Development of a New Component-Support Concept Using Energy Absorbing Device

M. TABUCHI, K. TAI, T. KAMBARA
Mitsubishi Atomic Power Industries, Inc., Tokyo, Japan

K. FUJITA, S. KAJII, M. OHASHI
Mitsubishi Heavy Industries, Ltd., Takasago/Kobe, Japan

I. SHIMODA, C. TSURUYA
Oiles Corporation, Fujisawa, Japan

ABSTRACT

This paper concerns the application of energy absorbing devices to the primary component supports of the PWR Reactor Coolant System. Previous studies have shown that the cylinder type Lead Extrusion Damper (L.E.D.) is useful for the major component supports such as the Steam Generator (SG) supports.

In this study, the vibration test of a 400 kN L.E.D. has been conducted using a test facility with a hydraulic servo actuator. Also the simulation analysis of the earthquake response of the PWR Reactor Coolant System supported by a large capacity L.E.D. (1 MN) has been performed by estimating the characteristics based on the 400 kN L.E.D. vibration test.

Through the study, it is confirmed that the energy absorbing device shall be applicable to the PWR SG support with high reliability and low costs.

1. INTRODUCTION

Many mechanical and hydraulic snubbers have been used in the recent seismic designs of nuclear power plants. But the initial and running costs of snubbers are relatively high, and the periodical maintenance of snubbers is a factor contributing to radiation exposure. To rationalize such systems, various types of energy absorbing devices have been developed with the aim of providing an alternative to conventional snubbers in the last two years.

Among those devices, L.E.D. is expected to have the following characteristics as the seismic support for major components of a nuclear power plant such as the SG.

- To absorb large amounts of energy in a seismic event.
- To produce relatively small drag forces when the component moves slowly, such as during thermal expansion.

Fig. 1 shows the sketch of the cylinder type L.E.D. used in this study. It consists of a cylindrical tube, the bulge shaft, and the lead filled in the space between them. The bulge shaft is supported by bearings which also serve to keep the lead in the space. As the shaft moves relative to the tube, the lead is extruded through the orifice formed by the bulge and the tube.

2. ELEMENT TEST

2.1 Test method

The test facility is shown in Fig. 2. The 400 kN L.E.D. is connected to the hydraulic servo cylinder through the load cell. The following two tests have been performed.

(1) Sinusoidal wave vibration test;
to obtain the force-displacement curve of the L.E.D. over a frequency range of 0.01 ~ 0.1 Hz, and displacement range of 1 ~ 5 mm.

(2) Low velocity drag force test;
to measure the reaction force caused in the L.E.D. when the shaft moves with a slow velocity ($2 \times 10^{-5} \sim 2 \times 10^{-2}$ cm/sec), corresponding to design thermal expansion speeds of PWR RCS loop piping.

2.2 Test results

(1) Sinusoidal wave vibration test

Typical examples of hysteresis loops obtained by 0.01 Hz sinusoidal wave tests are shown in Fig. 3 (maximum displacement 3 mm), and Fig. 4 (maximum 1 mm).

The shape of the hysteresis loop looks like a parallelogram, and it exhibits the effective energy absorbing function. The relation between the reaction forces and maximum displacement is shown in Fig. 5. The 400 kN L.E.D. reached the constant design load when the displacement became larger than 2 mm.

The shape of the hysteresis loops shows almost no changes in the tested frequency range.

(2) Low velocity drag force test

The reaction force of the L.E.D. gradually decreases from its design load as the velocity of the L.E.D. shaft becomes slow. Fig. 6 shows the relation between the reaction forces and the shaft velocities of an L.E.D. at a constant speed in the test facility.

In the velocity range less than 10^{-2} cm/sec, the plots of the reaction forces are nearly on a straight line in the log-log diagram.

3. SIMULATION ANALYSIS

To estimate the adequacy and the effect of using the energy absorbing devices in the seismic design, a simulation analysis based on the earthquake response of the PWR Reactor Coolant System have been performed, using the large capacity L.E.D. (1 MN) for the SG upper support.

3.1 Analysis model

Fig. 7 shows the trial design model with two levels of lateral supports using the 1 MN L.E.D. for the upper X-directional support of the SG. Fig. 8 shows the current design model using hydraulic snubbers with three levels of lateral support for the SG. In the case of the L.E.D. design, the upper X-directional support is substituted by the L.E.D. and the intermediate support is removed from the current design. The building and RCS coupled model, shown in Fig. 9, has been used in both cases, taking into account the soil-structure interaction and the coupled effect of building and RCS.

In the trial design case using the L.E.D., the increased energy absorbing element of damper such as the L.E.D. will be expected to be proportional to the maximum displacement. On the other hand, for the system reliability, it is required to minimize the displacement. As one of the ideas to solve this conflict, the link-mechanism shown in Fig. 10 will be useful to amplify the L.E.D. displacement relative to the SG displacement. The amplification α (that is the ratio of [L.E.D. disp.]/[SG disp.]) is defined in Fig. 10.

In the case of $\alpha=1$, it corresponds to the case that the Steam Generator is directly connected to the L.E.D.. To estimate the effect of the link-mechanism, the analysis case with an amplification of $\alpha=2$ is selected. Also analysis of the conventional type three level support is performed as the reference case.

Accordingly, the following three analysis cases have been performed.

Case 1: The trial design using the L.E.D. [refer to Fig. 7]
Case 2: The trial design using the L.E.D. and the link-mechanism ($\alpha=2$) [refer to Fig. 7 and Fig. 10]
Case 3: The current design using snubbers [refer to Fig. 8]

3.2 Analysis method and condition

The simulation analysis was performed using a modal time history method, in which the local non-linearity of the L.E.D. was treated as the pseudo-force element. The details of this method are reported in the reference (E. Kokubo et al., 1989).

In the analysis, the non-linearity of the L.E.D. is modeled using the simple bi-linear load-displacement curve shown in Fig. 11, assumed from the previous 400 kN L.E.D. test data.

The input seismic wave adopted is 1.5 times the El-Centro NS (1940) earthquake, as the base ground motion in Fig. 9.

3.3 Results

The maximum reaction forces of the component supports in each case are compared in Table 1. The sets of time histories for the support force and the relative displacement between SG and building are shown in Fig. 12 through Fig. 17.

Comparing these results, the following items are observed:

- Case 2 and Case 3 appear to have nearly equal responses for the maximum displacement of the SG, while the SG support forces are different. The support forces are decreased by the effect of the L.E.D. in Case 2.
- The results in Case 1 show large responses such as the maximum SG displacement, reaction force of SG column supports, and piping stress compared to the responses of Case 3.
- The stress in the SG inlet elbow are lower than the limiting stress in all cases, shown in Table 2.
- In the displacement history responses of Case 1 and 2, some drift appears during the earthquake. However, at the end of the earthquake motion, this drift has disappeared.

4. CONCLUSION

(1) The adequacy of applying the L.E.D. as the SG seismic support instead of the current snubber, is demonstrated.
The simple two point support system for a SG will be realized by the use of an L.E.D., and the seismic support loads are reduced by the energy absorbing effects.

(2) For the seismic design which uses the L.E.D., a mechanism which can amplify the L.E.D. displacement such as the link-mechanism, is found to be more effective for the energy absorbing device.

(3) To apply the L.E.D. as the SG support of an actual PWR plant, further research will be expected as follows.
- The further reduction of the L.E.D. drag force at the low velocities.
- Unit verification test of the large capacity L.E.D. (1 MN).
- The system vibration test using a scaled RCS model.

These research items are planned to be investigated in the extended research program as the co-operative study with the electric power company groups, started in 1991.

REFERENCES

T. Nomura, N. Kojima, et al., "Study on Lead Extrusion Damper as a Seismic Support", 10th SMiRT Vol.K2, pp.733-737, 1989.

E. Kokubo, M. Tabuchi, "Practical Application of Soil-Building and Reactor Coolant Loop Coupled Seismic Analysis", 10th SMiRT Vol.K1, pp.391-396, 1989.

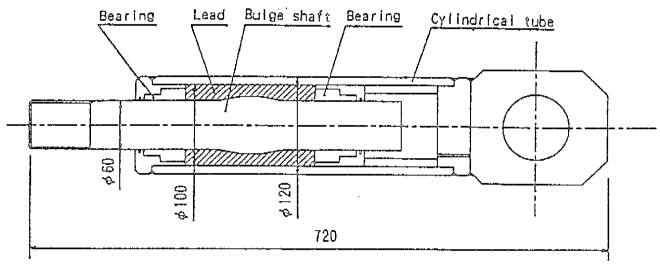

Fig.1 Cylinder type L.E.D.

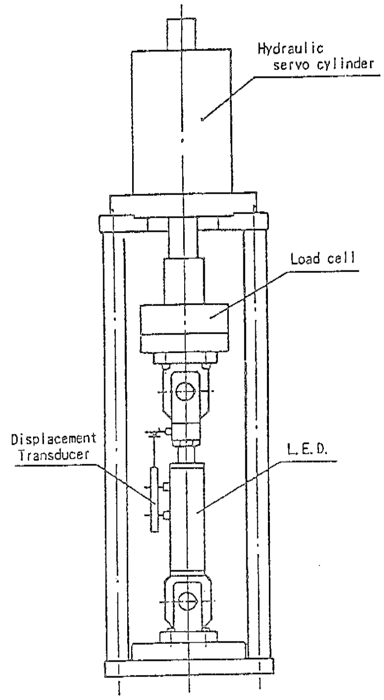

Fig.2 Test facility

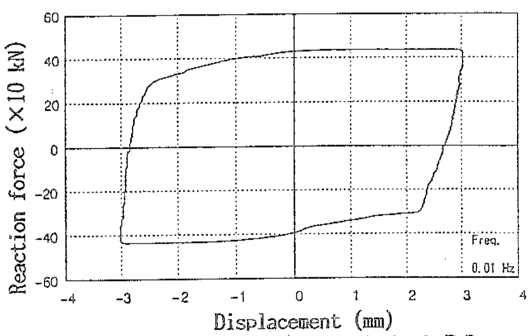

Fig.3 Hysteresis loop of the L.E.D.

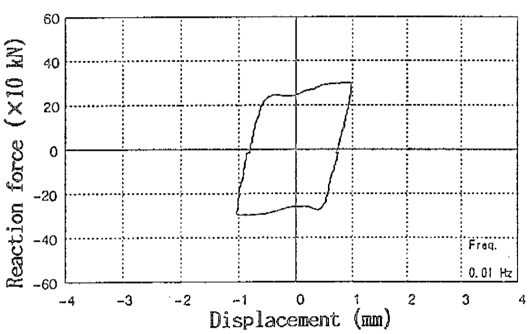

Fig.4 Hysteresis loop of the L.E.D.

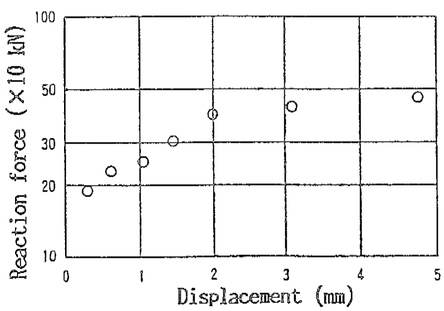

Fig.5 Relationship between reaction force and displacement

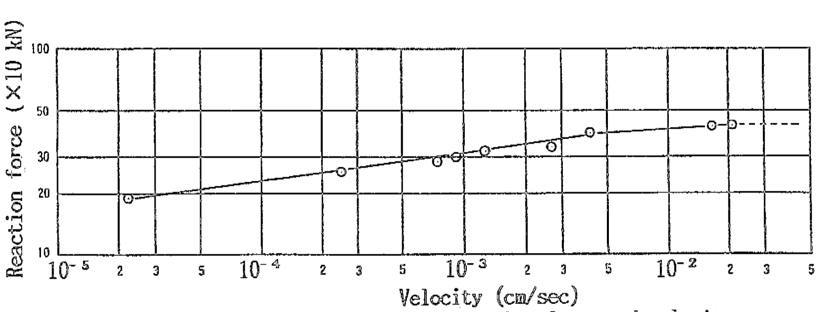

Fig.6 Relationship between reaction force and velocity

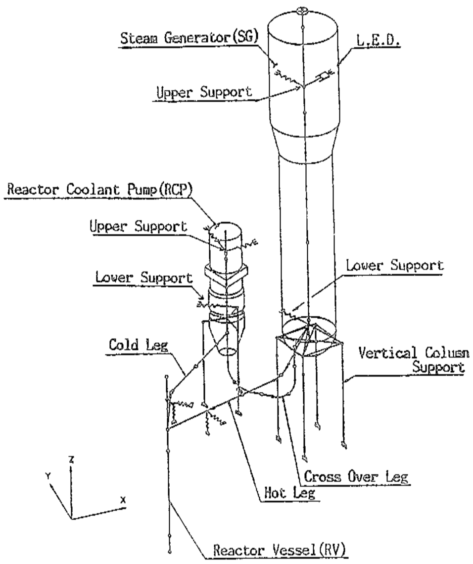

Fig.7 Analysis model
(Trial design with L.E.D.)

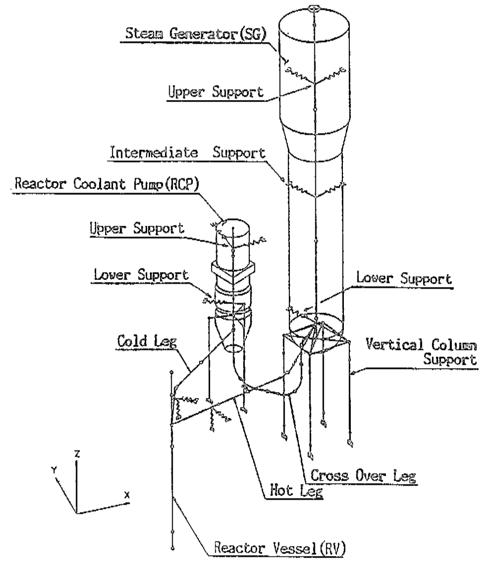

Fig.8 Analysis model
(Current design with Snubber)

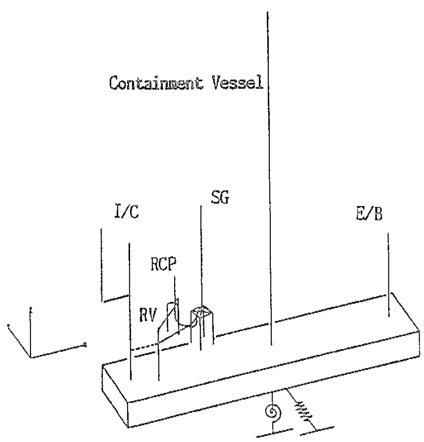

Fig.9 Whole analysis model
(Coupled soil-building-RCS model)

$\alpha = L_2 / L_1 = d_2 / d_1$

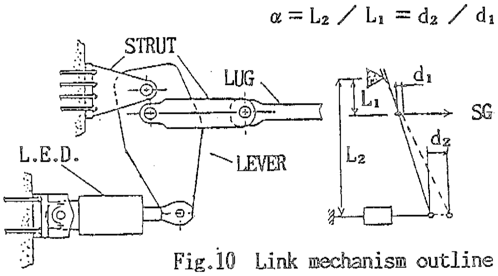

Fig.10 Link mechanism outline

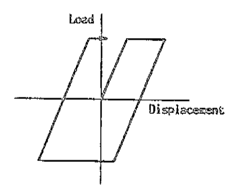

Fig.11 Load-displacement relationship
(Bi-linear)

Table 1 Reaction force of component supports (unit: kN)

	Support		Case 1	Case 2	Case 3
SG	Upper Support	Fx	(2000)	(2000)	5091
		Fy	2160	2433	1788
	Intermediate Support	Fx			4815
		Fy			2490
	Lower Support	Fy	1387	1645	671
	Vertical Column Support	1	1716	701	743
		2	2844	841	680
		3	2176	923	926
		4	2406	592	507
RCP	Upper Support	Fx	202	220	205
		Fy	76	88	50
	Lower Support	Fx	563	581	526
	Vertical Column Support	1	251	232	296
		2	100	108	124
		3	282	271	345

Table 2 Primary stress of SG inlet elbow (unit: MPa)

	Case 1	Case 2	Case 3
Primary Stress	124.3	77.5	70.3
Allowable Stress	357 (3Sm)	⇐	⇐

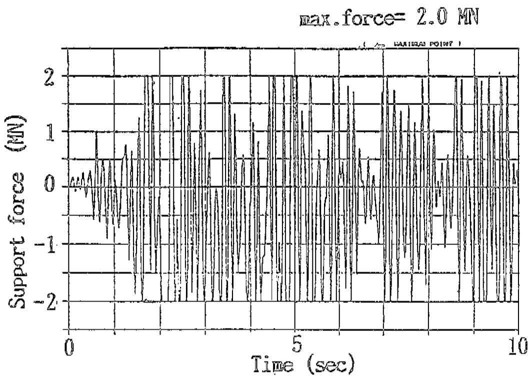

Fig.12 Case 1 Support force time history

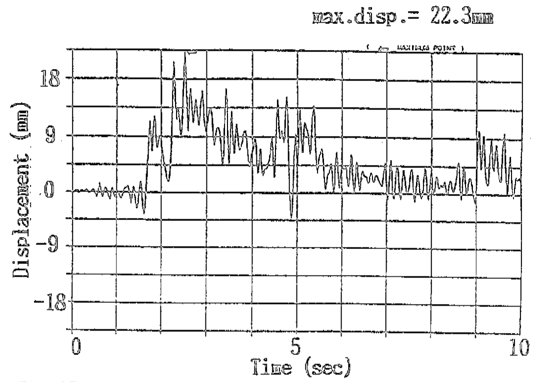

Fig.13 Case 1 Support displacement time history

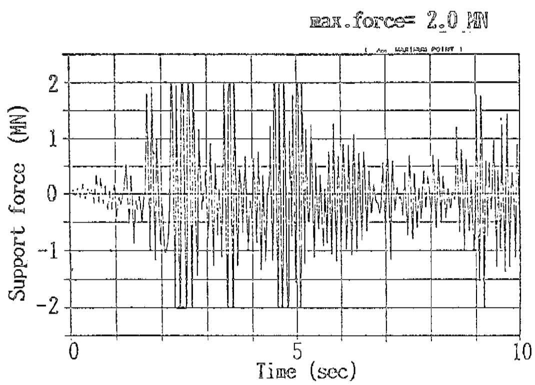

Fig.14 Case 2 Support force time history

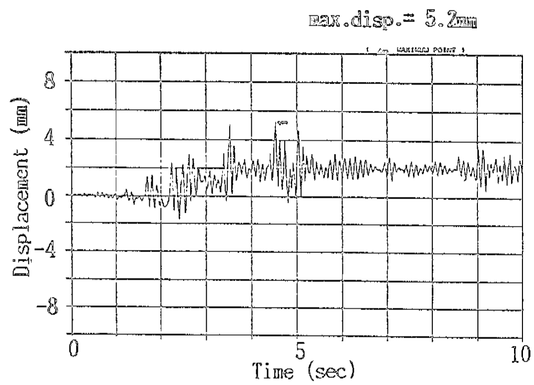

Fig.15 Case 2 Support displacement time history

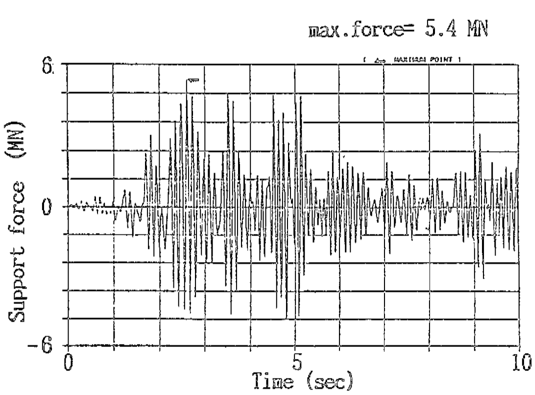

Fig.16 Case 3 Support force time history

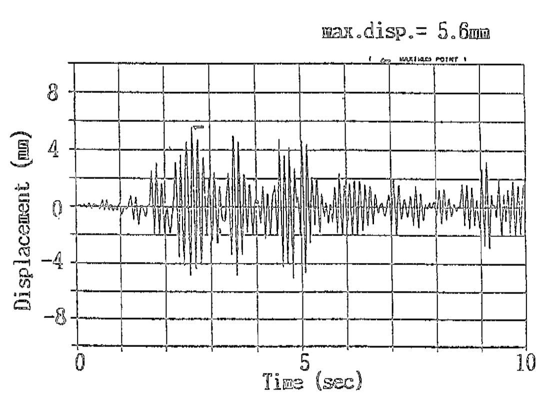

Fig.17 Case 3 Support displacement time history