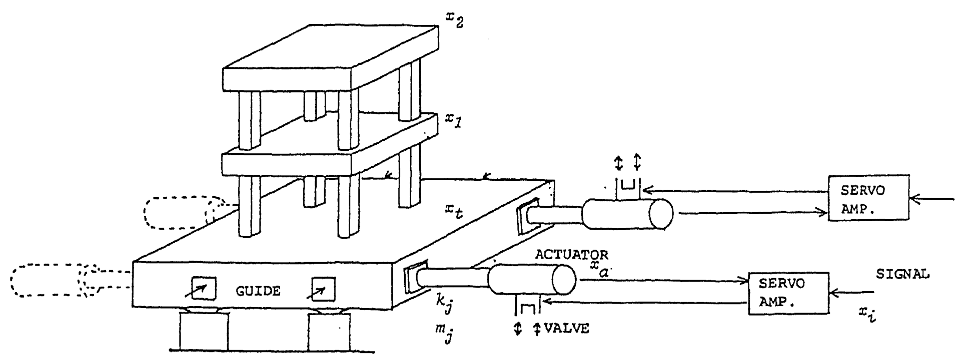


Fig.12 Computer simulation model

The equations of this models are shown as follows.

SERVO VALVE : $\ddot{x}_s + h_s \omega_s \dot{x}_s + \omega_s^2 x_s = \omega_s^2 k_G(x_i - x_a - k_p P_d - k_v \dot{x}_t - k_a \ddot{x}_t)$

ACTUATOR : $S \dot{x}_a + \frac{(V_1 - S x_a)(V_2 + S x_a)}{V} \dot{P}_d + k_l P_d = k_g f(x_s)\sqrt{1 - \left|\frac{P_d}{P_s}\right|}$

$k_g f(x_s)$: sarvo valve characteristic　　S : section area of piston

V_1: volume of c_1　　V_2 : volume of c_2

k_l : leak rate from contact　　V : v_1+v_2

P_d : difference pressure between c_1 and c_1

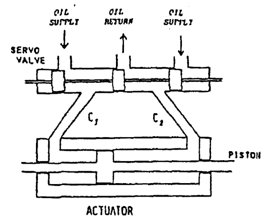


Fig. 13 Actuator and servo valve

The tests results of the frame without braces in X direction is shown in Fig. 14. The results of computer simulations of the shaking table tests are also shown in Fig. 14. The difference between the simulation and the test was recognized in the peak acceleration of the shaking table. But, the difference of the two results was a little, 7 % in the acceleration of the second story.

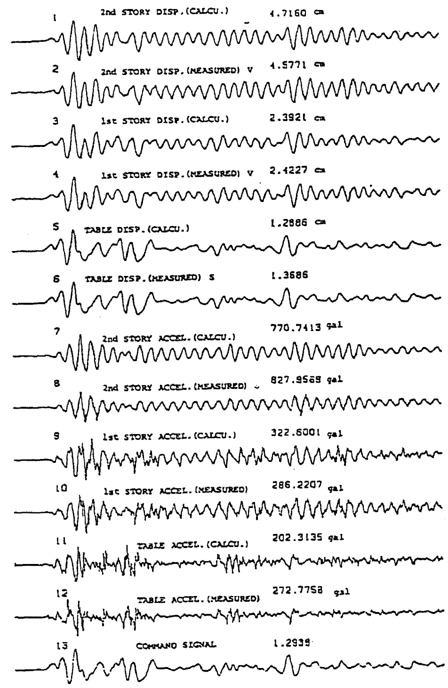


Fig. 14 Results of simulations

CONCLUSION

The vibration test of a structure in the impulse-hammer method is convenient compared with the test using a shaking table and effective in obtaining the frequency of the natural mode of the test frame. However, it is not suitable for evaluation of damping of the test frame.

Even a symmetrically shaped structure may generate twist vibration due to the scarcity of construction accuracies and impact such as earthquakes.

The computer simulation of shaking table tests are useful, and will be possible for non-linear structures.

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REFERENCES

1. Tajimi, H., "Basic Theories on Aseismic Design of Structures, "Report of the Institute of Industrial Science, Univ. of Tokyo, Vol. 8, No.4 1959
2. Second Research Division, Natinal Reseach Center For Disaster Prevention, "A Feasibility Study for The Renewal of The Large -Scale Shaking Table, "Review of Research For Disaster Prevention, No. 99 1987
3. Minowa, C., et al, "Vibration Tests of an Actual Size Steel Frame, "Summary of the Technical Report of the Annual Meeting of the A.I.J., Aug. 1986
4. Minowa, C., "Earthquake Observations of Steel Frame Foundation by Six Components Seismograph, "Summary of the Technical Report of the Annual Meeting of the A.I.J., Oct. 1987