Study on a Rotary Type Lead Extrusion Damper as a High Damping Support for Nuclear Piping Systems

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ABSTRACT

This paper aims to study an applicability of Lead Extrusion Damper (L.E.D.) for nuclear piping systems. In the study, the dynamic response characteristics of a piping model with L.E.D. are investigated experimentally and analytically.

The test results show that L.E.D. has large damping effects. Comparison analytical results with experimental results show good agreement.

INTRODUCTION

At present, seismic design for nuclear power piping systems is conducted under the rigid design philosophy by using mechanical snubbers or hydraulic snubbers as supports. However, initial and maintenance cost of such devices are high. Recently, several devices have been developed which can absorb the piping vibration energy, and are not expensive and have high reliability. The Lead Extrusion Damper (L.E.D.) is one of the alternative supports.

In this study, an applicability of Lead Extrusion Damper developed for piping systems in nuclear power plants are investigated experimentally and analytically. In the experiment, in order to grasp the dynamic characteristics of L.E.D., a piping system model supported by L.E.D. was shaked by a 3-dimensional large scale earthquake simulator. In the analytical study, the test results were compared with the results obtained by nonlinear time history analysis in which damping characteristics of L.E.D. were mathematically modeled as Ramberg-Osgood model.

From the study, it was confirmed that L.E.D. shows significantly larger damping effects for piping systems compared to the conventional supports such as snubbers.

MECHANISM OF L.E.D.

L.E.D. can absorb vibration energy by plastic deformation of lead which has the characteristics of super plasticity. Any deformation of lead at or above room temperature is in fact "hot work" in which the processes of recovery, recrystallization and grain growth are occurring simultaneously. Furthermore, lead does not have metal fatigue property.

There are two types of L.E.D.. One is a cylinder type which was originally developed as an energy absorbing device in New Zealand [1]. The other is a rotary type shown in Fig. 1 which was originally developed by the authors [2]. It consists of a housing, a rotational shaft with bulges and lead filling the space between them. As the shaft rotates relative to the housing, the lead must extrude through the path formed by the bulge and the housing. The relative movement of the housing and the

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lead is ristricted by the key.

VIBRATION TEST

To grasp the fundamental damping characteristics of the energy absorbing device, 1-span piping model supported by L.E.D. was tested on a large scale shaking table.

Fig. 2 shows the schematic drawing of the model. The size of the piping model is 3 inch schedule 40 with 4 meters length and the material is carbon steel. An additional mass of 200 kg is attached at the top end of the piping to adjust the fundamental frequency of the piping. A 500 kgf capacity of L.E.D. was installed at 3 m away from the fixed end.

In the shaking test, the piping model with L.E.D. was excited by sinusoidal waves to estimate fundamental modal response properties. Acceleration and displacement responses of piping, damper reaction forces, piping stresses, and input accelerations of the shaking table were measured.

TEST RESULTS

At first, predominent frequency and damping ratio of the piping without L.E.D. were measured as 1.3 Hz of frequency and 0.08 % of critical damping. The vibration mode is shown in Fig. 5. Comparisons between the test and analysis results are introduced in the next section.

The characteristics of frequency response functions of piping model with L.E.D. by using the sinusoidal wave are shown in Fig. 3 for five different input excitation levels. The figure shows that the predominant frequency of the piping is approximately 5.4 Hz at the maximum excitation level of 400 gal and the transfer functions of the piping decrease for the increasing excitation levels. Fig. 4 shows the relationship between the damping ratio and the input acceleration level. The result shows a tendency that the damping increases with the input acceleration levels and the damping value of the system is approximately 12 % of critical damping at maximum level. The results show that L.E.D. has a significantly larger damping effect compared with the conventional supports such as snubbers.

A seismic test was performed to investigate the vibration characteristics of the piping system under earthquake conditions. Fig. 6 shows the response spectrum characteristics of the input waves. The typical example of response time histories of the model are shown in Fig. 7. Fig. 8 shows the hysteresis loops of the damper. This figure shows that L.E.D. has effective energy absorber hysteresis characteristics for actual piping system. Fig. 9 shows the relationship between the excitation level (maximum excitation acceleration on the vibration table) and the typical responses of the piping and damper. The test results in Fig. 9 are compared with the analytical results in the next section.

ANALYTICAL SIMULATION

Analysis of the piping model was carried out by solving the nonlinear equation of motion directly. Fig. 10 shows the analysis model. The hysteretic characteristics of L.E.D. were represented by Ramberg-Osgood model as follows:

$$\frac{\delta}{\delta_y} = \frac{Q}{Q_y} \left\{ 1 + \alpha \left[\frac{Q}{Q_y} \right]^{n-1} \right\} \quad \cdots\cdots \quad (1)$$

Where δ : damper displacement (mm)
Q: damper force (kgf)
$\delta_y = 0.5$ (mm)
$Q_y = 350$ (kgf)
$n = 7$
$\alpha = 0.019$

Natural frequencies and mode shapes were compared to the test data as shown in Fig. 5. For the A-wave as shown at the bottom of Fig. 7 and maximum acceleration level of 500 gal, the analytical results of acceleration of the piping top end, displacement of the piping at the damper point and a reaction force of the damper were compared to the test data as shown in Fig. 7. The analytical results show good agreement with the test results. Input was A-wave shown in Fig. 7 and the maximum acceleration level was 500 gal. The hysteresis loops of the damper are compared to the test result in Fig. 8 for B-wave. Comparisons of the test and analysis results of acceleration at the piping top end, displacement of the piping at the damper point, reaction force of the damper and pipe stress at the fixed end are shown in Fig. 9. The analytical results show a good agreement with the test data. From the comparisons, it was confirmed that nonlinear time history analysis can simulate a behavior of piping system with L.E.D. by using Ramberg-Osgood model.

CONCLUSIONS

From the study, the followings were obtained.

(1) L.E.D. shows a significantly larger damping effect compared to the conventional supports such as snubbers.
(2) Nonlinear time history analysis by using Ramberg-Osgood damper model is effective to simulate a behavior of piping system supported by L.E.D. damper. And a simulation method for piping system with L.E.D. was established.
(3) From experimental and analytical approach, an applicability of L.E.D. to nuclear power piping systems was confirmed.

ACKNOWLEDGMENTS

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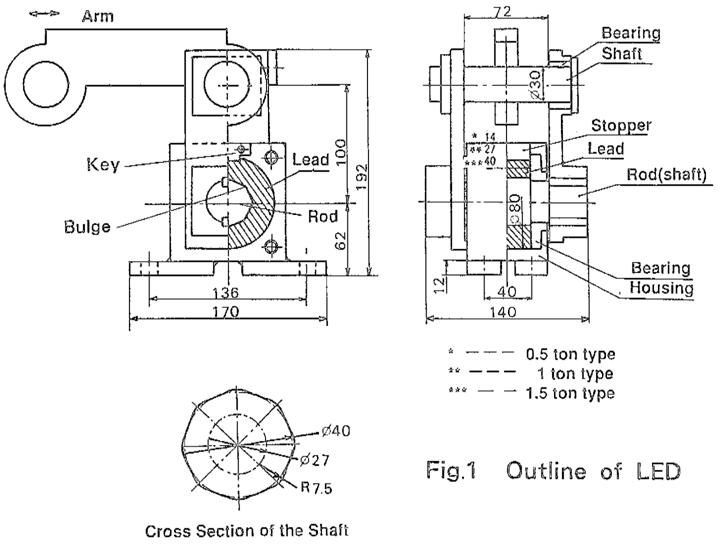
[2] Fujita, K., et al (1989). Study on Lead Extrusion Damper as a Seismic Support. Trans. 10th SMiRT, Anaheim, Volume K2, pp. 733 ~ 737.



Cross Section of the Shaft

Fig.1 Outline of LED

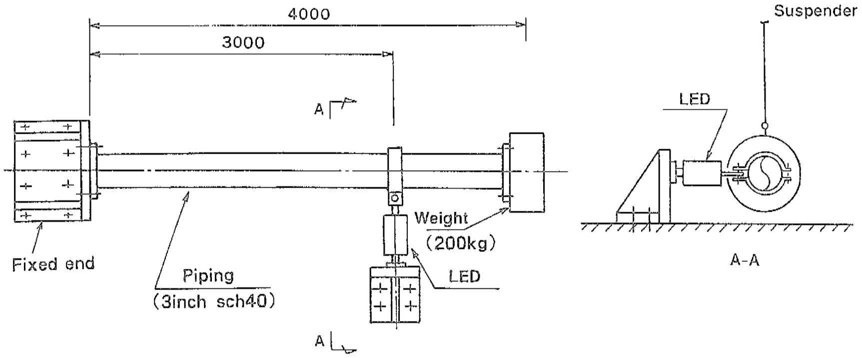


Fig.2 Test apparatus for 1 span piping model

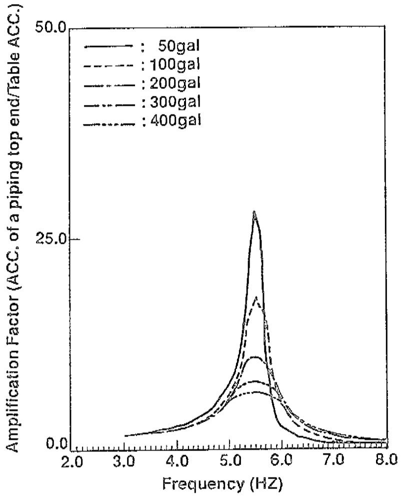


Fig.3 Vibration transfer function for various input accelerations

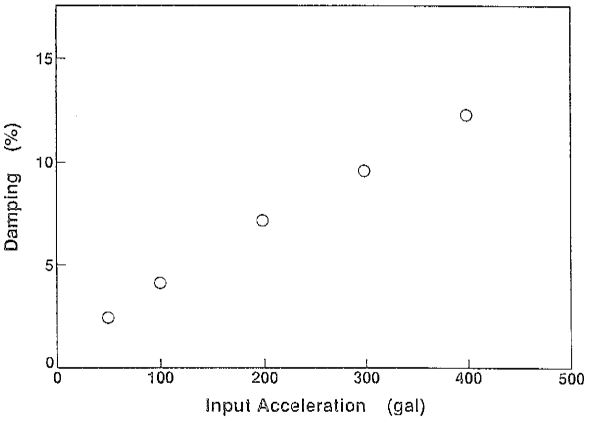
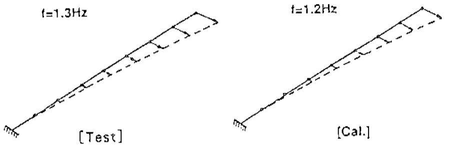
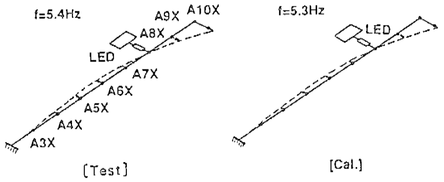


Fig.4 Damping vs. Input Acceleration



(a) No damper



(b) With damper

Fig.5 Compraison of vibration modes between test and analysis

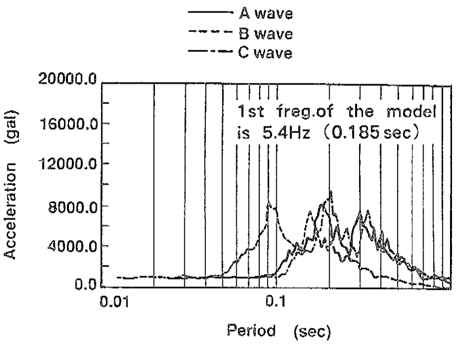


Fig.6 Response Spectra of Input Waves

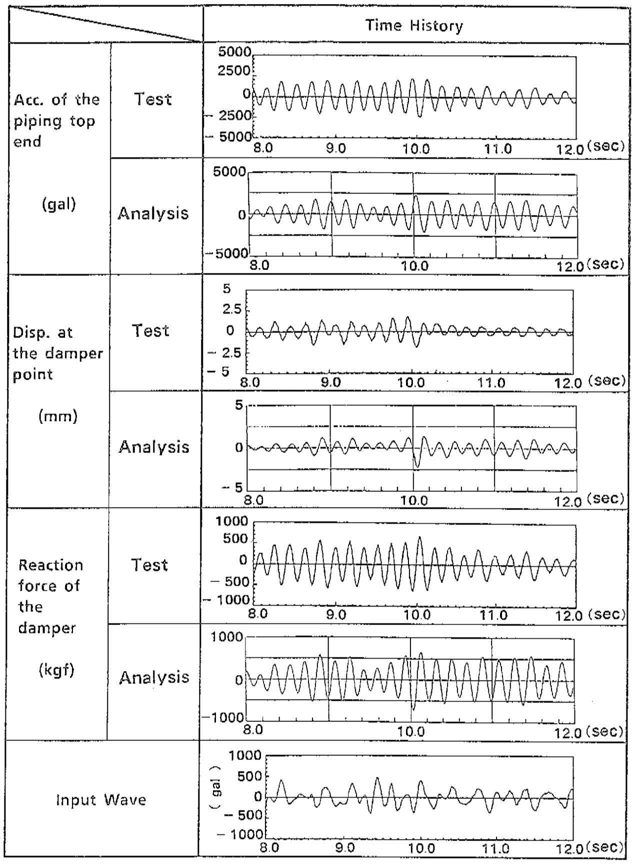
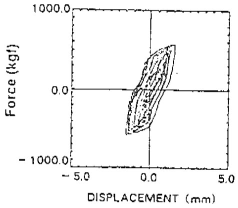
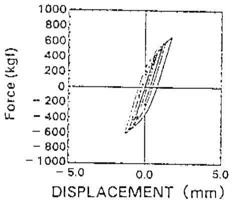


Fig.7 Compraison of response time history between test and analysis

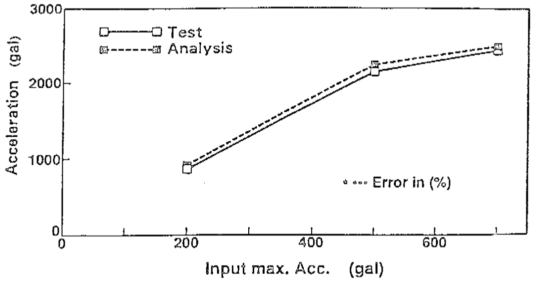


(A) Test

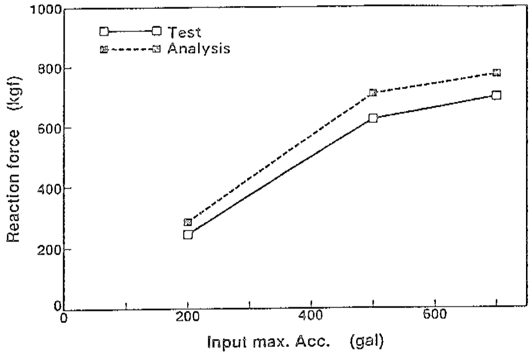


(B) Simulation

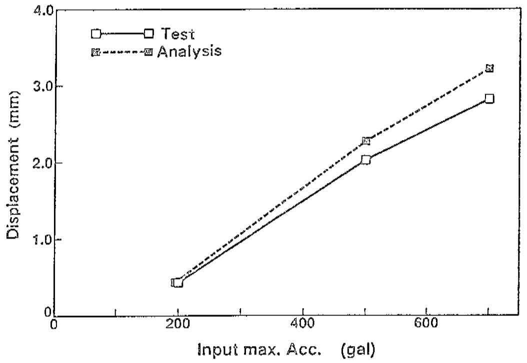
Fig.8 Typical hysteresis loops of LED (Wave B,Input max.acc = 500gal)



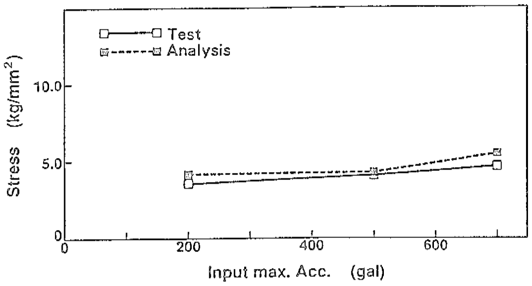
(a) Acceleration at the piping top end



(c) Reaction force of the damper

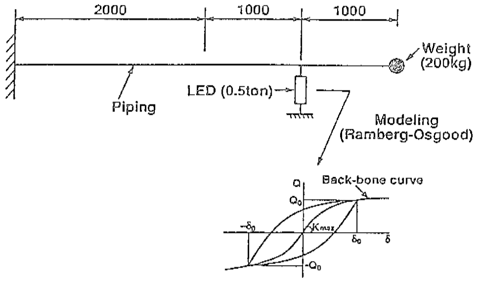


(b) Displacement at the damper point



(d) Stress of the piping

Fig.9 Analytical results for the relationship between input Acc. and response values



$$\frac{\delta}{\delta_y}=\frac{Q}{Q_y}\{1+\alpha[\frac{Q}{Q_y}]^{n-1}\}$$

Q_y =350 (kgf)
δ_y =0.5 (mm)
n =7
α =0.019

Dimension		3inch, sch40
Sectional Area	(cm^2)	14.45
Second moment of area I	(cm^4)	126.7
Young's Modulus	(kgf/cm^2)	1.96×10^6
Weight per unit volum	(kgf/cm^3)	7.8×10^{-3}

Fig.10 Analytical model