An Experimental Study of an Energy Absorbing Restrainer for Piping Systems

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INTRODUCTION

Recently, in the seismic design methodology of the piping systems in nuclear power plants, new and improved design criteria and calculation techniques which will lead to more reliable and cost saving design products have been investigated (1). For instance, problems for reducing the snubbers in nuclear power plants which provide high costs for their inspections and maintenances and related flexible design problems for the dynamic piping systems have been investigated (2).

Thus, in order to replace snubbers, various types of alternative supporting devices such as dynamic absorbers (3), gapped support(4) and energy absorbing support devices (5) have been proposed. Particularly, a number of energy-absorbing restrainers have been designed in Japan and United-States by allowing yield to occur during strong earthquakes (5, 6). Advantages and disadvantages of these restrainers were examined analytically and experimentally.

This research was also started as a preliminary study for a piping supporting device which utilizes excellent energy absorbing behaviour of super plastic alloy materials. In the previous paper (7), it was experimentally evaluated that the maximum response of piping system could be significantly suppressed according to the yielding of SPZ (super plastic zinc) particularly in the high temperature condition. However, this yielding effect was not so conspicuous in the normal operation situation. And it was also recognized that the supporting stiffness of the SPZ energy-absorbing restrainer should decrease as temperature rises.

In order to overcome these disadvantages, we have introduced new absorbing material LSPZ (laminated super plastic zinc) in which SPZ is expected to have reliable ductility and also efficient energy absorbability still under the normal temperature condition. This paper is devoted to an experimental works for this updated absorbing restrainer. First, the nonlinear yielding behaviour of the LSPZ itself are discussed, then after applying the material as energy absorbing devices to pipings, dynamic response reduction in terms of the restrainer is evaluated.

COMPONENT TEST OF LSPZ RESTRAINER

The LSPZ energy-absorbing restrainer is composed of three layer laminated plates of a super plastic zinc (SPZ) plate sandwiched between two aluminum plates as shown in Fig.1. A SPZ plate is an alloy of aluminum (22 Wt%), copper (0.15 Wt%) and zinc(balance) (8). To provide efficient energy absorption, the restrainer is designed to have X-shaped profile such as the Bechtel-developed energy absorbing device (5). This restrainer is installed with one rigidly fixed end and the other end connected to the piping system as shown in Fig.2. Therefore, the dynamic energy absorption is realized mainly due to the bending deformation

under seismic condition.

In the component tests, the same size steel plate devices for common supporting material were also introduced for comparison with the LSPZ plate. Four kinds of restrainers tested in this study were as follows;

(1) Model #1 was the restrainer of a LSPZ plate and model #2 was that of a steel plate as shown in Fig. 3.

(2) Model #3 was the restrainer of two LSPZ plates and model #4 was that of LSPZ and steel plates as shown in Fig. 4.

In order to investigate the dynamic yielding characteristics of the restrainer itself, component tests were carried out by using a small shaker. One free end of the restrainer was excited by sinusoidal waves as shown in Figs.3 and 4. Both displacement response and reaction force were measured and then hysteresis curve showing the energy absorption was obtained. The equivalent damping ratio ζ_e can be evaluated from this hysteresis curve by the following equation(9).

$$\zeta_e = \Delta W / (2\pi W) \tag{1}$$

where ΔW is the dissipated energy due to plastic deformation of the restrainer and W is its strain energy per unit cycle. ΔW corresponds to the area of a hysteresis curve.

PIPNG MODEL SHAKING TEST WITH LSPZ RESTRAINER

In order to evaluate the capacity of energy absorption of the LSPZ restrainer for piping response or its damping effect, vibration tests using two types of simplified piping models with the LSPZ energy-absorbing restrainer were conducted on a shaking table. Figure 5 shows the schematic drawing of a straight brass piping model (a) and a three dimensional brass piping model (b) having 10 mm diameter which were used in the test. Each model was supported by the LSPZ energy-absorbing restrainer at the point where a fundamental mode of vibration should be expected to be dominant.

In shaking tests, the piping models with four kinds of restainers described above were excited by swept sinusoidal waves and pseudo-random waves in order to estimate fundamental modal response properties. Displacement and acceleration responses at the supporting point and the strain amplitude at the fixed point of piping model are mainly measured. Using the frequency response function of piping model obtained through the test, the equivalent damping ratios are estimated by a modal curve fitting technique which is utilized as structure identification method (10).

TEST RESULTS

Component Test Results

An example of hysteresis curvers obtained from sinusoidal shaking test for the LSPZ enegy-absorbing restrainer are shown in Fig.6. This is the results for the restrainer having two LSPZ plates (#3) obtained for three different input force levels. From this figure, it can be recognized that the dissipated energy due to the yielding of the LSPZ restrainer increases as the input force level increases. However, in two kinds of restrainers of a steel plate(#2) and LSPZ and steel plates(#4), the values of dissipated energy almost keep constant irrespective of the input force level.

After the calculation of the dissipated energy by use of hysteresis curve, the equivalent damping ratios ζ_e can be calculated by Eq.(1) as shown in Fig.7, taking the ampilitude of input force as abscissa. In this figure, the equivalent damping ratios for the restrainers of a steel plate(#2) and LSPZ and steel plates(#4) almost take a constant value irrespective of the amplitude of input force. On the other hand, it can be shown that dynamic energy absorbing behaviour of the LSPZ restrainer strongly depends on the amplitude of input force. In other words, the more input level increases, the higher value the equivalent damping ratio takes. Accordingly, by comparisons of the hysteresis curves and the equivalent damping ratios, the energy dissipation due to the

ductility of the LSPZ restrainer becomes about 8 times that due to common materials such as steel.

Piping Model Test Results

The gain characteristics of frequency response functions obtained from a piping model test using the pseudo-random wave are shown in Fig.8. This is for a straight piping model with the LSPZ restrainer(#1) and for three different input excitation levels. From this figure, it can be recognized that both the peak value of gain characteristic and the fundamental natural frequency of piping model decrease in accordance of the increase of the input level. This results show that the LSPZ restrainer has a softening-spring nonlinearity even under the normal operation situation. In this figure, the curves correspond to the results calculated by a modal curve fitting technique using these experimental values.

The equivalent damping ratios obtained from the curve fitting are shown in Figs.9 and 10, taking the root mean square value of input acceleration as abscissa. Figures 9 and 10 are the results for a straigh piping model and a three dimensional piping model, respectively. The equivalent damping ratios ζ_e in these figures almost correspond to those obtained from the component tests. As mentioned above, the value of damping ratio of piping model with the LSPZ restrainer becomes about 3~5 times that with common steel restrainer. This energy-absorbing effect can be also influenced by the input acceleration level; that is the response power level. And also, it has been made clear that the equivalent damping ratio of piping model with the restrainer of LSPZ and steel plates(#4) becomes larger with the input level. This results are not clearly recognized in the component test, but appear to be useful for practical application.

In order to investigate the response reduction effect due to the LSPZ restrainer, the acceleration amplification factors of piping models are calculated as shown in Figs.11 and 12. It is obvious in these figures that the amplification factors for the LSPZ restrainer become smaller in accordance with increasing level. Consequently, the maximum response of piping models can be suppressed due to the energy absorbing effect of the LSPZ restrainer, especially in the case of high response level of piping model.

CONCLUSIONS

In order to develope the piping supporting restrainer using the LSPZ plate, the component test and shaking test with simple piping models are carried out. The results obtained herein are summarized as follows;

[1] The energy absorbing behaviour of the LSPZ restrianer can be recognized in the normal operation situation.

[2] The energy absorption due to the LSPZ restrainer becomes conspicuous compared with that due to the steel restrainer.

[3] The maximum response of piping models can be suppressed due to the energy absorbing effect of the LSPZ restrainer, particularly in the case of high response level of pipig system. This effect can be also obtained bythe LSPZ restainer including steel plate.

Finally, the authors wish to express their sincere gratitude to Professors, Dr. H. Nishimura and Dr. K. Manabe of Tokyo Metropolitan University for providing the LSPZ test plates and technical data.

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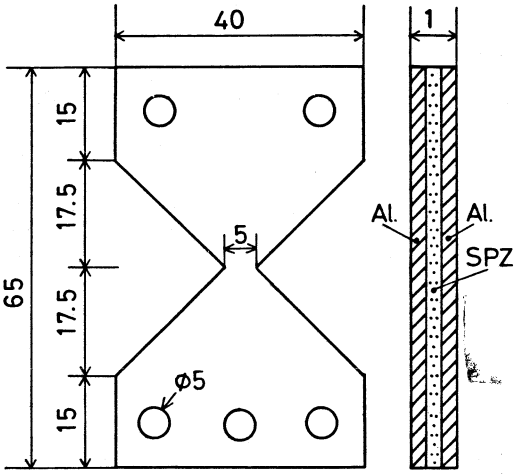

Fig. 1 X-shaped LSPZ plate

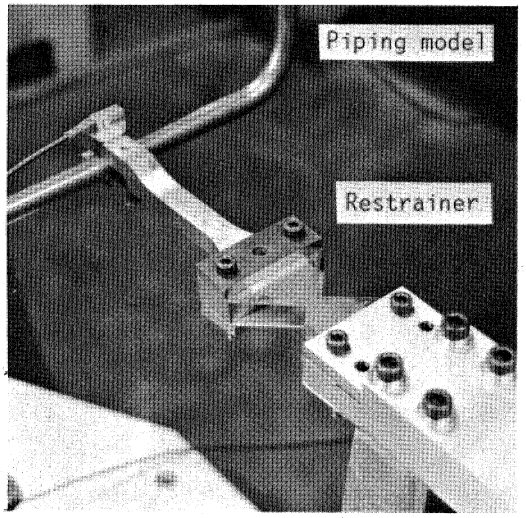

Fig. 2 Piping model with LSPZ restrainer

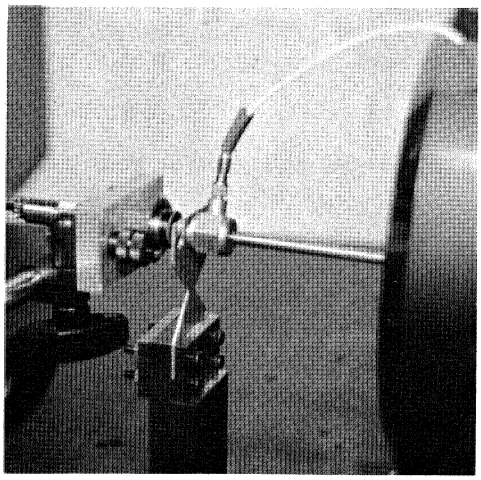

Fig. 3 Restrainer of one plate

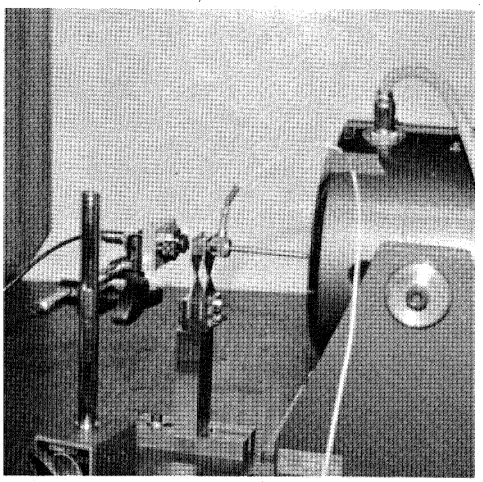

Fig. 4 Restrainer of two plates

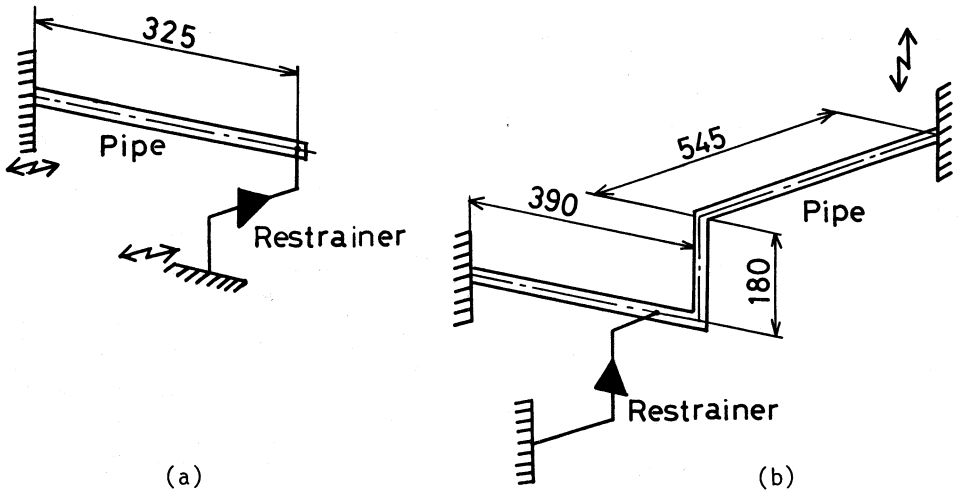

Fig. 5 Schematic drawing of piping models with restrainer

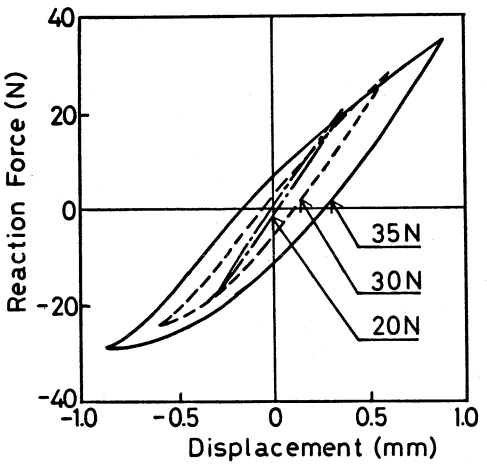

Fig. 6 Hysteresis curves for LSPZ restrainer

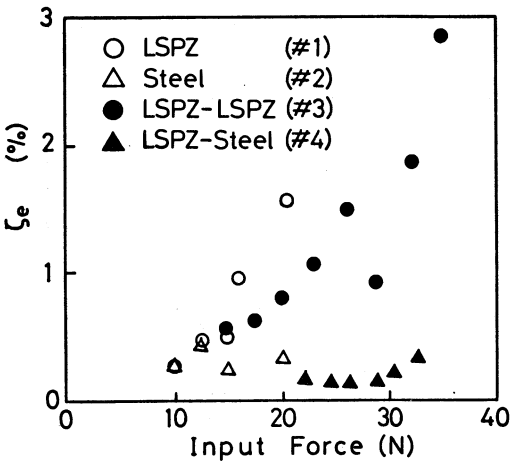

Fig. 7 Comparison of equivalent damping ratio (in component test)

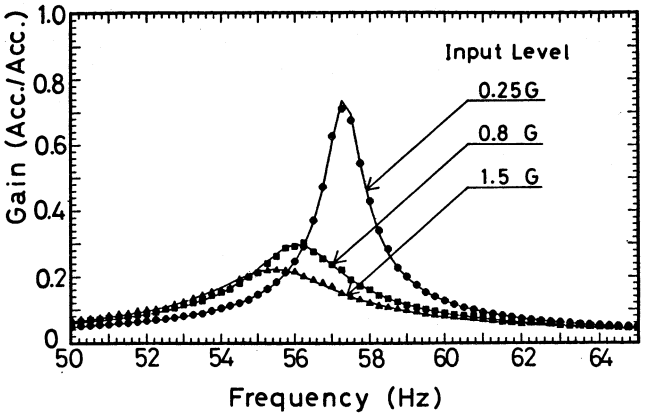

Fig. 8 Frequency response functions of straight piping model

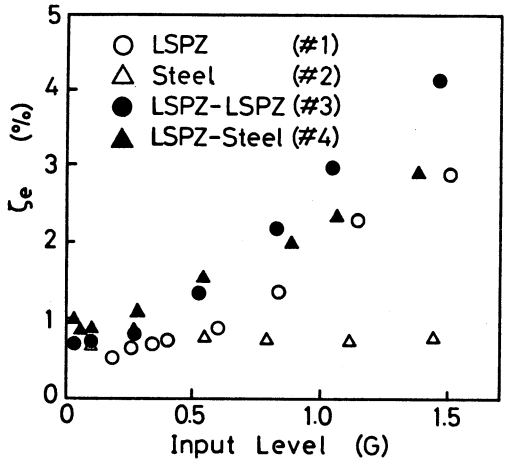

Fig. 9 Comparison of equivalent damping ratios (in the case of straight piping model)

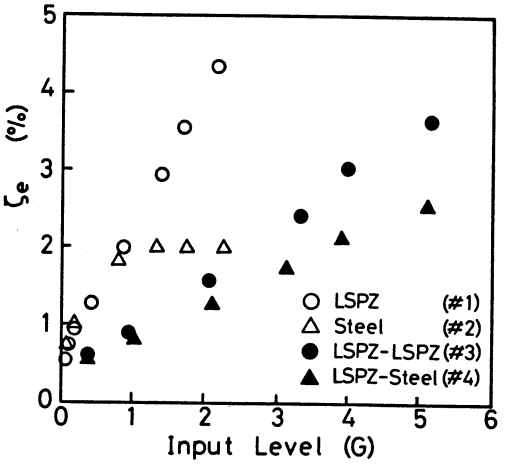

Fig. 10 Comparison of equivalent damping ratios (in the case of 3-D piping model)

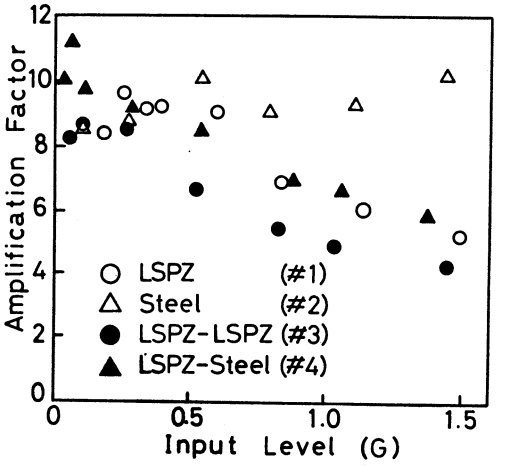

Fig. 11 Comparison of amplification factors (in the case of straight piping model)

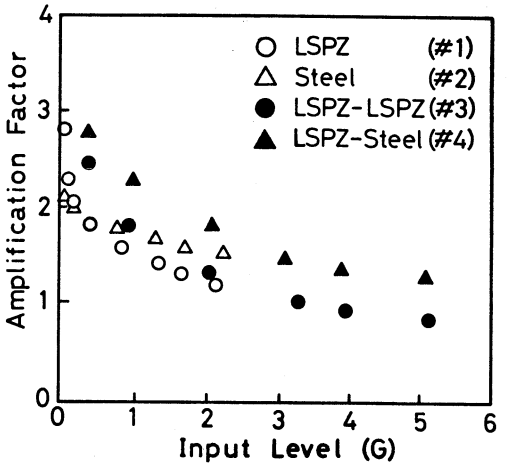

Fig. 12 Comparison of amplification factors (in the case of 3-D piping model)