Seismic isolation design analysis on pool-type LMFBR

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1 Introduction

A pool-type LMFBR is studied in Japan as one of the candidates of the future LMFBR, which has a large diameter main vessel (M/V). But in our country we have so severe regulations, that it is difficult to design a M/V without any seismic supports. So we have studied a seismic isolation design in which a M/V is supported by an isolation system in expectation that the seismic response acceleration of a M/V would become lower and that the seismic loads would be reduced. In this study a M/V and a building are modeled to beam elements with lumped masses respectively and connected by a non-linear spring which represents the isolation system. Then we have carried out the seismic response analysis and have investigated the feasibility of the isolation.

2 Model and case of analysis

We performed two kinds of analyses, one of which was to investigate the influence of an isolated M/V to the response of a building using a coupled model of the M/V and the building, the other was to survey the appropriate parameters of the isolation systems using a single model of the M/V.

2.1 Model of analysis

The building in a conceptual design was supposed to be approx. 90m in width, 70m in length and 88m in height and approx. 414,000 ton in weight including components and a base mat. And the M/V was supposed to be approx. 18m in dia. and 15m in height and approx. 10,330 ton in weight including core internals, sodium and so on.

In the analysis of the coupled model, the M/V and the building were modeled to lumped masses and beams, and the isolation systems were modeled to a non-linear spring (Fig. 1).

In the analysis of the single model, only the M/V was modeled (Fig. 2). Equations of motion are as follows,

$$\left.\begin{aligned} &[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = -[M]\{1\}\ddot{Z} + \{Y\} \\ &\{Y\} = [\ -F\ 0 \ldots 0\ ]^T. \end{aligned}\right\} \quad \ldots (1)$$

Where F is the imposed force on the supported point of the M/V from the isolation system, which depends on its properties, and $\ddot{Z}$ is the acceleration of the M/V's floor. Solving the equations (1), we got seismic responses.

The data of the models are shown in Tables 1 and 2.

2.2 Input of seismic wave

The input of a seismic wave in the analysis was determined as follows. At first, we selected a seismic wave having strong component at relatively low frequency regions out of the ones recorded recently in Japan. The wave was enlarged so that the peak acceleration of the wave was equaled to 300 Gal. Then we applied the acceleration time-history of the wave to the mass of a rock in Fig. 1.

2.3 Case of analysis

For the coupled model, we chose two values i.e. 0.5 H_Z and 1.0 H_Z as a frequency of the isolation system, and selected two kinds of yielding loads of the isolation system. And also we calculated seismic responses according to the model without isolation systems for comparison.

In the analysis of the single model, we selected several parameters for searching the most appropriate parameters of the isolation systems. We considered three kinds of the systems ; a hysterisis damper model, a series model of a friction damper and a spring, and a parallel model of a friction damper and a spring. In the analysis of the single model, we applied the response accelerations at the M/V floor obtained from a seismic response analysis of the building.

3 Results

3.1 Analysis of the coupled model

Natural frequencies and mode shapes of the coupled model are shown in Fig. 3.

Peak seismic response accelerations of the building and the M/V are shown in Fig. 4. Floor response spectra of the M/V floor are shown in Fig. 5 for the two cases of yielding acceleration under the condition that the isolation frequency was 1 H_Z. The following observations were obtained through the results.

(i) The peak acceleration at the M/V floor was increased up to 450 ~ 600 Gal while the input to the rock was 300 Gal. And the peak value was similar with or without isolation systems. And also it was not so affected by the isolation frequency, and by the yielding acceleration.

(ii) The spectrum was not so affected by the yielding acceleration.

3.2 Analysis of the single model

Results of analyses of the single model are shown in Table 3 and Figs. 6 ~ 9.

(1) Hysterisis damper. We could control the both responses of the acceleration and the displacement of the M/V at low value using an appropriate isolation condition. The peak acceleration was 300 ~ 600 Gal and the maximum relative displacement was about 35mm when the ratio of initial stiffness to yielded stiffness was 6 ~ 8 in the case of this study (Fig. 6).

The examples of response acceleration time history are shown in Fig. 7 for the input of sine wave. It is observed that the M/V responded having components of high frequency and having inversed phases at the upper part and at the bottom.

(2) A parallel model of a friction damper and a spring. We could control the both responses of the acceleration and the displacement of the M/V at low value using an appropriate isolation condition. The peak acceleration was 500 ~ 750 Gal and the maximum relative displacement was about 25mm when the isolation frequency was near 1 H_Z in the case of this study (Fig. 8).

The example of the relation between the peak accelerations and the coefficients of friction are shown in Fig. 9 for each level. When a coefficient of friction is zero, the M/V responses uniformly at each level, but when the coefficient is increased, the M/V responses intensely at the top and at the bottom.

Table 3 shows suitable parameter combinations of the isolation systems which could control both seismic responses of the acceleration and the displacement of the M/V at low value.

4 Discussions

(1) The M/V supported by the isolation systems did not have influence on

seismic responses of the building, and the analysis using a single model was adequate for searching appropriate parameters of the isolation systems.

(2) The fundamental frequency became low when the M/V was supported by the isolation system, but the response wave of the M/V's acceleration had high frequency components. The cause of this phenomenon was estimated to be that the isolation system had a discontinuous stiffness at the yielding points then the M/V suffered the impact when the isolation system yielded.

(3) The both responses of acceleration and displacement of the isolated M/V could be controlled at low value when the parameters of the isolation system were appropriately chosen.

(4) The isolated M/V should be modeled in a multi mass model when the seismic responses of the M/V was calculated, judging from the fact in Fig. 9.

5 Conclusions

From the results of analysis, we estimated that selecting suitable parameters of the isolation system, we could reduce the peak response acceleration of the M/V from about 2500 Gal to 1000 Gal for the strong seismic motion in Japan, and then the maximum relative displacement became about 50mm between the M/V and the floor. Each model of the systems would become effective on controlling the M/V's both responses of acceleration and displacement at low value if parameters were appropriately chosen. But even if the M/V was isolated, the M/V might respond having vibration components of higher frequency. So the designer should pay attention to such facts in designing the seismic components on the isolated M/V.

For one example we designed a conceptual isolation system which supports a M/V using coil springs and friction dampers in parallel (Fig. 10). In future we have to solve the following problems. The first is whether we could design and fabricate such isolation systems that have constant and reliable properties of an isolation. The second is whether we could have piping systems connected to the M/V which tolerate displacement of about 50mm. After successful solution of such problems we could have a M/V of a large pool-type LMFBR without seismic supports which coud keep the integrity against strong seismic motions.

Table 1 Data of analysis for a coupled model (see Fig.1)

Structure	No. of mass	Level of mass (EL m)	Weight (ton)	No. of element	Area of shear (m^2)	Second moment of area (m^4)
Reactor build.	RB08	62.5	10,080			
				8	108	252,870
	RB07	49.0	19,570			
				7	216	373,510
	RB06	24.0	42,700			
				6	481	536,360
	RB05	16.0	42,350			
				5	817	694,870
	RB04	7.5	45,110			
				4	903	794,020
	RB03	0.0	47,950			
				3	1013	813,030
	RB02	− 6.0	39,830			
				2	1013	813,030
	RB01	−12.5	45,490			
				1	1044	813,230
	BSTP	−19.5	−			
				9	Isolation systems	
	BASE	−22.5	110,520			
	BSBM	−25.5	−			
Reactor main vessel (M/V)	RV01	0.0	4,550			
				11	1.495	113.6
	RV02	− 3.75	1,040			
				12	1.495	113.6
	RV03	− 7.50	2,260			
				13	1.495	113.6
	RV04	−10.00	630			
				14	1.389	91.3
	RV05	−13.70	1,850			
Total weight of structures (with components)		413,930 ton		Moment of inertia ($ton \cdot m^2$)	BASE $=7.49\times10^7$ RV01 $=6.31\times10^4$	

Table 2 Data of analysis for a single model (see Fig.2)

Part	Mass ($kg\text{-}s^2/mm$)		Spring stiffness (kg/mm)		Coefficient of viscosity (kg-s/mm)	
Roof slab	m_1	455.6	K_1	41,600	C_1	87.07
M/V upper	m_2	65.8	K_2	2,609,400	C_2	262.07
M/V middle	m_3	269.0	K_3	2,609,400	C_3	529.88
M/V bottom	m_4	74.4	K_4	1,448,100	C_4	207.60
Sodium	m_5	37.2	K_5	114	C_5	1.30
UIS	m_6	11.7	K_6	75,500	C_6	18.80
Core internal	m_7	140.3	K_7	2,090,900	C_7	342.55

Table 3 Optimum parameters of the isolation systems and maximum responses for a single model

Damper	Hysterisis	Friction in series	Friction in parallel	Rigid support
Parameters / Results of response	spring stiffness 3.0×10^5 kg/mm	frequency 2Hz	frequency 1Hz	frequency 10Hz
	ke/kp 6.5	μk 0.15	μk 0.1	−
	yield load 1.0×10^6 kg	−	−	−
Acc. of m_1 (Gal)	490	470	500	900
Acc. of m_4 (Gal)	673	500	732	2600
Disp. of m_1 (mm)	31	50	21	4
Rel. disp. of m_6-m_7 (mm)	6	10	6	16
Residual disp. (mm)	0	0	6	0

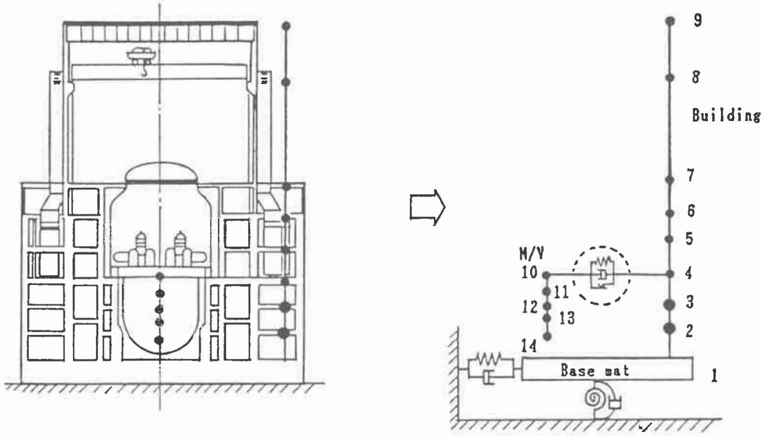

Fig.1 A Coupled model of a building and a M/V

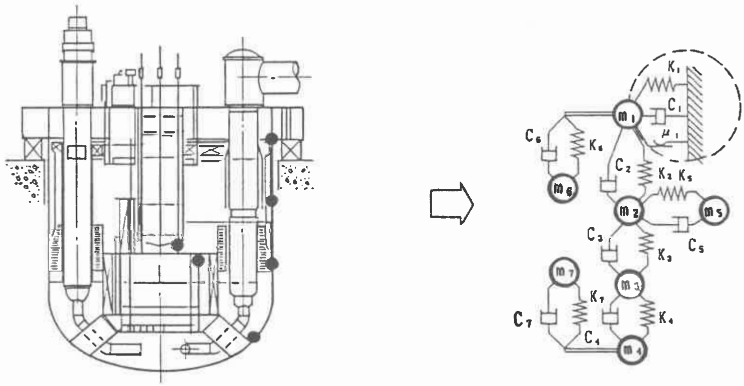

Fig.2 A Single model of a M/V

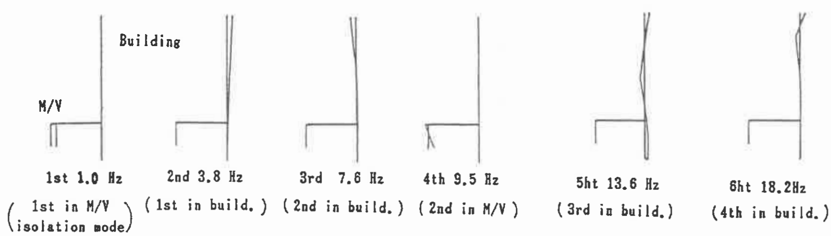

Fig.3 Mode shapes in the coupled model

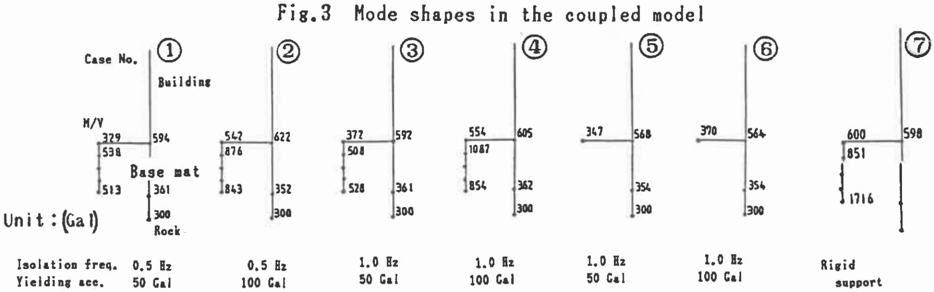

Fig.4 Peak acceleration responses in each case for the coupled model

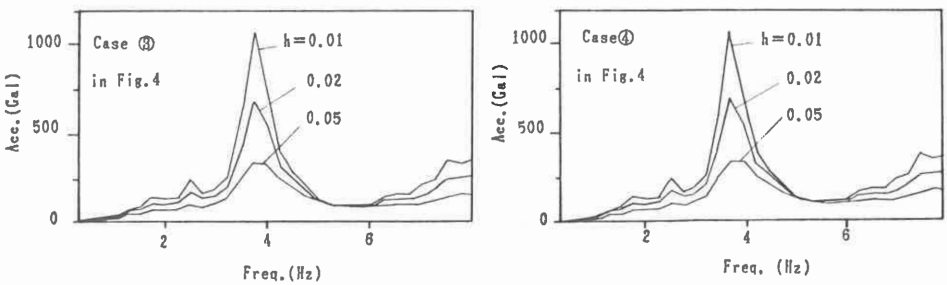

Fig.5 Comparison of floor response spectra of the building

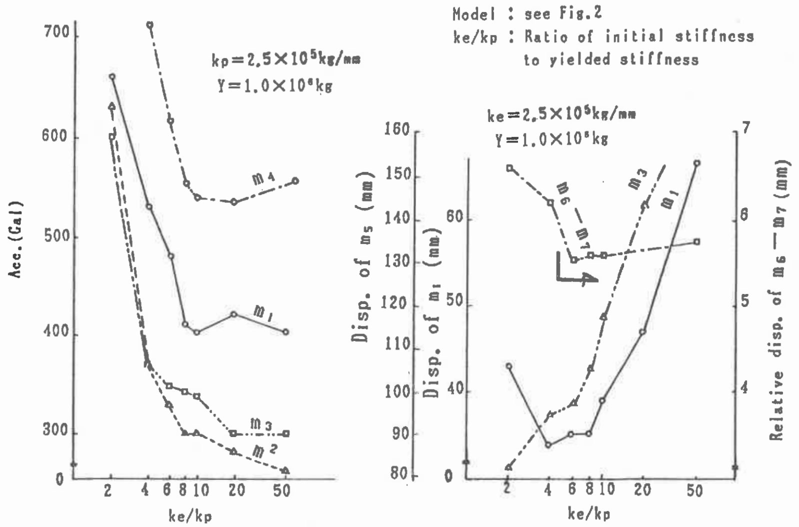

Fig.6 Responses for the models with hystersis damper

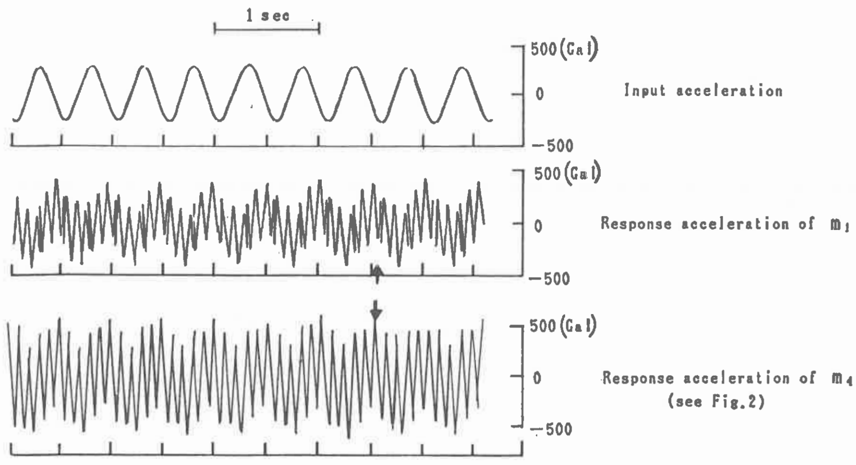

Fig.7 Time history sample of response accelration of the M/V for the single model isolated

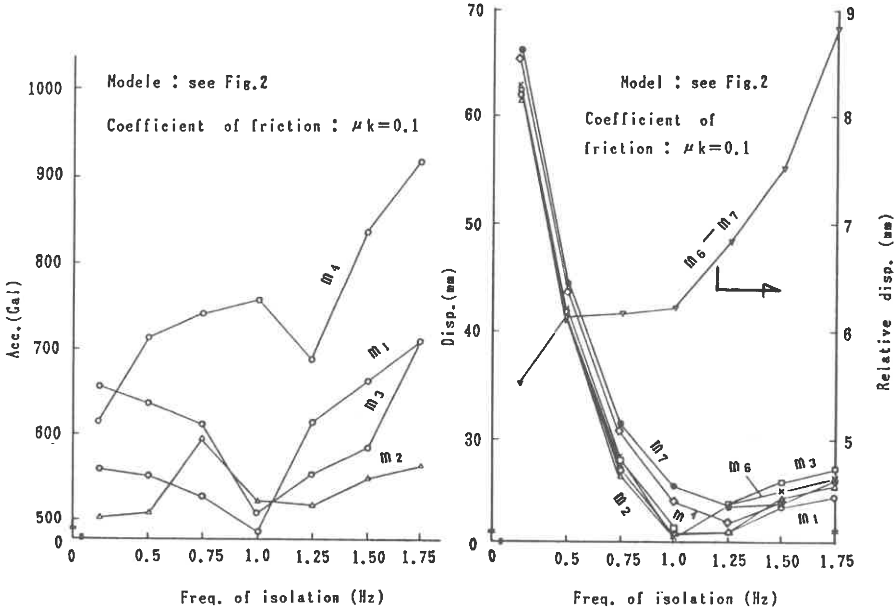

Fig.8 Resposes for the parallel models of a friction damper and a spring

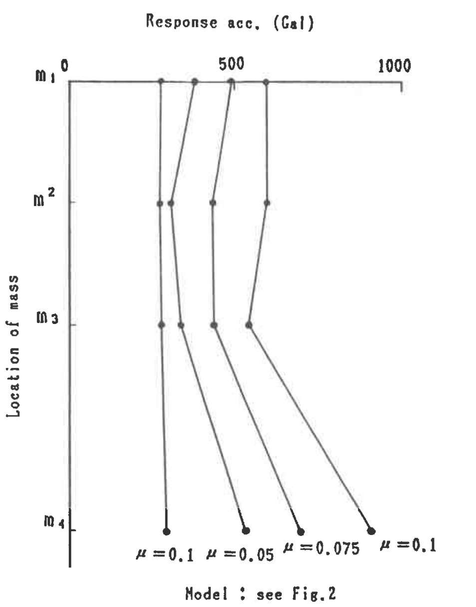

Fig.9 Peak response acceleration distribution in the M/V isolated

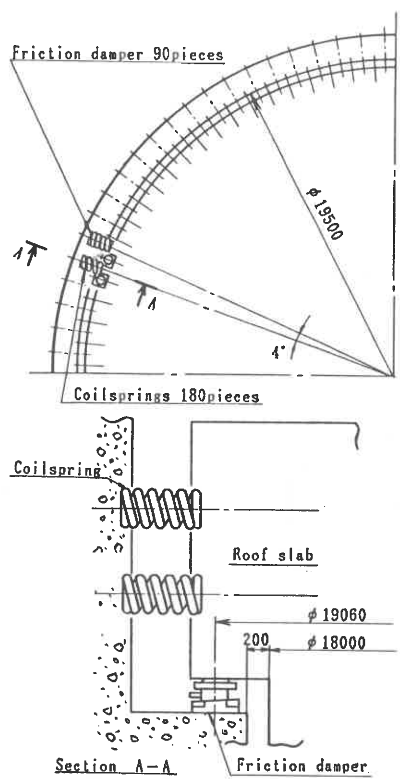

Fig.10 A sample of M/V isolation supporting system