Earthquake Response Analysis of Base Isolated Building

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1.INTRODUCTION

Recently, the seismic isolation has become one of the popular methods in the design of important structures or equipments against the earthquakes.
However, it is desired to accmulate the demonstration data on reliability of seismically isolated structures and to establish the analysis methods of the those structures.
Based on the above recognition, the vibration tests of a base isolated building were carried out in Tsukuba Science City. After that, many earthquake records have been obtained at the building. In order to examine the validity of numerical models, earthquake response analyses were executed by using both Lumped Mass model, and Finite Element model.

2.OUTLINE OF BASE ISOLATED BUILDING AND ISOLATION DEVICE

(1) Base Isolated Building
The base isolated building, a object of test and observation, is a four-story reinforced concrete building. The floor area is 1,330 m² and the weight is 2,250ton. Seismic isolation devices are installed between the basemat and the first floor.
(2) Seismic Isolation Device
The seismic isolation devices consist of laminated rubber bearings and elasto -plastic steel dampers, which provide the 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 damper cosisting of four spiral steel bars which allows to provide almost the same functional characteristics for every direction. 25 rubber bearings and 12 dampers are installed as shown in Fig.1.
The rubber bearing is considered as a linear material up to the displacement of 200 mm from the results of element test conducted before installation. The average stiffness of the rubber bearings used for this isolated building is 0.82ton/cm. The yielding displacement of the steel elasto-plastic damper is about 30 mm 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.

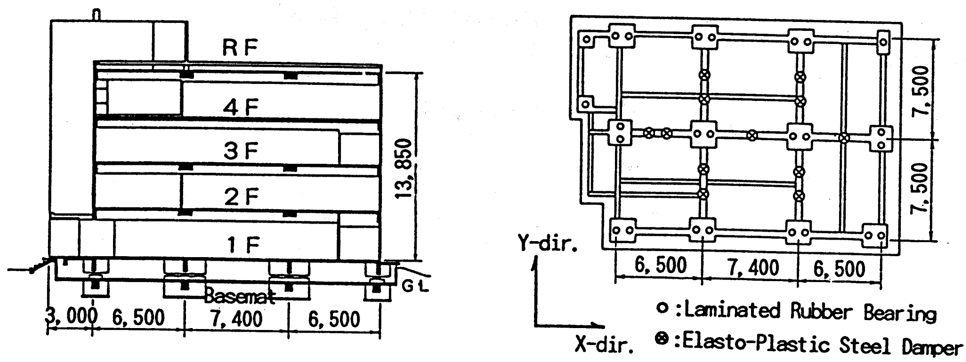

Fig. 1 Section and Plan of Building

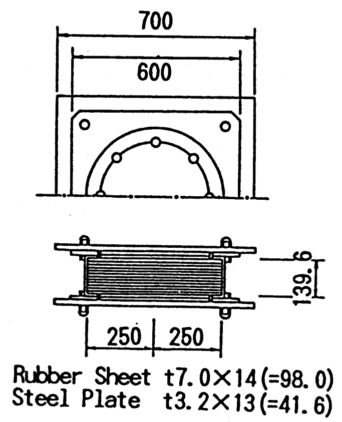

Fig. 2 Laminated Rubber Bearing

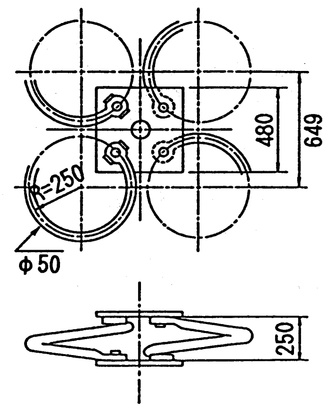

Fig. 3 Elasto-Plastic Steel Damper

3.EARTHQUAKE RESPONSE ANALYSIS

(1) Input Ground Motion

The steel dampers didn't yield during any observed earthquake.
SW Ibaraki Earthquake (1987.6.30, Magnitude=5.1, Epicental distance=11km) was adopted as input motion. This earthquake ground motion contains large amounts of heigh frequency components.

(2) Lumped Mass Model

1)Numerical model

The building above isolation devices was modeled into five lumped mass system. Weight of each floor was lumped at floor level. Each mass was connected by equivalent spring that considered effects of bending and shearing.

Isolation devices were modeled by a pair of sway and rocking spring. Fig. 4 shows the lumped mass model. Modal analysis was used to evaluate the earthquake response of the building. Newmark - β method was used in numerical integration of the response of each mode. Modal damping was estimated from both the forced vibration test and the earthquake response observation. As a result, it was assumed that damping ratio of first mode was 2.5%, and all of other modes were 0.3%.

Analysis condition of this model shows in Table 1.

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2)Numerical results

Fig. 6 shows the mode shapes obtained by the analysis.

Every floor of the building moves in the same direction in the first mode, and roof floor and first floor moves in the opposite direction in the second mode.

Fig. 7 shows the comparison of the observed acceleration of first floor with calculated one.

High frequency component corresponding to the second mode is excited in observed record, but excitation of high frequency component is much less in lumped mass model. This is considered to be due to the effects of multi -input motion and three-dimensional vibration mode of the building which cannot be well considered by this model. As to the acceleration of the third floor,(See Fig. 8) the calculated result is well agreed with the observed record.As to the relative displacement between the base mat and the first floor, (See Fig. 8) the shape of calculated time history is quite similar to that of observed record. Also, Fourier spectrum, is very similar to observed one around first natural frequency. From above results, it can be said that lumped-mass model is useful in the simulation of the first mode response of isolated building. So, it will be possible to estimate the deformation of isolation devices during earthquakes by using this model.

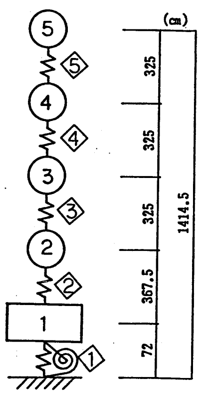


Fig. 4 Lumped Mass Model

Table 1 Analysis Condition of Lumped Mass Model

Mass or Member No.	Weight (tonf)	Stiffness (tonf/cm)	Mode No.	Damping Ratio(%)
5	408.9	1719	1	2.5
4	479.2	2718	2	0.3
3	424.0	3534	3	0.3
2	431.3	4515	4	0.3
1	502.5	71.66	5	0.3
	1.34×10^{9} (tonf·cm²)	2.05×10^{10} (tonf·cm)	6	0.3

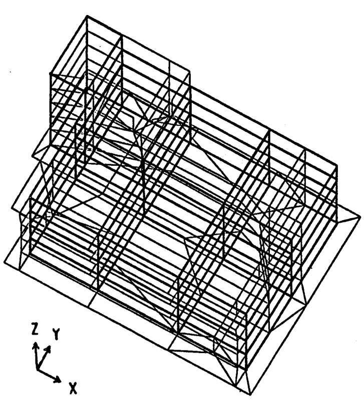


Fig. 5 FEM Model

Table 2 Analysis Condition of FEM Model

Isolation Device					
Rubber Bearing				Steel Damper	
Horizontal Stiffness (tonf/cm)	Damping Ratio (%)	Vertical Stiffness (tonf/cm)	Damping Ratio (%)	Horizontal Stiffness (tonf/cm)	Damping Ratio (%)
1.61	2.5	1304	1.0	2.61	2.5

Reinforced Concrete				
Modulus of Elasticity (kgf/cm²)	Shearing Modulus of Elasticity (kgf/cm²)	Poisson's Ratio	Density (gf/cm³)	Damping Ratio (%)
6.3×10^{5}	2.7×10^{5}	0.167	2.9	0.3

(3) Finite Element Model

1)Numerical Model

In this case, Finite Element model is used for the upper structure.

Floors and main walls are modeled by shell elements, pillars and garters are modeled by three-dimentional beam elements. Stiffness and damping of the upper structure was estimated from both design values and the results of the forced vibration test.

The models of 25 rubber bearings and 12 steel dampers are put in each position. Steel dampers are modelled by horizontal shearing springs. Rubber bearings are modelled by horizontal shearing springs and vertical springs. In time history analysis, the damping matrix proportional to the stiffness matrix is used. Fig. 5 shows the finite element model, and analysis condition shows in Table 2.

2)Numerical Results

The result of finite element model is very similar to the observed record of the first floor. (See Fig. 7) Especially excitation of the second mode is expressed very well by the model.

As to Fourier spectra of responses, those of numerical results are similar to those of observed records not only around the first mode, but also around the second mode. The acceleration of the third floor and the relative displacement between the first floor and the base mat calculated by this model are almost the same as those by the lumped-mass model, since these responsses are dominated by the first mode.

From above results,it can be said that evaluation of the second mode will be possible by finite element model.

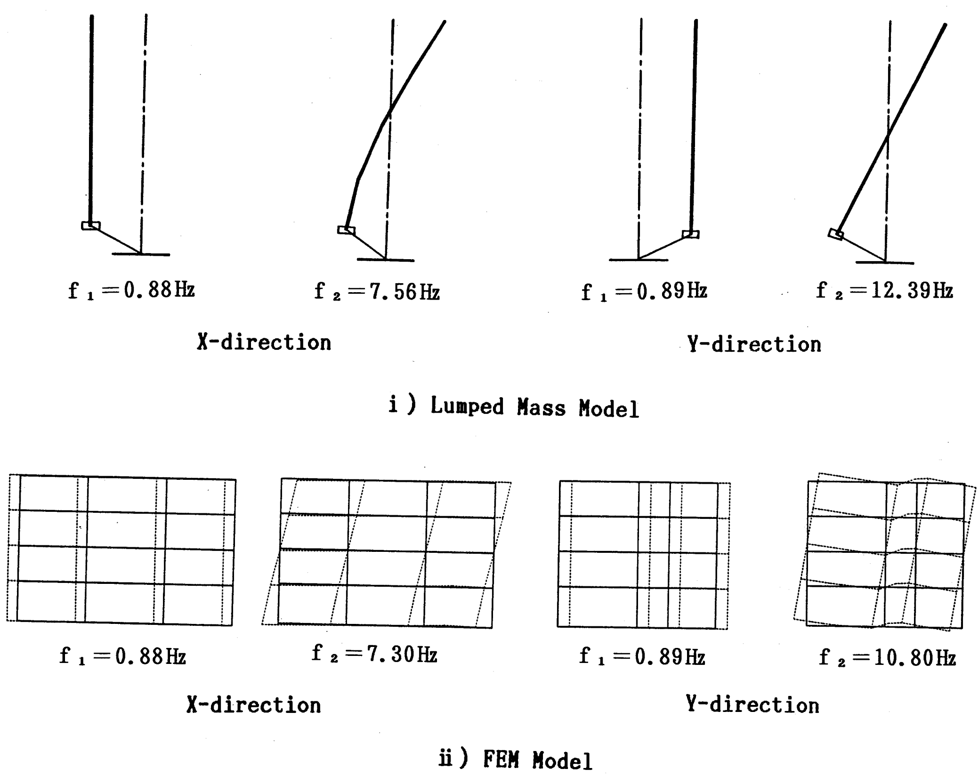
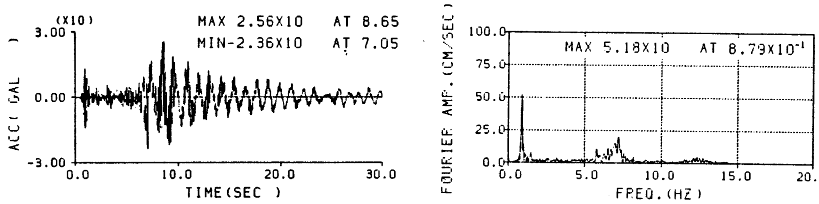
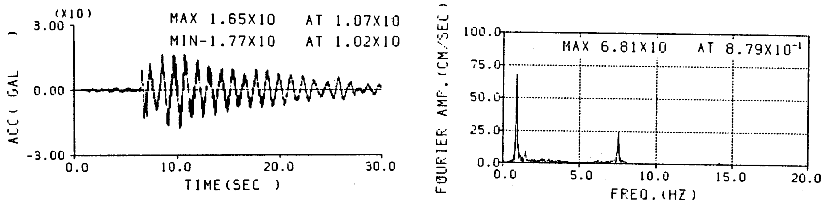


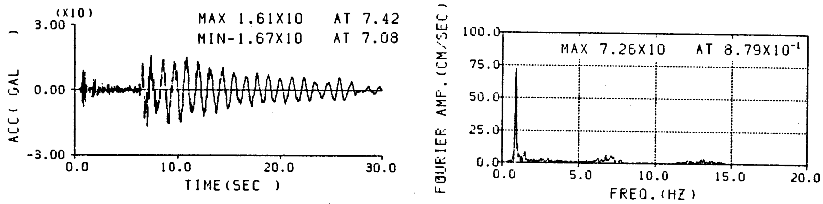
Fig. 6 Results of Modal Analysis



i) Observed Record

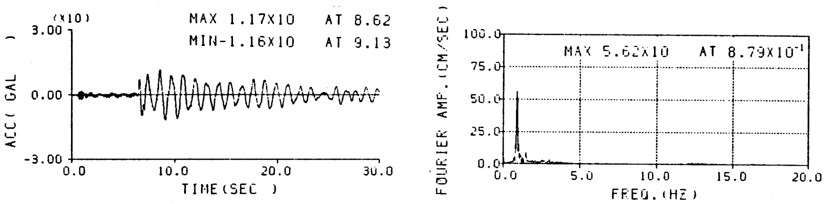


ii) Lumped Mass Model

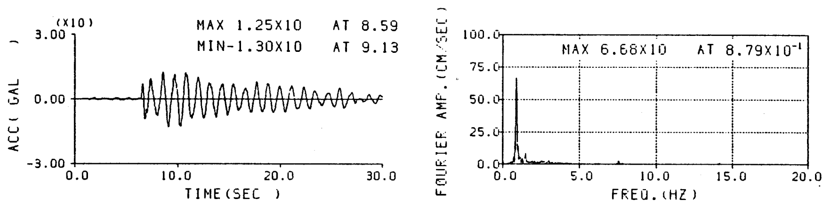


iii) FEM Model

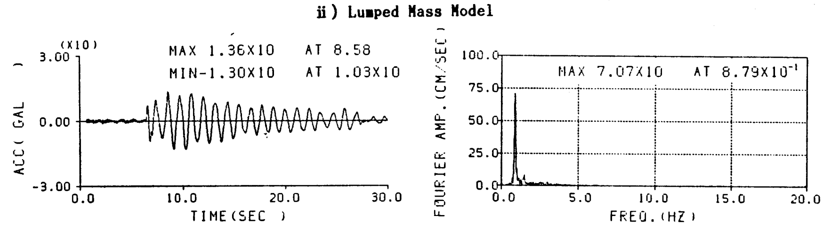
Fig. 7 Comparison of Observed Record with Calculated Results (Acceleration of First Floor)



i) Observed Record



ii) Lumped Mass Model



iii) FEM Model

Fig. 8 Comparison of Observed Record with Calculated Results (Acceleration of Third Floor)

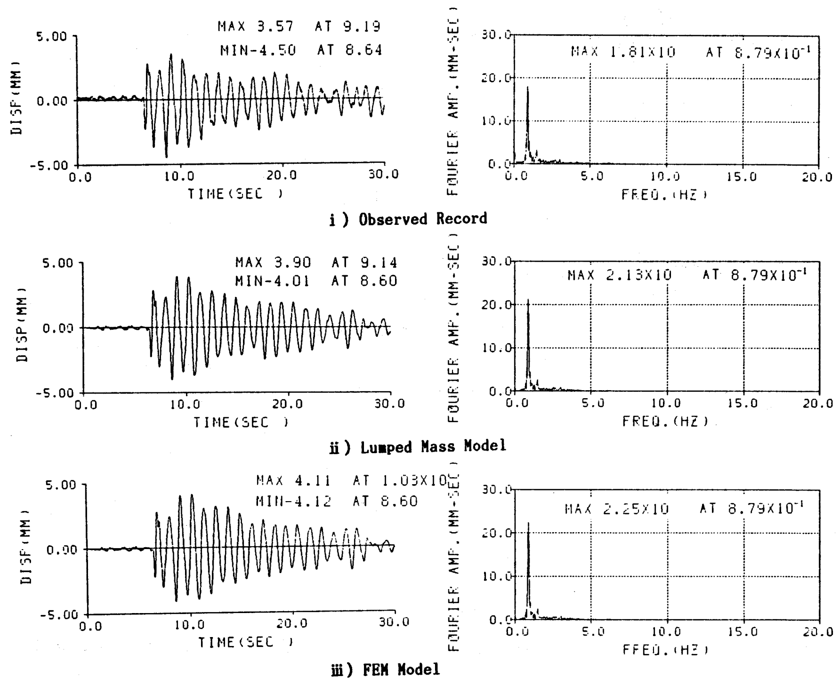


Fig. 9 Comparison of Observed Record with Calculated Results (Relative Displacement between Base Mat and First Floor)

4.CONCLUSIONS

Earthquake response analyses by using both lumped mass model and finite element model are carried out. The results are compared with the observed one, and the followings are confirmed.

i) Lumped mass model is available to estimate the response of the upper structure and the deformation of the isolation devices, as the dynamic behavior of the base isolated building is dominated by the first mode.

ii) Higher mode is more accuratelly simulated by finite element model, and the use of this model is recomended when the effect of high frequency mode is significant.

5.REFERENCES

1. S. Aoyagi, T. Mazda, O. Harada, M. Takeuchi et al., Experimental Study on the Dynamic Behavior of the Base Isolated Building, 9th SMIRT (1987),pp.687-692.
2. S. Aoyagi, T. Mazda, O. Harada, S. Ohtsuka, Vibration Test and Earthquake Responce Observation of Base Isolated Building. 9th WCEE(1988).