IDENTIFICATION OF DYNAMIC CHARACTERISTICS AND SIMULATION ANALYSIS FOR A BASE ISOLATED BUILDING IN COLD SITE

Koichiro Kimoto, *Member of A.I.J,*
2-8-12, Rengaya, Dazaifu, Fukuoka, Japan, TEL 81+92-922-8699
e-mail:kimo@to.email.ne.jp
Yoshio Ito , *Technical Research Institute, Hazama Corp., Dr. Eng.*
515-1,karima,tsukuba,Japan, TEL 81+29-858-8812 FAX 81+29-858-8819
e-mail:itogiken@hazama.co.jp
Shigeki Sakai , *Technical Research Institute, Hazama Corp.*
515-1,karima,tsukuba,Japan, TEL 81+29-858-8812 FAX 81+29-858-8819
Takashi Kato, *Technical Research Institute, Hazama Corp.*
515-1,karima,tsukuba,Japan, TEL 81+29-858-8812 FAX 81+29-858-8819

Keywords: Base Isolation, Identification, Earthquake Observation, 2003 Tokachi-oki Earthquake, High Damping Multi Rubber Bearing

SUMMARY

Strong motion records of 70 earthquakes including Tokachi-oki earthquake in 2003 are obtained at a base isolated building located in the cold district (Kushiro city, Hokkaido Pref.). The accelerations of the records of the base and the upper structure, and the temperature of the base isolated story is measured. The dynamic parameters are presumed by means of two methods with these records. One is a curve fit method on the transfer function in frequency domain ; the other is nonlinear time history response analysis what is general method in design of structure. Thus the natural frequency and the damping factor are calculated.

As a result, the behavior of the structure during the earthquake can be explained by element examinations of high damping multi rubber bearings. In addition, it was confirmed that the dynamic analysis model in design has been appropriated.

The temperature has been 8-15 in the centigrade through the years.

1. Introduction

Hoshigaura hospital is a base isolated (it is called Menshin after this) hospital that is located Kushiro City, Hokkaido Pref. constructed first in Japan as a Menshin hospital, and the first Menshin building in Hokkaido. Menshin was adopted for this neurosurgery hospital because there was a successful example of the USC hospital in California under the Northridge earthquake in 1994, and it was located in the region where the seismic activity is high. There is a feature of Menshin building that builts in the cold district, and the temperature measurement in the Menshin story is done to this building with the earthquake observation. Strong motion records of the Tokachi-oki earthquake in 2003 are observed, the acceleration level are almost equal to that of level 1 design earthquake.

2. Outline of Building

2.1 Outline of Building and Structural Design

This building has three stories, and has about 45m×40m plane dimension, and has total area of floor space is 5000m^2, and it is supported with 50 high damping rubber bearings that are arranged below the first floor. The high damping rubber with the smallest characteristic change in the low temperature are used. It is known that stiffness of natural rubber becomes solidify suddenly when the temperature becomes -20℃ or less. On the other hand, high damping rubber solidifies slowly as the temperature becomes extremely lower.

Photo-1 Outward of Hoshigaura Hospital

Total thickness of rubber is 16.2cm and the long-term pressure is 5.9 N/mm^2 on the average, and the

outside diameter are 60-75cm, and the second shape coefficients are 3.7-4.6. The material of high damping rubber is KL302 in the code of the Bridgestone Co., Ltd., and the damping factor is about 16%.

Structure is a reinforced concrete and Rahmen construction with the shear wall partially. The site's soil condition is soil profile type 2 (medium) in Japanese regulation, the base is mat foundation, and the bottom of base is supported at the gravel layer (GL-3m). Kushiro City is famous for low temperature, while it doesn't have heavy snow. Therefore, the level difference between the scarcement and the ground level has been 30cm or more so that freezing after the snowfall should not hinder Menshin performance. Moreover, the seal is done with rubber packing by the space between retaining wall and scarcement, in order to shut out the cold air.

2.2 Outline of Earthquake Observation and Temperature Measurement

The sensor of seismograph are set up on three places ,the base, the first floor, and the roof, as figure-1. The direction of the installation is adjusted in the direction of frame of the building, so the direction of X corresponds to east-west (EW) otherwise the direction of Y corresponds to the south-north (NS). Three component's consist of two horizontal directions and vertical directions of Z (up-down component) are measured in the base and the first floor, and in the roof two horizontal directions (X and Y) are measured. The sensors are servo type accelerographs. Additionally, the temperature of the Menshin story is measured.

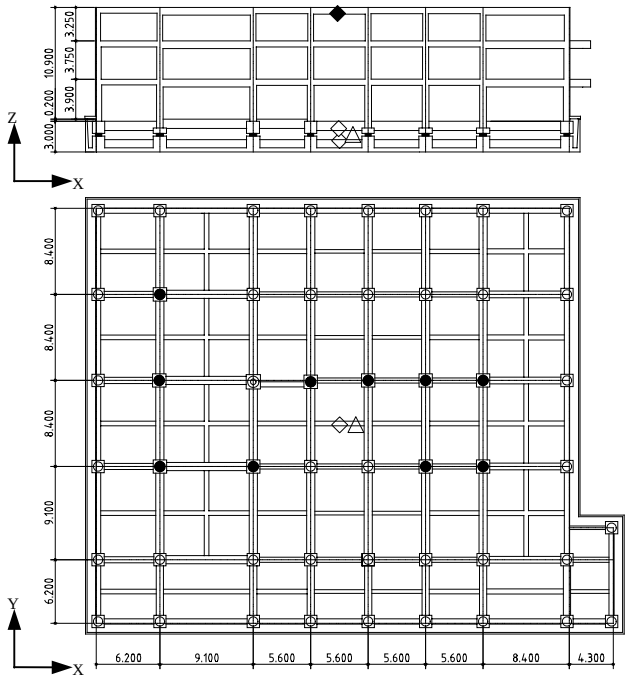
3. Result of the Observation

The observation has been carried out in July in 1996, and 70 records of earthquakes including the Tokachi-oki earthquake on September 26 in 2003 that is the damage earthquake were obtained by May in 2004. In these earthquakes, the range of observed maximum acceleration is 2-212cm/s^2 on the base.

3.1 Temperature of Menshin Story

Figure-2 shows the relationship between the recorded temperature in Menshin story when the earthquake occurred and the outdoors temperature of Kushiro City, that were measured by the Japan Meteorological Agency's Automated Meteorological Data Acquisition System.

Though we expected the temperature in Menshin story becomes to be -15 centigrade in design, range of temperature is stable as 8 to 15 centigrade through the year regardless of the temperature change in outdoor. However, it is necessary to note the following. The outer part of Menshin story has been sealed up with the rubber plate (Figure-3), and the building was air-conditioned through 24 hours because of hospital.



Menshin Members			Sensors	
Mark	Diameter	Quantity	Mark	Component
○	600	39	◇	Acc.(XYZ)
●	700	10	◆	Acc.(XY)
◎	750	1	△	Temperature

Fig.-1 Outline of Structure and Arrangement of Sensors

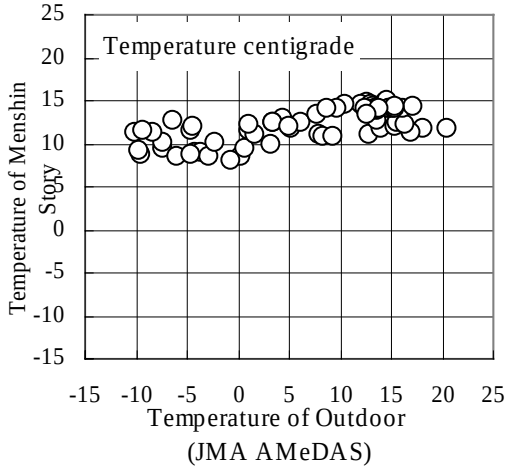


Fig.-2 Relation of Temperature

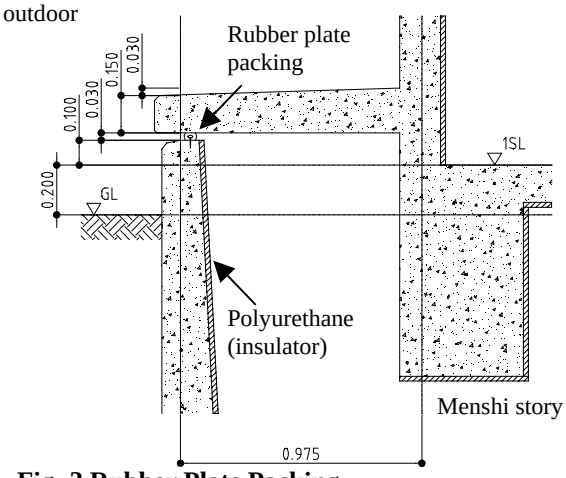


Fig.-3 Rubber Plate Packing

Table-1 Maximum Values of Tokachi-oki Earthquake

	Max. Acc. cm/s^2			Max. Vel. cm/s		
	EW	NS	UD	EW	NS	UD
Roof	162	126	-	44	49	-
1F	155	123	145	44	48	8
Base	212	142	100	33	31	7

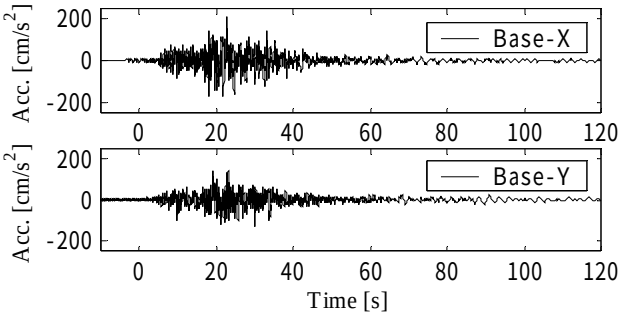


Fig.-4(a) Time History of Tokachi-oki at the Base

3.2 The Tokachi-oki Earthquake in 2003

The strong motion records of Tokachi-oki earthquake is obtained by the seismograph(figure-4(a)), and the maximum values are indicated in Table-1. Moreover, its Fourier spectra are shown in Figure-4. The velocities of the strong motion are a little larger than that of design level 1 (allowance stress design), that the maximum input velocity was 25cm/s.

3.3 Acceleration Response Magnification

Figure-5 is shown compared with the maximum acceleration of the upper structure to the horizontal maximum acceleration of the base. The magnification are about 0.2-3 in weal motion in the base, it is about 1 or less in a little strong motion, and an Mensin effect can be confirmed. The value in design level 1 and level 2 by the star mark is indicated. The result of the Tokachi-oki earthquake is values of level 1.

3.4 Fourier Spectral Ratio

Figure-6 shows compared with the Fourier spectral ratio of the upper structure roof to the base. As for them, the ensemble averaging have been done according to the level of the maximum acceleration of

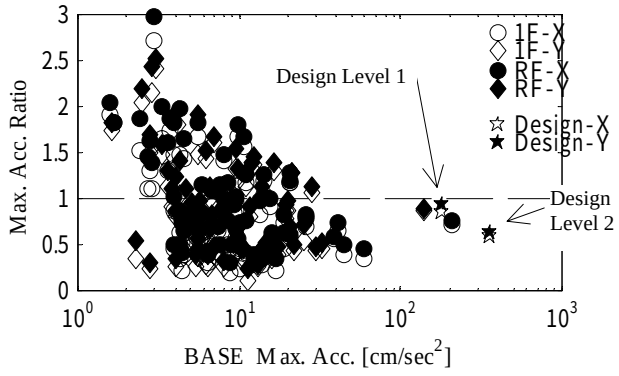


Fig.-5 Max. Acc. Ratio (RF/Base)

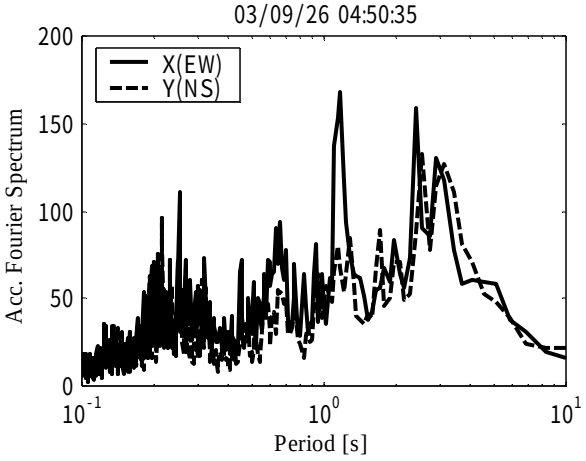


Fig.-4(b) Fourier Spectrum of Tokachi-oki at the Base

the base. The natural frequencies become lower as for the acceleration level of the base become large Therefore, it is thought that the shearing stiffness of the high damping rubber bearings depends on the amplitude, for the level of strong motion.

4. Presumption of Dynamic Parameters by the Curve Fit Method

4.1 Transfer Function by Observation

The transfer function between the roof and the first floor (Fourier spectral ratio) based on the base were calculated. The high-speed Fourier transform have done with time extracted at 4096 points each frame and the overlap of 7/8 and 0.01 seconds sampling, and each spectrum was calculated by the average of the ensemble.

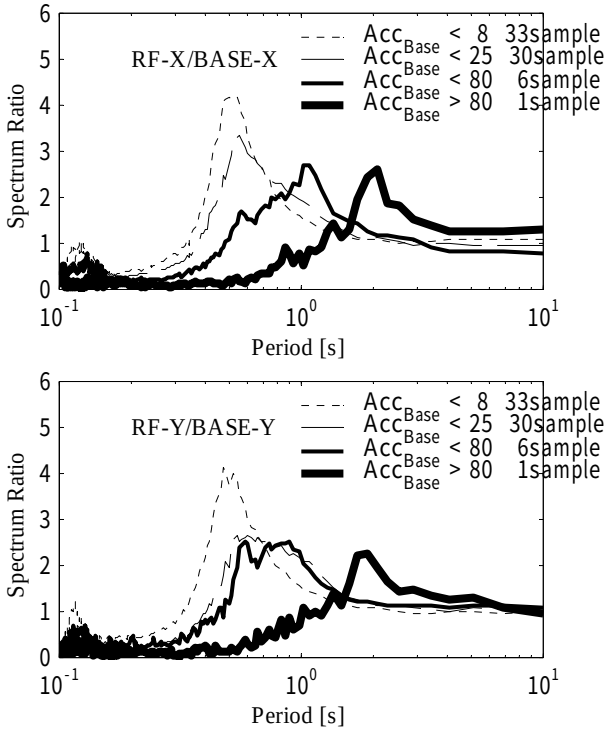


Fig.-6 Transfer Function by Observation (RF/Base)

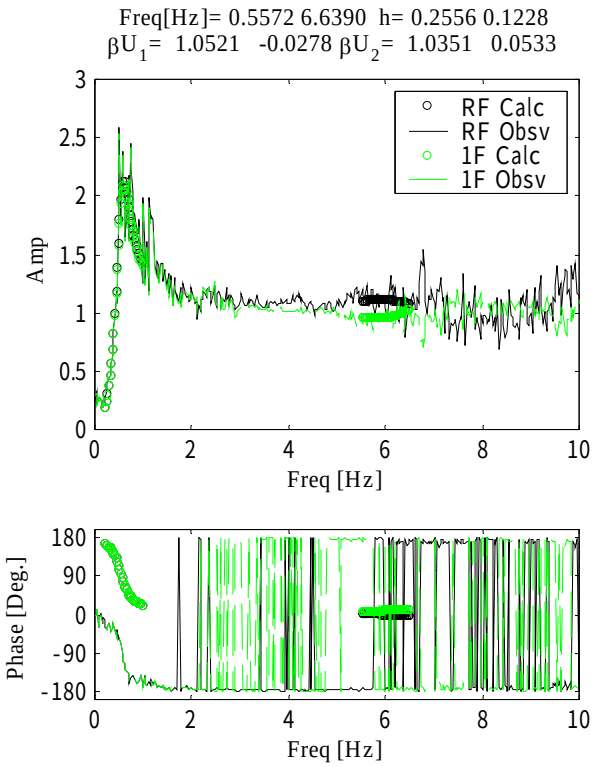


Fig.-7(a) Result of Curve Fit (Tokachi-oki)

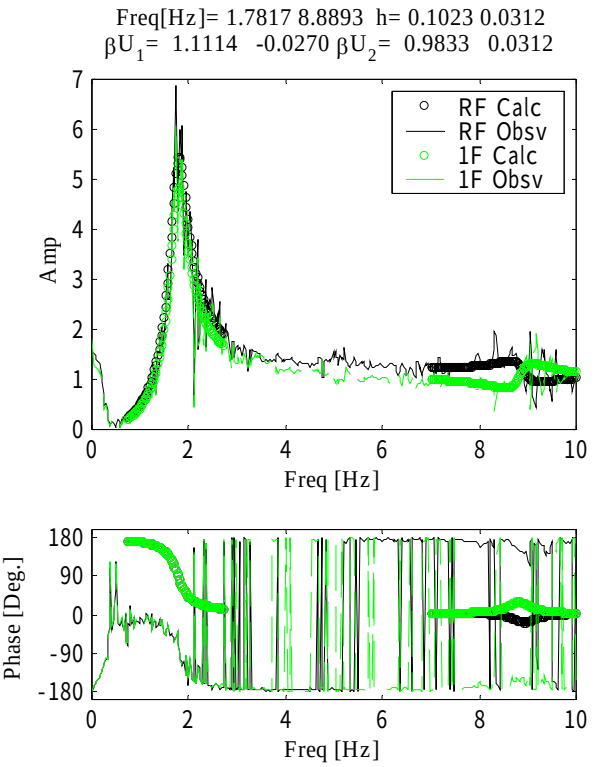


Fig.-7(a) Result of Curve Fit (1997/06/15)

4.2 Presumption method

The parameters of the theoretical transfer function that suits the observation transfer function obtained by the above-mentioned method most are searched by Quasi-Newton method[1)2)]. The motion equation of two mass two degree of freedom to the earthquake is converted into the mode coordinate system by the Laplace transform (operator r)[3)]. Then, the theoretical transfer function of the absolute input acceleration to the relative acceleration of the structure becomes the following expression.

$$H_i(r)=\sum_{s=1}^{2}\frac{-{}_s\beta u_i}{r^2+2{}_sh(2\pi{}_sf)r+(2\pi{}_sf)^2} \qquad (1)$$

$_sf$: Natural Frequency
$_sh$: Damping Factor
$_s\beta u_i$: Participation Vector
i : Output Point (1F or RF)
s : Mode Number

In ranges of the frequency including first and second modes, each parameters ($_sf$, $_sh$, $_s\beta u_i$) are searched at the same time by minimizing the evaluation function that shows the sum total of the error margin of the amplitude between observation and the theory.

4.3 Result of Presumption

The examples of the result of presumption are shown in Figure-7. Such presumption of the direction X and Y of each 70 earthquakes was done. Because

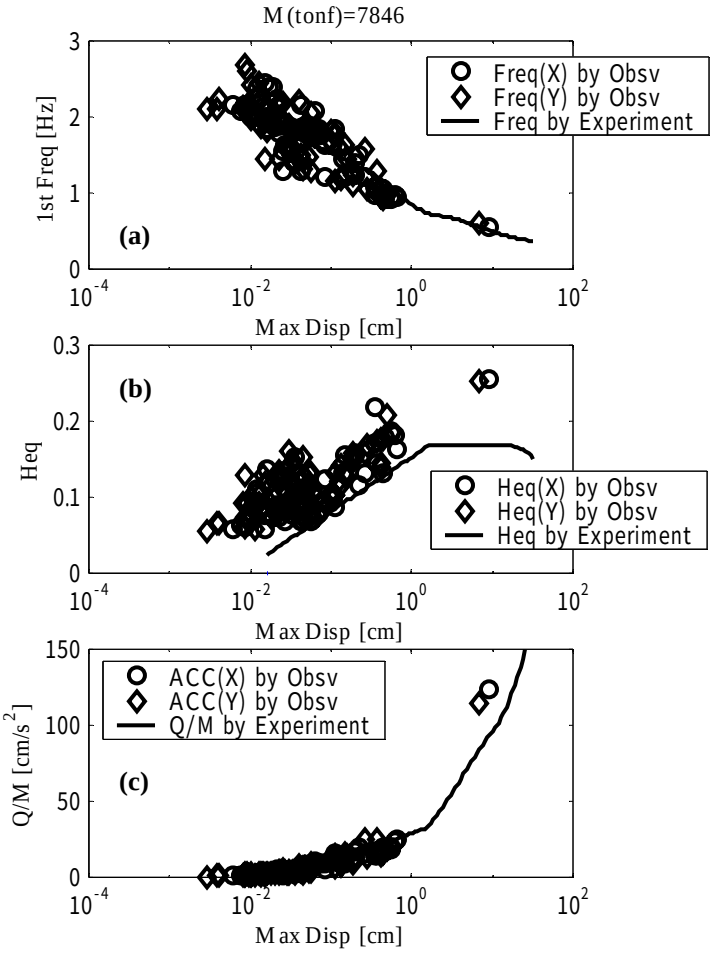


Fig.-8 result of Presumption

the shape of the first peak has fallen into disorder, it seems that the error margin of presumption is large though Figure-7(a) in the Tokachi-oki earthquake. Figure-7(b) it is an earthquake of next large 1997/6/15, it fits well. Other records also are well like this earthquake. In addition, the displacement of the upper structure's first floor was calculated by using the presumption value of the first mode. The displacement of the first floor reaches the value in which $_1\beta u_{1F}$ is multiplied by the calculation value with using the Nigam method's. The relation between presumed maximum displacement of the first floor and presumed vibration parameters are shown in Figure-8. The element experiment[4] results of high damping multi rubber bearing (solid line) are additionally shown in these figures. The first mode frequency decreases when the maximum displacement grows, and it has been suited well with the experiment result.

At the same time the damping factor increases and the dynamic characteristic of high damping rubber appears. The damping factor is generally estimated more larger than that of the experiment, and it is guessed that the radiation damping is added. Next, the value (Q/M) is indicated in Figure-8(c) as shearing force Q divided by mass M of the building. The presumption value almost corresponds to Q/M (skeleton) obtained from the experiment result.

The results of the seismic observation almost corresponded to the results of the element experiments.

5 Simulation of Seismic Response Analysis

The strong motion of the Tokachi-oki earthquake in 2003 was targeted for the analysis among observed records.

5.1 Analysis Method

The acceleration of the base observed to four mass-shear spring and high damping rubber is substituted for the modified bilinear model which was used in design, and numerical integration had been done by Newmark-β method with β is 1/4, time interval is 0.005 second.

Thus analytical results were compared with the observation results.

5.2 Result of Simulation

The horizontal acceleration responses of the roof are shown in Figure-9. The analytical results agree with the observation result well and the maximum value has also adjusted roughly.

Because the time history in a slight amplitude cannot be explained by the analytical model, the post-vibration is not attenuate in the calculation results.

Next, orbits of the displacement of the Menshin

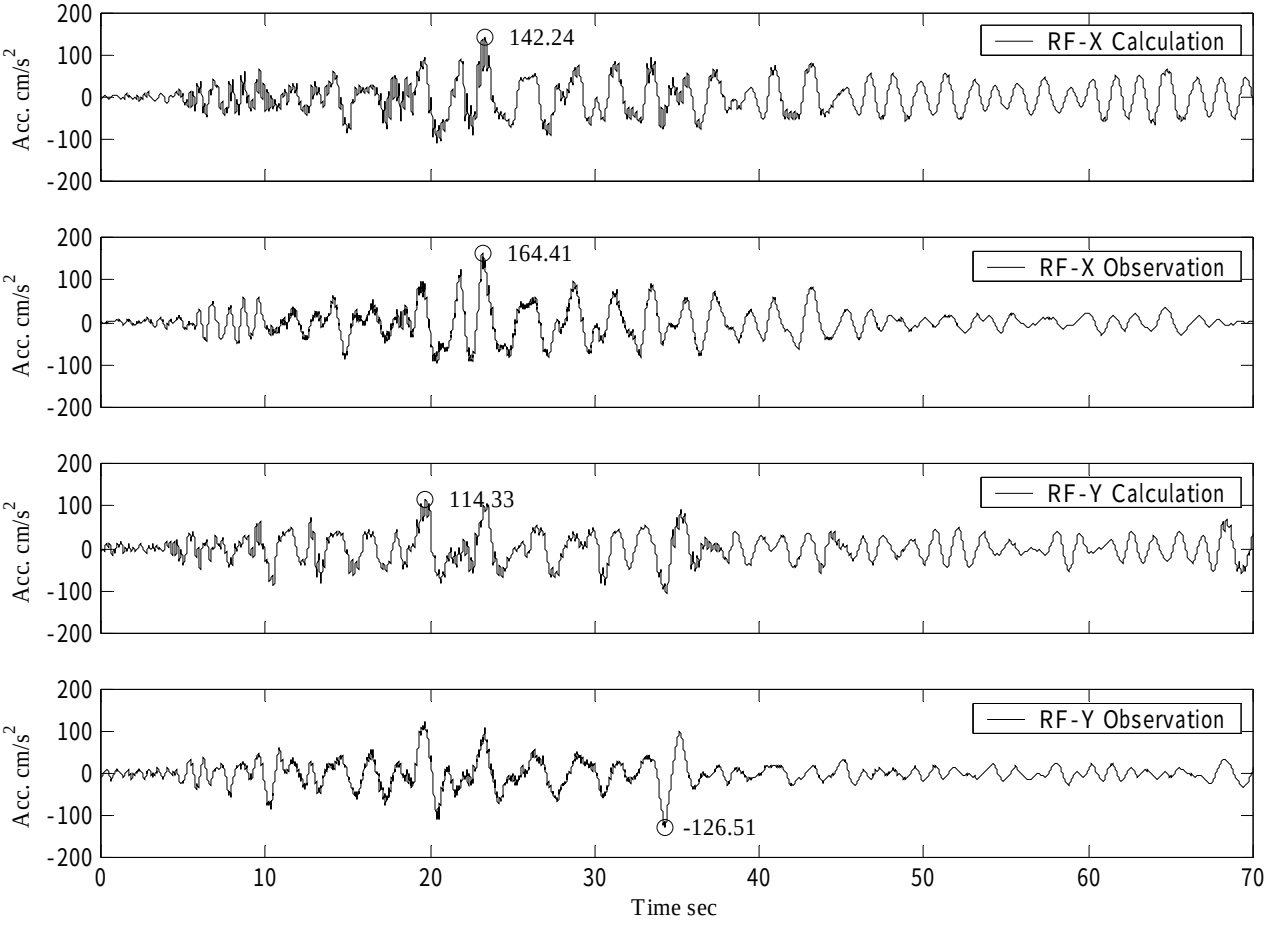


Fig.-9 Comparison between Simulated and Observed Time History of Acceleration

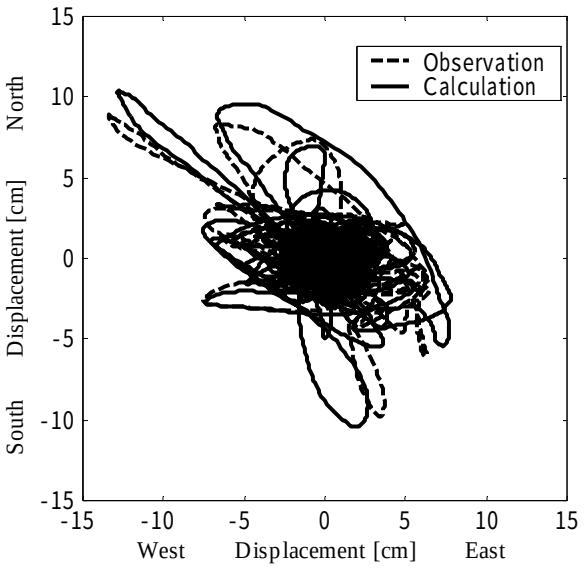


Fig.-10 Orbits of Menshin Story

story are shown in Figure-10. The solid line is an orbit that is given by the relative displacement between the base and the first floor, which are estimated by twice integration by means of the FFT method, of the observed acceleration. The observation and the analysis correspond well in the result. Besides, it was in the range that could be considered that behavior in each floor of the upper structure was linear. It was confirmed that the analytical model used for the design was appropriate as the model to evaluate the maximum response in the main exciting duration.

6 Conclusion

The following were confirmed.

1) The effect of the quake absorbing of the acceleration decrease was confirmed. And, the effect becomes more remarkable as for it as the input level becomes large.

2) The identification of dynamic parameters for structure model shows the amplitude dependency, and it has the cause mainly in the dynamic characteristics of the high damping isolator as Menshin members, and the characteristics can be expressed by element examination of the Menshin members.

3) Results of the simulation are well adapted to the measurement results.

4) The temperature of the Menshin story was stably 8-15 degrees centigrade through the year, regardless of the fluctuating of the outside temperature.

<Address of thanks>

We wish to express our gratitude to everybody of medical corporation Koujinkai Hoshigaura hospital who have understanding and cooperation of the seismic observation.

<References>

1)Ohno et al,(1990), Suchi Kaiseki Handbook, Chapter 9, (in Japanese)

2)Mathworks Co.,(1999), Optimization Toolbox User's Guide

3)Shibata,(1981) Saishin Taishin Kouzou Kiseki, Chapter 2, (in Japanese)

4)Bridgestone Co. LTD., (1996), Technical Report No.1996.2.6, (in Japanese)