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# DAMPERS FOR HEAVY COMPONENTS IN PWR NUCLEAR POWER PLANTS

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## ABSTRACT

At present, the components in the primary loops of PWR plants are designed to behave in a very rigid manner during an earthquake. Large rigid supports and many snubbers are employed as seismic supports. Recently, many types of the alternative support have been proposed including the lead extrusion damper (LED). In this study, an analytical method was developed to obtain the response of the steam generator supported by the large capacity LEDs. We also confirmed the applicability of the large capacity LEDs to the heavy components in the primary loops of PWR plants. This paper describes the experiments and analysis of the large scale LEDs to be applied to the heavy components in the primary loops of PWR plants.

## KEY WORDS

Damper; Time history response analysis; LED; Nuclear Power Plant.

## INTRODUCTION

Recently, in the field of seismic design of buildings, the technologies of the vibration control and the seismic isolation has been at the stage of practical usage and these new devices have been already installed in many buildings. For the seismic design of mechanical components in the nuclear power plants, the applications of these technologies have been also studied such as seismic isolations of FBR and vibration control of general piping systems (Fujita et al., 1987, Fujita et al., 1988, Fujita et al., 1991, Kokubo et al., 1992).

At present, to the heavy components that compose the primary loops of PWR plants, many large-scaled seismic supports are installed. There are high possibilities to enhance the reliability and maintenance-ability of the supports if seismic dampers for heavy components are developed based on the new concept. This adoption of new type supports will lead improvement of the exiting plants and rationalization of the future plants. We, therefore, study feasibility to apply lead extrusion dampers (LEDs) to the steam generator. LEDs are generally considered to have good ability to dissipate vibration energy.

In this paper, we describe the characteristics of the large capacity LED and the analytical method to simulate the behavior of the heavy components with LED under seismic excitation.

## COMPONENT TEST

### Characteristics of Lead Extrusion Dampers (LEDs)

LEDs have been developed as seismic dampers to apply mainly to bridges and buildings. Figure 1 shows the typical structure of LEDs. When the relative displacement is taken place between the rod and the outer tube,

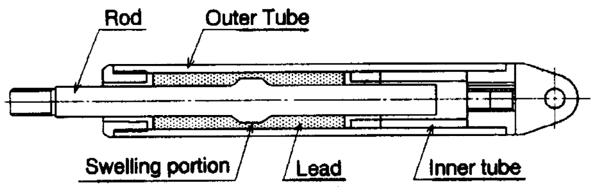


Fig. 1. Structure of lead extrusion damper

the lead enclosed inside the tube is extruded at the swelled portion of the rod and the resistance force is generated. The plastic flow of the lead creates a large effect of energy dissipation. The characteristics of LEDs are: (1) large hysteresis loop to dissipate vibration energy efficiently, (2) simple structure and easy maintenance, (3) high durability and small quality change for a long period, and (4) relative easiness to construct large capacity dampers.

## Outline of Test

As a component test, we conducted energy dissipation test and resistance test at low excitation velocity in order to confirm the performance of LED. Here, the results of energy dissipation test are reported.

The capacity of the test specimen was decided to be 180 tf taking into account the various constraints.

The specimen is directly excited in a sinusoidal way by employing electro-hydraulic actuator. Table 1 shows the test cases conducted. The universal joints were employed at the connection between damper and actuator and one between damper and reaction support to ensure that the LED receives only axial force. The resistance force and temperature of the LED and displacements at various places are measured under excitation.

Table 1. Component test condition

| Displacement (mm) | Frequency (Hz) | | | | |
|---|---|---|---|---|---|
| | 1 | 3 | 6 | 9 | 12 |
| ±5 | ○ | ○ | ○ | ○ | ○ |
| ±8 | ○ | ○ | ○ | ○ | |
| ±10 | ○ | ○ | ○ | | |
| ±13 | ○ | ○ | | | |
| ±18 | ○ | ○ | | | |

## Test Results

Figure 2 shows the time histories of resistance forces and displacements of the LED. This figure indicates that the maximum of resistance forces are not constant during excitation. The relation between the number of vibration wave and the temperature increment at the swelled portion of the rod was obtained. This relation showed that the temperature increases along with the increment of the number of vibration wave. The relation between the temperature and the resistance force was also obtained. This relation demonstrated that the resistance force apparently decreases following the temperature increment.

Figure 3 shows a typical example of the hysteresis loop concerning the displacement and the resistance force of the LED used in the test. This figure indicates that the LED posses the typical bi-linear behavior in the displacement - resistance force relation. The resistance force stays constant and only the displacement increases when the damper enters the plastic domain. This figure also shows that hysteresis loop remains the shape of parallelogram even though the resistance force decreased along with the increment of number of vibration waves. This demonstrates that the LED can keep an excellent ability of energy dissipation in spite of the decrement of the resistance force during excitation.

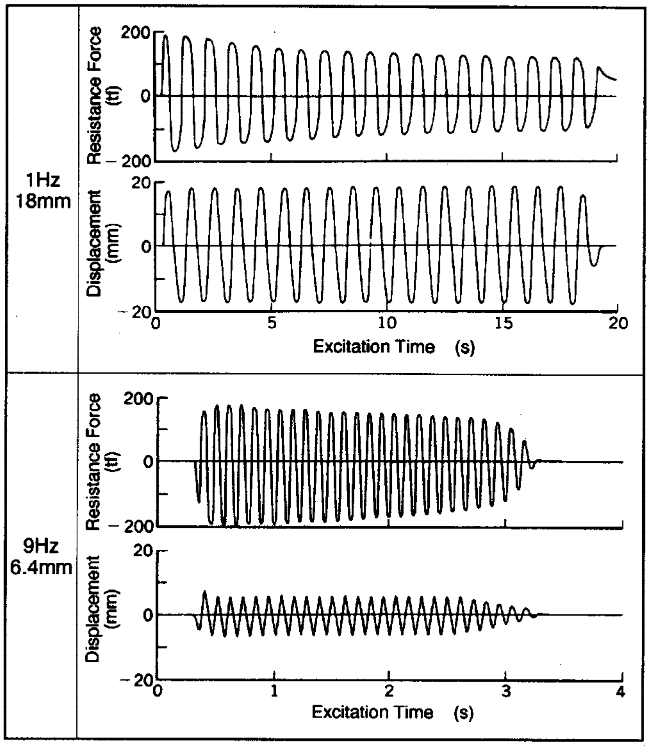


Fig. 2. Time histories of LED's resistance force and displacement

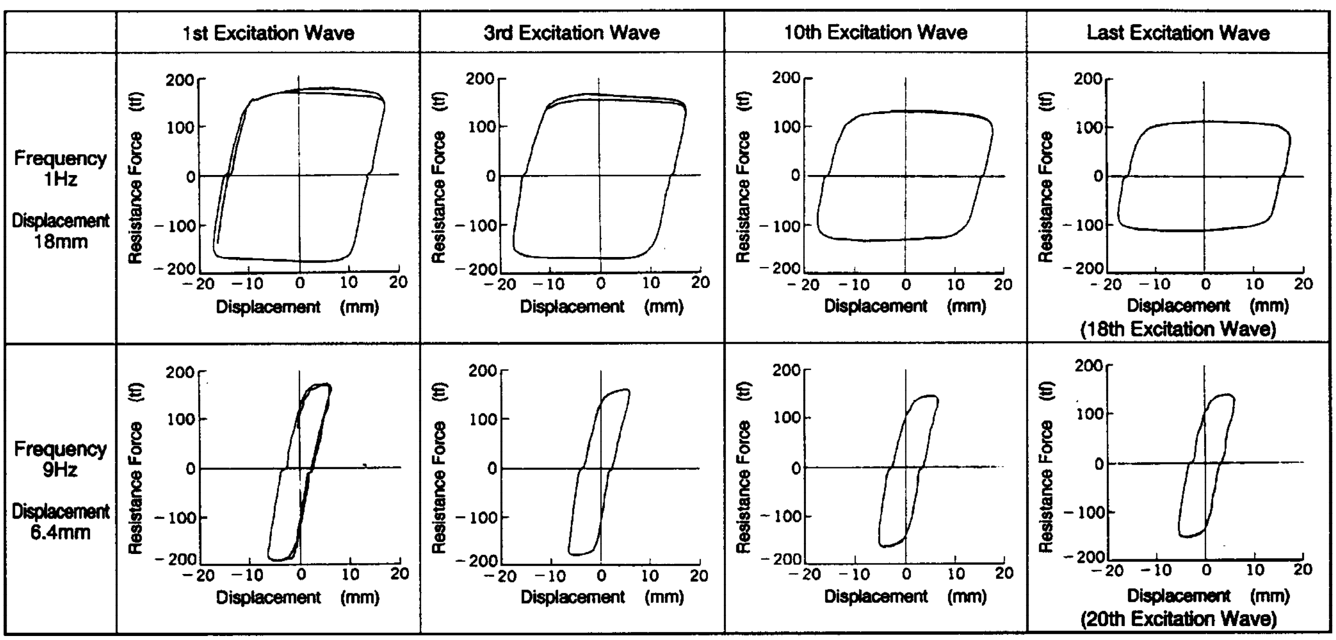


Fig. 3. Hysteresis loop of LED's displacement and resistance force

The dissipated energy can be obtained from the hysteresis loop of the displacement and resistance force by computing the area inside of the hysteresis loop. The relation of the excitation displacement and dissipated energy was obtained. This relation showed that the dissipated energy increases almost proportional to the excitation displacement and their relation does not depend on the excitation frequency.

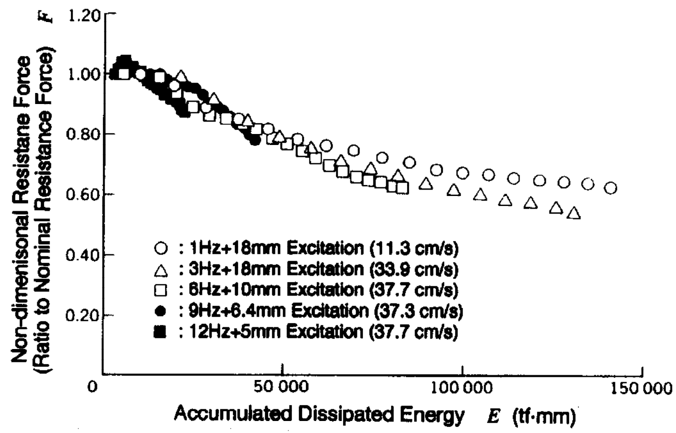


Fig. 4. Relation between accumulated dissipated energy and resistance force

## Estimation Method of Resistance Force

Since the resistance force of the LED varies during excitation, as Figure 2 shows, it is necessary to predict the resistance force during excitation to simulate the behavior of the vibration system with the LED. The change of resistance force is caused by the temperature increment and this temperature increment is supposed to be generated by the vibration energy dissipated by the LED.

Here, we examine the relation between the accumulated dissipated energy and the resistance force. Figure 4 shows that the resistance force decreases along with the increment of the accumulated dissipated energy and the rate of decrease is not constant. The decrease rate is larger when the excitation velocity is higher. This is because the resistance force of the LED is strongly influenced by the temperature around the swelled portion of the rod. When the excitation velocity is low, (1) the amount of the dissipated energy per unit time is small, (2) the heat around the swelled port of the rot can escape to the circumference before the next energy, generated by the movement of the rod, enter the LED and (3) the temperature increment can be small. On the other hand, when the excitation velocity is high, before the heat of the swelled portion escape to the circumference, new energy injected into the lead and the temperature increment becomes large.

From the relation between the accumulated dissipated energy and the resistance force obtained under various excitation conditions, we found that the resistance forces and the accumulated dissipated energies have a linear relation when they are plotted on the semi-logarithmic graph. Namely, the relation of the non-dimensional resistance force $F$ (ratio of the resistance force to the nominal resistance force) to the accumulated dissipated energy $E$ can be formulated as

$$F = a \times 10^{-b \times E} \tag{1}$$

where, Coefficients a and $b$ have different values depending on the excitation conditions (excitation velocity). Figure 5 is obtained by grouping the coefficient $a$ based on the energy dissipation velocity (dissipated energy per unit time).

As shown in Figure 5, the relation between Coefficient a and the energy dissipation velocity is linear when the relation is plotted on the semi-logarithmic graph. Similarly, Coefficient $b$ and energy dissipation velocity also have a linear relation on the semi-logarithmic graph. By taking the mean of the coefficients, we can obtains the relation between Coefficients $a$ and $b$ and energy dissipation velocity $V_E$ as follows.

$$\left.\begin{aligned} a &= 0.9062 \times 10^{3.600 \times 10^{-6} V_E} \\ b &= 1.436 \times 10^{1.410 \times 10^{-5} V_E} \end{aligned}\right\} \tag{2}$$

By employing Equations (1) and (2), the resistance force at a certain time can be obtained as a function of the accumulated dissipated energy $E$ at the time and the overall energy dissipation velocity $V_E$.

When the energy dissipation velocity $V_E$ is larger, Coefficient $b$ becomes remarkably greater than Coefficient $a$. The greater energy dissipation velocity yields the smaller resisting force than the smaller velocity even if the amount of the accumulated dissipated energy is equal.

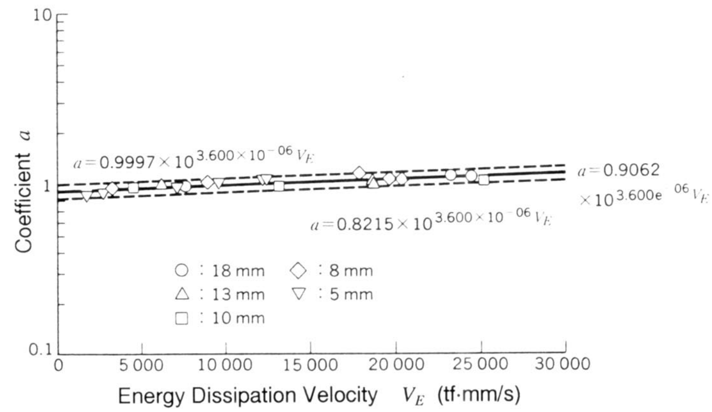


Fig. 5. Relation between energy dissipation velocity $V_E$ and Coefficient $a$

In this way, the change of the resistance force of the LED can be neatly formulated by the parameters of the accumulated dissipated energy and the overall energy dissipation velocity. This formulation plays a very important role in the analysis as discussed later.

## MODEL VIBRATION TEST

### Outline of Test

There are two purpose to conduct the vibration test employing the model. One is to confirm the damping effect of LEDs attached to steam generators under $S_2$ Earthquake (ultimate design earthquake). The other purpose is to investigate the validity of the analysis method. In this test, we used the model that imitated the dynamic characteristics of steam generators attached by LEDs. The model test was conducted on the shaking table at Takasago Research & Development Center of Mitsubishi Heavy Industries, Ltd.

Figure 6 shows the test apparatus of the model test. The model was composed of a steel pipe that imitates a steam generator and a 5 tf small-sized LED attaching to the pipe. The coolant pipes of the primary loop and supporting legs of the steam generator were replaced with coil springs that simulate the their stiffness. The length of the pipe was determined in such a way that the ratio of an actual steam generator to the model is 5. For the frequency and displacement, the ratio to the actual one was set to 1:1.

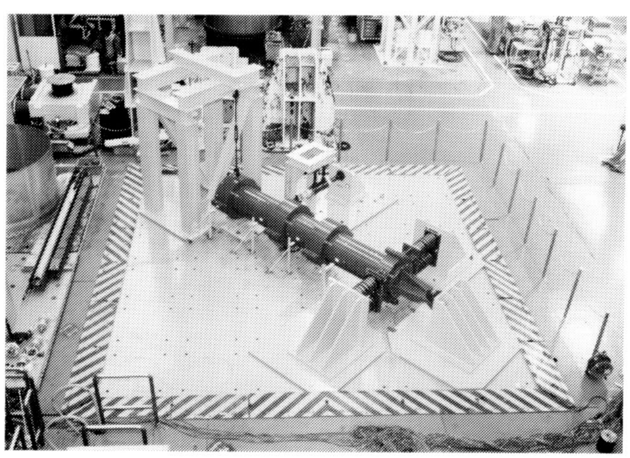

Fig. 6. Test specimen fot model test

As an excitation wave, we used the floor response at the support of the steam generator under an equivalent $S_2$ earthquake.

The test results and analytical results have a quite good agreement as shown in Figure 7 and the validity of the newly-developed analytical method is confirmed. We, however, can see the slight differences in the time history of the displacement. This is because the energy is dissipated even in the small displacements at model test and no energy dissipation is assumed in the small displacements for the analysis.

## CONCLUSIONS

In this study, we studied feasibility to apply LED to steam generators in PWR plants as a way to rationalize the support structures of steam generators.

Component test was conducted employing the 180 tf LED and it was confirmed that the LED was high energy dissipation capability. Model test was conducted by 1:5 scaled model of a steam generator with 5 tf LED. In this test, it was revealed that LED was sufficient damping effect for the steam generators under $S_2$ earthquake.

The resistance force of LED is not constant during excitation. From the result of the component test, it was derived that the resistance force can be predicted by the overall energy dissipation velocity and the accumulated dissipated energy. Based on this derivation, a time history response analysis method was newly developed to consider the resistance force change. By comparing the analytical results to the model test results, the validity of the analytical method was confirmed.

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