Seismic isolation structure for pool-type LMFBR – Isolation building with vertically isolated floor for NSSS

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1 Introduction

In the design of nuclear power plants, a critical issue is the determination of loadings and response due to earthquakes. A key principle in structural developments of nuclear power plants is the need to maintain elastic behavior during earthquake. Therefore, usual aseismic design requires stiffened structural design for equipments as well as buildings in order to avoid excessive response to seismic waves and to maintain elasticity.

On the other hand, for a fast breeder reactor which is operated under as low pressure as atmospheric pressure and at elevated temperature thin-walled structure is designed to avoid high thermal stresses during operation. In the majority of cases, wall thickness of the main vessel and the core support structure is determined by earthquake condition.

Seismic isolation is an alternative approach of design for earthquake which aims to reduce seismic input to buildings and equipments. Using isolation structure, there is potential of simplification of structure, cost reduction, and improvement of reliability of plant.

2 Seismically Isolated FBR Plant

In high seismic zone, vertical as well as horizontal isolation structure for a FBR plant may be required, because a reactor structure is dependent on not only horizontal but also vertical seismic characteristics. In the case of horizontally and vertically isolated plant, the plant configuration depends on absorption methods for relative displacement between isolated area and non-isolated area. Especially, for sodium pipings, long length pipings are required in order to absob relative displacement by using the piping flexibility. However, it is difficult to design the long length sodium piping.

In this studies, combination of horizontally isolated building and vertically isolated floor for NSSS (Nuclear Steam Supply System) as shown in Fig. 1 was selected as a reference seismically isolated structure for FBR plant. In this plant, all sodium components are installed on the NSSS vertical isolation floor. The relative displacement caused by earthquake is absorbed by non-sodium components. The NSSS isolation floor is 40 m x 40 m and about 20000 ton in weight including installed components. Vertical isolators for the floor are composed of coil springs and dampers. Further, rubber bearings are set up on the floor side wall as side support bearing. In the horizontal isolation building, horizontal isolators are composed of rubber bearings and dampers.

3 Seismic Response Analysis

3.1 Analytical Model and Condition

Seismic response analyses were performed in order to investigate effects of building structural features, damper characteristics for isolators and soil conditions on responses of the reactor buildings and equipments. For building structural features, two structure categories were considered. One was a conventional structure, designed by usual seismic design methods. The other is a seismic isolation structure, as shown in Fig. 1.

Analytical models in the horizontal direction and the vertical direction for these building were considered. Horizontal model for the seismic isolation building is shown in Fig. 2. The NSSS isolation floor position corresponds to main vessel support position (mass point 4) in Fig. 2. Horizontal natural frequency of the isolation building is 0.5 Hz for the rubber bearing support only. In the vertical analytical model for the isolation building, the NSSS isolation floor is simplified by a linear single-degree-of-freedom system, which moves only in a vertical direction. Vertical natural frequency of the NSSS floor is 1.5 Hz for the coil spring support only. For dampers, 3 kinds of dampers (linear viscuous damper, friction damper and elasto-plastic damper [ex. Lead shear damper]) were considered for horizontal isolator (see Fig. 2). Further, a linear viscous damper was considered for the vertical isolator in the NSSS floor. Three kinds of soil shear stiffness were considered ($V_s = 700$, 1500 and 2000 m/s).

3.2 Response Calculation

Input seismic wave for seismic isolation design was developed, based on the observed earthquake data. Wave form and response spectrum for the input are shown in Fig. 3. In the response analyses, this seismic wave was used as both horizontal and vertical inputs. But, maximum accelerations for horizontal and vertical inputs are 3 and 2.1 m/s^2, respectively.

First, in eigen value analysis, 1st, 2nd and 3rd natural frequencies of the conventional building ($V_s = 1500$ m/s) are 3.57, 4.97 and 10.44 Hz, respectively. Natural frequencies and participation factors for the isolation building without dampers are shown in Table 1 and 2.

Second, in horizontal seismic response analysis, response acceleration time history of the main vessel support position, in the case of the isolation building with the elasto-plastic dampers (50 gal trigger), is shown in Fig. 4. Floor response acceleration spectrum on the main vessel support positions for the conventional building and the isolation building with 3 dampers are shown in Fig. 5. Effects of viscous damper damping ratio and trigger level of the friction and elasto-plastic dampers on maximum relative displacement of the isolator are shown in Fig. 6. Further, effects of the above-mentioned damper parameter on maximum response acceleration for the main vessel support position in the isolation building are shown in Fig. 7.

Third, in vertical seismic response analysis, maximum vertical response acceleration and relative displacement for the NSSS isolation floor are 1.692 m/s^2 and 0.0175 m, respectively. It is assumed that vertical damper damping ratio is 0.30.

3.3 Results

(1) Effective seismic isolation for the reactor components can be expected by adopting the proposed isolation building.
(2) In the isolation building, low frequency range responses, in which liquid sloshing in the main vessel increases, are not amplified by using the hysteric dampers.
(3) The viscous damper is most effective for response acceleration control, but is not effective for relative displacement control. The friction damper is most effective for relative displacement control, but is not effective for acceleration control. The elasto-plastic damper is relatively excellent for practical frequency range in the three kinds of dampers. Proper trigger level for this damper is about 50 gal.

4 Scale Model Test on NSSS Isolation Floor

4.1 Scale Model Structure

A 1/18 scale model, in which the NSSS floor, the main vessel, the S/G and the pump are simplified, was used (see Fig. 8) in order to investigate vibration characteristics for the NSSS isolation floor and side support bearing effects on rocking responses for the isolation floor. The similarity rule on the dynamic properties between scale model and actual structures was applied for fundamental natural frequency, structual vertical stiffness and masses. The scale model, whose total mass is 3.45×10^3 kg, is supported by 8 coil springs and 4 oil dampers. Further, 4 or 8 high damping rubber bearings are set up between the floor side wall and the pedestal as side support bearings in order to restrain horizontal floor motion and control rocking motion. Designed vertical natural frequencies for the floor model and the main vessel model are 4.5 Hz and 18 Hz, which correspond to 1.5 Hz and 6 Hz for actual structure frequencies.

4.2 Model Tests

In model tests, static loading test for a vertical isolator, vibration test for model components and vibration test for the scale model in Fig. 8 , were performed in order to investigate load-displacement relation of the isolator, vibration characteristics of the model components and the whole isolation floor model. Load-displacement relation for the vertical siolators, containing 8 coil springs and 4 rubber bearings, is shown in Fig. 9. Resonant frequencies for the model components and the scale model are shown in Table 3.

In seismic vibration tests, response wave on the main vessel support position of the isolation building with the elasto-plastic damper for the seismic wave in Section 3, Akita wave (1983), and El Centro wave (1949) were used as seismic inputs. Maximum response accelerations for isolated scale model and non-isolated scale model for the seismic inputs, whose time scale was reduced to 1/3 for the actual scale, are shown in Table 4.

4.3 Results

(1) The NSSS isolation floor vibration characteristics were made clear. Especially, the side support bearing (rubber bearing) is effective for horizontal floor motion restraint and rocking motion control.
(2) Seismic isolation effects for responses of the reactor components can be sufficiently expected, using the vertical seismic isolation floor.

5 Conclusion

From the analytical and experimental studies, the following has been concluded:

(1) Seismic isolation structure, which is suitable for large pool-type LMFBR, were proposed.

(2) Seismic response characteristics of the seismic isolation structure were investigated. It was made clear that the proposed seismic isolation (Combination of the isolated building and the isolated NSSS floor) was effective.

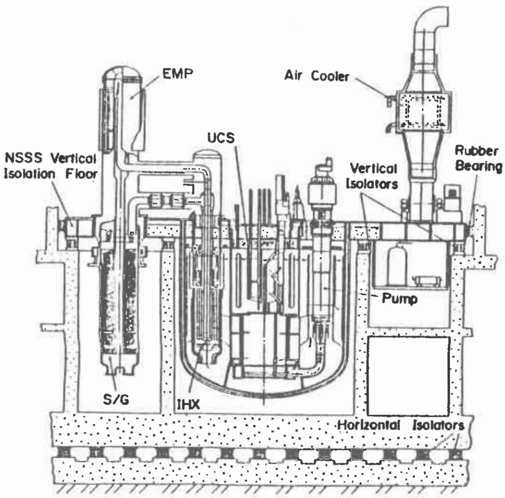


Fig.1 Reference seismic isolation structure for FBR plant

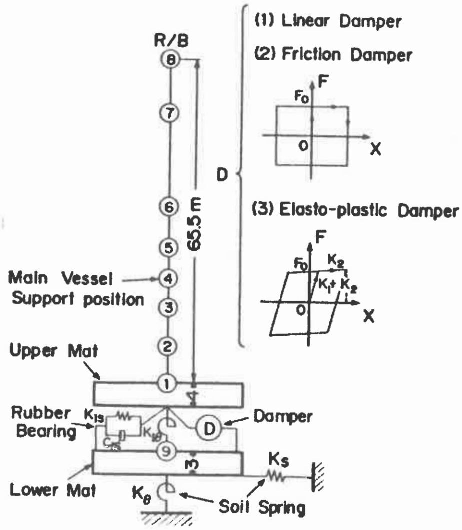


Fig.2 Analytical model for seismic isolation building (Horizontal direction)

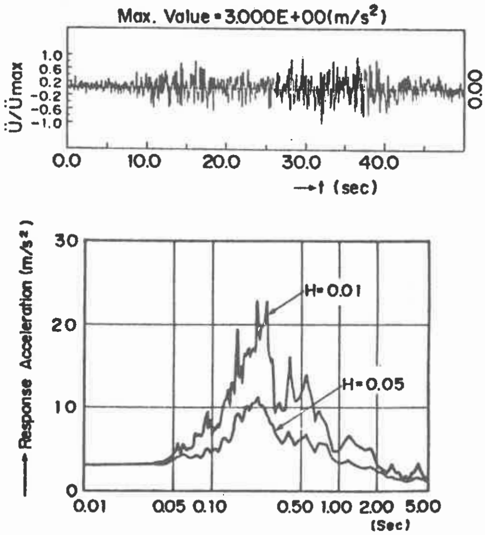


Fig.3 Time history of acceleration and response spectrum for seismic wave input (Wave B)

Table 1 Horizontal eigen value of seismic isolation building

mode	Vs (m/s)	N.Frequency (Hz)	Period (sec)	Participation Factor
1	700	0.495	2.020	1.060
	1500	0.498	2.007	1.048
	2000	0.498	2.006	1.046
2	700	2.64	0.379	0.047
	1500	2.68	0.373	0.046
	2000	2.69	0.372	0.046
3	700	5.79	0.173	0.040
	1500	9.32	0.107	0.026
	2000	9.82	0.102	0.018
4	700	9.92	0.101	0.259
	1500	9.96	0.100	0.035
	2000	10.23	0.098	0.022
5	700	10.22	0.098	0.977
	1500	17.01	0.059	0.056
	2000	18.99	0.053	0.024

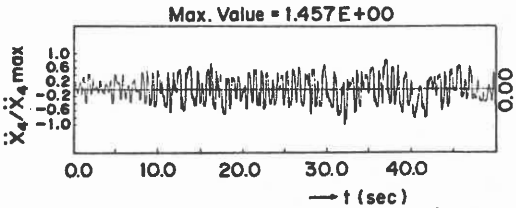


Fig.4 Response acceleration time history of main vessel support position in the case of elasto-plastic damper (50 gal trigger)

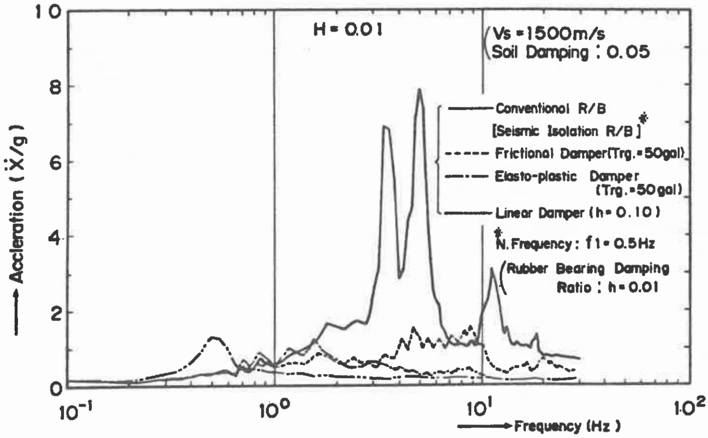
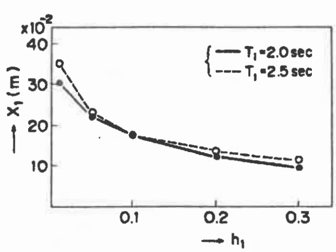
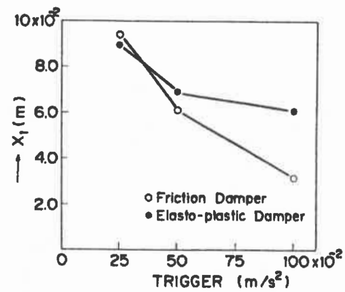


Fig.5 Response acceleration spectrum on main vessel support position (Comparison of conventional building with isolation building)

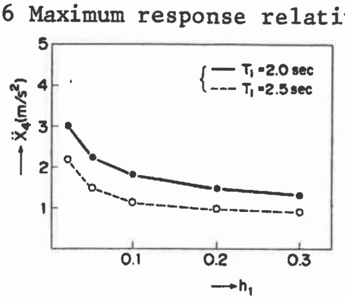


(a) Effects of damping ratio (Viscous damper)

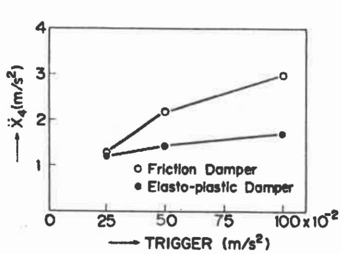


(b) Effects of trigger level (Hysterisis damper)

Fig.6 Maximum response relative displacements for three kinds of damper



(a) Effects of damping ratio (Viscous damper)



(b) Effects of trigger level (Hysterisis damper)

Fig.7 Maximum response accelerations of main vessel support position for three kinds of damper

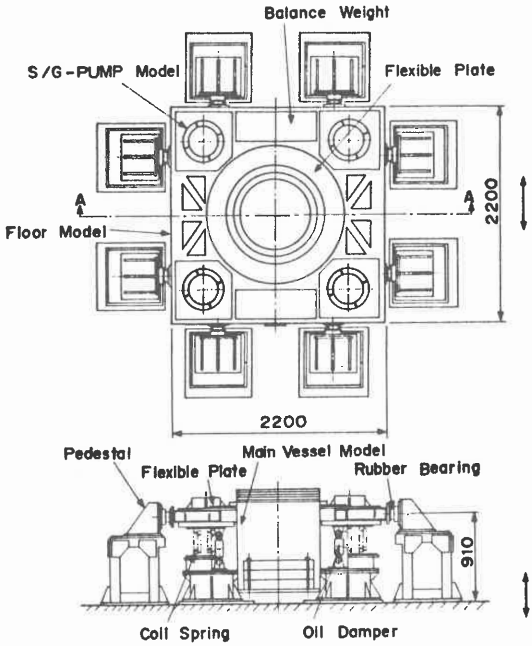


Fig.8 Scale model of NSSS isolation floor

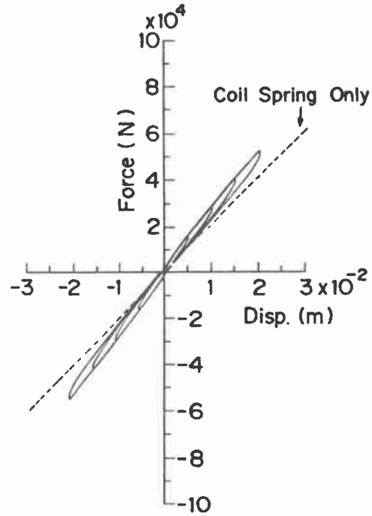


Fig.9 Load-displacement relation for vertical isolators

Table 2 Vertical eigen value of seismic isolation building

mode	Vs (m/s)	N.Frequency (Hz)	Period (sec)	Participation Factor
1	700	1.491	0.671	1.095
	1500	1.497	0.668	1.027
2	700	5.156	0.194	1.291
	1500	9.535	0.105	2.872
3	700	12.30	0.081	0.332
	1500	12.76	0.078	1.965
4	700	27.64	0.036	0.086
	1500	30.04	0.033	0.337
5	700	45.04	0.022	0.045
	1500	45.17	0.022	0.177

Table 3 Resonant frequency of NSSS isolation floor model

Test Case	Resonant Frequency (Hz)	Mode
Model Components Test	10.6	Hor. 1st (M/V Rocking)
	18.8	Ver. 1st (M/V)
Isolated Model Test (Coill Springs Only)	2.2	Hor. 1st (Floor)
	3.8	Ver. 1st (Floor)
	4.2	Rocking 1st (Floor)
	25.0	Ver. 2nd (M/V)
Isolated Model Test (Coil Springs, Rubber Bearings, Oil dampers)	5.0	Ver. 1st (Floor)
	10.0	Hor. 1st (M/V Rocking)
	22.6	Rocking 1st (Floor)
	25.8	Ver. 2nd (M/V)

Table 4 Maximum seismic response acceleration of NSSS isolation floor model (Comparison of isolated floor with non-isolated floor)

Seismic Wave (Floor Response)	Max. Input Acceleration (m/s^2)	Floor Support Type	Max. Response Acceleration (m/s^2)		
			Floor Hor.	M/V Lower End Hor.	M/V Lower End Ver.
Wave B	Hor. 0.74	Non Isolation	0.93	2.33	6.67
	Ver. 1.80	Isolation	1.27	1.10	1.69
Akita Wave	Hor. 1.13	Non Isolation	1.24	1.93	3.87
	Ver. 1.49	Isolation	1.30	1.40	1.76
El Centro Wave	Hor. 0.58	Non Isolation	1.13	1.27	4.72
	Ver. 4.42	Isolation	1.15	0.69	3.30