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CONCEPTUAL FRAMEWORK DESIGN AND SHAKING TABLE VERIFICATION TEST ON A SEISMICALLY ISOLATED LMFBR REACTOR BUILDING

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SUMMARY

An intensive 3-year feasibility study was conducted on seismic base isolation for a pool-type liquid metal fast breeder reactor (LMFBR). In this paper, it is shown through a series of conceptual design studies that lightweight reactor buildings with increased aseismic safety can be designed by employing new structural concepts when seismic isolation is utilized. Also presented are the results of a shaking table test using an isolated building model and the corresponding correlation analysis. This confirmed the effectiveness of seismic base isolation as well as the appropriateness of the earthquake response analysis approach used in the conceptual design study.

INTRODUCTION

One of the important tasks in the development of practical liquid metal fast breeder reactors (LMFBR) is to ensure economic benefits, especially in construction cost. In the case of LMFBRs, seismic load has a greater effect on the structural design than for light water reactors because the operational coolant pressure is low and its temperature is high. Therefore, reduction of seismic load is an effective way to attain a simple and lightweight LMFBR plant structure.

With this background, an intensive 3-year feasibility study (1984 to 1986) was conducted on seismic base isolation for a 1000 MWe pool-type LMFBR. The content of the study was in two parts, as shown in Fig. 1. The first part was to evaluate the effectiveness of base isolation for reducing seismic load and for rationalizing the plant structure, and the second part was to develop isolation devices applicable to an LMFBR.

This paper describes first the investigation of new structural design concepts for a seismically isolated LMFBR building. Second is described a shaking table test conducted to confirm the effectiveness and integrity of base-isolation devices and to verify the adequacy of the earthquake response analysis technique.

CONCEPTUAL FRAMEWORK DESIGN STUDY

Basic Conditions   The followings are the basic conditions for the conceptual design work.

(1) Seismic isolation concept: Horizontal base isolation of an entire reactor building was selected in this study because of the greater technical

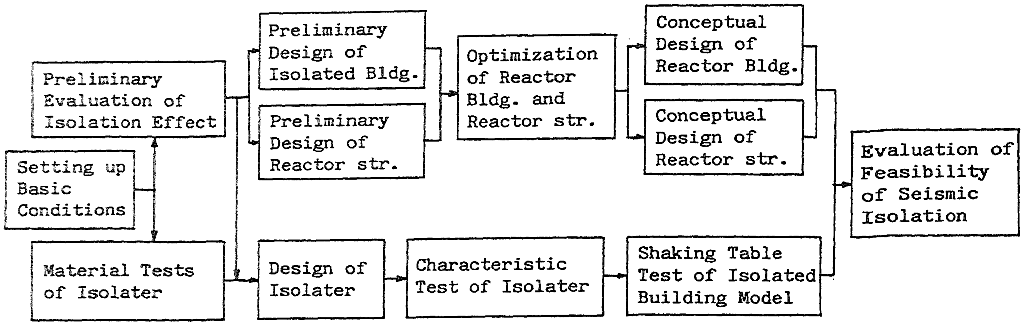


Fig. 1 Flow Chart of Feasibility Study

simplicity over other concepts such as partial isolation, 3D isolation, and so on, from design and development points of view.

(2) Soil conditions : Hard soil with the shear wave velocity of 1500 m/sec was assumed because the merit of base isolation is expected to be large in such circumstances.

(3) Input earthquake ground motion : The near and far field S1 earthquake ground motions for the high seismicity zone in Japan were used. As for the latter, a new synthetic wave was generated using a target spectrum with low frequency components leveled up as shown in Fig. 2. S2 level was assumed to be 1.5 times of S1.

(4) Seismic response requirements : The response acceleration of the reactor structure was required to be lower than 0.4 G, with relative displacement between isolated and non-isolated structures lower than 30 cm.

<u>Conceptual Framework Design Study</u> Through preliminary parametric analysis using a models with one or multiple degree of freedom, the following bilinear properties were selected for the horizontal characteristics of seismic isolation devices which can meet requirement (4) above (Ref. 1).

- first rigidity : 1.0 Hz
- second rigidity : 0.5 Hz
- yield level : 0.05 W (W: total weight of isolated part of building)

Based on the following check points, several types of building structure concepts were investigated.

(1) Are the natural frequencies of the upper structure different enough from the isolation frequency to prevent resonance?

(2) Can the seismic forces are transmitted smoothly especially between the neutron shielding walls and other structural part?

(3) Are the high frequency peaks of the floor response spectra due to higher vibration modes not excessive?

(4) Is the out-of-plane rigidity of the base mat large enough so as not to cause excessive variation of the vertical load distribution of the isolation devices?

As a result of the investigation, the two structural concepts shown in Fig. 3 were selected. They have reduced weight together with increased structural safety margin compared with conventional non-isolated reactor buildings. In Concept A, the building structure, except for the neutron shielding walls, is composed of a reinforced concrete beam-column frame with shear walls of drastically reduced thickness. In Concept B, the whole building, except for the neutron shielding walls, is replaced by a steel frame with bracings. The steel frame is erected on the upper base mat and isolated from the reinforced concrete shielding walls by using an expansion joint. These two types of building structures were designed to remain elastic even under S2 earthquake excitation so as not to reduce their natural frequency close to the isolation frequency.

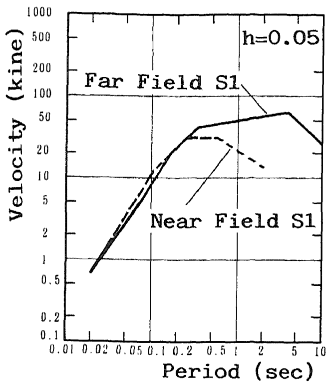


Fig. 2 Ground Motion Spectra

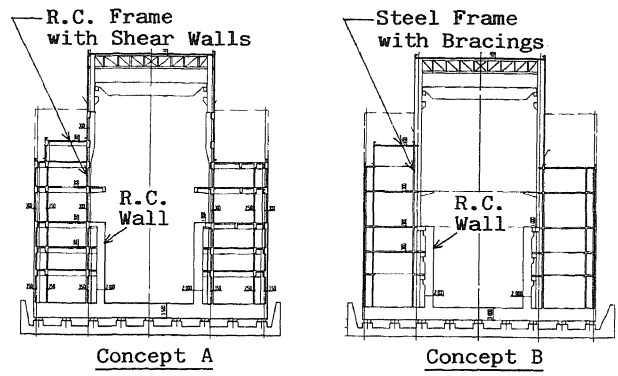


Fig. 3 Lightweight Base Isolated LMFBR Reactor Buildings

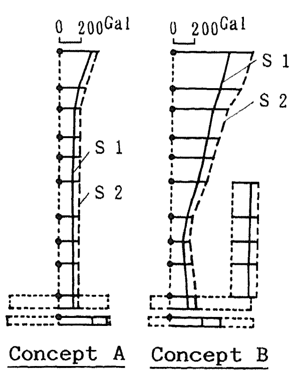


Fig. 4 Maximum Response Acceleration (Far Field E.Q.)

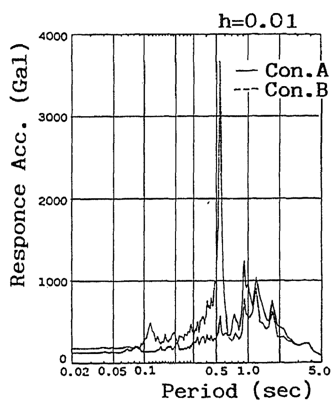


Fig. 5 F.R.S. at Reactor Structure Support (Far Field E.Q. S1)

Table 1 Maximum Response to Far Field Earthquake

Building Type	Base Shear Coefficient	Max. Relative Disp. (cm)
Concept A	0.128 0.186	8.84 14.88
Concept B	0.198 0.265	8.23 14.15

Upper Value : S1
Lower Value : S2

Figs. 4 and 5 and Table 1 show the earthquake response analysis results of above two reactor buildings. The maximum response acceleration is reduced to 1/3 - 1/10 of that of a non-isolated building, and the relative displacement is within acceptable limits from both the isolation device design and piping design points of view. The total building weight including the lower base mat is about 130,000 tons for Concept A and about 110,000 tons for Concept B, while that of a deeply embedded-type non-isolated reactor building is about 170,000 tons.

Response Reduction Effect of Connection Damper   Concerning Concept B, an analytical study was conducted on a connection damper installed between the reinforced concrete shielding walls and surrounding steel frame structure, aiming at further reduction of the seismic response in both the building and reactor structures.

Fig. 6 shows an analytical model of the building with the connection damper whose properties are varied as shown in Table 2. The analytical results shown in Figs. 7 and 8 indicate that the response acceleration, especially in the steel frame, is reduced to 40 - 75% of that of buildings without the connection damper, and that the floor response spectrum at the reactor structure support is also reduced in the high frequency range. Fig. 9 shows the reduction of the spectrum peak in the range of $f \geqq 4$ Hz with increase of the damping coefficient of the connection damper. The same effectiveness can be expected when an elasto-plastic damper is used.

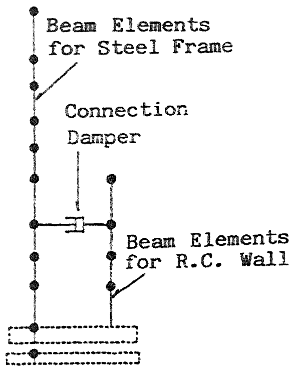
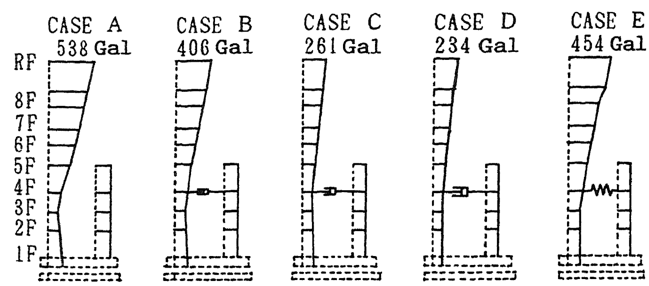


Fig. 6 Analytical Model

Table 2 Analytical Case

CASE	A	B	C	D	E
Para-meter	Without Damper	Viscous Damper			Elasto-Plastic Damper
		C=35 t sec/cm	C=175 t sec/cm	C=350 t sec/cm	K_1=1600 t/cm K_2= 400 t/cm Q_y= 800 t



C_B(Steel)=0.212 0.175 0.125 0.119 0.161

C_B(R.C.) =0.181 0.160 0.150 0.148 0.150

Fig. 7 Maximum Response Acceleration and Base Shear Coefficient (Far Field E.Q. S1)

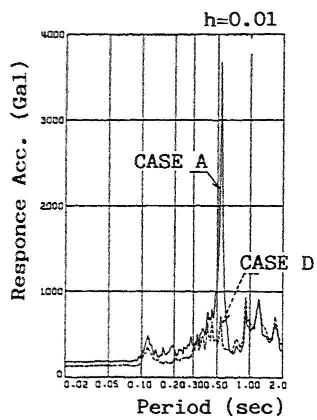


Fig. 8 F.R.S. at Reactor Structure Support (Far Field E.Q. S1)

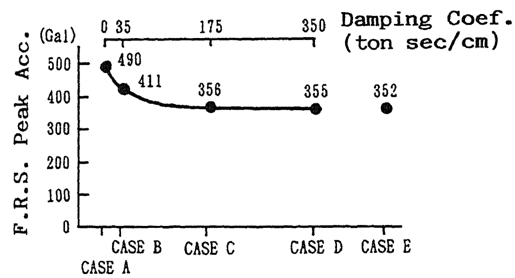


Fig. 9 Reduction of F.R.S. Peak (f ≧ 4Hz)

SHAKING TABLE VERIFICATION TEST

A shaking table test was conducted using a simplified scale model of the isolated LMFBR reactor building using lead rubber bearings (LRB) (Refs. 2 and 3). The purpose of the test was to confirm the dynamic behavior of an isolated structure and to verify the adequacy of the response analysis approach used in the conceptual design study.

Test Model A 4-story, 1-bay steel frame shown in Fig. 10 was used as test model to represent the dynamic characteristics of the reactor building of Concept A. The frame was mounted on four sets of LRB with 4 tons each design load (see Fig. 11). Each bearing is an 1/11 scale model of a prototype 500 ton bearing. Shown in Fig. 12 are the horizontal load-deflection curves of the 1/11 scale LRB model obtained by a loading test. Rupture occured when the average shear strain γ (γ=d/he, where d: shear displacement, he: total thickness of rubber,=30 mm) reached 450 %.

Test Results   Figs. 14 to 18 show the test results under far-field earthquake excitation. The response of the model can be characterized by sway motion as a rigid body with large displacement and low acceleration. The response acceleration at 2F, which corresponds to the support level of the reactor structure in a real reactor building, is reduced to 40 - 60 % of the input acceleration. The maximum average shear strain of the LRB is around 50 % even under 450 Gal input, which exceed the S2 level, comfortably below the rupture strain of the bearing.

Correlation Analysis   Correlation analysis with the test results was performed using the simple analytical model shown in Fig. 13, in which the isolation bearings are modeled as a bilinear horizontal spring together with a linear rotational spring. The damping ratio was assumed to be 0.5 % for the steel frame, 2 % for the horizontal spring and 10 % for the rotational spring.

The results of the analysis are shown in Figs. 14, 15 and 18 in the case of far field earthquake input of 440 Gal maximum acceleration. They indicate a good agreement with the observed results regarding both maximum acceleration and floor response spectra. It can be said from these results that the seismic response of base isolated buildings can be evaluated with an enough accuracy from an engineering point of view by using rather simple analytical models.

CONCLUSION

The results from the conceptual design studies and the shaking table test performed on a seismic base isolated LMFBR reactor building can be summarized as follows.

(1) The reduction of seismic load by applying a base isolation system can increase the structural design freedom of LMFBR plants to a large extent. It is shown in this paper that a lightweight reactor building can be designed with increased structural safety margin even for the high seismicity area in Japan, in which a reinforced concrete frame structure with thin shear walls or a steel frame structure with bracings are employed.

(2) In the case of using a steel frame structure, further response reduction can be achieved by installing connection dampers between the steel structure and the reinforced concrete neutron shielding walls.

(3) The results of the shaking table test and the correlation analysis confirmed the effectiveness and integrity of the base isolation devices as well as the appropriateness of the seismic response analysis approach used in the conceptual design study.

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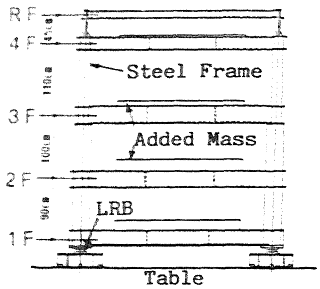


Fig. 10 Test Model

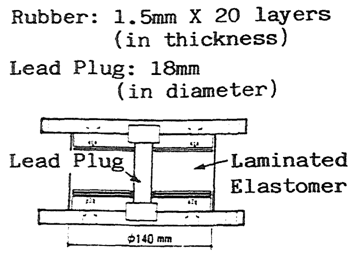


Fig. 11 1/11 Scale LRB

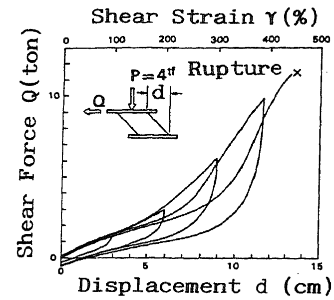


Fig. 12 Load-Displacement Curve of LRB

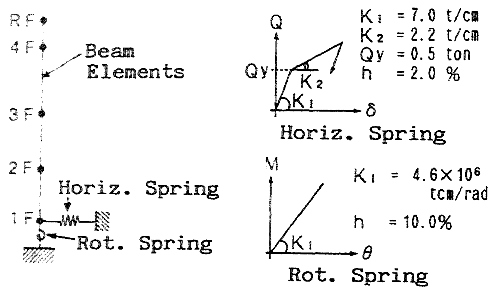
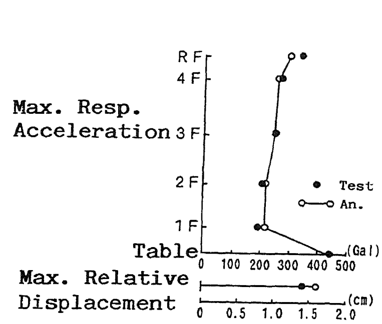


Fig. 13 Analytical Model



(Gal)

Test	An.
336	290
263	256
245	246
214	220
194	220
440	440

(cm)

1.39	1.60

Fig. 14 Maximum Response (Far Field E.Q., 440 Gal)

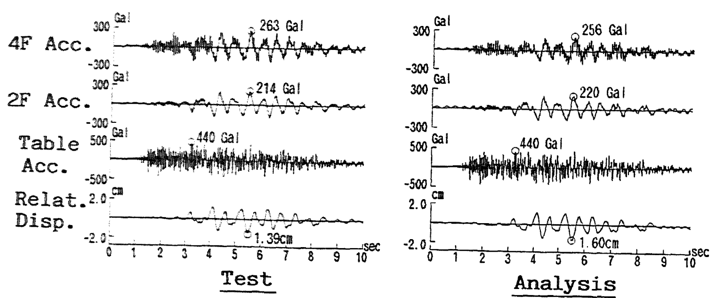


Fig. 15 Input and Response Time Histories (Far Field E.Q., 440 Gal)

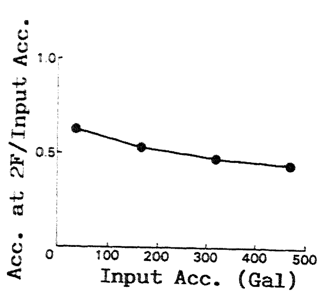


Fig. 16 Ratio of Accereletion Amplification (Far Field E.Q.)

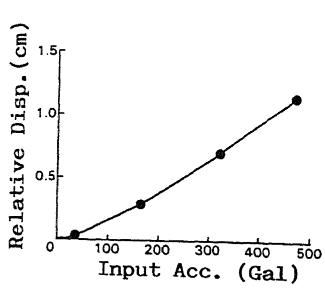


Fig. 17 Maximum Relative Displacement (Far Field E.Q.)

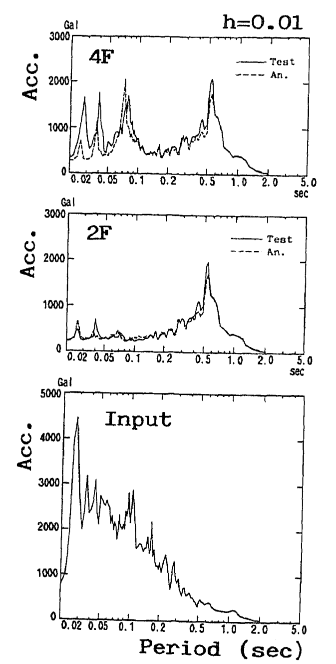


Fig. 18 Input and Floor Response Spectra (Far Field E.Q., 440 Gal)