Investigation of Base Isolation for Fast Breeder Reactor Building

M. Morishita
Power Reactor and Nuclear Fuel Development Corporation, Ibaraki, Japan
M. Kobatake, K. Ohta, Y. Okada
Shimizu Corporation, Tokyo, Japan

INTRODUCTION

Achievement of great rationalization for seismic-resistant design of equipment system is necessary and indispensable from the viewpoints of economical and structural validity for a fast breeder reactor to be made practical. The method of reducing seismic loads on the building and equipment by application of base isolation may be an effective method, but in application to nuclear facilities, it will become necessary to examine the feasibility to actual design considering the severe seismic design requirements in Japan.

With these considerations as the background, the authors carried out analytical studies from various viewpoints such as restoring force characteristics of base isolation device, influence of input earthquake motion, soil-structure interaction in base-isolated structure, etc. in case of providing base isolation system for a fast breeder reactor building (Morishita et al, 1987). Based on these analytical studies, vibration tests on a base-isolated structure using a triaxial shaking table and simulation analyses of the tests were performed attempting to verify the effectiveness of the base isolation system and appropriateness of the analysis method.

APPLICATION OF BASE ISOLATION TO FBR BUILDING

Construction of base-isolated buildings has been going on actively in Japan in recent years. In many of the buildings, the base isolation system adopted is that of combining laminated natural rubber bearings and various types of dampers, and buildings using lead rubber bearings or high-damping rubber bearings are now gradually increasing. It is considered that a base isolation method for ordinary buildings will be also suitable for a fast breeder reactor building, and in particular, the combination of laminated natural rubber bearings and steel hysteretic dampers, which have clearer mechanical properties and durability, has sufficient examples in ordinary base-isolated buildings, and it is thought possible to apply this system to nuclear facilities which are important structures and particularly requires reliability. The study of the combination of laminated natural rubber bearings and steel hysteretic dampers as the first stage in examining the applicability of base isolation to a fast breeder reactor building is reported in this paper.

In order to select the appropriate restoring force characteristics in case of combining laminated rubber bearings and steel hysteretic dampers, modeling was done by a two-lumped-mass system as shown in Fig.1, with the base isolation device modeled by a bilinear type spring shown in Fig.2, and analyses were made with device characteristics, soil properties, and maximum input acceleration of input waves as parameters. As for base isolation device, laminated rubber bearings were modeled as a linear spring, and steel dampers were modeled as an elasto-plastic spring, then the total device was represented as a bilinear spring synthesizing both elements. The artificial wave (Magnitude;8.4, Epicentral Distance;90km) and the EW component of the Hachinohe Harbor record in Tokachi-oki Earthquake in 1968 shown in Fig.3 were used in the analyses. Base isolation frequency(f)=1.0 Hz, yielding coefficient(β)=0.1, and second stiffness ratio(α)=0.1 were selected as appropriate restoring force characteristics based on the analysis results.

Next, the case of applying these base isolation device characteristics to the 1,000MWe class loop-type fast breeder reactor building was assumed and earthquake response analyses were performed inputting the artificial wave to the multiple-lumped-mass model shown in Fig.4. Regarding the base-isolated building, analyses were performed for two cases of wall thickness, one was the same as no base isolation and the other was reduced considering the effect of reduction in response due to base isolation. The weight of the superstructure (including the upper base mat) was reduced from about 210,000tons to 140,000tons and the first natural frequency was lowered from 7.71Hz to 4.41Hz by reducing wall thickness. The results of earthquake response analysis (maximum response acceleration and floor response spectra at the support position of the reactor containment vessel) are shown in Fig.5. Through these, it was ascertained that by adopting base isolation, maximum response acceleration and floor response spectra in short period range could be greatly reduced, and that the reduction in wall thickness hardly affected on response values in base-isolated building. The maximum relative displacement of the base isolation device at this time was approximately 6cm, while the ductility factor of the steel damper was approximately 2.5.

DESIGN OF SHAKING TABLE TEST MODEL

With the base isolation device selected as the object, reduced specimens used in shaking table tests were designed and fabricated. The shaking table used was a large-sized triaxial shaking table of load capacity 20tons. And the base-isolated building, which was 16tons in weight, adopted a structure supported by four laminated rubber bearings of 4tons rated load. On the other hand, laminated rubber bearings used for the actual building were designed for 300tons rated load in consideration of the layout of the devices and fabrication, so the reduced model was designed in accordance with the reduction ratio shown in Table I.

The reduced models of the superstructure, laminated rubber bearing, and steel hysteretic damper are shown in Fig.6. The superstructure was designed as a steel frame structure to satisfy the reduction ratio with regard to the primary natural frequency of the superstructure of the fast breeder reactor building reduced in wall thickness. For the laminated rubber bearing, a precise model was designed with regard to rubber thickness, number of rubber layers, etc. in relation to the actual one of 300tons rated load. The steel hysteretic damper was made of three mild steel bars of diameter 13mm used as beams having both ends fixed for 4tons of upper weight, with the system of absorbing vibrational energy by bending deformation in the horizontal direction while absorbing axial deformation by a cylinder at the upper part. The configuration of the reduced model was determined to satisfy the scale effect with regard to stiffness, yielding displacement, etc.

TEST RESULTS

Before the shaking table tests, the static loading tests were performed to grasp the properties of each device element. The hysteresis curves obtained in the tests are shown in Fig.7. As a result of the tests, characteristics approximately according to the design values were obtained regarding elastic stiffness etc. for each element.

Concerning the superstructure of the steel frame, natural frequency and other properties were ascertained by resonance tests using the shaking table. The transfer functions of base-isolated and non base-isolated buildings in the horizontal direction of each story obtained from the white-noise wave excitation tests are shown in Fig.8.

Next, earthquake excitation tests were performed inputting the Tokachi-oki Earthquake wave to the shaking table reducing the time axis in accordance with the reduction ratio. Test cases are shown in Table II and the results (maximum response acceleration and floor response spectra at the top of the building) are shown in Figs.9 to 12. The test results are summarized as follows.

1) The comparison of responses by existence of the base isolation device is shown in Fig.9. It was confirmed that the response acceleration at the top of the building was reduced to approximately 1/2 and the short period range of the floor response spectrum was greatly reduced by adoption of the base isolation system.
2) The comparison of responses according to input level is shown in Fig.10 The ratio of increase in response acceleration of the building was lower than that of

increase in input level, and the base isolation device acted more effectively the higher the input level. The deformation of the laminated rubber bearing was about 3.6cm and within the allowable limit (7cm) even in inputting triple the original wave.

3) The comparison of responses in the EW direction in cases of horizontal one-directional (EW), horizontal two-directional (EW+NS), and horizontal two-directional and vertical (EW+NS+UD) input is shown in Fig.11. The figure shows that the influence of orthogonal input on one-directional maximum response value was small, and that the vertical motion input hardly affected on horizontal responses.
4) The comparison of responses in inputting the same wave repeatedly is shown in Fig.12. The difference between the 1st and 2nd excitation tests was almost negligible and it was found that the steel dampers had sufficient durability.

SIMULATION ANALYSES

One-directional simulation analyses for the cases of three input levels were performed with the three-lumped-mass model shown in Fig.13. For the stiffness and damping of the superstructure, properties modifying the design values based on resonance test results were used. Regarding the rubber bearings, the average value obtained by the static loading tests, which was almost same as the design value, were used, and as for the steel dampers, two types of hysteretic models, one was elasto-plastic model used as the design model, and the other was a Ramberg-Osgood (R-O) type set up to conform to the hysteresis curve obtained by static loading tests, were considered. Regarding the characteristics of steel dampers, the comparisons of the test results and the calculated values by the two kinds of analysis models are shown in Fig.14. According to the figures, values of the design model were larger than experimental values regarding damping factor, but by using the Ramberg-Osgood model, it became possible to represent the properties of the actual damper more precisely.

The results of analyses are shown in Figs.15 to 18. According to the figures, it was found possible to simulate the maximum response accelerations and the floor response spectra of the shaking table tests for each input level by modeling steel dampers by R-O model and that the analysis results by the design model were a little larger than the test results especially in large input level, but approximate response characteristics of the building could be sufficiently evaluated by each model.

CONCLUSIONS

Analytical and experimental studies were made for application of a base isolation system to a fast breeder reactor building, and the basic properties and effectiveness of laminated rubber bearings and steel hysteretic dampers proposed as one of the base isolation systems were ascertained. Then by the simulation analyses, the appropriateness of the analysis method was verified. It is planned that the shaking table tests and simulation analyses using the superstructure in this paper with high-damping rubber bearings or lead rubber bearings are to be performed hereafter.

ACKNOWLEDGEMENTS

This paper is a part of the results of research carried out by Shimizu Corporation under contract to the Power Reactor and Nuclear Fuel Development Corporation, and the authors wish to express their appreciation to the many persons who participated in the study and provided much valuable advice.

REFERENCES

M. Morishita, T. Kuroda, M. Kobatake, Y. Okada (1987). Investigation of Base Isolation for Fast Breeder Reactor (Part 1-3). Annual Meeting of Atomic Energy Society of Japan, Nagoya

M. Morishita, M. Kobatake, Y. Okada, S. Aoki (1987). Investigation of Base Isolation for Fast Breeder Reactor (Part 4-6). Fall Meeting of Atomic Energy Society of Japan, Sapporo

M. Morishita, M. Kobatake, K. Ohta, Y. Okada (1988). Seismic Base Isolation Tests of Fast Breeder Reactor Building (Part 1-3). Fall Meeting of Atomic Energy Society of Japan, Kobe

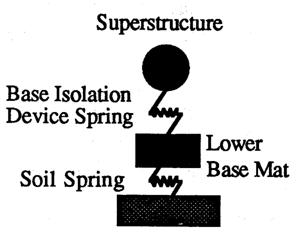


Fig.1 Analysis Model of Parametric Study

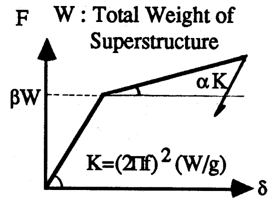


Fig.2 Hysteresis of Base Isolation Device

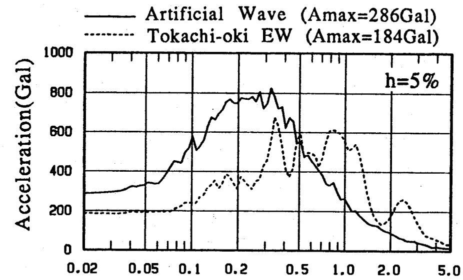


Fig.3 Acceleration Response Spectra of Input Earthquake Motions

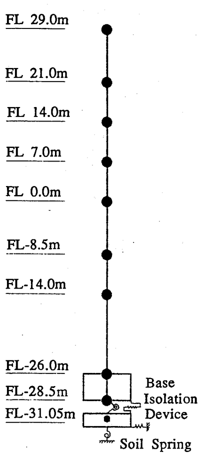
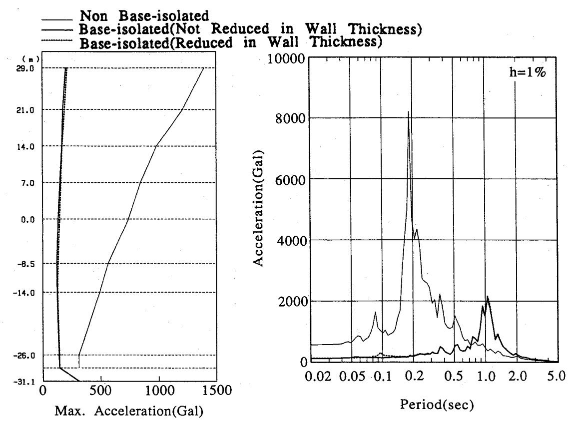


Fig.4 Analysis Model



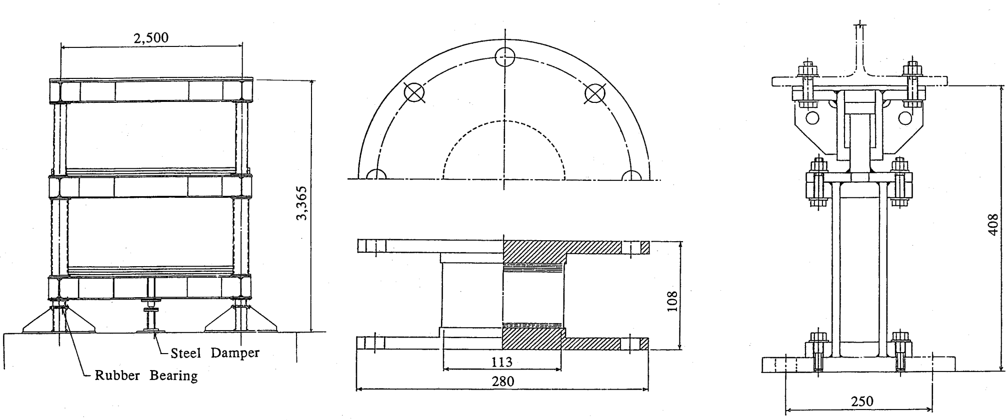
(a) Max. Response Acceleration (b) Floor Response Spectra

Fig.5 Results of Response Analysis

Table I. Reduction Ratio from the Actual Building

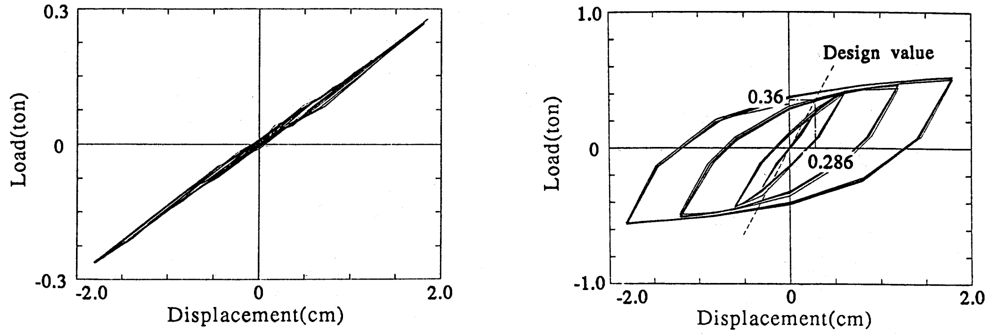
	Reduction Ratio
Weight	$1/\lambda^2$
Length	$1/\lambda$
Density	1.0
Frequency	λ
Stiffness	$1/\lambda$

$\lambda^2=300/4=75=8.66^2$



(a) Superstructure (b) Laminated Rubber Bearing (c) Steel Hysteretic Damper

Fig.6 Specimens of Base-isolated Structure Model



(a) Laminated Rubber Bearing

(b) Steel Hysteretic Damper

Fig.7 Hysteresis Loop of Device

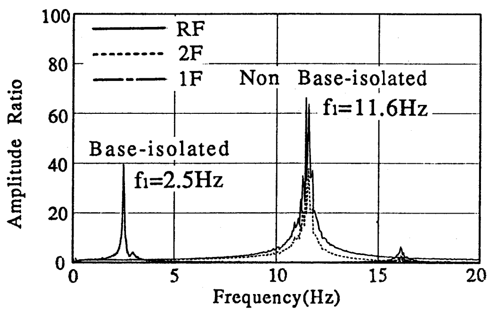
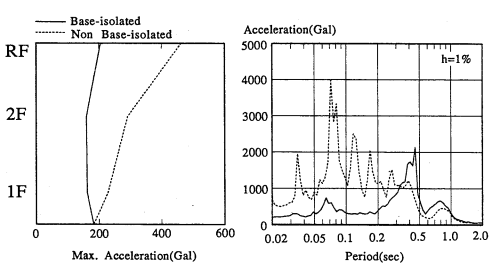


Fig.8 Horizontal Transfer Function

Table II. Test Cases of Earthquake Excitation

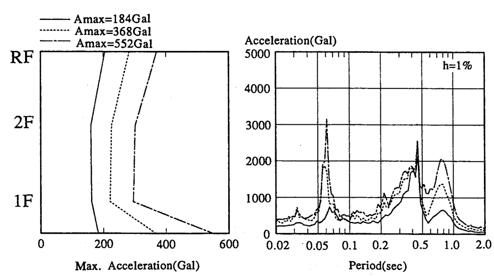
Model \ Input		Max. Acc. (Gal)	Input Direction etc.
Non Base-isolated		184	EW
Base-isolated	A	184	EW
	B	368	EW (2.0 X original wave)
	C	552	EW (3.0 X original wave)
	D	184	EW+NS (2-D input)
	E	184	EW+NS+UD (3-D input)
	F	184	EW (2nd excitation of A)



(a) Max. Response

(b) Floor Response Spectra

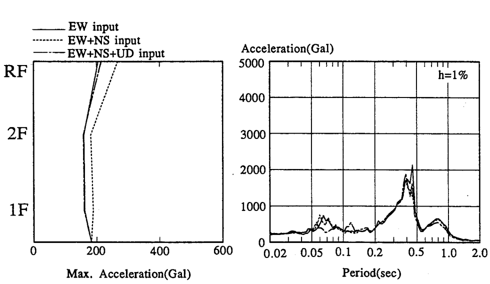
Fig.9 Comparison of Base-isolated and Non Base-Isolated



(a) Max. Response

(b) Floor Response Spectra

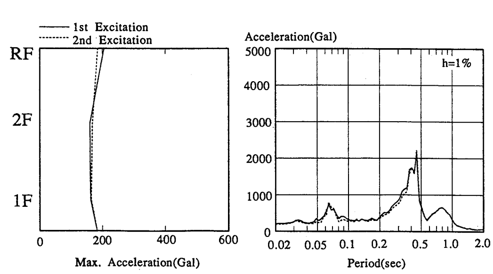
Fig.10 Comparison by Maximum Input Acceleration



(a) Max. Response

(b) Floor Response Spectra

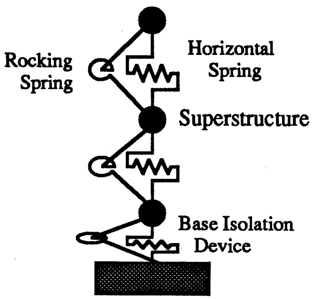
Fig.11 Comparison by Input Direction



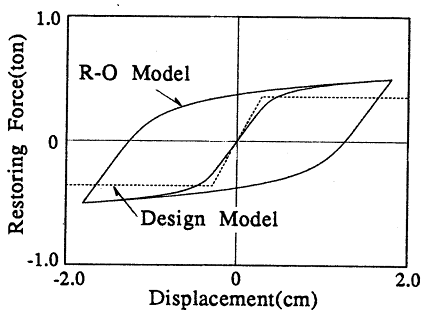
(a) Max. Response

(b) Floor Response Spectra

Fig.12 Comparison of 1st and 2nd Excitation



(a) Base-isolated Building



(b) Hysteresis of Steel Damper

Fig.13 Simulation Analysis Model

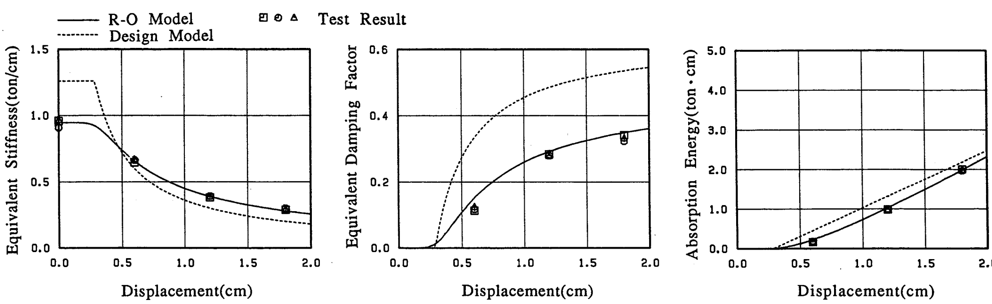
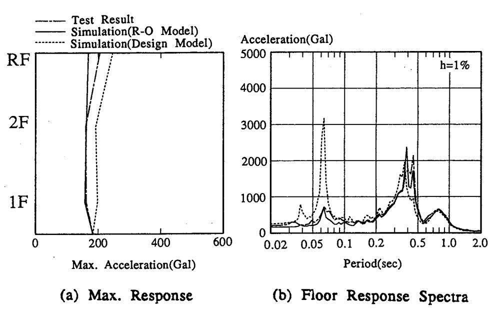
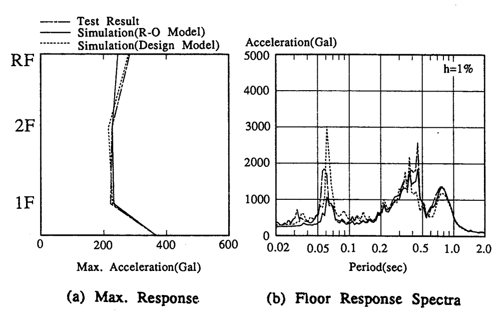


Fig.14 Characteristics of Steel Damper



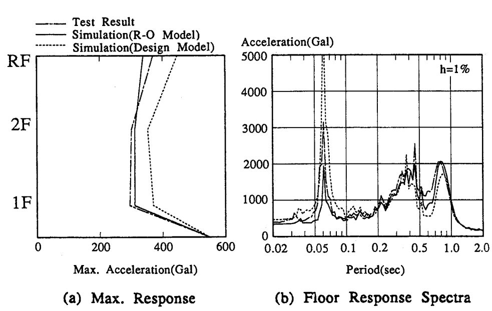
(a) Max. Response (b) Floor Response Spectra

Fig.15 Results of Simulation Analysis (Input Amax=184Gal)



(a) Max. Response (b) Floor Response Spectra

Fig.16 Results of Simulation Analysis (Input Amax=368Gal)



(a) Max. Response (b) Floor Response Spectra

Fig.17 Results of Simulation Analysis (Input Amax=552Gal)

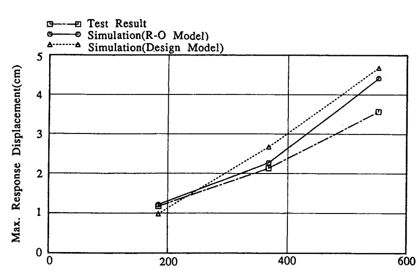


Fig.18 Maximum Displacement of Base Isolation Device