Comparison of Seismic Isolation Concepts for FBR

H. Shiojiri, T. Mazda, H. Kasai
Central Research Institute of Electric Power Industry, Abiko, Japan
J. N. Kanda
University of Tokyo, Tokyo, Japan
T. Kubo
Nagoya Institute of Technology, Nagoya, Japan
M. Madokoro
Hitachi Ltd., Ibaraki, Japan
T. Shimomura
Mitsubishi Heavy Industries, Ltd., Kobe, Japan
Y. Kawamura
Toshiba Corporation, Yokohama, Japan
O. Nojima
Takenaka Komuten Company, Ltd., Tokyo, Japan
N. Kawai
Okumura Corporation, Tokyo, Japan

1. Introduction

Seismic isolation is expected to be effective in raising the reliability during earthquake, reducing the construction cost, enlarging the siting possibility, and promoting the design standardization for FBR.

A test and research program was started in 1987 [1], to verify the reliability and effectiveness of seismic isolation for FBR.

In this paper, some results of the preliminary study of the program are described.

First, seismic isolation consepts and corresponding seismic isolation devices were selected. Three kinds of seismically-isolated FBR plant concepts were developed by applying promising seismic isolation concepts to the non -isolated FBR plant, which was proposed in the past,and by developing plant component layout plans and building structural designs. Each plant was subjected to seismic response analysis, and on the basis of the results of their responses, reduction in the amount of material of components and buildings were estimated for each seismic isolation concepts. Furthermore, research and development items, which will be required on applying these seismic isolation concepts, were evaluated.

2. Selection of Candidate Seismic Isolation Concepts and Devices

2.1 Selection of Isolation Concepts

Possible seismic isolation concepts are classified by the scope of isolation as shown in Table 1. Of these concepts, concept ① through ⑥ correspond to component isolation, ⑦ and ⑩ to building isolation, and ⑧ and ⑨ to combined isolation. Since horizontal ground motion has dominant effect on the design of buildings and components, concepts in which buildings or some of components are isolated only in vertical direction were excluded.

(1) Building Isolation

At present, there are no effective isolation system which are capable of supporting a load of about 150,000 tons and at the same time achieving three -dimensional seismic isolation. Development of such a system will require many tasks such as devising an effective anti-rocking measue.

As for the horizontal seismic isolation of buildings, there exist LWR plants (Cruas and Koeberg) which adopt such system in addition to some experiences of conventional buildings in and out of Japan. It is expeted to allow material reduction of building structure and many components. Hence the horizontal seismic isolation of buildings (⑦ of Table 1) was selected for the present investigation.

(2) Component Isolation

It was considered inadequate to use three dimensional isolation devies, since it will be difficult to adjust them in such a way to avoid rocking, since the isolation devices may have material or geometric nonlinearity. It is also difficult to obtain the optimal horizontal and vertical isolation properites since the horizontal and vertical vibrations are coupled with each other.

In the present investigation, concepts for seismically isolating the primary system alone (① and ③ of Table 1) were examined. Evaluation of concepts of which seismic isolation covers both primary and secondary systems were made by reflecting the findings of the combined isolation described next subsection.

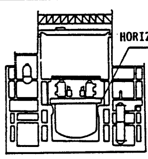
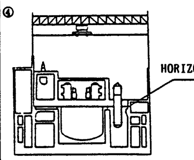
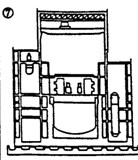
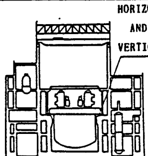
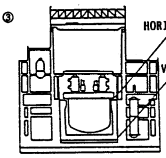
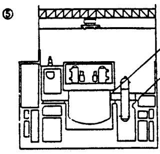
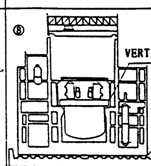
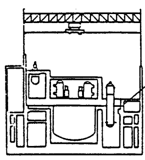
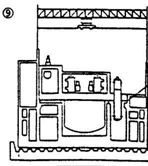
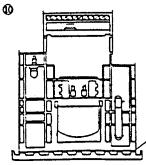
(3) Combined Isolation

The building is given a horizontal isolation for the reason stated above. Hence components are given a vertical isolation.

As the seismic isolation of the primary system is mainly examined in component isolation, a system for vertical isolation of the primary and secondary systems (⑨ of Table 1) is examined in combined isolation.

This system prevents any relative displacement of the sodium system piping. (⑨ of Table 1)

TABLE 1 CANDIDATE ISOLATION CONCEPT

VERTICAL \ HORIZONTAL		NO ISOLATION	COMPONENT ISOLATION		BUILDING ISOLATION
			PRIMARY COMPONENT	SECONDARY COMPONENT	BUILDING
NO ISOLATION		NON-ISOLATED PLANT	① 	④ 	⑦ 
COMPONENT ISOLATION	PRIMARY COMPONENT		②  ③ 	⑤ 	⑧ 
	SECONDARY COMPONENT				⑨ 
BUILDING ISOLATION	BUILDING				⑩ 

2.2 Seismic Isolation Devices

(1) Devices for Horizontal Isolation of Buildings

The basic requirements of a device for horizontal isolation of buildings are that the device has a large capacity sufficient to bear the building weight, that the device has a high vertical rigidinty and a low horizontal rigidinty and that devices are reliable and durable. Furthermore, the device needs to have a large deformability which can cope with a relative displacement, since a relative displacement of several tens of centimaters is expected. Since the device is placed in an outdoor environment, any special high temperature or radiation are not expected.

At present, a laminated elastomer is most appropriate as a spring or a load-bearing device which meets all of basic requirements, in terms of reliability, load-bearing capacity, stiffness, deformability, and durability.

Since laminated elastomers does not have the damping capability, a combined use of some damping devices (dampers) is required. Possible seperated dampers include hysteresis type dampers (elasto-plastic dampers, a friction damper, and combination of the two) and viscous type dampers (an oill damper and a viscous damper). The formers are generally simple in construction and inexpensive, and have excellent weatherability and durability. On the other hand, viscous type dampers have larger damping capability and have an excellent acceleration-reducing effect since their load-displacement curves are smooth and they do not excite high frequencies in components. Oil dampers have advantages in that their characteristics are independent of the frequency and amlitude. However, as one device has its damping effect in only one direction, many devices are needed. Furthemore, the oil dampers have a larger construction and are expensive in comparison with elasto-plastic dampers. Viscous dampers, in general, have a high temperature-dependency, and extra care is needed in maintenance to assure a long-term reliability. In general, the deformability of dampers is significantly less than that of laminated elastomers.

The laminated elastomer with lead pulg and the laminated high-damping rubber bearing have damping capacity, in addition to the above-mentioned properties of a laminated elastomer. It is compact and allows easier arrangement and installation.

For the present study, the laminataed elastomers with damping capability were selected.

(2) Devices for Horizontal Isolation of Components

The basic requirements of the devices for horizontal isolationn of components are generally identical to those of the devices for horizontal isolation of buildings. In comparison with the devices for buildings, however, the devices for components are required to be more compact and have a smaller relative displacement, since their installation space is limited. The environmental conditions such as temperture and radiation are more severe.

Combinations of slide supports and coil springs are compact and have excellent environmental properties, but they pose problems of a large dispersion of friction coefficient, and of excitation of high frequencies in components. On the other hand, the laminated elastomer may be applicable, provided that the arangement plan, radiation shielding design, and air conditioning design are made appropriately.

In the present study, the laminated elastomer with lead plug is under investigation.

(3) Devices for Vertical Isolation of Components

The basic performance requirements of a device for vertical isolation of components are to lower the vertical natural frequency, and to damp the vibration, as well as to bear the load. Smaller flexural displacement response of the vertically-isolated floors are desirable.

To achieve them, it is necessary to have a relatively smooth load -displacement relationship and to achieve fabrication with small variation of the properties from the design values.

As for a spring or a load bearing device, the coil spring was selected on the ground that there are many experience and the dispersion of the properties are small and that it is compact and inexpensive.

As for the damping device, the oil damper is selected, since it is excellent in vibration characteristics, damping capability and fatigue characteristics. In the case of vertical isolation, it is sufficient to be effective in one direction only. In contrast with the oil damper, elasto -prastic dampers are compact and inexpensive, but yielding points of dampers can scatter and rather abrupt change of stiffness at the point can excite flexural vibration of the floor. The friction damper, at present, has large variation in its characteristics, and is not selected.

3. Evaluatiion of Isolation Concepts

Response reduction, relative displacement, material reduction, and necessary technical development item were selected as the items for evaluating the applicability of a seismic isolation system to FBR plants.

To make a comparative evaluation of various systems under the same conditions, the seismically -isolated FBR with respective isolation systems were set according to the following rules, on the basis of a 1000 MWe semi -underground non-isolated FBR system.

i) Each seismically-isolated FBR is to be installed on the ground surface.

ii) The structure of the proposed FBR is to be modified to allow the introductin of the isolation system and to enhance its effects. However, no modification of the structure of any systems or components irrelevant to the introduction of the isolation system will be made.

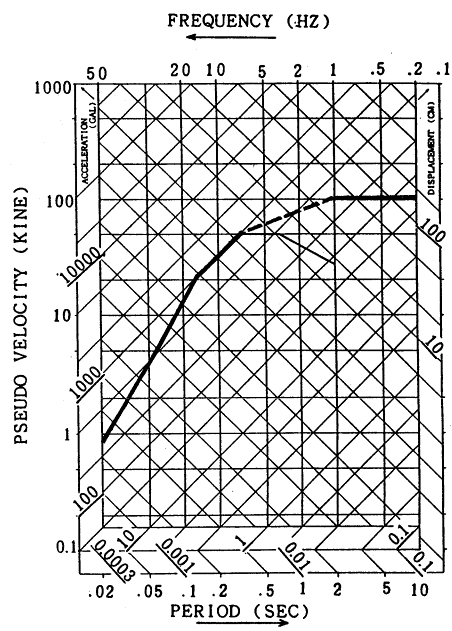


Fig. 3 TENTATIVE DESIGN RESPONSE SPECTRUM

Table 2 RESPONSE OF ISOLATED PLANTS TO S1 ERTHQUAKE

ITEM		BUILDING ISOLATION	COMPONENT ISOLATION		COMBINED ISOLATION
			HORIZONTAL	HORIZONTAL AND VERTICAL	
DEVICE CHARACTERISTICS	NATURAL FREQUENCY	0.5Hz	1.0Hz	HORIZONTAL 1.0Hz VERTICAL 1.5Hz	HORIZONTAL 0.5Hz VERTICAL 1.5Hz
	DAMPING			VERTICAL 30%	VERTICAL 30%
	YIELDING ACCEL.	50GAL	100GAL	HORIZONTAL 100GAL	HORIZONTAL 100GAL
MAX. RESPONSE ACCEL. AT REACTOR SUPPORT		216GAL	330GAL	HORIZONTAL 330GAL VERTICAL 175GAL	HORIZONTAL 217GAL VERTICAL 179GAL
MAX. RELATIVE DISP.		18cm	6.1cm	HORIZONTAL 6.1cm VERTICAL 1.7cm	HORIZONTAL 18cm VERTICAL 1.7cm

TABLE 3 FINDINGS OF EVALUATION OF RATIONALIZING EFFECTS AND APPLICABILITAY

	SYSTEM	BUILDING ISOLATION	COMBINED ISOLATION		COMPONENT ISOLATION				REMARKS
	DIRECTION: HORIZONTAL	BUILDING	BUILDING	BUILDING	PRIMARY SYSTEM	PRIMARY SYSTEM	PRIMARY + SECONDARY SYSTEMS	PRIMARY + SECONDARY SYSTEMS	
	DIRECTION: VERTICAL	———	PRIMARY SYSTEM	PRIMARY + SECONDARY SYSTEMS	———	PRIMARY SYSTEM	———	PRIMARY SYSTEM	
MATERIAL REDUCTION	REACTOR VESSEL (SIDE WALL)	IT IS POSSIBLE TO REDUCE THE WALL THICKNESS OF THE REACTOR VESSEL TO 1/2 TO 1/4 BY ADOPTING SEISMIC ISOLATION. 30 MM APPROX.	23 MM APPROX.	23 MM APPROX.	30 MM APPROX.	23 MM APPROX.	30 MM APPROX.	23 MM APPROX.	VERTICAL ISOLATION EFFECT IS SMALL.
	REACTOR VESSEL (BOTTOM)	50 MM APPROX.	20 MM APPROX.	20 MM APPROX.	50 MM APPROX.	20 MM APPROX.	50 MM APPROX.	20 MM APPROX.	60 % BY HORIZONTAL ISOLATION. REDUCTION BY ABOUT 1/4 WHEN VERTICAL ISOLATION IS COMBINED.
	ROOF SLAB	125 MM APPROX.	25 MM APPROX.	25 MM APPROX.	100 MM APPROX.	25 MM APPROX.	100 MM APPROX.	25 MM APPROX.	EFFECTS OF VERTICAL ISOLATION ON POOL TYPE REACTOR ARE GREAT. EFFECTS ON LOOP TYPE ARE SMALL.
	VERSAL SUPPORT SKIRT	IT IS POSSIBLE TO REDUCE THE WALL THICKNESS TO ABOUT ONE THIRD BY ADOPTING SEISMIC ISOLATION. 40 MM APPROX.	40 MM APPROX.	40 MM APPROX.	40 MM APPROX.	40 MM APPROX.	40 MM APPROX.	40 MM APPROX.	VERTICAL ISOLATION EFFECT IS SMALL.
	QUANTITY OF BUILDING MATERIALS	UPPER BUILD-ING / LOWER FOUNDA-TION	UPPER BUILD-ING / LOWER FOUNDA-TION	UPPER BUILD-ING / LOWER FOUNDA-TION	UPPER BUILDING / LOWER FOUNDATION		UPPER BUILDING / LOWER FOUNDATION		BUILDING ISOLATION REDUCES CONCRETE REQUIREMENT BY ABOUT 60 %. AND REBAR BY ABOUT 50 %. BUT IT IN-CREASES STEEL FRAME QUANATITY.
	O CONCRETE (M^3)	48,000 / 8,500	49,800 / 9,600	49,800 / 9,600	71,400 / ——		71,400 / ——		
	O REBAR (T)	7,200 / 1,300	7,500 / 1,450	7,500 / 1,450	14,200 / ——		14,200 / ——		
	O STEEL FRAME (T)	2,400 / ——	2,300 / ——	2,300 / ——	2,300 / ——		2,300 / ——		
	O OTHERS	—— / ——	—— / ——	NSSS FLOOR STEEL FRAME 1,000 T / ——	—— / ——		NSSS FLOOR STEEL FRAME 1,000 T / ——		
	ISOLATION DEVICE: HORIZONTAL	500 T 264 UNITS	500 T 280 UNITS	500 T 280 UNITS	200 T 38 UNITS	200 T 38 UNITS	200 T 73 UNITS	200 T 73 UNITS	RUBBER BEARING WITH LEAD PLUG
	ISOLATION DEVICE: VERTICAL	———	20 T 900 UNITS	50 T 68 UNITS 100 T 10 UNITS 150 T 67 UNITS	———	20 T 900 UNITS	———	20 T 400 UNITS	COIL SPRING
APPLICABILITY	SECONDARY SYSTEM PIPING	———	THE PRESENT LAYOUT OF THE SECONDARY SYSTEM PIPING IS EXPECTED TO BE APPROPRIATE FOR THE RELATIVE DISPLACEMENT BETWEEN THE PRIMARY AND SECONDARY SYSTEMS DURING EARTHQUAKE.	———	THE PRESENT LAYOUT OF THE SECONDARY SYSTEM PIPING IS EXPECTED TO BE APPROPRIATE FOR THE RELATIVE DISPLACEMENT BETWEEN THE PRIMARY AND SECONDARY SYSTEMS DURING EARTHQUAKE.	THE PRESENT LAYOUT OF THE SECONDARY SYSTEM PIPING IS EXPECTED TO BE APPROPRIATE FOR THE RELATIVE DISPLACEMENT BETWEEN THE PRIMARY AND SECONDARY SYSTEMS DURING EARTHQUAKE.	———	THE PRESENT LAYOUT OF THE SECONDARY SYSTEM PIPING IS EXPECTED TO BE APPROPRIATE FOR THE RELATIVE DISPLACEMENT BETWEEN THE PRIMARY AND SECONDARY SYSTEMS DURING EARTHQUAKE.	
	MAIN STEAM PIPING	IT IS POSSIBLE TO PERMIT UP TO 30 CM OF RELATIVE DISPLACEMENT FOR 1/2 S1 EARTHQUAKE.	IT IS POSSIBLE TO PERMIT UP TO 30 CM OF RELATIVE DISPLACEMENT FOR 1/2 S1 EARTHQUAKE.	IT IS POSSIBLE TO PERMIT UP TO 30 CM OF RELATIVE DISPLACEMENT FOR 1/2 S1 EARTHQUAKE.	———	———	IT IS POSSIBLE TO PERMIT UP TO 30 CM OF RELATIVE DISPLACEMENT FOR 1/2 S1 EARTHQUAKE.	IT IS POSSIBLE TO PERMIT UP TO 30 CM OF RELATIVE DISPLACEMENT FOR 1/2 S1 EARTHQUAKE.	
	SLOSHING RESPONSE	WHEN RAUNION PHASE 100 KINE EARATHQUAKE OCCURS, EACH ISOLATION SYSTEM WILL EXPERIENCE SLOSHING OF LARGE AMPLITUDE. WAVE FRONT IMPACT PRESSURE PHENOMENON OR CRUSH OF FREE WAVE SURFACE AGAINST THE LOWER SURFACE OF THE ROOF SLUB WILL BE GENERATED. HOWEVER, IT IS EXPECTED TO POSE NO PROBLEM TO THE PRESENT STRUCTURAL SPECIFICATION. THE ISSUES CONCERNING MAINTENANCE OF FUNCTIONS ARE EXPECTED TO BE PROPERLY HANDLED BY MODIFICATION OF PLANT OPERATION AND DESIGN.							WAVE HEIGHT WILL BE HARDLY AMPLIFIED BY SEISMIC ISOLATION.
	REACTIVITY	CHANGES IN REACTIVITY ARE EXPECTED TO BE WITHIN LIMITS EVEN WHEN THINNER WALLS ARE USED AS A RESULT OF ISOLATION.							
	THERMAL RATCHETTING	THE POSSIBILITY OF THERMAL RATCHETTING WILL BE VERY SMALL EVEN WHEN THINNER WALLS ARE USED AS A RESULT OF ISOLATION.							
ESEARCH AND DEVELOPMENT REQUIRED		O ESTABLISHMENT OF DESIGN SEISMIC MOTION. O CONFIRMATION OF APPROPRIATENESS OF ANALYTICAL METHOD. O LAYOUT PLAN. O RELIABILITY OF DEVICES.	O SHIELDING AND AIR CONDI-TIONING. O VERIFICATION OF INTEGRITY OF TRANSITION PIPING. O DEVELOPMENT OF MECHANISM FOR ABSORBING RELATIVE DISPLACEMENT OF FUEL SYSTEM.	O CONFIRMATION OF VERTICAL ISOLATION FLOOR. O SHIELDING.	O ESTABLISHMENT OF SHIELDING AND AIR CONDITIONING MEASURES. O VERIFICATION OF INTEGRITY OF TRANSITION PIPING. O DEVELOPMENT OF MECHANISM FOR ABSORBING RELATIVE DISPLACEMENT OF FUEL SYSTEM.		O SHIELDING	O SHIELDING AND AIR CONDITION-ING. O VERIFICATION OF INTEGRITY OF TRANSITION PIPING. O DEVELOPMENT OF MECHANISM FOR ABSORBING RELATIVE DISPLACEMENT OF FUEL SYSTEM	

The resulting seismically-isolated plants of the resepective systems were subjected to response analysis to evaluate their response characteristics. The design spectrum for horizontal ground motion is shown in Fig 1. The ratio of the vertical component spectrum to the horizontal one was assumed to be 0.6 〔Ishida, 1989〕. The results are shown in Table 2.

On the basis of these findings, each isolation system was examined in terms of its material reduction effects, it applicability, and technical tasks to be examined in the future. A comparative evaluation was shown in Table 3.

The findings may be summarized as follwos:

(i) As for horizontal isolation, building isolation, component isolation and combined isolation are virtually identical in terms of material reduction of isolated portions and improvement of the reliability of such portions. The wider the scope of the isolation, the greater the material reduction and the reliability improving effects.

(ii) The material reduction due to vertical isolation are relatively small. Expected effects are reduction relative displacement between the core and control rods, prevention of lifting of the core elements, and reduction of axial compression of vessels.

(iii) As for the relative displacement, it is expected to be accomodated by deformation of the piping in each isolation system. However, when the primary system components only are isolated, it will be necessary to make detailed investigation of methods for accomodating relative displacements of the secondary cooling system piping, which contains sodium, and fuel handling systems.

(iv) Required R & D items are relatively few for building isolation. Component isolation needs some measures for shielding and air conditioning of the seismic isolation elements. The addition of vertical isolation will add more R & D items, such as the reliability of vertical isolation elements, and confirmation of performance of vertical isolation mechanisms.

4. Conclusion

Isolation concepts were evaluated, As a preliminary study for applying seismic isolation to FBR.

At present, horizontal building isolation requires the smallest number of R & D items, and is expected to have ample cost reduction effects. It, therefore, is considered to have a high feasibility. Furthermore, there is a good prospect of fabricating isolation devices with appropriate properties.

The present research was conducted under a contract given by the Ministry of International Trade and Industry.

5. References

〔1〕 Sawadam Y. et al., 1989, " Seismic Isolation Test Program ", Trans. 10th SMiRT, to Appear.

〔2〕 Ishida, K. et al., 1989, " Tentative Design Response Spectrum for Seismically Isolated FBR ", Trans. 10th SMiRT, to Appear.