Feasibility study on the seismic isolation of pool-type LMFBR
1. Horizontal seismic isolation of Nuclear Island Building

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1. INTRODUCTION

In case of pool-type liquid metal fast breeder reactors (LMFBRs), structural design is strongly influenced by the seismic loads because the operational coolant pressure is relatively low. This is one of the important differences of LMFBRs from light water reactors from the viewpoint of structural design. Therefore, the reduction of seismic force will be of great assistance for attaining a simple and lightweight LMFBR, especially when stringent seismic conditions are imposed as in Japan.

Based on the background, an intensive 3-year feasibility study was performed on the seismic isolation of LMFBRs. The objectives of the study were; firstly, to evaluate the effectiveness of seismic isolation for reducing structural masses and increasing structural margin, and secondly, to develop and validate seismic isolation techniques compatible with the strict requirement from nuclear facilities. The first part of the study is composed of the investigation into the input earthquake motion, a conceptual design study of the nuclear island building (NIB) and the reactor structure, and the investigation into the seismic behaviors of the structures. The second part of the study comprises of material tests, scale model tests of isolation devices and the confirmation of mechanical characteristics by prototype models. Shaking table tests of an NIB model was performed in order to confirm both the seismic behaviors of the structures and the mechanical characteristics of the isolation devices.

This paper presents the former part of the study, where as the latter part will be covered by two separate papers in this session.

2. DETERMINATION OF INPUT EARTHQUAKE MOTION

The seismic response of isolated structures is strongly influenced by the low frequency components (0.5 - 1.0 Hz) of the ground motion, while that of conventional nuclear facilities is sensible to higher frequency components. Considering the recent earthquake observations in Japan and the U.S. NRC spectrum, a synthetic ground motion has been generated which has larger low frequency components than Japanese conventional ones.

As a result, the response spectrum at 1.0 Hz is twice as high as the conventional spectrum in the synthetic earthquake motion. Fig. 1 shows the response spectrum of the earthquake motion defined at a free surface of the base stratum.

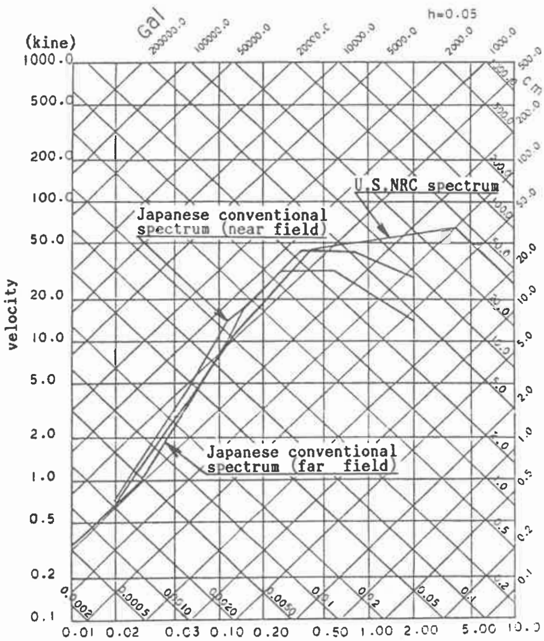

Fig 1 Floor Response of Imput Acceleration

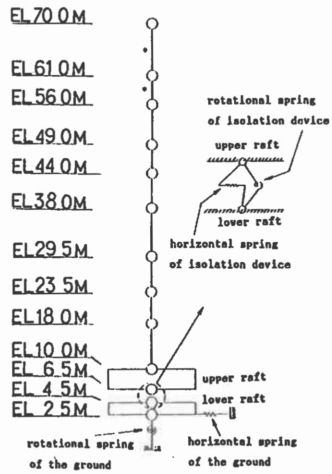

Fig 2 Analysis model (A-building)

Table 1 Characteristics of seismic isolation devices

Natural frequency \ No.		1	2	3	4	5
Horizontal	f1 (Hz)	1.6		1.0		
	f2 (Hz)	0.5				1.0
Vertical	f (Hz)	20				
Yield level		0.05 w	0.025 w	0.05 w	0.025 w	—

Table 2 Conceptual frameworks of NIBs

elevation \ concept		A	B	C
EL>17.0 m		Reinforced concrete frame	Steel frame	Steel frame
EL≤ 17.0m	Outer part		Reinforced concrete frame	
	Inner part	reinforced concrete wall		

3. EARTHQUAKE RESPONSE OF NIB

Table 1 shows the characteristics of the seismic isolation devices. Five mechanical properties, four elasto-plastic and an elastic ones, are selected based on the preliminary selection of mechanical properties. Table 2 shows three types of the conceptual frameworks A, B and C, of the NIB, studied. All three buildings are reduced in weight compared to a conventional (non-isolated) building. The NIB concept A is a reinforced concrete frame structure building whose wall thicknesses are drastically reduced reflecting the reduction of seismic force by isolation. In the NIB B, the upper half of the building is replaced by a steel frame. In the NIB C, the whole building except for the neutron shielding walls is replaced by a steel frame and the two portions are connected by expansion joints. More drastic efforts for the mass reduction is employed in the NIB C than in concept A. The NIB B stands intermediate.

Fig. 2 shows the seismic analysis model. The soil is modelized as a so called sway-and-rocking model, the isolation devices are modelized by bi-linear springs and the building is modelized as shear-and-bending spring with concentrated masses. Fig. 3 shows the earthquake responses of the NIB A for each isolation characteristics. It also shows the response of the non-isolated building for comparison. The maximum response acceleration of the isolated buildings is 1/3 - 1/10 of that of the non-isolated building. The difference is remarkable at the top of the building. The maximum relative displacements of the isolated buildings are almost identical from the basemat to the top, which indicates that the building sways as a rigid body during earthquakes. Relative displacements between the isolated and the non-isolated buildings may cause a problem to the piping which runs between them. But the relative displacements can be absorbed without difficulties by expanding the support intervals as long as the relative displacement falls in the order of 10 cm as in this case.

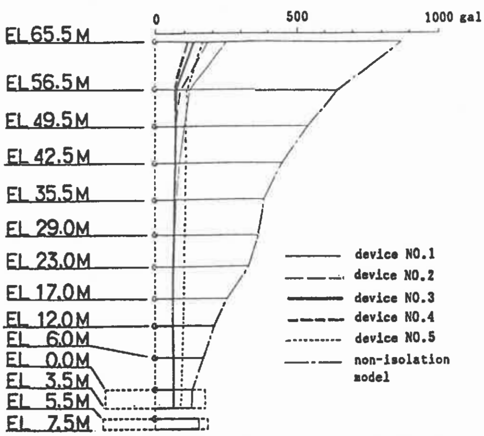

Fig 3 Maximum Acceleration of Each Isolation Devices

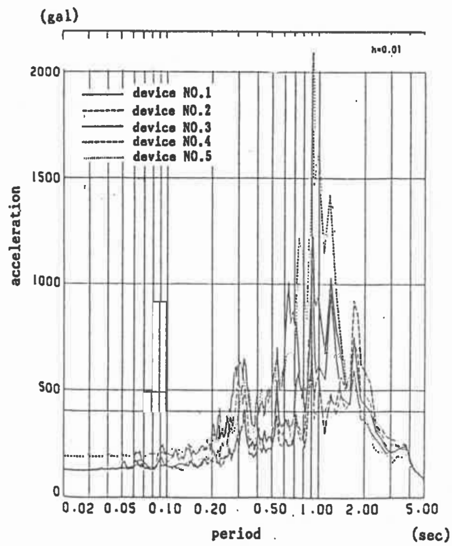

Fig 4 Floor Response of Each Isolation Devices

Fig. 4 shows the floor response spectrum (FRS) at the elevation of the reactor structure installation. When the elastic isolation device is used (Case 5), FRS of the isolated building becomes higher than that of the input ground motion at the first natural period of the isolated building itself (1.0 Hz). For the elasto-plastic isolation devices (Cases 1 to 4), on the other hand, the peaks at 0.5 -1.0 Hz are not evident. Table 3 shows the maximum FRS levels for the frequencies higher than 4 Hz which cover the natural frequencies of the reactor structure. The table shows that the characteristics of Devices 3 and 4 are most effective in reducing the response of the reactor structure. Therefore, the characteristics of Device 3 is adopted as a reference for the following comparisons.

Fig. 5 shows the natural modes of different structural frameworks based on the initial stiffness of the restoring characteristics of Device 3 . Participation factors of the first swaying modes are predominant for all framnworks. Deformations at the top of the building is larger for the buildings B and C than for the building A because of their low stiffness at the upper part of the buildings. Fig. 6 shows the maximum earthquake response of the buildings. Amplification at the upper part of the building is observed in the buildings B and C. But they are still much lower than that of the non-isolated

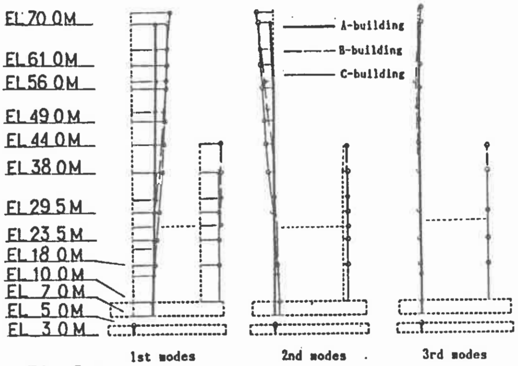

Fig 5 Natural Modes of Different Structural Frameworks

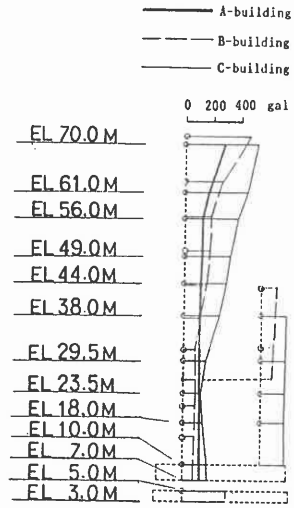

Fig 6 Maximum Acceleration of Different Structural Frameworks

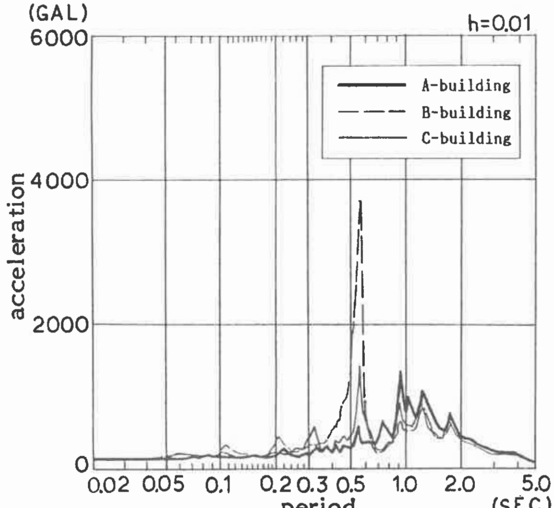

Fig 7 Floor Response of Differental Structual Frameworks

Table 3 Maximum FRS level at higher than 4Hz

device / Concept A	1	2	3	4	5
max FRS (G)	0.41	0.28	0.21	0.22	0.35

building. The maximum relative displacement between the reinforced concrete cavity wall and the adjacent steel frame is around 3 cm, which is not impedimental for the piping design. The base shear coefficient and the overturning moment indicate that the building utilizes the seismic force reduction in increasing the stability and structural margin against the seismic force. FRS shown in Fig. 7 shows that it is reduced below around 0.4G for the frequencies higher than 4.0 Hz. Table 4 shows that the weight of the isolated NIBs is reduced to around 120,000 tons including the lower raft while that of non-isolated NIB is around 200,000 tons. Reduction reaches about 50%. A remarkable reduction is obtained together with increased structural margin by the seismic isolation. This is the largest merit of seismic isolations on the NIB.

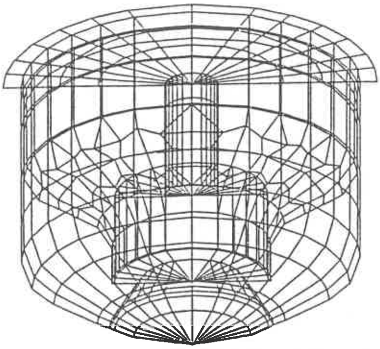

Fig 8 Analysis Model of Reactor Structure

Table 4 Weight of NIB

	Weight (ton)
Isolated NIB A	116,000
Isolated NIB B	106,000
Isolated NIB C	101,000
Non-Isolated NIB	198,000

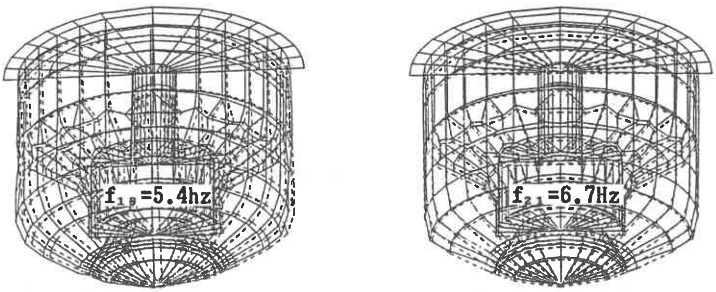

Fig.9 Typical vibration modes and frequencies

4. EARTHQUAKE RESPONSE OF REACTOR STRUCTURE

Fig. 8 shows the analysis model of the reactor structure, a three dimensional shell model, in which the liquid sodium is treated as a so called added mass matrix having significant non-diagonal terms. The effects of gravity, so the sloshing, is neglected in the analysis.

Fig. 9 shows the natural frequencies and modes of which the participation factors are significant. The most significant horizontal mode appears as the 18th mode (5.4 Hz) which is the in-phase horizontal deformation of the reactor vessel and the core. The most significant vertical mode is the 21st mode (6.7 Hz), which is the vertical in-phase deformation of the roof deck and the core. Time domain modal response analysis were performed based on the lowest 23 modes including the above mentioned two important modes. Fig. 10 shows the acceleration time history at the lower raft, the top of the cavity wall and the reactor core. The time history indicates that once an input acceleration is reduced by the isolators, it is no longer amplified significantly through the reactor building nor the reactor strucutre. This notably contrasts with the non-isolation case where the maximum acceleration at the core becomes more than ten times higher than the input at the ground.

Fig. 11 shows the resultant stresses at the reactor structure. The maximum stress of 11.5 kg/mm^2 appears at the junction of the bottom head and the core support structure. At the other parts, the stress is much lower. It indicates that the reactor structure with 20 mm thick wall has enough strength to stand in the seismically isolated conditions. This is also a significant reduction of the thickness as well as the increased structural margin compared to the conventional seismic design of a reactor structure.

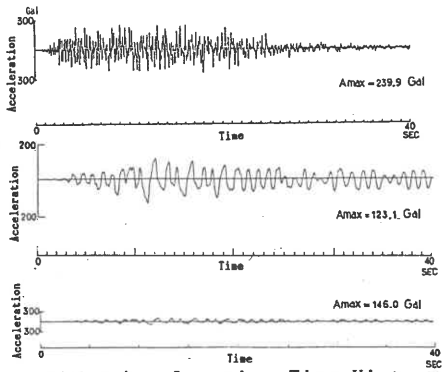

Fig 10 Acceleration Time History

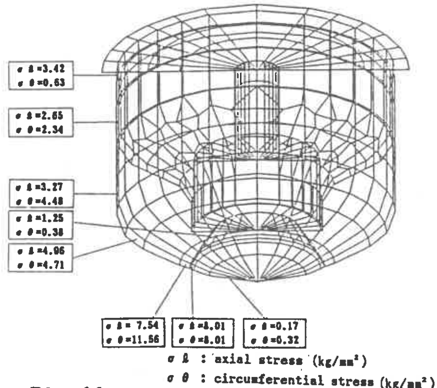

Fig 11 Resultant Stress at The Reactor Structure

5. CONCLUSION

Feasibilities and effectivenesses of a horizontal seismic isolation applied to the NIB of an LMFBR have been evaluated. The results are summarized as follows.

1) Seismic responses of seismically isolated NIBs and the reactor structure are characterized by a large sway motion displacement as a rigid body with low acceleration. The maximum response acceleration is reduced to 1/3 - 1/10 for the NIB and and reactor structure when isolated.
2) Structural integrity of a seismically isolated NIB is shown by the study not withstanding nearly 50% of the weight has been reduced compared to the non-isolated building.
3) As for the reactor structure, the seismic isolation can result in reduced wall thicknesses down to about 20 mm or, around 20% in weight.
4) The stability and structural margin of the building and the reactor yet increase in spite of the above-mentioned weight reduction of the structures.

By the experimental studies on the seismic isolation devices that will be presented in the succeeding papers, the seismic isolation is found feasible and effective for LMFBRs of Japan.

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6. REFERENCE

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