

## Study on the Seismic Base-Isolated Reactor Building for Demonstration FBR Plant in Japan

KATO Muneaki, WATANABE Yukio, KATO Asao  
*The Japan Atomic Power Co., Tokyo, Japan*

### 1 INTRODUCTION

Feasibility study of demonstration FBR plant of 100 MWe is proceeding in Japan, following construction of prototype FBR plant, "Monju" of 300 MWe. Rational design of FBR plant is very sensitive to aseismic design requirements. To eliminate the seismic impact, it seemed to be the best method to apply seismic base-isolated system.

Under such conditions, the seismic base-isolated FBR plant has been studying taken into consideration the economical effect with seismic safety, in compare with ordinary seismic resistant design plant in Japan.

### 2 CONCEPTUAL DESIGN

#### 2.1 Basic design conditions

Fundamental design specification of the seismic base-isolated FBR reactor building (Hereinafter, BIFR) was as; 1) Reactor: Tank type, 2) Isolation methods: Horizontally isolation beneath base mat, 3) Isolation device: Laminated rubbers and steel bar dampers, 4) Bearing soil: Typical rock, 5) Seismic input: Max. probable motion having long period components, 6) Seismic safety: Compatible to seismic resistant design plant.

#### 2.2 Reactor building and component

In order to keep higher level of seismic resistant capacity, BIFR was planned so as to have lower center of gravity and wider basement to overcome low tensile capacity of the laminated rubbers, or to reduce tensile load due to seismic overturning moment.

From result of preliminary seismic response analysis, ratio of height of gravity center to width of basement mat was to be 1/4 (Fig.1).

#### 2.3 Base isolation devices

The base isolation devices were assumed as the system composed of laminated rubbers and steel bar dampers (Fig.1 and 2).

Conceptual design specification of the devices was set as; 1) Rated supporting load of the one device is 500 ton, 2) Horizontally 1st natural period in elastic range of the steel damper is to be 1 sec, 3) Horizontally 2nd natural period in elastic range of the rubber and in yielding range of the steel bar is to be 2 sec, 4) Expected capability of horizontal relative displacement of the device, or between building (Upper) basement and the device (Bottom) basement is to be 1000 mm, 5) Vertically 1st natural period

is to be less than 0.05 sec for vertical rigidity of the laminated rubber.

### 3 SEISMIC RESPONSE OF BASE-ISOLATED STRUCTURE

#### 3.1 Determination of design basis earthquake

Design basis earthquake (hereinafter, DBE) for feasibility study of BIFR were selected as the maximum probable one. As ordinary DBE for LWR of rigid structure built on the rock had predominantly short period component but not long period, DBE for BIFR has to examine on the long period components.

Based on conditions above, the short period range of less than 0.5 sec of the DBE (Response spectra on rock) were assumed to be equal to the largest one among DBEs for LWRs in Japan, while long period range were estimated taking into consideration the conservatism to new technology and the latest knowledge such as theoretical calculation of fault slippage, and calculated a simulated earthquake motion corresponded to the DBE spectra (Fig.3 and 4). Moreover, as for vertical earthquake motion were selected one of about a half horizontal motion of the DBE, in short period range.

#### 3.2 Results of response analysis

Analytical model for BIFR was composed of conventional lumped masses model of the building, the upper and bottom base mat assumed as rigid bodies, and the base isolation devices and the rock as equivalent stiffness elements (Fig.5).

Response analysis results of the model subjected to the DBE gave the max. acceleration 480 gal at the upper mat, base shear coefficient 0.41 and horizontal relative displacement 380 mm for the base-isolation device, and which was almost within elastic range of the structural elements and remarkably lower response level in comparison with that of the conventional seismic resistant design plant in Japan (Fig.6 and 7).

### 4 STRUCTURAL INTEGRITY OF BASE-ISOLATION DEVICES AND THEIR FOUNDATIONS

#### 4.1 Conditions and model

It is important problem to confirm structural integrity of the base-isolation devices (Hereinafter, BID) against the DBE, because that design of every safety related components of the BIFR are dependent to ability of the BID.

For confirmation of the above, the BIDs and their foundations including the upper and bottom mat slabs were examined as for conceptual design with about 400 laminated rubber bearings (Fig.5).

The mat slabs of reinforced concrete were taken into consideration bending and shearing rigidity out of plane, and the bottom mat slab of thickness 3 m was mounted on a half space elastic body assumed for base rock of shear velocity 1500 m/sec. Stiffness elements between the bottom slab of thickness 2 m and the half space body applied as springs effective only to compressive reaction. Stiffness of BID assumed to be linear spring up to degree of seismic response due to DBE, and vertical stiffness to be linear spring.

#### 4.2 Analyses and evaluation

The max. response of compressive and tensile forces due to DBE were 1460 ton (73 kg/cm<sup>2</sup> as rubber pressure) and 100 ton (5kg/cm<sup>2</sup>), respectively (Fig.8).

Preliminary design target for DBE shown in Fig.8 were set including appropriate safety factor such as 1.5 into linear limits of BID based on tests and investigations, and response values of BID were within the design target.

### 5 REVIEW OF ULTIMATE STATE FOR BASE-ISOLATED PLANT

#### 5.1 Conditions and model

It is vital problem for BIFR to evaluate the seismic margin, or ultimate state of BIFR and BID and to guarantee that the margin be equal to the margin of conventional seismic resistant design plant.

Earthquake input motion was assumed as DBE multiplied by factor of 1.5, 2.0, 3.0, parametrically.

Building and soil model utilized the above-mentioned one of Fig.5 and given elasto-plastic characteristics onto the structural elements. Horizontal restoring characteristics of BID were expressed as summation of those of laminated rubbers and steel dampers (Fig.9). Rigidity of stress hardening range of laminated rubber was assumed to be 3 times that of linear range. vertical stiffness in range subjecting to tensile load to be 1/4 of compressive range. Furthermore, elastic limit of the steel damper was designed as to correspond to base shearing coefficient 0.1. Expected damping ratio to critical damping was assumed as 2 percents in the linear and elastic range of BID.

In order to know sensitivity of the factors above to seismic response, major factors of BID including stress hardening stiffness, tensile and compressive stiffness depending to horizontal relative displacement were given as parametric variation (Table 1).

## 5.2 Analyses and evaluation

From result of seismic response analysis of BIFR designed to be in elastic behavior in case of DBE, the response increased rapidly and was beyond elastic range in case of multiplication factor 2.0 of DBE, and also shear wall of building came into ultimate shear strength level in the factor 3.0 (Fig.10).

Regards to BID, horizontal relative displacement was 600 mm which equals to beginning point of stress hardening of rubber in the factor 1.5, 800 mm in the factor 2.0, and 1100 mm of design rupture level of laminated rubber in the factor 3.0 (Fig.11).

As for vertical response of BID, outer peripheral rubber device subjected to tensile load in the factor 2.0, and became into tensile yielding range and vertical relative displacement was 4 mm in the factor 3.0 (Fig.12).

Moreover, on the soil and bottom slab interaction, compressive contact area between them became 100, 70 and 20 percents in the factor 1.5, 2.0 and 3.0, respectively. Base shearing coefficient of the building structure was 0.67, 1.36, and 1.82 in the factor 1.5, 2.0, 3.0, respectively.

Results of the parametric analyses showed for the outer peripheral devices to be kept structural safety up to the factor 2.0 as a minimum (Fig.13).

## 5 CONCLUSIVE REMARKS

In order to confirm feasibility of the seismic base-isolated FBR plant in a big earthquake country, Japan, conceptual design of the plant fitted to the base-isolation and of base-isolation device having the maximum credible capacity at present, and seismic response analysis and evaluation including ultimate status were executed.

From results of these studies, it was expected that the base-isolated FBR plant may be endured to big seismic motion, and do not give severe seismic loads to the safety related components.

As the studies have, however, included uncertainties based on little proven data, further experimental studies such as mechanical strength tests of isolation devices and simulated seismic response tests for scaled plant model has been starting, referring to research activities by the CRIEPI etc..

## ACKNOWLEDGEMENT

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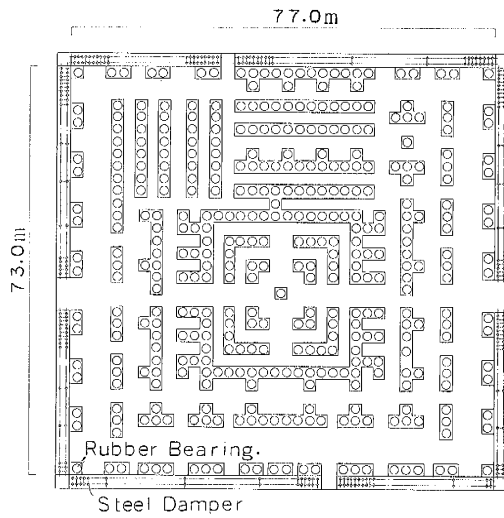
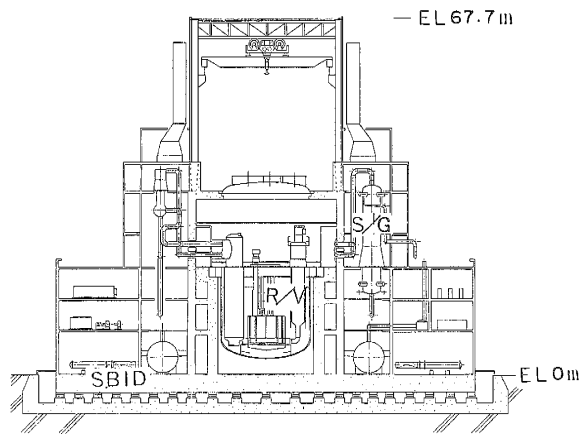


Fig.1 Seismic Base Isolated Reactor Building for FBR Plant

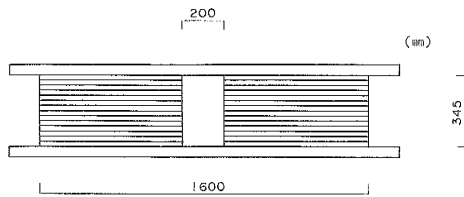


Fig.2 Laminated Rubber Bearing for FBR Plant

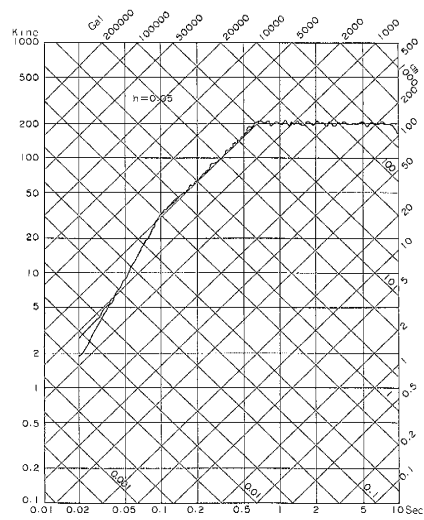


Fig.3 Response Spectrum of Design Basis Earthquake

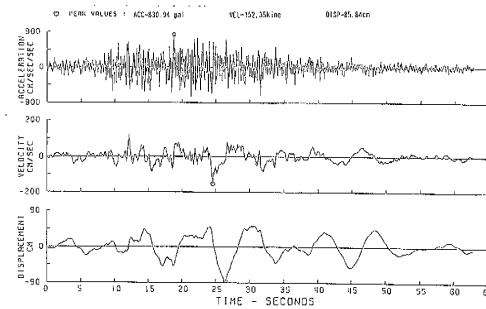


Fig.4 Simulated Seismic Wave -DBE-

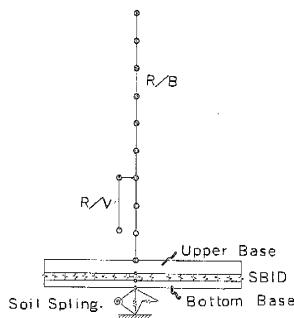


Fig.5 Seismic Response Analysis Model

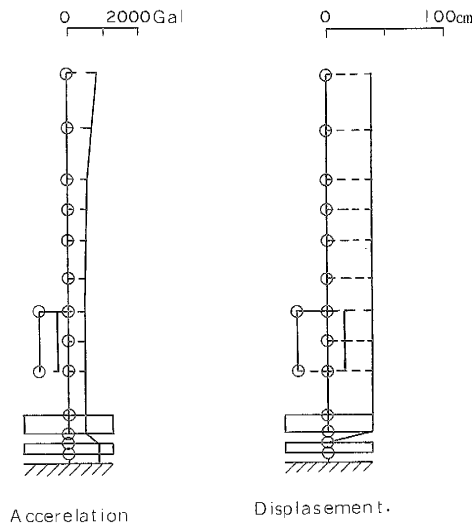


Fig.6 Seismic Response -DBE-

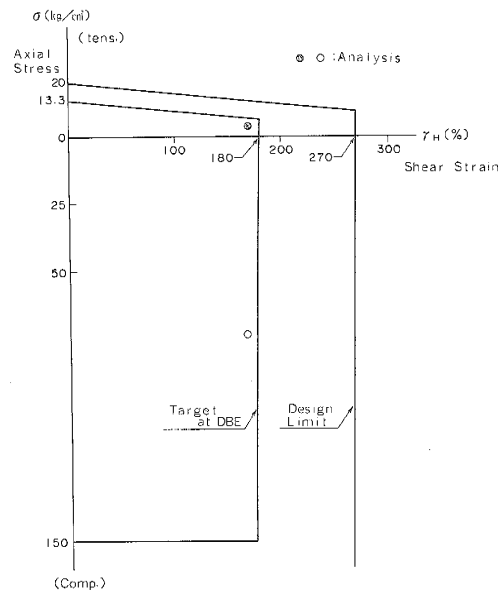


Fig.8 Response Result and Design Target

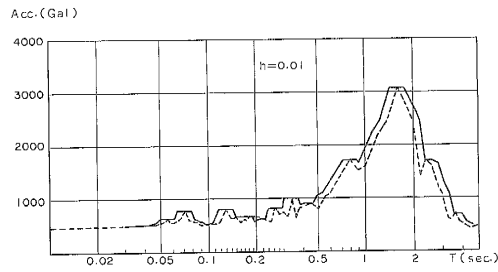


Fig.7 Floor Response Spectrum at Reactor Vessel Support

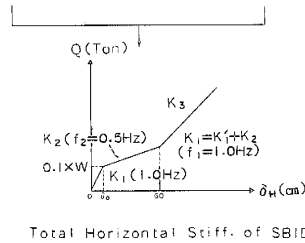
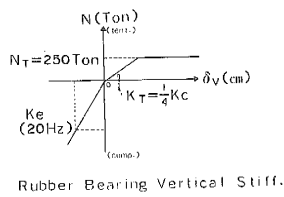
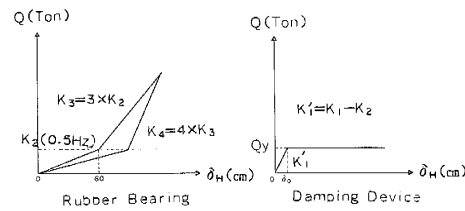


Fig.9 Skelton Curves of Seismic Base Isolation Device

Table 1 Modeling Condition of Laminated Rubber Bearing

ITEM	STANDARD	MODEL A	MODEL B	MODEL C
HORIZ. INITIAL STIFF. K2	(0.5Hz)	(0.5Hz)	(0.5Hz)	(0.5Hz)
HARDENING STIFF. K3	3 K2	6 K2	3 K2	3 K2
UNLOADING STIFF. K4	4 K3	4 K3	4 K3	4 K3
VERT. COMPRESS. STIFF. Kc	(20Hz)	(20Hz)	(20Hz)	Reduced Stiff. due to disp.
TENSION STIFF. Kt	$(1/4) \cdot Kc$	$(1/4) \cdot Kc$	$(1/8) \cdot Kc$	$(1/4) \cdot Kc$
TENSILE YIELD FORCE Ny	250ton	250ton	250ton	250ton

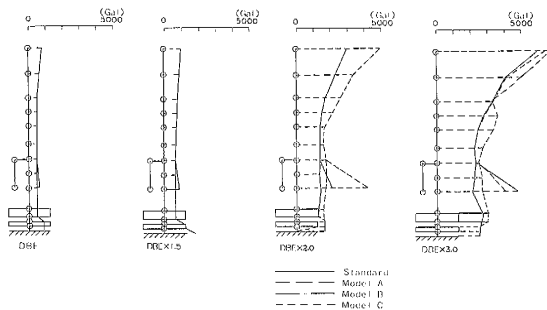


Fig.10 Max. Response Acceleration

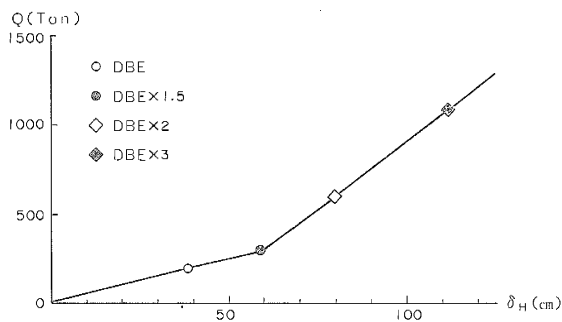


Fig.11 Max. Displacement (Hori.) of Rubber  
-Standard model-

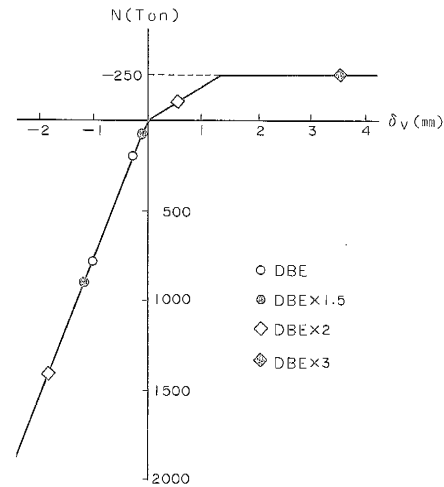


Fig.12 Max. Axial Response of Rubber Bearing  
-Standard model-

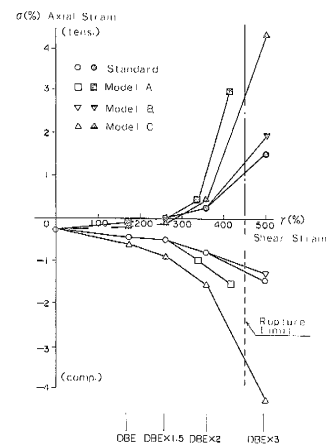


Fig.13 Max. Strain of Rubber  
(Shear & Axial)