SHAKING TABLE TEST AND ANALYSIS ON BASE ISOLATED FBR PLANT MODEL WITH NATURAL RUBBER BEARING

Yukio WATANABE[1], Asao KATO[2], Masaaki OBA[3], Junji SUHARA[4], Tsutomu HIROTANI[5], Ryozo TANAKA[6], Katsuhiko UMEKI[7] And Takahiro SOMAKI[8]

SUMMARY

The demonstration fast breeder reactor (DFBR)[1)] incorporating seismic base isolation has been developed in Japan. In this study, to confirm effectiveness and seismic safety of the DFBR plant which is isolated by a laminated rubber bearing with a high axial stress, shaking table tests and analytical studies are performed. The experiment model represents the dynamic characteristics of the DFBR. The superstructure consists of three stories steel frame and the scale of the model to a prototype for length is about 1/16.As an isolation device, a natural rubber bearings(NRB) with a steel damper(SD) is used in the tests. The isolated natural period of 2.0, 2.8 and 4.0 seconds in an actual scale are set up in rubber bearings.As the results of shaking table tests, though the isolated natural period becomes long with a high axial stress, it is confirmed that integrity for seismic isolation devices and a building is ensured.Simulation analysis on the shaking table tests are carried out. As a restoring force model of an isolation device, a bi-linear model, a tri-linear model and a Ramberg-Osgood model are considered. A model of superstructure is evaluated by a lumped mass model with shear and bending components. As the results of simulation analysis, it is found that these analysis models can evaluate the seismic response of isolation devices and a building and the floor response exactly.

INTRODUCTION

In the dynamic property which has been developed in the DFBR incorporating seismic base isolation in Japan, the initial horizontal natural period is 1.0 second, the isolated natural period is 2.0 seconds and the axial stress of a laminated rubber bearing is 25 kgf/cm^2. We try to develop a rubber bearing whose material is the same as an ordinary rubber bearing, but the axial stress is 50kgf/cm^2. In this study, to confirm seismic safety of the DFBR plant which is isolated by rubber bearings with high axial stress, shaking table tests and analytical studies are performed.

SHAKING TABLE TEST

Outline of the shaking table tests

[1] *THE JAPAN ATOMIC POWER COMPANY, 1-6-1 Otemachi Chiyoda-ku Tokyo Japan*
[2] *THE JAPAN ATOMIC POWER COMPANY, 1-6-1 Otemachi Chiyoda-ku Tokyo Japan*
[3] *THE JAPAN ATOMIC POWER COMPANY, 1-6-1 Otemachi Chiyoda-ku Tokyo Japan*
[4] *SHIMIZU CORPORATION, 1-2-3 Shibaura Minato-ku Tokyo Japan E-mail :suhara@eng.shimz.co.jp*
[5] *SHIMIZU CORPORATION, 1-2-3 Shibaura Minato-ku Tokyo Japan*
[6] *SHIMIZU CORPORATION, 1-2-3 Shibaura Minato-ku Tokyo Japan*
[7] *OBAYASHI CORPORATION, 1-19-9 Tsutsumitoori Sumida-ku Tokyo Japan*
[8] *OBAYASHI CORPORATION, 1-19-9 Tsutsumitoori Sumida-ku Tokyo Japan*

Test cases

Test cases are shown in Table 1. Test parameters are an isolated natural period, an initial natural period of an isolation device and input motions. The isolated natural period of 2.0, 2.8 and 4.0 seconds corresponding to a prototype are set up in a rubber bearing. As an initial natural period, 1.0 second and a half of an isolated natural period are set up. As a ratio of an yield force to total weight in a rubber bearing, 0.05 or 0,1 is designed according to the intensity of input motions.

Superstructure and isolation device

The experiment model represents the dynamic characteristics of the DFBR in Japan[1)]. The superstructure consists of three stories steel frame and the gravity center is located on the second story as the same as a prototype. The outline of experiment model is shown in Fig. 1. The scale ratio of the model to a prototype is 1/15.3, and both acceleration and stress are equal to those of a prototype.

As a isolation device, natural rubber bearings with steel dampers are used in tests. The diameter of a rubber bearing is about 10 cm.

A steel damper is designed as a cantilever beam type with a fixed base and a free rotational support by a spherical bearing. A steel damper has an uniform section and the number, diameter and length of the steel damper are designed according to the test parameters. The outline of these isolation devices is shown in Fig. 2

The axial and shear forces acting on rubber bearings and the shear forces on steel dampers are measured by a component force transducer installed under every rubber bearing and steel damper. The relative horizontal displacements between the shaking table and the superstructure, accelerations and velocities on shaking table and the superstructure are measured.

Input motion

The standard earthquake ground motion(S2-S) and the maximum probable earthquake ground motion(S2-M) are used as an input motion to a shaking table test. The response velocity spectra with 5 % damping in long periods from 2 seconds to about 10 seconds of S2-S are 70 kine and those of S2-M is 200 kine. A rubber bearing is designed to have a margin against a hardening point in a deformation by each input motion. Three input motions whose spectra are the same but phase properties are different, i.e. La Union record on Mexico earthquake 1985, Taft record 1952 and random phase are used.

Test results

Response of isolation device

The maximum responses of horizontal displacements and shear forces of isolators are shown in Fig. 3. The solid lines indicate skeleton curves which are set up in design for each test parameter. The horizontal displacement of a rubber bearing whose isolated natural period is made longer by using a high axial stress, doesn't increase when the initial natural period is set up to 1.0 second. The horizontal displacement of a rubber bearing whose isolated natural period is made longer increases and enters to a hardening zone when the initial natural period is set up in proportion to the isolated natural period

Hysteresis loops between the shear force and the horizontal displacement of an isolation device against amplified S2-S and S2-M are shown in Fig. 4.

As the response of a rubber bearing stands within a hardening point against an input beyond the design earthquake, it is found that a rubber bearing which has a margin against a hardening point in design possesses sufficient seismic safety.

Responses of superstructure

Distribution of the maximum response acceleration of the superstructure is shown in Table 2. It is found that the maximum response acceleration on each floor of the superstructure is smaller than those of shaking table, so, the effectiveness of isolation system is confirmed.

SIMULATION ANALYSES

Analysis cases and analysis model

Outline of analysis model

The model for a simulation analysis is shown in Fig. 5. The model of the superstructure is evaluated by three lumped mass model with shear and bending components. The model of the isolation layer consists of shear springs and axial springs. Shear springs represent the horizontal restoring force of rubber bearings and steel dampers and axial springs evaluate the rocking vibration caused by axial stiffness of rubber bearings.

Model of superstructure

Stiffness of an superstructure model is determined by sweep(sine wave input) tests. Constants of three shear springs are identified with three natural frequencies which are obtained by transfer functions of sweep tests. Stiffness of a rotational spring is evaluated by the axial stiffness of steel columns. The damping ratio of 1% for the superstructure is set up by shaking table tests.

Model of isolation device

As for the analysis model of an isolation device, two models are considered. One is a design model which has the same property as the design condition and is evaluated by a bi-linear model. The other is a simulation model whose property is modified to evaluate the test results.

In a design model, stiffness of a rubber bearing and a steel damper is the same value as the design. In a simulation model, stiffness of a rubber bearing is obtained by the static element tests and stiffness of a steel damper is modified by the shaking table tests.

The restoring force property of a rubber bearing is modeled by tri-linear as shown in Fig. 6 when a deformation of a rubber bearing enters the hardening zone.

The restoring force property of a steel damper is modeled by a bi-linear, tri-linear or a Ramberg-Osgood model. The property of a simulation model is set up to adjust the hysteresis loops of a shaking table test result. The hysteresis loops of experiments and calculations are compared in Fig. 7. These figures show that results calculated by a tri-linear or a Ramberg-Osgood model can evaluate the experiment results more similarly than a bi-linear model.

Damping ratio of a rubber bearing is 2% and that of a steel damper is 2% to the initial stiffness.

ANALYSIS RESULTS

Fig. 8 shows the comparison of the maximum response of the experiments and calculations in case of the amplified input motion and conventional isolation properties, i.e. the initial natural period is 1.0 second and the isolated natural period is 2.0 seconds. Theses figures show the ratio of calculation results to experiment results on the maximum response displacement of the isolation devices and the maximum response acceleration of the 2nd story. Fig. 9 shows the comparison of the maximum response of the experiments and calculations in case of the longer isolated natural period.

From these figures, it is found that the results by the simulation model is more similar to the experiments than the results by the design model and analysis accuracy becomes well when a tri-linear and a Ramberg-Osgood model which represents the actual hysteresis property are used as the model of a steel damper. As for the stiffness of a rubber bearing, the simulation model evaluates the experiments more similarly than the design model. But the design specification to the stiffness of a rubber bearing can be used in practice as the difference between responses by a design model and a simulation model is small.

Fig. 10 shows the typical floor response spectra(FRS) on the 2nd story with damping ratio h=1%. Through the simulation analyses, it is found that the results by a tri-linear and a Ramberg-Osgood model are more similar to the experiment results than the results by the bi-linear model. But the bi-linear model can be used in the design as FRS is overestimated by a bi-linear model.

CONCLUSION

To investigate applicability of a rubber bearing with the high axial stress, shaking table tests and analytical studies for NRB+SD are carried out. The results of studies are summarized as follows.

1) Though an isolated natural period becomes long with a high axial stress, it is confirmed that integrity for seismic isolation devices is ensured when the initial natural period keeps short.

2) For the seismic analysis model of a rubber bearing with a high axial stress, the conventional analysis model whose restoring force models of an isolation device is a bi-linear model and superstructure is modeled by the lumped mass with shear and bending components can evaluate the seismic response of isolation devices, a building and the floor response exactly.

ACKNOWLEDGEMENT

This study was carried out as a part of the FBR common research of the electric power companies in Japan, entitled “Conceptual Design of DFBR”. And this study was based on the support of Professor T. Fujita of Institute of Industrial Science, University of Tokyo, whom the authors gratefully acknowledge.

REFERENCE

1) Kato, M. et al. “Design study of the seismic-isolated reactor building of demonstration FBR plant in Japan,” *Trans. of the 13th SMiRT*, Vol.3, Division.K, pp579-584, Brazil, August, 1995.

Table 1 Parameters of Test Models

No.	Isolated Natural Period[2] T2(sec)	Ratio of Yield Force to Supporting Load β	Initial Natural Period[2] T1(sec)			Number of Isolators	Total Weight (tonf)	Axial Stress (kgf/cm^2)	Input Motion
			1.0	1.41	2.0				
1	2.0	0.05	NRB1020S[1]	-	-	4	17.2	50	S2-S
2		0.1	NRB1020	-	-	8	17.2	25	S2-M
3	2.83	0.1	NRB1028	NRB1428	-	4	17.2	50	S2-M
4	4.0	0.1	NRB1040	-	NRB2040	4	34.4	100	S2-M

1) A symbol represents an abbreviation of test case.
2) Natural Period represents that of prototype.

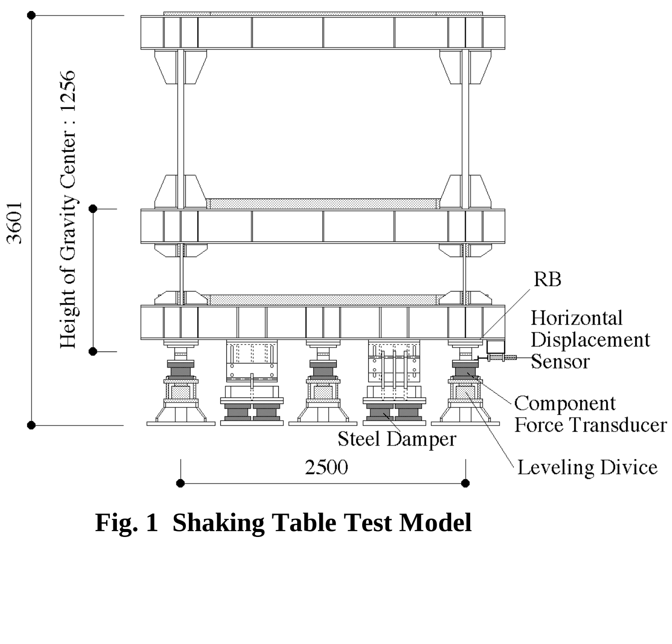


Fig. 1 Shaking Table Test Model

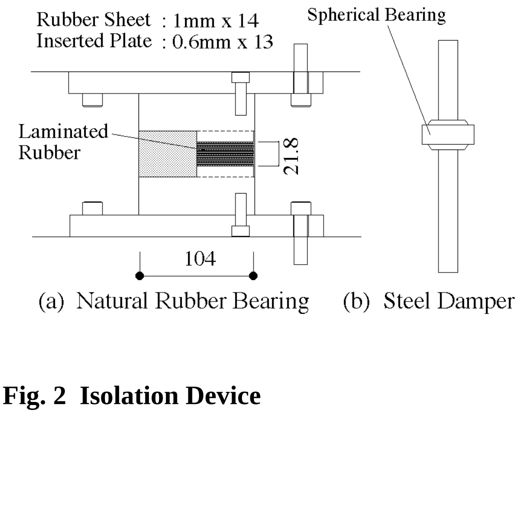
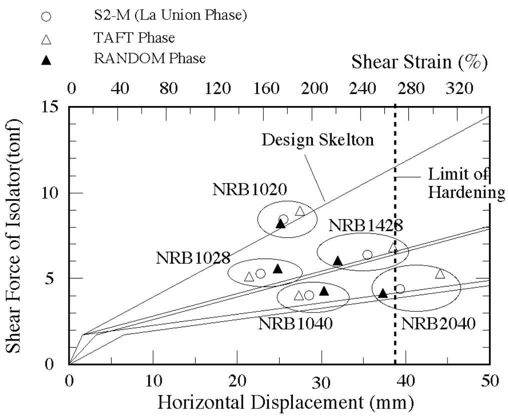


Fig. 2 Isolation Device



(a) NRB + SD

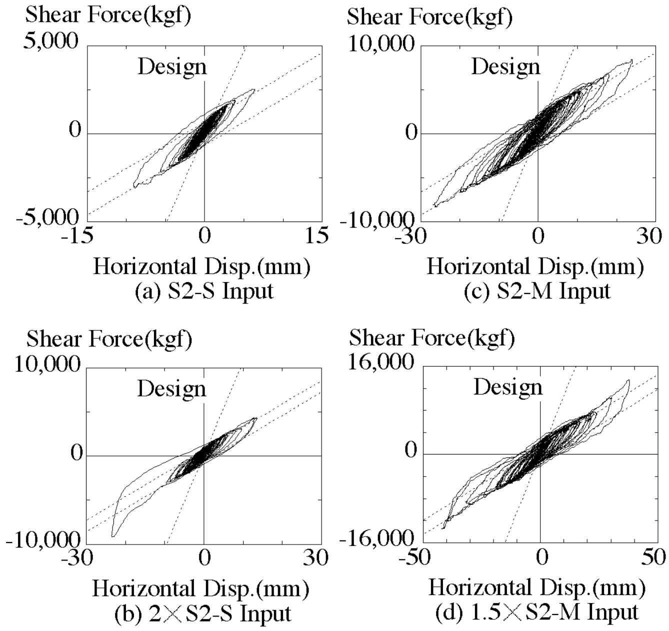
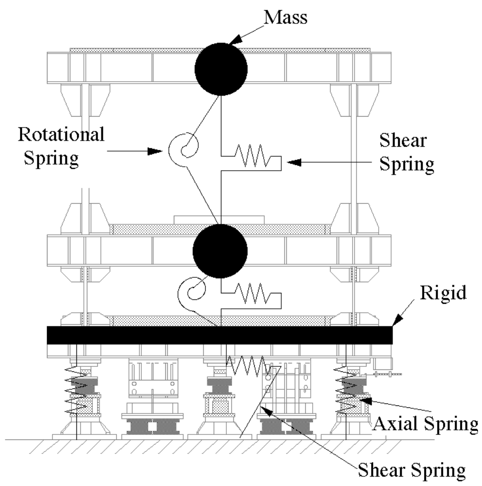


Fig. 3 Maximum Response of Isolated Layer

Fig.4 Hysteresis Loop of Isolated Layer

Test Case & Input / Position	NRB1020S		NRB1020		NRB1028	NRB1428	NRB1040	NRB2040
	S2-S	2xS2-S	S2-M	1.5xS2-M	S2-M	S2-M	S2-M	S2-M
3rd layer	301	693	671	1088	558	477	410	350
2nd layer	205	593	504	850	359	385	261	274
1st layer	210	534	577	888	416	403	288	313
Shaking Table	472	884	973	1391	954	1006	932	993

Table 2 Distribution of Maximum Response Acceleration (Unit : Gal)



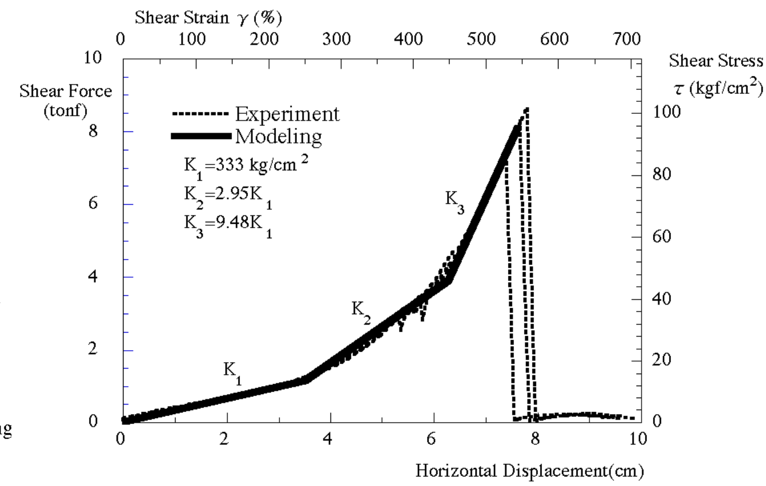
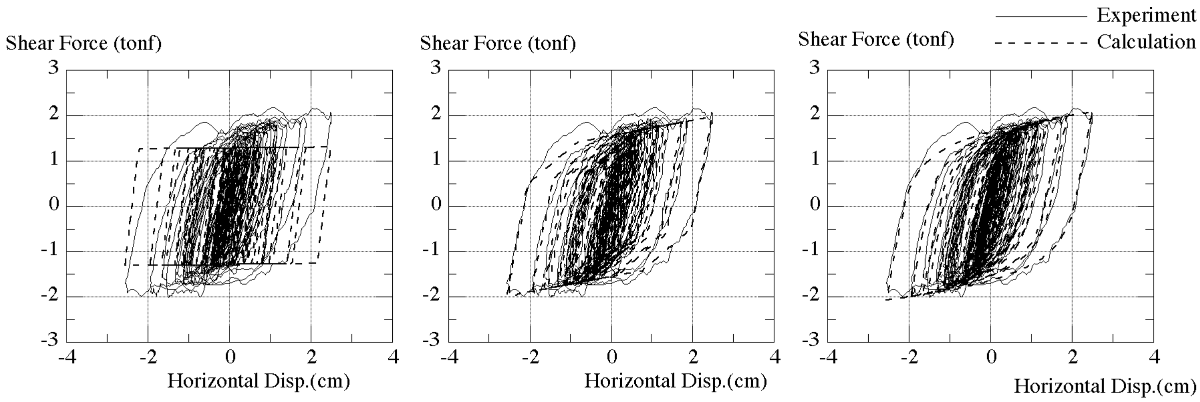


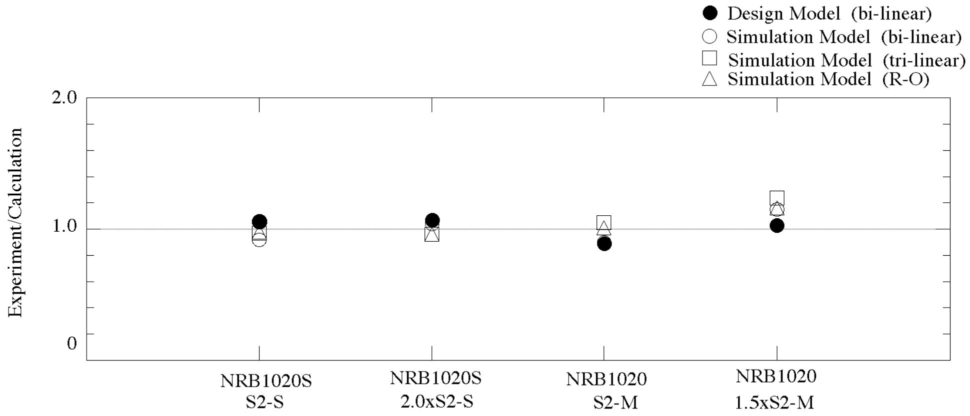
Fig. 5 Analysis Model

Fig.6 Skelton Curve and Exoeriment Results against S2-M

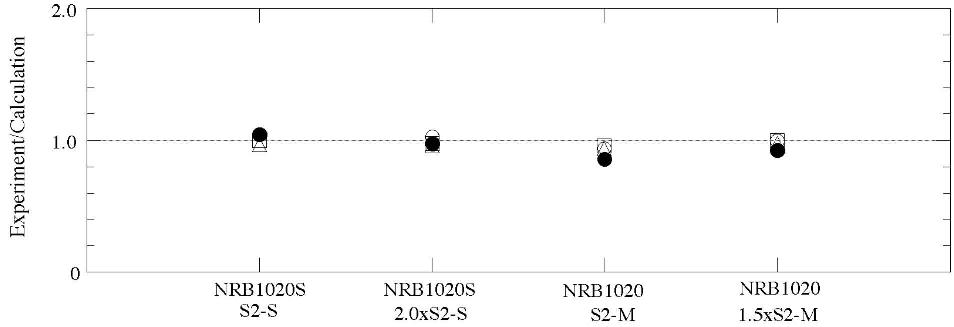


(a) Bi-linear Model (b) Tri-linear Model (c)Ramberg-Osgood Model

Fig.7 Restoring Force Model of Steel Damper (T1=1.0s,T2=2.0s,β=0.1).

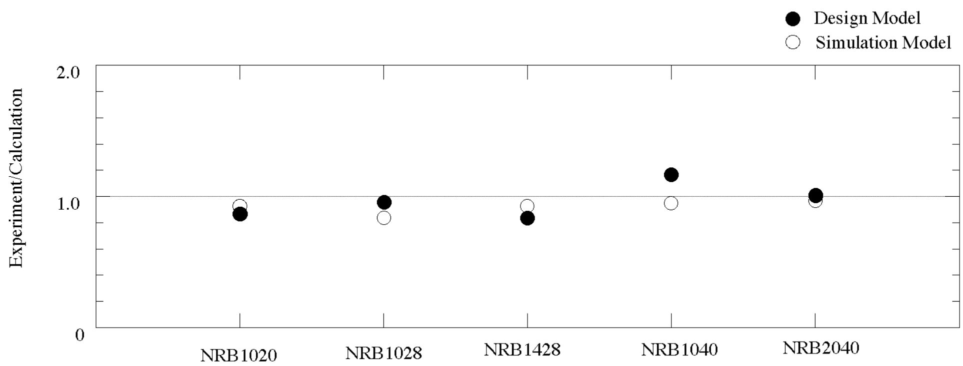


(a) Maximum Response Acceleration on the 2nd Story

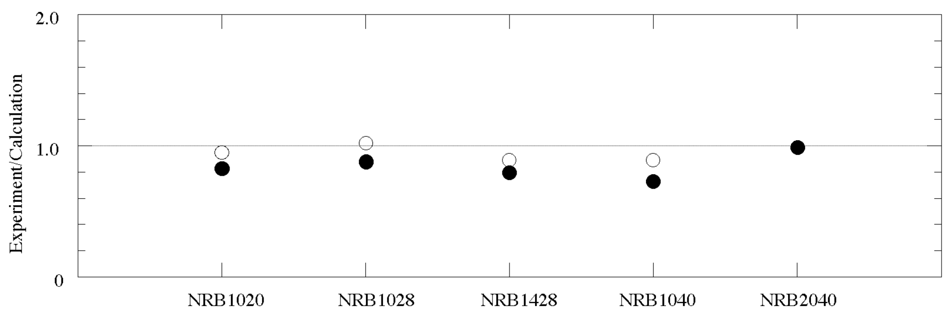


(b) Maximum Response Displacement of Isolator

Fig. 8 Comparison between Experiment Results and Calculation Results in case of NRB 1020S(T1=1.0(s),β=0.05) and NRB 1020(T1=1.0(s),T2=2.0(s),β=0.1)

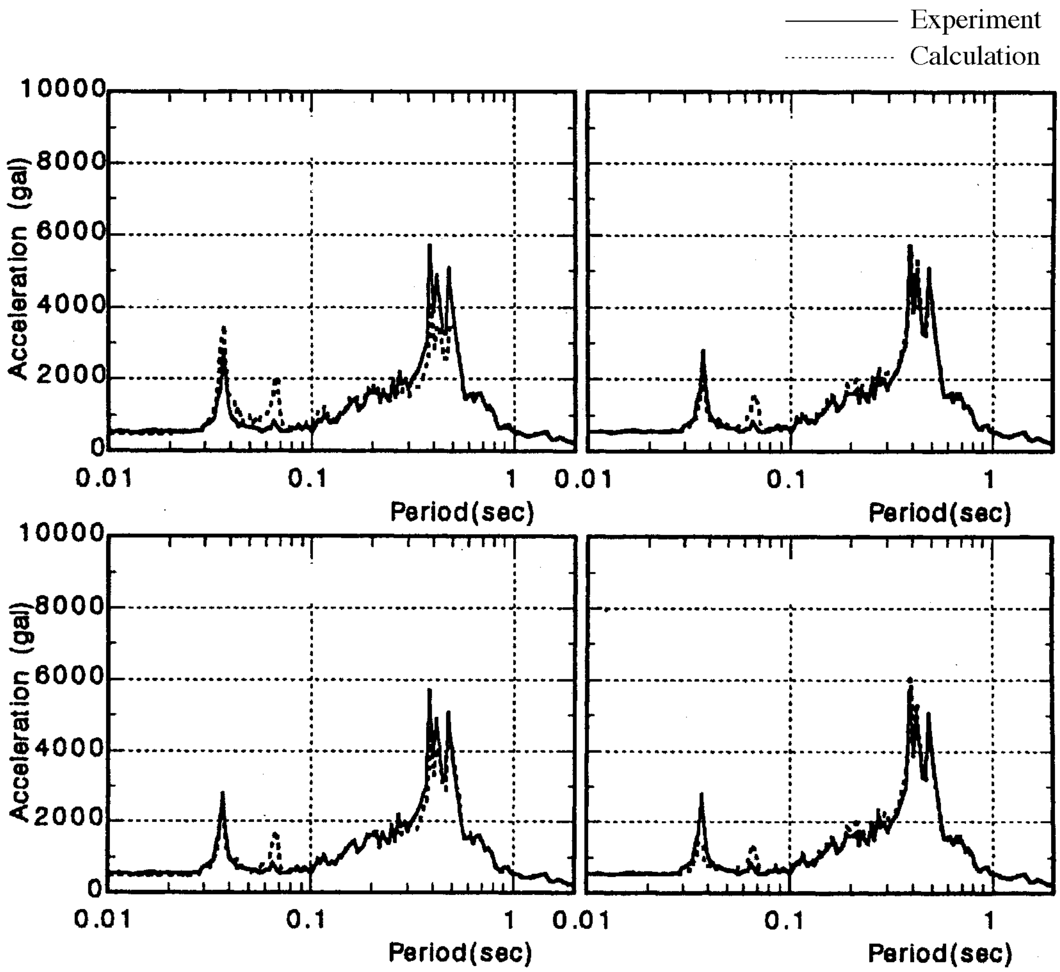


(a) Maximum Response Acceleration on the 2nd Story

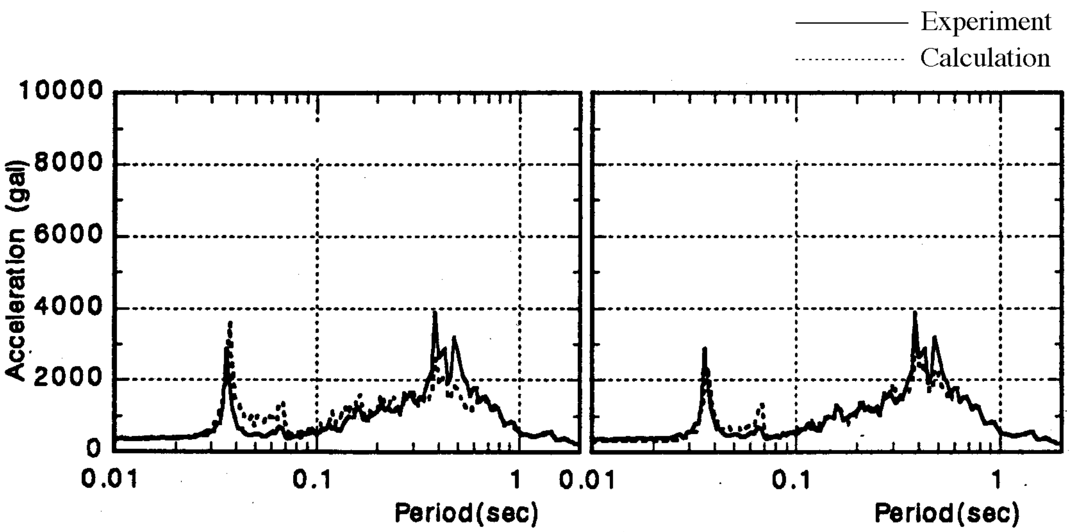


(b) Maximum Response Displacement of Isolator

Fig. 9 Comparison between Experiment results and Calculation Results in S2-M Input



(a) NRB1020 (T1=1.0s,T2=2.0s,β=0.1)



(b) NRB1028 (T1=1.0s,T2=2.8s,β=0.1)

Fig.10 Floor Response Spectra on the 2nd Story.