Simulation Analysis of Free Vibration Test in a Building "Chisuikan" using Three-dimensional Seismic Base Isolation System

S. Mori, J. Suhara, I. Kurosawa, M. Saruta & K. Okada
Shimizu Corporation, Tokyo, Japan

T. Tomizawa
Kozo Keikaku Engineering Inc., Tokyo, Japan

Y. Tsuyuki
Kayaba System Machinery Co.,Ltd., Tokyo, Japan

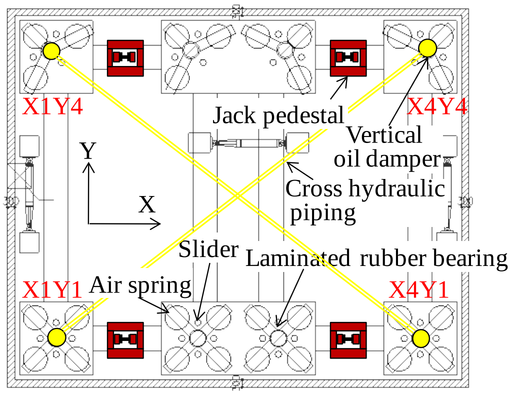
T. Fujita
The University of Tokyo, Professor Emeritus, Tokyo, Japan

SUMMARY:
Chisuikan that adopted three-dimensional seismic base isolation system was completed in March, 2011. The three-dimensional seismic isolation devices of this building consist of laminated rubber bearings for horizontal isolation and air springs for vertical isolation. Against a rocking motion, we design the rocking suppression system with oil dampers connected by oil pressure piping. The free vibration test of this building was performed as follows in December 2010. Two types of test are carried out. One is the test of vertical vibration test. In this test, after lifting the both ends of the building simultaneously, the vertical motion occurs by releasing load. Another is the test of rocking vibration test. In this test, after lifting the one side of the building, the rocking motion occurs by releasing load. In this paper, simulation analyses of the free vibration test by the design model are reported.

Keywords: three-dimensional seismic isolation, vibration test, simulation analysis

1. INTRODUCTION

Chisuikan that adopted three-dimensional (3D) seismic base isolation system was completed in March, 2011. The earthquake observation records were obtained in the 2011 off the Pacific coast of Tohoku Earthquake in this building. It was confirmed that the performance of the building with three-dimensional seismic base isolation system was effective and that the analysis model of this system was valid by the simulation analysis.
This building is an apartment house of three stories and 9m in height. It is made by reinforced concrete structure. Three-dimensional base isolation device is arranged on the underground story.
Three-dimensional seismic base isolation devices of Chisuikan consist of the laminated rubber bearing for horizontal direction and the air springs for the vertical direction.
In order to suppress the rocking motion caused by softening of the vertical stiffness, the rocking suppression systems using the oil dampers are setting. A rocking suppression system consists of two oil dampers and hydraulic piping which connected these dampers. Two pipes are connected with upper and lower oil rooms of the oil dampers oppositely.
In order to verify the performance of three-dimensional seismic isolation building, two types of free vibration test using jacks of rapid load release type was performed in December 2010 before completion. One is the test of vertical vibration test. In this test, after lifting the both ends of the building simultaneously, the vertical motion occurs by releasing the load rapidly. Another is the test of rocking vibration test. In this test, after lifting the one side of the building, the rocking motion occurs by releasing the load rapidly.
Arrangement of the seismic isolation devices and the rapid load release type jacks which were used at the vibration test are shown in Fig. 1.
In this paper, simulation analyses of the free vibration test by the design model are reported.



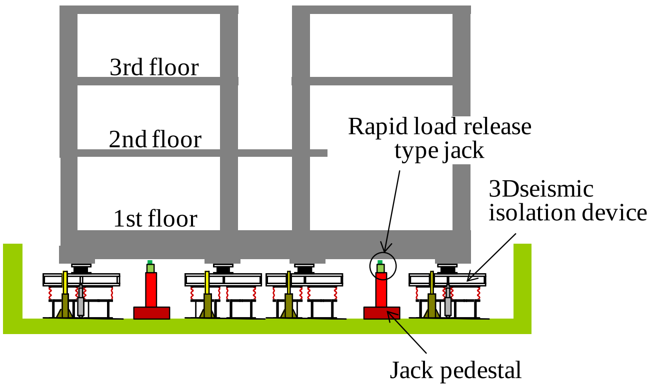
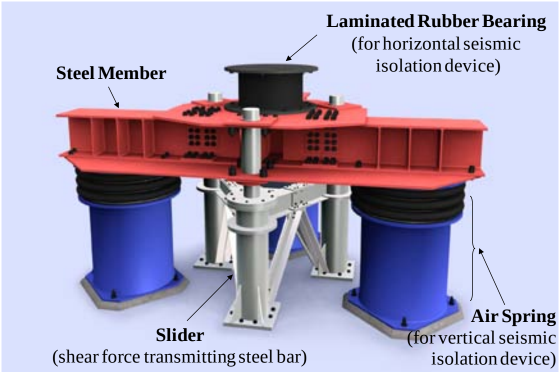


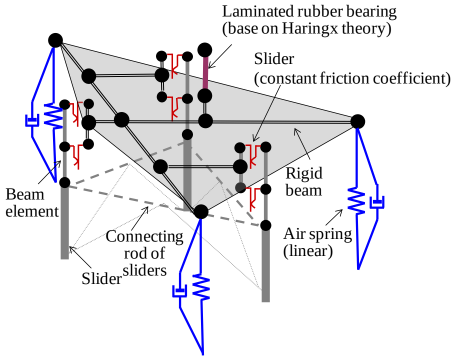
Figure 1. Arrangement of seismic isolation devices on the base mat and of jacks in the vibration test

2. ANALYSIS MODEL AND CONDITION

The simulation analysis model of the free vibration test is the same as the design model as a general rule. The three-dimensional seismic isolation devices are modelled by the laminated natural rubber bearing, the steel members, the air springs, and the shearing force transmitting steel bars (sliders) respectively. The actual device and the analysis model are shown in Fig. 2.
A rocking suppression system consists of two oil dampers and hydraulic piping which connected these dampers. Two pipes are connected with upper and lower oil rooms of the dampers oppositely. Four vertical oil dampers are arranged on corners of the building. A rocking suppression system uses two oil dampers of the diagonal position. There are two rocking suppression systems in Chisuikan. This system was modelled with the Maxwell model that represents a rocking control by the oil damper and the Maxwell model that represents a viscous damping in the vertical direction by the pipe resistance. The principle of rocking suppression system and the analysis model are shown in Fig. 3.
The superstructure is modelled by a three-dimensional frame model. Figure 4 shows the simulation analysis model that is included the superstructure, three-dimensional seismic isolation devices, horizontal oil dampers and the rocking suppression system. The constants of the model are the same as the reference value of design model as a general rule. Because the level of the input at this vibration tests were lower than the design, the stiffness of laminated rubber bearing, the stiffness of the beams and others are modified. The stiffness of laminated rubber bearing is 1.5times as large as the design value. The friction constant of the slider is 0.12 as the same as the design value.

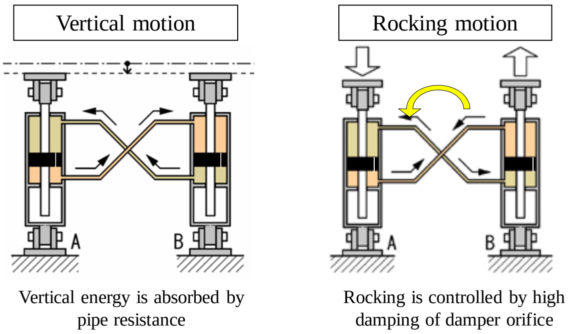


a. Actual Device

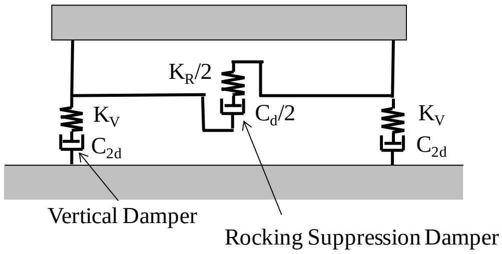


b. Analysis model

Figure 2. Modeling of three-dimensional seismic isolation device



a. Principle of suppression of rocking



b. Analysis model

Figure 3. Modeling of rocking suppression system

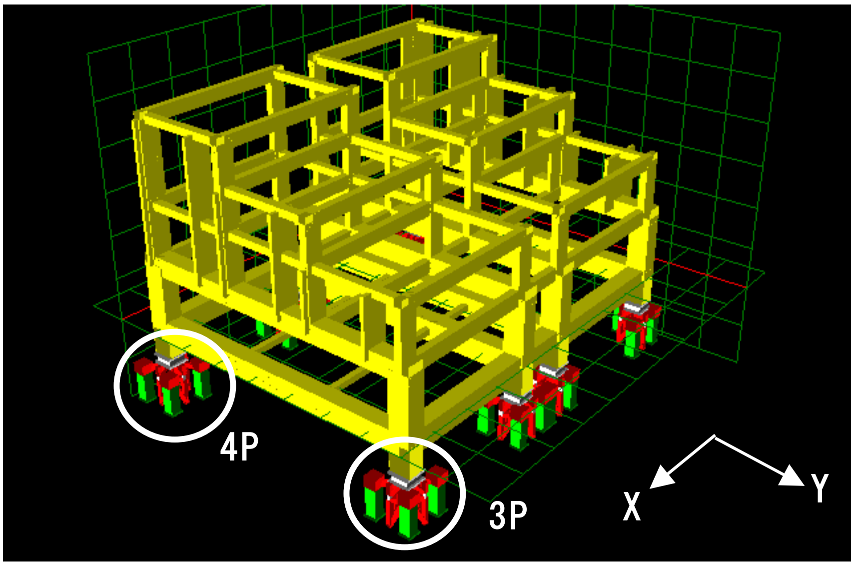


Figure 4. Simulation analysis model of free vibration test

It was recognized that the damping ratio evaluated by test results was larger than the damping ratio of the design. The damping ratio of the test may become large because there are damping mechanisms which are not taken into consideration in the design analysis, such as friction of an expansion joint, the rubber sheet which seals up the surroundings of a building, a damping force caused by the air flowing from an underground story to the exterior by vibration of the building Constant horizontal forces were made to act on seismic isolation devices so that frictional forces occur to sliders. Horizontal forces were adjusted so that analysis results and test results in vertical displacement might suit.

On the other hand, in the rocking free vibration tests, responses of rocking suppression system of the X1Y4-X4Y1 group differed from the responses of the X1Y1-X4Y4 group. The stiffness of the oil of the rocking suppression system of the X1Y4-X4Y1 group was adjusted so that analysis results and test results in vertical displacement were suited. As a reason of the reduction of oil stiffness, it is possible that air mixed in oil pressure piping and there can be a slight gap in construction.
In the vertical free vibration test, first, a force is made to act upward on the first floor beams of both sides of four points till the building lifts up to the displacement recorded by the test. After a force is released in an instant, the free vibration is occurred. In the rocking free vibration test, first, a force is made to act upward on the first floor beams of one side of two points till the building lifts up to the displacement recorded by the test. After a force is released in an instant, the free vibration is occurred.
The calculation cases of vibration test simulation analysis are shown in Table 1. Analyses with and without the rocking suppression systems were carried out for both vertical free vibration test and rocking free vibration test.

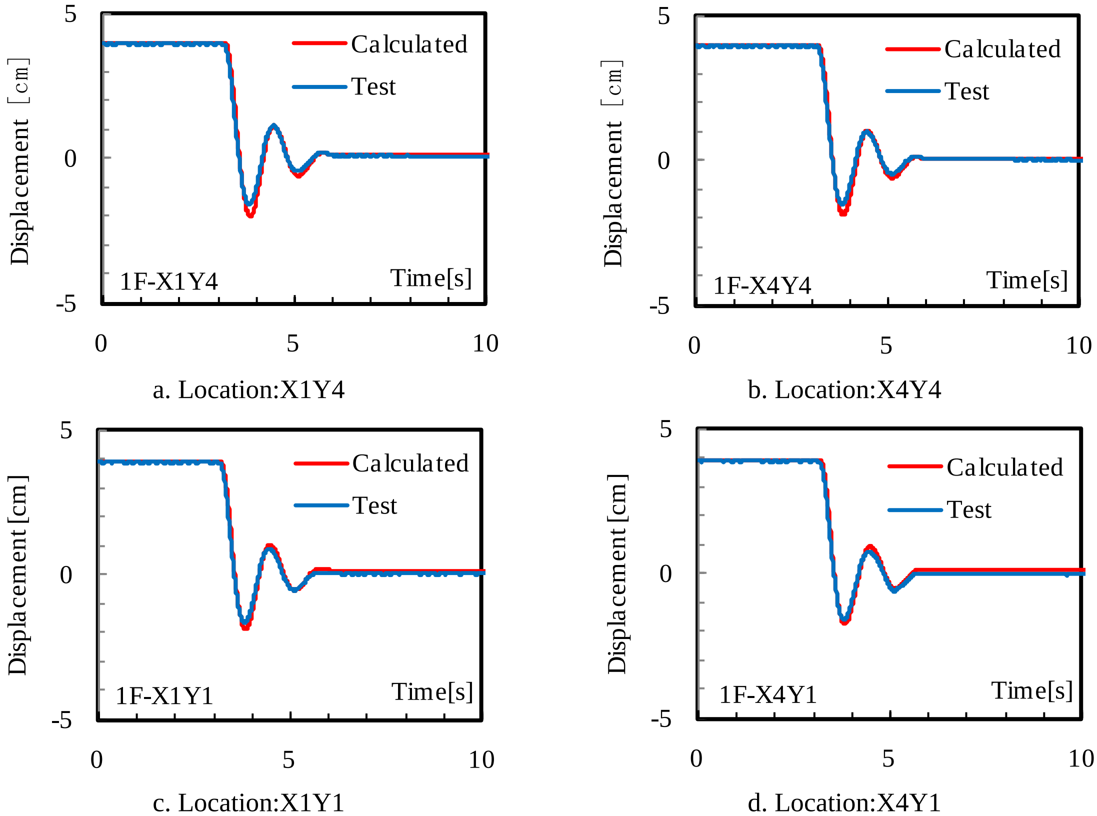
Table 1. Analysis case

No.	direction of vibration	with or without of rocking suppression system	initial vertical displacement
1	vertical	with	50 mm
2	rocking	with	50 mm
3	vertical	without	50 mm
4	rocking	without	50 mm

3. SIMULATION ANALYSIS RESULTS

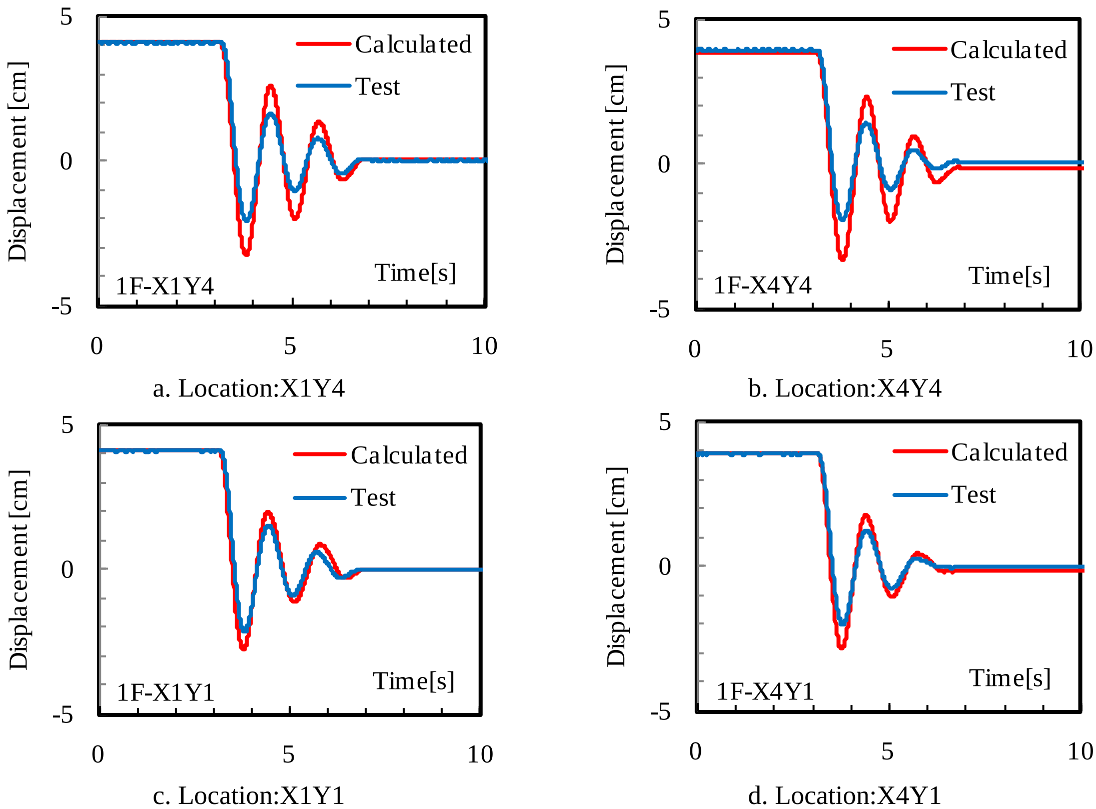
3.1. Vertical free vibration test

Fig. 5 and Fig. 6 show the analysis and test results of vertical displacement at the four corners in the cases with and without a rocking suppression system, respectively.
In the case with a rocking suppression system, it is recognized that analysis results and test results show good correspondence. In the case without a rocking suppression system, the analysis results are larger than the test results. It is considered that there are some damping mechanisms which are not taken into consideration in the analysis model, such as friction of expansion joints, the rubber sheet which seals the surroundings of a building, a damping force caused by the air flowing from an underground story to the exterior by vibration of the building and others.
Fig. 7 shows analysis results of the response acceleration on each floors, comparing with the test results. The analysis and test results are almost equal for acceleration waves. But, in analysis results, more waves of a short period are recognized than test results.
Fig. 8. shows the analysis and test results of the damping force of an oil damper. The test values are calculated by axial strain of stuck gauges on the piston of an oil damper. The analysis values are estimated by the damping force of vertical oil dampers. It is found that the damping force of two pairs of oil dampers are almost the same. Therefore, the rocking suppression force of cross hydraulic piping is working effectively. Analysis results are reproducing the test results well about the damping force of a vertical damper.



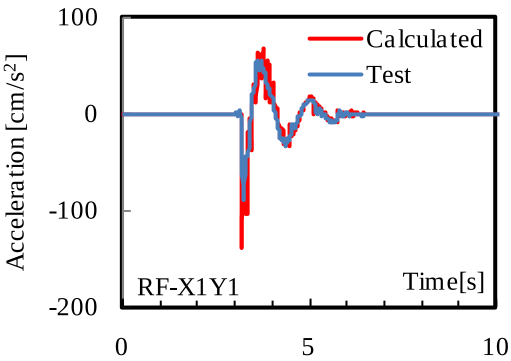
a. Location:X1Y4
b. Location:X4Y4
c. Location:X1Y1
d. Location:X4Y1

Figure 5. Vertical displacement in vertical free vibration test with rocking suppression system

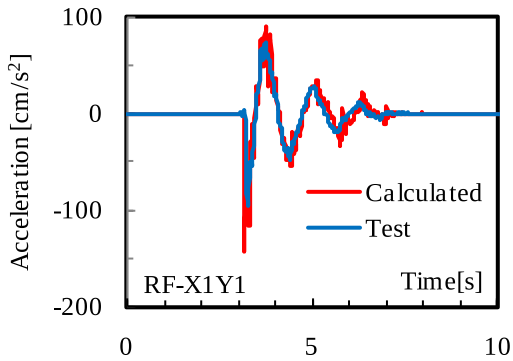


a. Location:X1Y4
b. Location:X4Y4
c. Location:X1Y1
d. Location:X4Y1

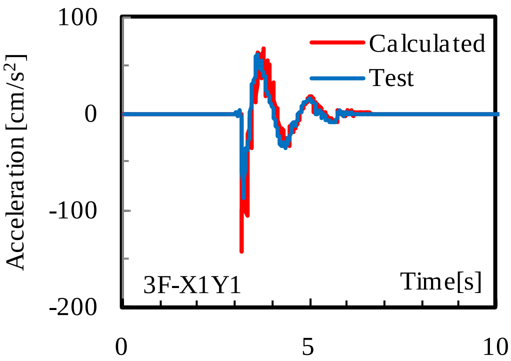
Figure 6. Vertical displacement in vertical free vibration test without rocking suppression system



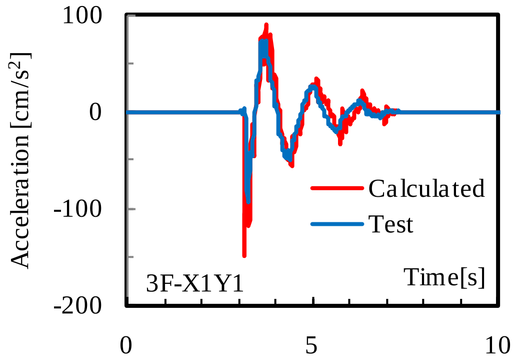
a. RF-X1Y1 with rocking suppression system



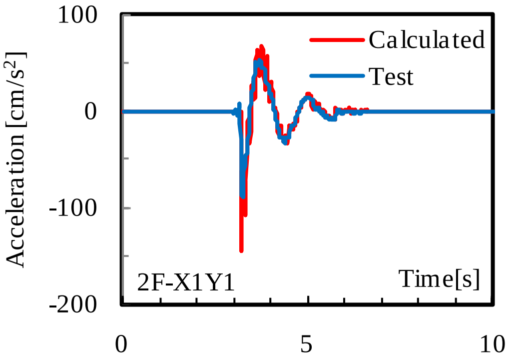
b. RF-X1Y1 without rocking suppression system



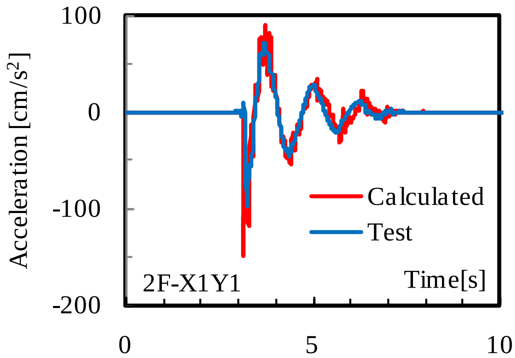
c. 3F-X1Y1 with rocking suppression system



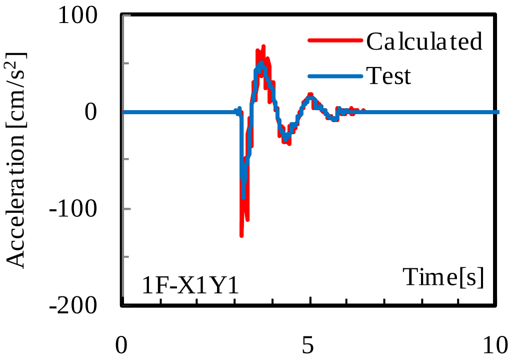
d. 3F-X1Y1 without rocking suppression system



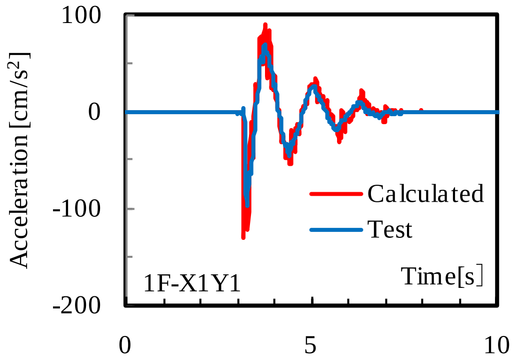
e. 2F-X1Y1 with rocking suppression system



f. 2F-X1Y1 without rocking suppression system

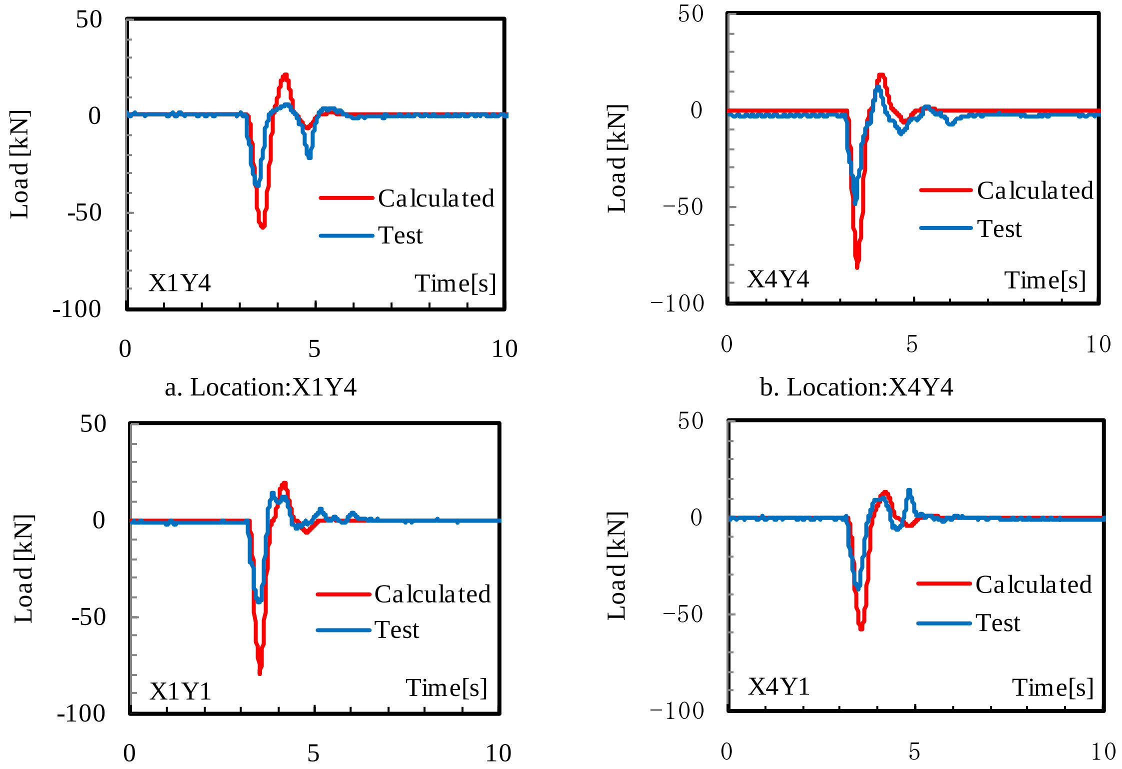


g. 1F-X1Y1 with rocking suppression system



h. 1F-X1Y1 without rocking suppression system

Figure 7. Vertical acceleration in vertical free vibration test with and without rocking suppression system



a. Location:X1Y4

b. Location:X4Y4

c. Location:X1Y1

d. Location:X4Y1

Figure 8. Damping force of oil damper in vertical free vibration test with rocking suppression system

3.2. Rocking free vibration test

Fig. 9. and Fig. 10. compare the analysis and test results of vertical displacements at the four corners of the building in the cases with and without a rocking suppression system, respectively.

When there is a rocking suppression system, it is recognized that analysis results and test results show good correspondence. When there is no rocking suppression system, the analysis result and the test result are almost same for the 1st cycle response wave and for a following vibration, the analysis results are vibrating longer than the test results. It is considered that there are some damping mechanisms which are not taken into consideration in analyses, such as friction of expansion joints, the rubber sheet which seals the surroundings of a building, a damping force caused by the air flowing from an underground story to the exterior by vibration of the building and others.

Fig. 11 shows analysis results of the response acceleration on each floors, comparing with the test results. The analysis and test results are almost equal for acceleration waves. But, in analysis results, many waves of a short period are recognized as well as the vertical free vibration test.

Analysis results are compared with test results for the damping force of an oil damper, and they are shown in Fig. 12. The test values are calculated by axial strain of stuck gauges on the piston of an oil damper. The analysis values are estimated by the damping force of a rocking suppression damper. Since the damping force of two pairs of oil dampers are almost the same, it is found that the rocking suppression force of cross hydraulic piping is working effectively. Analysis results are reproducing the test results well about the damping force of a vertical damper.

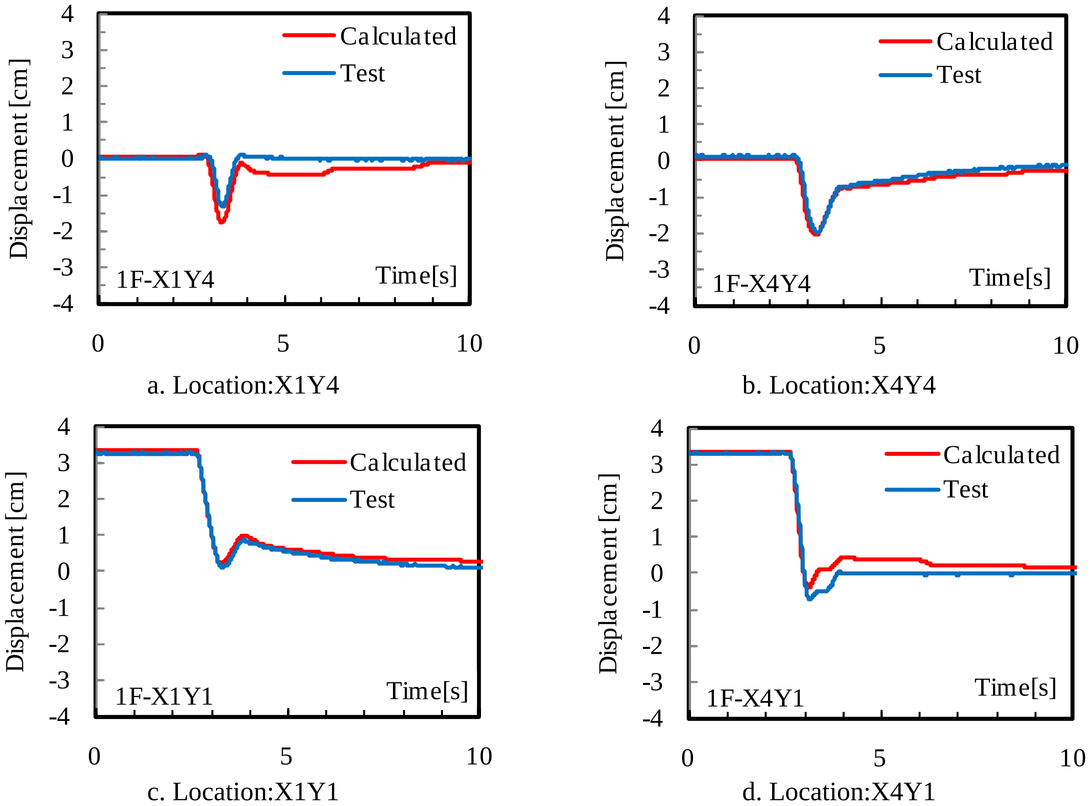


Figure 9. Vertical displacement in rocking free vibration test with rocking suppression system

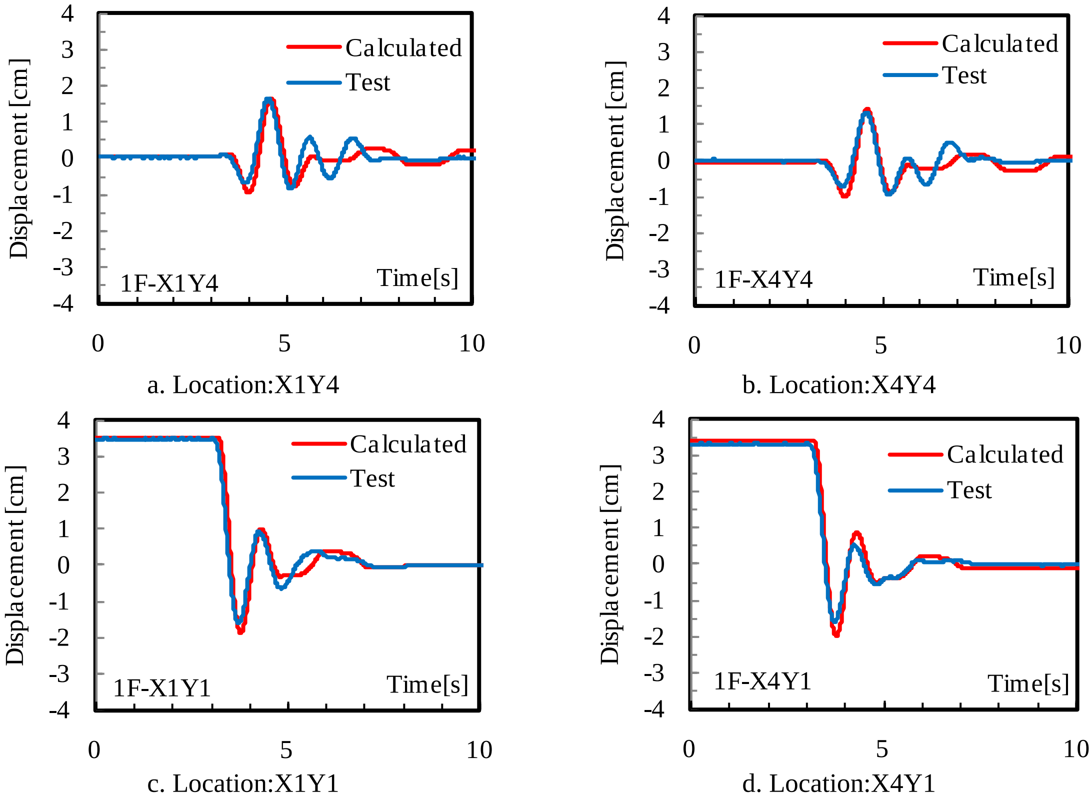
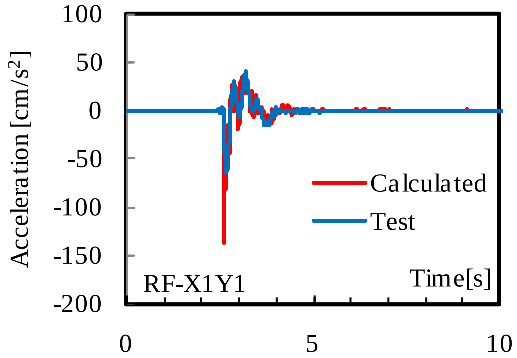
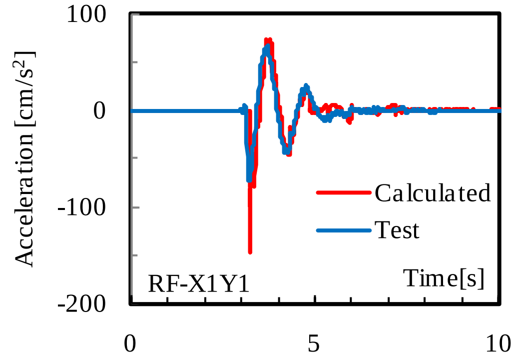


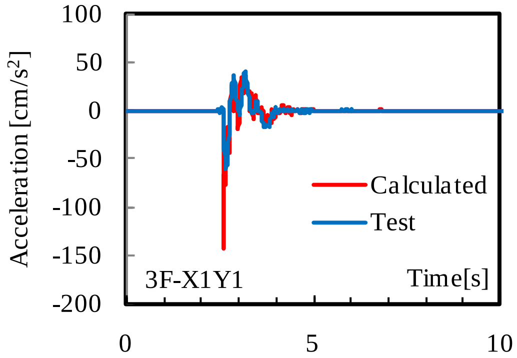
Figure 10. Vertical displacement in rocking free vibration test without rocking suppression system



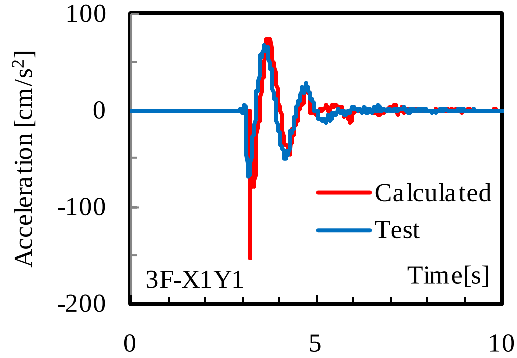
a. RF-X1Y1 with rocking suppression system



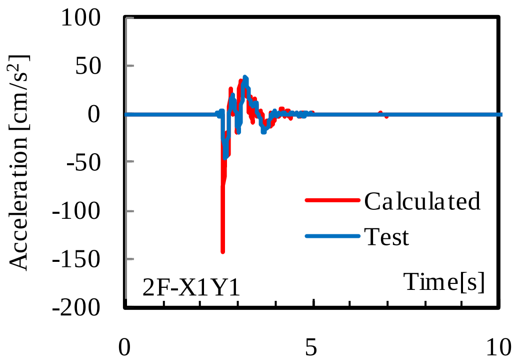
b. RF-X1Y1 without rocking suppression system



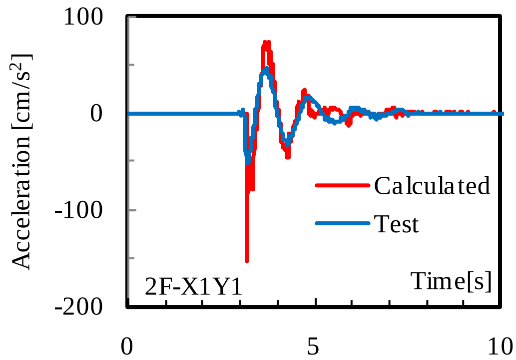
c. 3F-X1Y1 with rocking suppression system



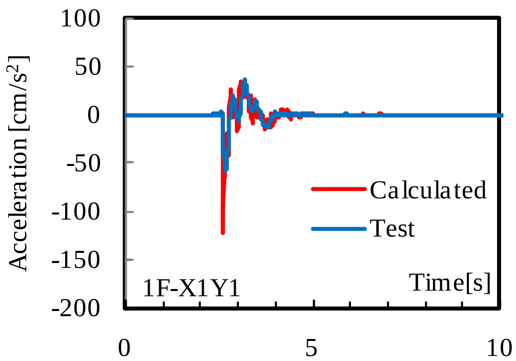
d. 3F-X1Y1 without rocking suppression system



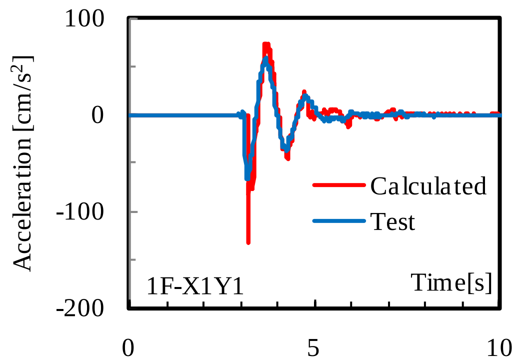
e. 2F-X1Y1 with rocking suppression system



f. 2F-X1Y1 without rocking suppression system



g. 1F-X1Y1 with rocking suppression system



h. 1F-X1Y1 without rocking suppression system

Figure 11. Vertical acceleration in vertical free vibration test with and without rocking suppression system

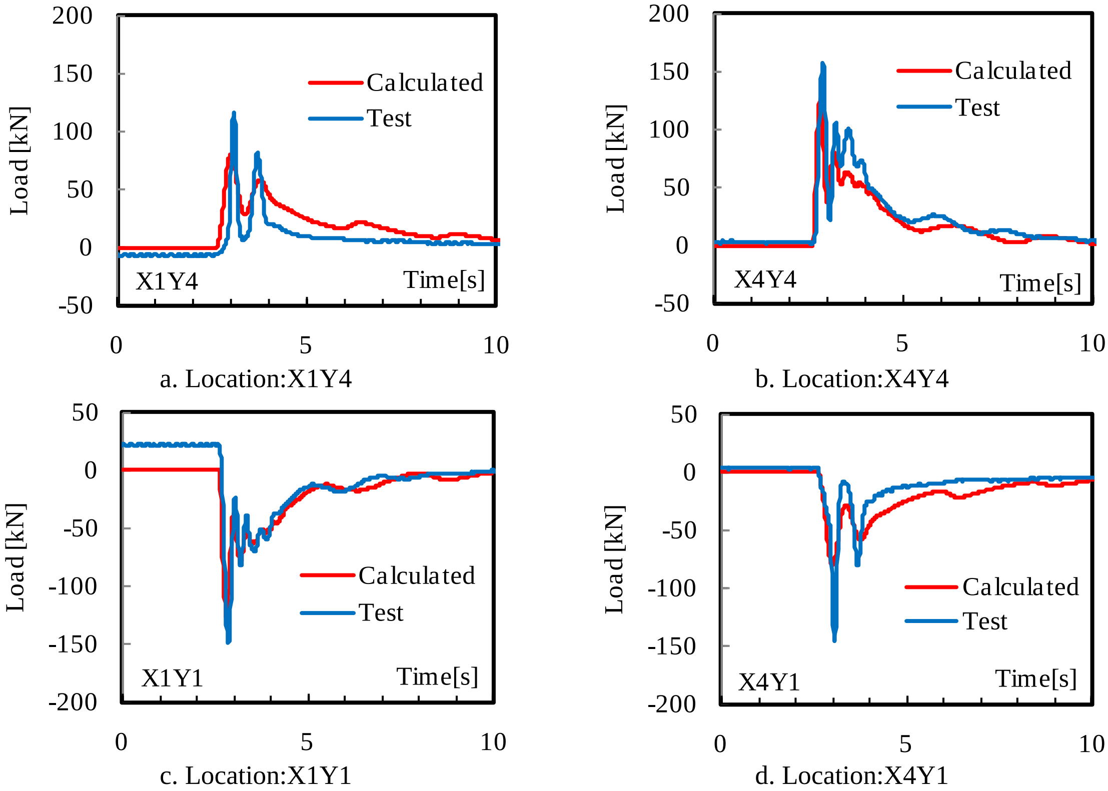


Figure 12. Damping force of oil damper in rocking free vibration test with rocking suppression system

4. CONCLUSION

Simulation analysis of free vibration test which was performed before completion was carried out. Analysis results reproduced the test results on the response vertical displacement wave, the response acceleration wave of the building, the response damping force of the oil damper and others.
As the results, the validity of an analysis model for three-dimension seismic base isolation building can be confirmed.

REFERENCES

Suhara, J., Matsumoto, R., Okamoto, S., Himeno, Y., Kurosawa, I., Kai, Y., Tsuyuki, Y., Kamei, T., Fujita, T., Takahashi, O., Hasegawa, H., Tomizawa, T. and Aida, H. (2009). Construction of Civil Building Using Three Dimensional Seismic Isolation System (Part 2, Tests for Three Dimension Seismic Isolation System). 13th Asia Pacific Vibration Conference

Suhara, J., Okamoto, S., Kurosawa, I., Mori, S., Saruta, M., Okada, K., Takahashi, O., Tomizawa, T. and Fujita, T. (2011). Simulation Analysis of Earthquake Observation Record in a Building named “Chisuikan” using Three-dimensional Seismic Base Isolation System. 14th Asia Pacific Vibration Conference

Tomizawa, T., Takahashi, O., Aida, H., Suhara, J., Saruta, M., Okada, K., Tsuyuki, Y., Suzuki, T. and Fujita. T. (2012). Vibration testing in a Building named "Chisuikan"using Three-dimensional Seismic Base Isolation System. 15th World Conference of Earthquake Engineering. under contributionin