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VIBRATION TEST AND EARTHQUAKE RESPONSE OBSERVATION OF BASE ISOLATED BUILDING

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SUMMARY

For the purpose of investigating dynamic behavior and proving reliability of the base isolated building using laminated rubber bearings and elasto-plastic steel dampers, vibration test, earthquake response observation and numerical analysis were performed. Through these studies, the followings are verified.

i) In the large deformation region of the isolation device, the natural period of the base isolated building becomes longer considerably and the elasto-plastic damper provides a enough large damping as designed.
ii) Acceleration response of the base isolated building during earthquakes differs according to the frequency characteristics of the ground motion. However, it is sufficiently reduced in comparison with that of the ground surface.
iii) Numerical result using a lumped-mass model well agrees with the observed record.

INTRODUCTION

Base isolation system is reaching a stage for practical use in Japan. In order to apply this system to various structures, accumulations of verification data are necessary.

From this point of view, the vibration test and the earthquake response observation of the base isolated building using laminated rubber bearings and elasto-plastic steel dampers were conducted for the purpose of investigating its dynamic behavior and of proving the reliability of the base isolation system. Since September 1986, more than thirty earthquakes have been observed. This paper presents the results of the vibration test, earthquake response observation and the numerical simulation.

OUTLINE OF BASE ISOLATED BUILDING AND ISOLATION DEVICE

Base Isolated Building The base isolated building, a object of test and observation, is a four-story reinforced concrete building with dimensions of 15m in width, 20m in length and 14m in height as shown in Fig.1. Total floor area is 1,330m^2 and the weight is 2,250ton. Seismic isolation devices are installed between the basemat and the first floor.

Seismic Isolation Device The seismic isolation device consists of laminated rubber bearings and elasto-plastic steel dampers, providing the

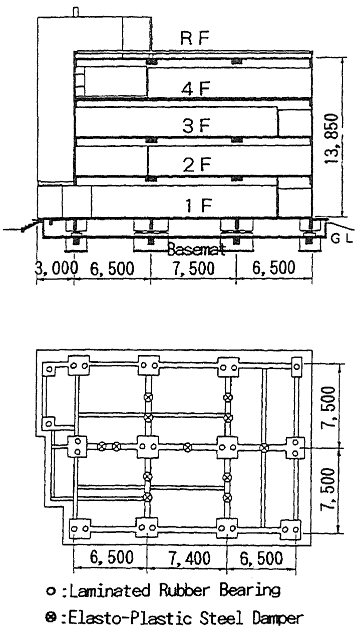

Fig. 1 Elevation and Plan of Building

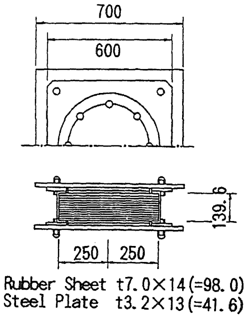

Fig. 2 Laminated Rubber Bearing

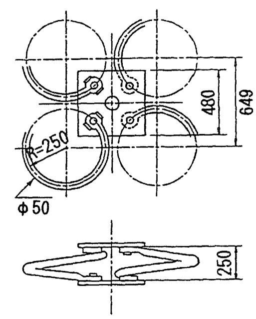

Fig. 3 Elasto-Plastic Steel Damper

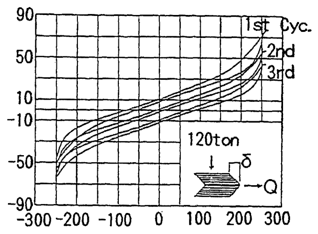

Fig. 4 Element Test Result of Rubber Bearing

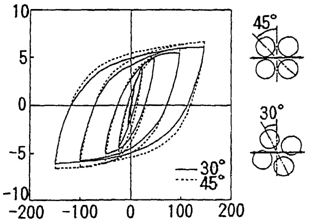

Fig. 5 Element Test Result of Steel Damper

functions to lengthen the natural period and to absorb the vibration energy during strong earthquakes respectively. Fig.2 shows the laminated rubber bearing, consisting of thin natural rubber sheets and steel plates. Fig.3 shows the elasto-plastic dampers consisting of four spiral steel bars which allow to provide almost same functional characteristics for every direction. 25 rubber bearings and 12 dampers are installed as shown in Fig.1.

The result of the shear loading test under vertical compression load of 120ton is shown in Fig.4. The rubber bearing can be considered as a linear material up to the displacement of 200mm. The average stiffness of the rubber bearings used for this isolated building is 0.82ton/cm. Fig.5 shows the force-displacement relationship of the steel elasto-plastic damper. It can be seen that the yielding displacement is about 30mm and the stiffness before yielding is about 2.0ton/cm. Under the assumption that the damper behaves elasto-plastically, the horizontal periods of this building with the isolation devices are 1.4sec and 2.1sec corresponding to pre-yielding stiffness and post-yielding stiffness respectively.

VIBRATION TEST (Ref.1, 2)

Forced Vibration Test Forced vibration test was carried out setting up the eccentric mass vibrator on the first floor to obtain the response characteristics of the base isolated building in the small deformation region of the isolation devices. Fig.6 shows velocity frequency responses at each floor level and a vibration mode at resonance in the case of x-direction excitation. The velocity frequency response of the first floor, the third floor and the roof per unit vibration force coincide with each other, showing a typical first mode of a base isolated building. Natural frequency is 0.88Hz(1.1sec), which is a little higher than the design value. It is because the stiffness of the rubber bearing and the damper is higher than that used in the design in the small deformation region. Relative displacement of the isolation device at the resonance is 1.7mm and damping ratio of 2.5% for the first mode is obtained by half-power method.

Free Vibration Test Free vibration test was carried out to obtain the non-linear characteristics in the large deformation region of the base isolation devices, giving the maximum relative displacement of 100mm between the basemat and the first floor with hydraulic jacks and releasing. Fig.7 shows the relationship between average displacement and vibration period and damping ratio, obtained from the free vibration record. The vibration period becomes longer and the damping ratio increases according to the increase of displacement due to the hysteretic behavior of the damper. Damping ratio of more than 10% at the ductility ratio of 2, corresponding to 60mm, is obtained from this test.

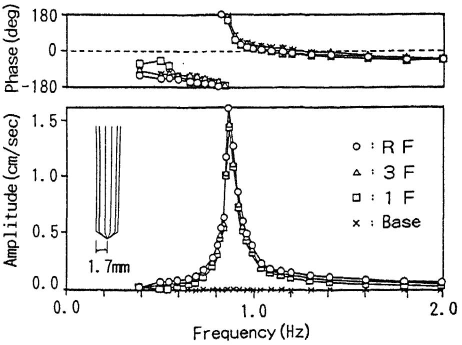

Fig. 6 Velocity Frequency Response

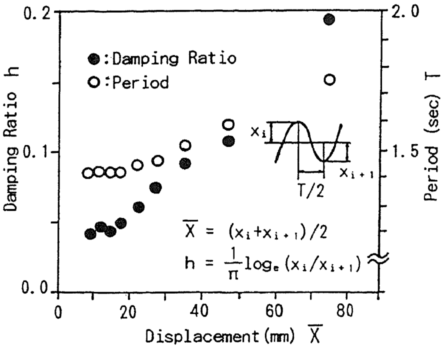

Fig. 7 Vibration Period and Damping Ratio derived from Free Vibration Record

EARTHQUAKE RESPONSE OBSERVATION

Earthquake response observation has started since September 1986, and more than thirty earthquakes have been observed in the base isolated building. Epicenter of each earthquake is shown in Fig.8. These earthquakes are classified into three groups as follows(Δ :Epicentral distance).

① Far distance earthquake (Δ >150km, Off Fukushima earthquakes)

② Intermediate distance earthquake (50<Δ <150km, Off Ibaragi earthquakes)

③ Near distance earthquake(Δ <50km, South-West Ibaragi earthquakes)

Fig.9 shows the ratio of maximum acceleration between the first floor and the basemat and the maximum acceleration of the basemat. It can be seen from these figures that the horizontal acceleration ratio differs according to the location of the epicenter, that is, the nearer the epicenter, the lower the acceleration ratio. On the other hand, the vertical acceleration ratio is almost constant irrespective of the distance and the maximum acceleration of the basemat. The average ratio is around 0.6 in both X and Y direction and is 1.25 in vertical direction. It must be noted here that the relative displacement of the isolation device in these earthquakes are all less than yielding displacement of the dampers of 30mm, so in these cases dampers do not work as a damping device.

Two typical response records are introduced. One is the response for the SW Ibaragi Earthquake on June 30, 1987, the epicenter of which is very close to the observation point. Another is for the SE Off Boso Peninsula on Dec. 17, 1987 which includes much long period components in comparison with the other earthquakes. Data of two earthquakes are shown in table 1. Maximum acceleration, time history and acceleration response spectrum for 5% damping of each floor level are shown in Fig.10,11 and 12 respectively.

Table 1 Data of the Earthquakes

N A M E	D A T E	Magnitude	Focal Distance	Epicentral Distance	Depth
SW Ibaragi	June 30, 1987	5.1	56km	11km	55km
SE Off Boso Peninsula	Dec. 17, 1987	6.6	125km	104km	70km

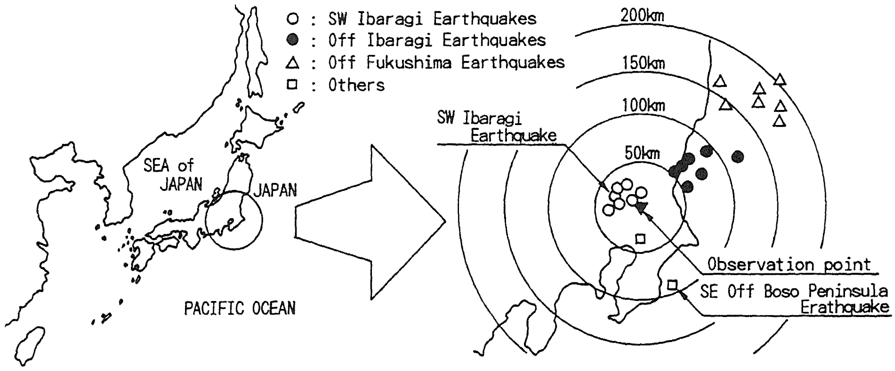

Fig. 8 Epicenter of Observed Earthquakes

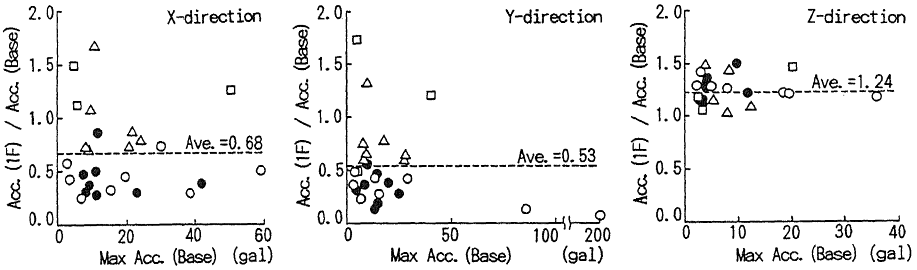

Fig. 9 Relationship between Acceleration Response Ratio of First Floor and Maximum Acceleration of Basemat

SW Ibaragi Earthquake, June 30, 1987 This earthquake has a lot of short period components as shown in the time history and the acceleration response spectrum of the basemat. Maximum horizontal acceleration of 269gal was recorded on the ground surface at the begining of a main shock. On the other hand, those of the building were around 20gal, showing a remarkable seismic isolation effect, especially in y-direction(long-side direction of the building). It is also noticed that the acceleration response spectra of the building are reduced in comparison with that of the basemat in the short period range. The response spectrum of the first floor and the roof have a peak at the period around 0.15sec(7Hz), but that of the third floor does not have a peak around 0.15sec. This is because the second mode is excited by this earthquake. The third floor behaves as a node of vibration at the second mode.

SE Off Boso Peninsula Earthquake, December 17,1987 In this earthquake, more long period components are found than in the SW Ibaragi earthquake. Maximum horizontal ground surface acceleration is 83gal, on the other hand, those of the building are around 60gal in x-direction. The acceleration of building is not so reduced in this case. It can be recognized that the acceleration response spectra peak of the building at the period of 1.2sec, corresponding to the first mode of the isolated building, is 6 times as high as that of the basemat. It is because the ground motion has a peak at this period and that the dampers do not work since their relative displacement are less than the yielding displacement of 30mm.

It is concluded from above mentioned observation results, the acceleration response of the building is remarkably reduced for the ground motion including short period components, on the other hand, not so greatly reduced for the ground motion including much long period components.

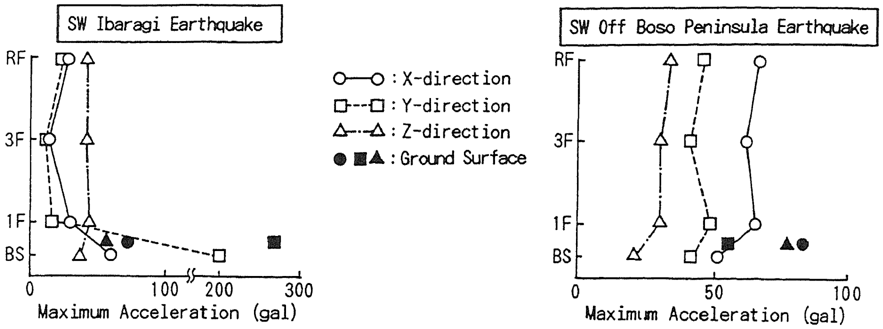

Fig. 10 Maximum Acceleration

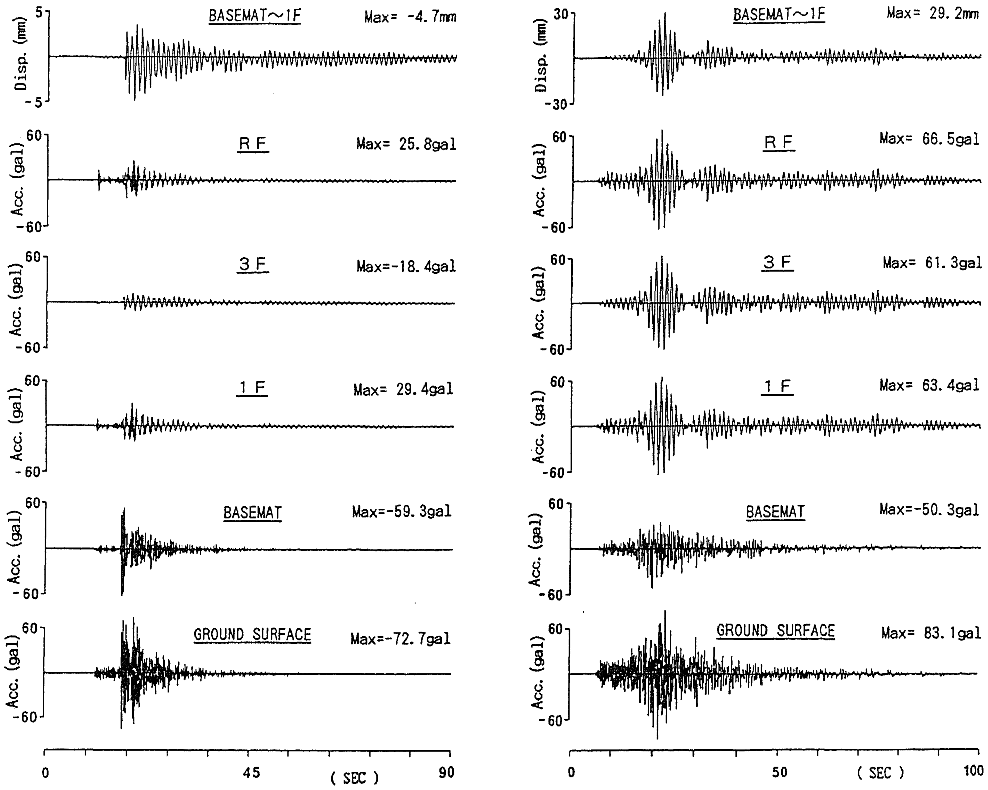

Fig. 11 Time Histories of Acceleration and Diaplacement

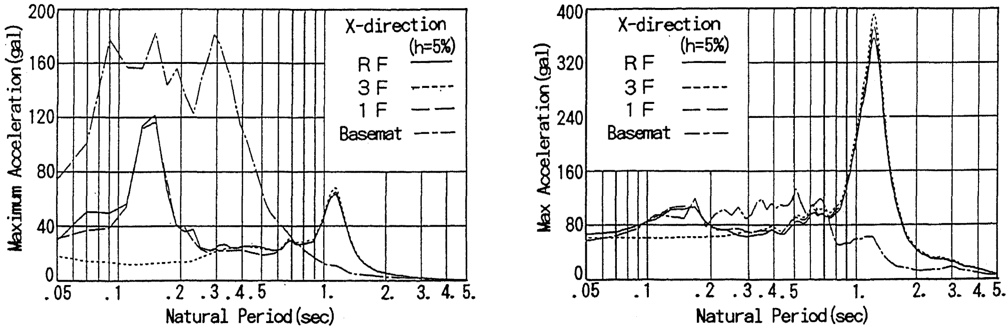

Fig. 12 Acceleration Response Spectra

But the isolated building behaves as a rigid body translational motion and the acceleration is not amplified in the building.

NUMERICAL ANALYSIS

Numerical simulations were performed using a lumped-mass model with translational and rotational springs as shown in Fig.13. The translational spring of the isolation device is assumed as a bi-linear hysteretic spring. Fig.14 shows the calculated result and the observed record of the first floor in the case of SE Off Boso Peninsula earthquake. The calculated result well agrees with the observed record, especially around the first natural frequency as is seen in the fourior spectrum.

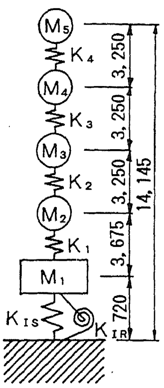

Fig. 13 Analytical Model

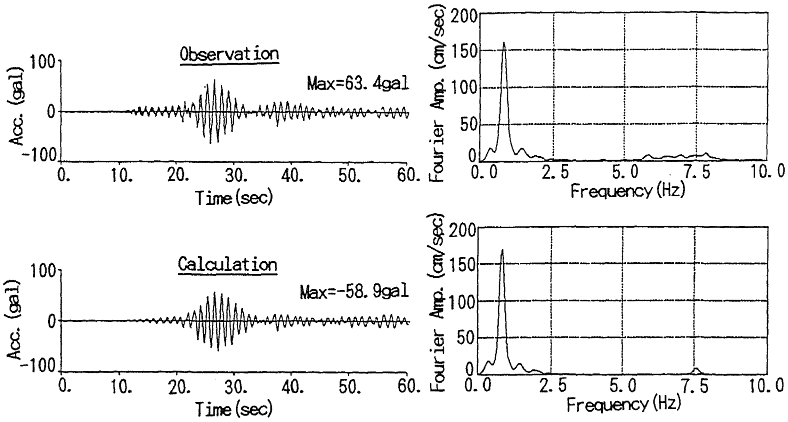

Fig. 14 Comparison between Observation and Analysis

CONCLUSIONS

The vibration test, the earthquake response observation and numerical analysis of the base isolated building were carried out. Although severe earthquakes are not yet observed, the followings are confirmed.

i) In the large deformation region of the isolation devices, the natural period becomes longer considerably and the elasto-plastic steel damper provides a enough large damping as designed.

ii) Acceleration response during earthquake differs according to the frequency characteristics of the ground motion, especially, intensity of the frequency component around the first natural period of the base isolated building. However, for any earthquake, it is sufficiently reduced in comparison with that of the ground surface.

iii) The result of numerical analysis using a lumped-mass model well agrees with the observed record.

REFERENCE

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