Dynamic Characteristics of the Base-Isolated Building Constructed on a Soft Ground

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1. Introoudction

Construction of a base-isolated building on a soft ground has been thought of to be very difficult, considering its dynamic characteristics which the ground presents at an earthquake. This paper, in all aspects, discusses the dynamic characteristics of the base-isolated building constructed on a soft ground; for the purpose of spreading the use of the isolation system, December 1988, we have constructed a building which is isolated in its base from earthquake oscillation, in Edogawa Ward, typical soft ground in Tokyo (classified as the third class in Building Standard Law). Using this full-scale model, we studied its vibration-behavior and conducted an analysis by simulation on the basis of earthquake data obtained on the model building.

2. Description of the ground, building and isolation system

2.1. Outlines of the ground and building

The tested building is a dormitory of 10.5 m in eaves height, of three story reinforced concrete structure, weighing 1400 tons and covering 770 m^2 in total (Photo 1).

As shown in Figure 1, geologically, a thick alluvium extends on the diluvium which consists, from above, of the upper Tokyo formation, the Tokyo gravel bed and the lower Tokyo formation.

2.2. Isolation system

The proposed isolation system features combination of a standard type laminated rubber bearing and a steel damper, but the latter is designed and developed especially for this purpose. Details of the laminated rubber bearing and the steel damper are shown respectively in Figures 2 and 3. The layout of the isolation system is given in Figure 4.

3. Vibration test and its results

Through the test, we have conducted two kinds of vibration test, free vibration and forced vibration in order to know basic vibration characteristics of the base-isolated building and the performance of the isolators in a wide frequency range.

3.1. Free vibration test

(1) Test method

As shown in Figure 5, the upper footings are connected, with PC steel wires, to a hydraulic jack set in the lower footing. By using the jack, relative displacement was made occur between the foundation and the building, releasing restraining force by cutting the breaking pin at the joining part to produce free vibration in the building. The relative displacement between foundation and building is 100 mm, equivalent to a response deformation appearing to the building when attacked by an earthquake of class VI (about 250 cm/s^2).

(2) Test results and observations

- The restoring force immediately after the free vibration and the analysis value are shown in Figure 6. As they demonstrate good agreement, featuring the bilinear type restoring force used for analysis.
- The deformation time history wave form in the isolation story and its analysis value are given in Figure 7 and the vibration mode in Figure 8. From the Figure 7, we understand that after the release, the amplitude rapidly converge at less than 20 mm in onc cycle.
  The analysis value and the experimental value show good agreement. From the vibration mode, we can see that it demonstrates the rigidity behavior inherent in the isolation structure.

3.2. Forced vibration test

(1) Test method

A shaker of 50 tons was installed on the building roof. Parallel vibration is applied in the short sides (X direction) and long sides (Y direction). Excentric shaking is made in the X direction (Fig. 9).

(2) Test results and observations

- The resonance curves (parallel and excentric accelerations on each floor) are given in Figures 10, 11 and 12. The vibration mode at parallel acceleration is shown in Figure 13.
  The natural vibration of this building is 0.96 Hz, in X direction, 0.99 Hz in Y direction, having no difference in direction; they coincide well with the frequency (1.0 Hz) of the initial rigidity obtained by the free vibration test. Furthermore, the vibration mode shows, even in small amplitude, the rigidity behavior inherent in the isolation structure.
- As the torsion peak at each acceleration is 1.02 Hz, almost same as the resonance point obtained by the parallel acceleration, we can consider that torsion exerts almost no effect on the seismic behavior of the building.

4. Earthquake study on the base-isolated building and simulation analysis

This building is designed as a total system to experiment the ground, isolation system and building, performing a series of surveys and collecting the data concerning the behavior. Figure 14 shows the layout of seismometers. In this section, we discuss the analysis of the earthquake waves recorded on the building as well as the simulation analysis using the above results.

4.1. Seismic observation

(1) Characteristics of the earthquake waves recorded

After the completion of the building, it has experienced several earthquake attacks. Of them, the relatively larger attack, occurred at the south-east of Ibaragi-Prefecture, was selected to study the base-isolated building. The results of the study are given hereunder. Table 1 shows the specifications of the earthquake.

(2) Analysis results and observations

Through the analysis of the ground, a ground model is created as shown in Figure 15, taking into consideration the boring survey of the site and the in-laboratory test results. After inputting the earthquake wave obtained at 51.5 m under the ground level by one dimensional wave theory (SHAKE), the model is compared with the earthquake wave given at the building foundation. Figure 16 shows Fourier spectra of the both cases. For the analysis of the building, using the characteristics of an isolation system confirmed through the shaking test of the building, we produced a multiple particle system model (Figure 17).

We inputted the actual earthquake waves to the model to perform the earthquake response analysis. Its results are compared with the survey results (Figure 18). From the analysis, it is confirmed that its results coincide well with the measured values.

4.2. Simulation analysis of the building

In order to ensure the propriety of the characteristics discussed in the precedent chapter and the analysis method, and to study the dynamic characteristics of the building, we have prepared two kinds of artificial earthquake waves different in nature, but which can be assumed to occur on this ground. These waves are inputted to the model, providing two input levels of 25, 50 cm/s as standard, to perform the earthquake response analysis of the building. Figures 19 and 20 present the response analysis results. The analysis confirms that in each response value, Case B is larger than Case A, with a minor difference of 10 to 20%. By comparing with the conventional type aseismic structure, we know that the isolation system works effectively, because the acceleration of the building is reduced to one-third. The base-isolated building, even if attacked by larger earthquakes, may demonstrate a good isolation effectiveness to earthquake waves of different nature.

Conclusion

Through the vibration test, the following are demonstrated:

- The restoring force characteristics of the isolation system coincide well the design values. In the larger deformation field, a large attenuation is obtained by yielding of dampers.

- In the field of small amplitude, the natural vibration frequency in the parallel direction presents good agreement with the frequency calculated from the initial rigidity. The natural vibration frequency torsion approximates the peak in the parallel direction.

- The building features a rigid behavior with less inter-story displacement for the fields of small amplitude and large amplitude. The vibration observed in the building is shifted into the isolation frequency, and this means that the building has the isolation performance as designed.

In the seismic observation and the simulation analysis of the building, the following are confirmed:

- The analysis results of the ground and the building, using the seismic survey, shows good agreement with the measured values.

- The simulation analysis shows that the building can produce an isolation effect of high reliability.

As mentioned above, by means of the seismic observation and the vibration test, we can confirm that the base-isolated building constructed on the soft ground demonstrate a sufficient isolation effect.

Continuing the seismic observation, we will pursue our study on the isolation effect of our base-isolated building constructed on the soft ground, especially for large earthquake attacks.

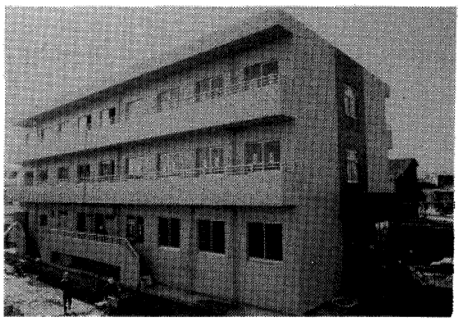

Photo 1 View of the building

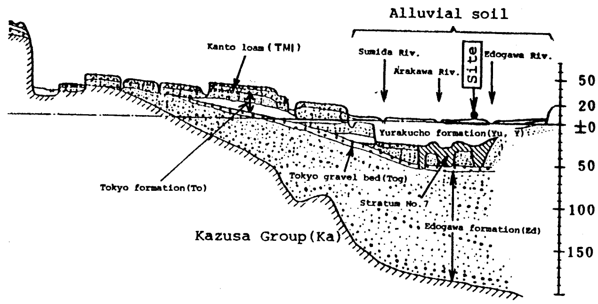

Fig. 1 Geologic profile

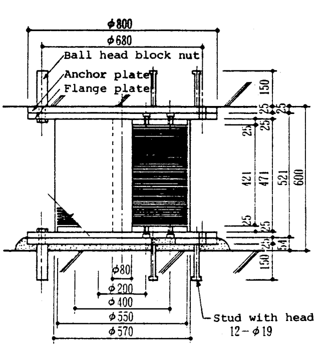

Fig. 2 Detail of the laminated rubber bearing

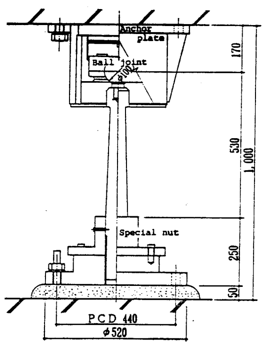

Fig. 3 Detail of the damper

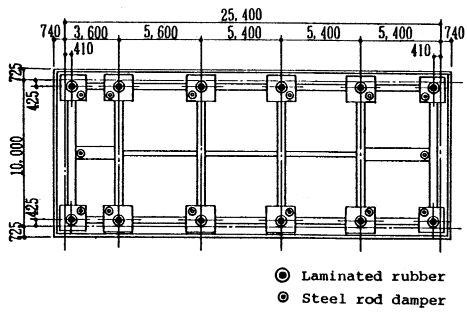

Fig. 4 Layout of the isolation system

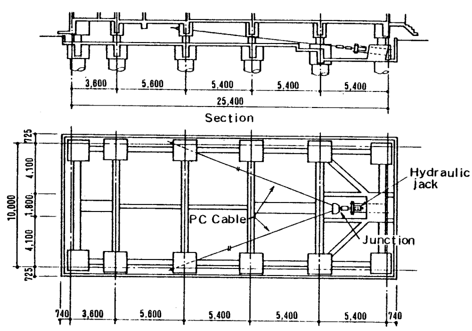

Fig. 5 Schematic diagram of the experiment system

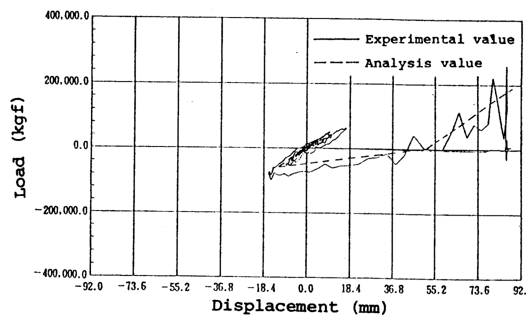

Fig. 6 Comparison of restoring characteristics (relative displacement: 100 mm)

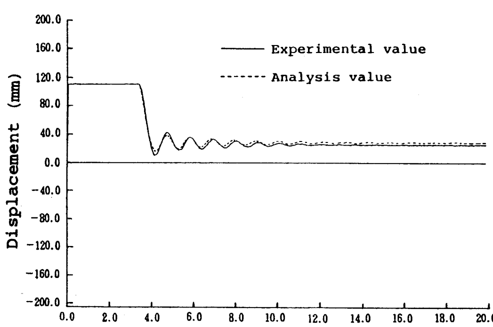

Fig. 7 Displacement-time history wave form in the isolation story (relative displacement: 100 mm)

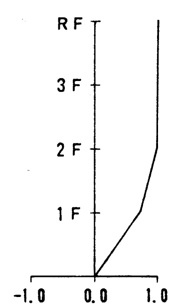

Fig. 8 Vibration mode (relative displacement: 100 mm)

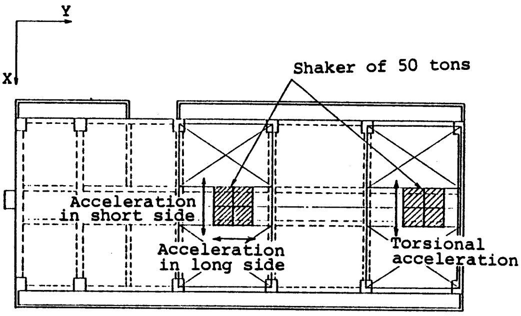

Fig. 9 Position of the shaker and acceleration direction

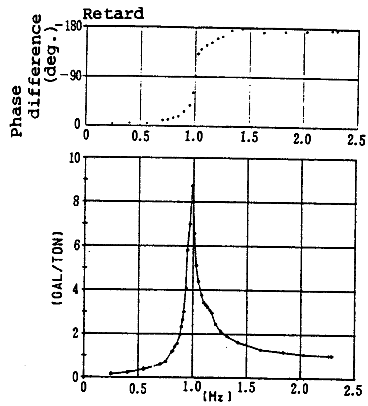

Fig. 10 Resonance curve (parallel acceleration in Y direction)

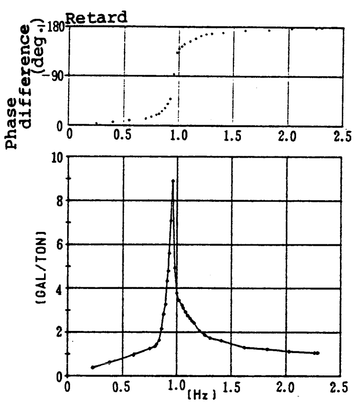

Fig. 11 Resonance curve (parallel acceleration in X direction)

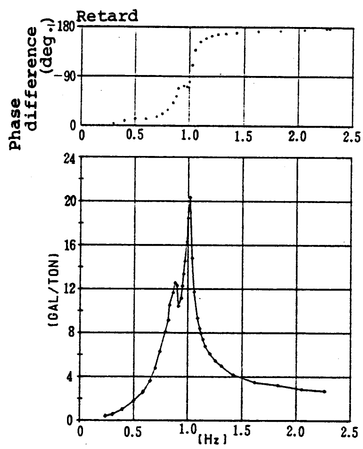

Fig. 12 Resonance curve (torsional acceleration)

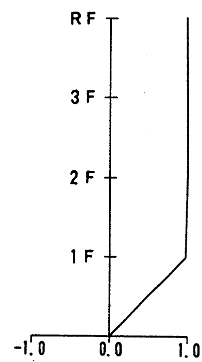

Fig. 13 Vibration mode (parallel acceleration in X direction)

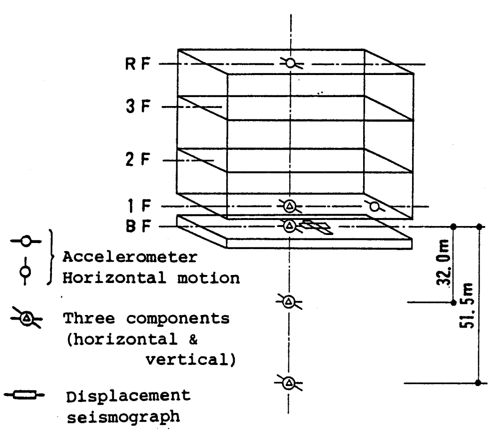

Fig. 14 Layout of the seismometers

Table 1 Specification of the earthquake

Occurrence of earthquake (time)	Epicenter latitude / longitude	Magnitude (M)	Depth (km)	Epicentral distance (km)	Intensity in Chiba
H1. 2. 19 21:27	South-east of Ibaragi Pref. 36° 00'N 139° 55'E	5.6	54	36	III

Depth (m)	ρ (t/m³)	Vs (m/sec)	H (m)	h (%)
−0.0				
	1.65	110	10.0	※
−10.0				
	1.6	150	16.0	※
−26.0				
	1.7	220	12.0	※
−38.0				
	2.0	440	325.0	2.0
−363.0				
	1.9	680	1,137.0	1.7
−1,500.0				
	2.2	1,500	800.0	1.0
−2,300.0				
	2.5	3,000	∞	

* The above data are taken from the dynamic deformation curve obtained through the in-laboratory soil test.

Fig. 15 Ground model

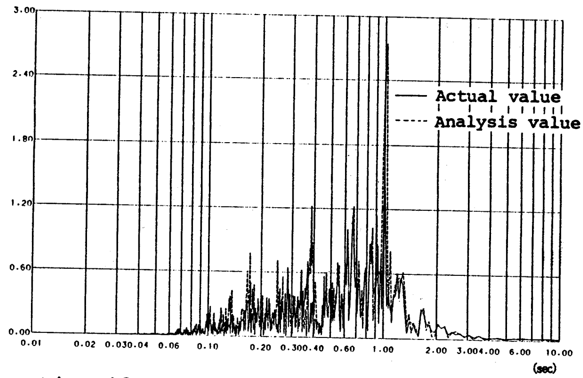

Fig. 16 Fourier spectra (building foundation)

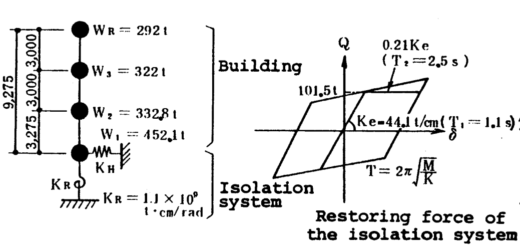

Fig. 17 Analysis model

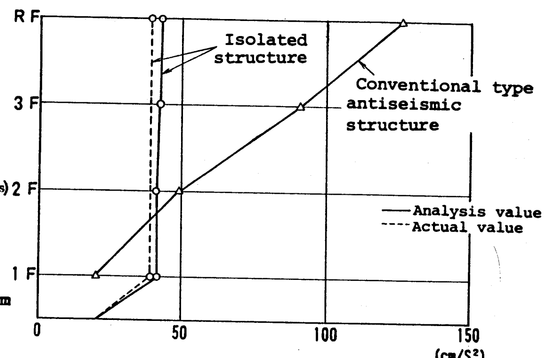

Fig. 18 Maximum acceleration response

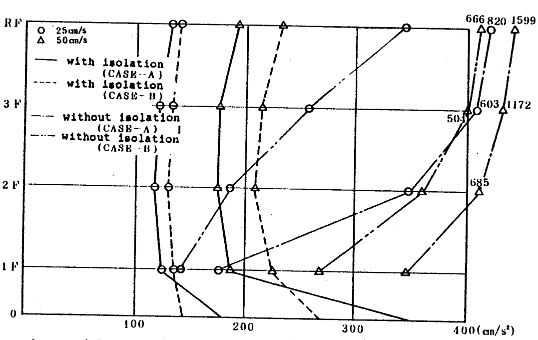

Fig. 19 Maximum response acceleration

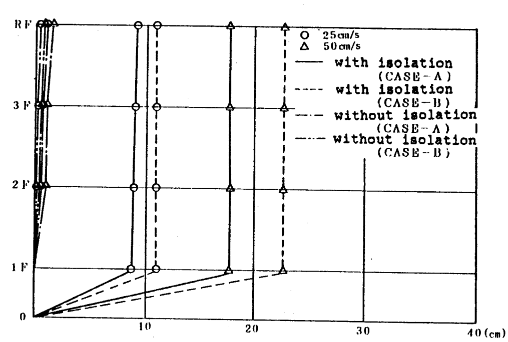

Fig. 20 Maximum response displacement

References

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Seki and Okada et al., "Study on the seismic isolation of the structures" (Part 1 to 11), Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan 1984.10, 1985.10, 1986.8