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Vibration Control of Piping System in Nuclear Power Plant Using Elasto-plastic Steel Coil Spring Damper under Earthquake

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1. Introduction

It has been taken as a reasonable way that a vibration control system is used to actively absorb the seismic energy to obtain the damping effects against the seismic motion of beyond design basis earthquake (BDBE).

The actual damping value of the piping system including the support structure increases as the level of input motion increases [1]. Nakamura [2] studied on the seismic safety capacity of a piping system with pipe supports based on the shake table test.

This study developed an elasto-plastic steel coil damper (SCD) to control the vibration response of the piping system under huge earthquakes. The design equations of SCD are introduced in this paper. The actual margin of the piping system with SCD under the severe accident was evaluated through the seismic analysis. Based on the study results, this paper discusses on seismic safety and function maintenance margin of actual piping system against BDBE event.

2. Steel Coil Damper

Figure 1 shows the general shape and dimension of a coil spring. When the spring is compressed by the external force, P, a torsional force, T is developed inside the spring as shown in Figure 2.

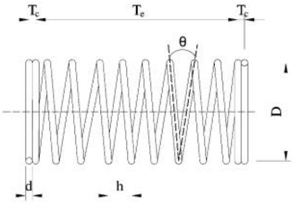

Figure 1. Dimension of Steel Coil Damper

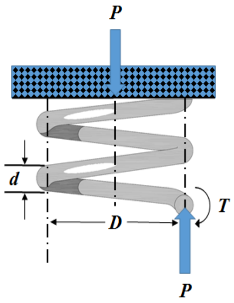

Figure 2. Forces in Compressive Spring

The torsional force will generate the torsional stress in the wire. The stress and strain relations of the bi-linear spring are shown in Figure 3. This study derived design equations of the SCD through the parametric study.

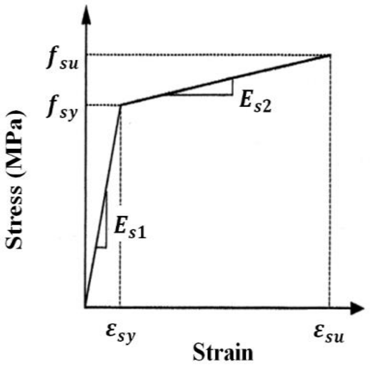

Figure 3. Bi-linear Stress Strain Relationship

The yield strength represents the load resistance of the piping system. The 1st stiffness of the system within the allowed thermal expansion range in operation is represented by:

$$k_e = 0.19 \frac{\pi d^2}{4} \frac{1}{\pi D N_e} \left(\frac{D}{d}\right)^{-2} \tag{1}$$

The equation (2) represents the second stiffness to absorb the energy of the external event.

$$k_p = 0.024 \left[E_{s1} \frac{\pi d^2}{4} \frac{1}{\pi D N_e}\right] \left(\frac{D}{d}\right)^{-1.28} \left(\frac{h}{D}\right)^{0.22} \left(\frac{E_{s1}}{E_{s2}}\right)^{-0.75} \tag{2}$$

3. Mathematical Model of Damping

The Rate Model [3] was selected to represent the damping force characteristic of SCD. This model parameters were determined from loading test for several specimens. Figure 4 compares analytical and experimental hysteresis loops in the case of 0.3Hz of loading frequency and 80mm of loading displacement were applied as experimental condition. As shown in the figure, the analytical results are very coincident with the experimental results.

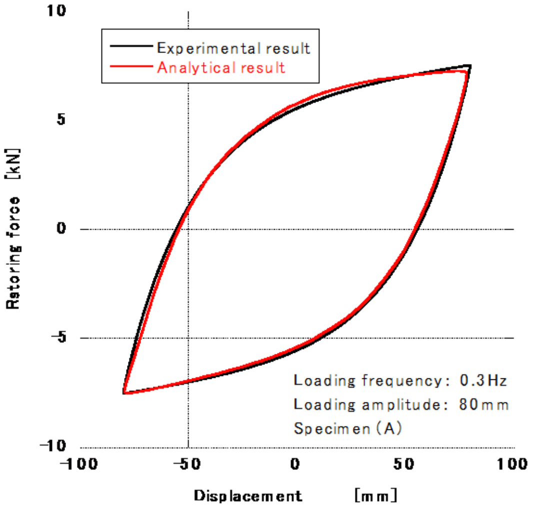

Figure 4. Comparison of analytical and expetimenl hysteresis loops

4. Dynamic Response Analysis

This study analyzed the vibration control effects of the SCD on the dynamic response of the piping system. For the study, a simple piping system was designed and tested on the shaking table to identify the modal frequencies. The analytical model was also constructed as shown in Figure 5. ABAQUS PIPE31 elements were used to express the model.

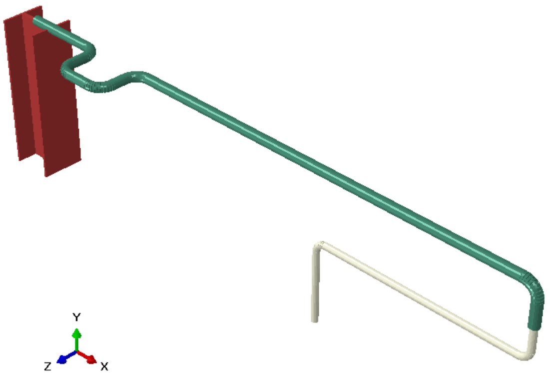

Figure 5. FE Model of the piping system

Dynamic analyses were performed before and after adding the coil spring damper in the analytical model at various points on the model. The damper was attached at the point next to the reducer.

A harmonic motion was input at the base. The analysis results demonstrate the good control performance of the damper for the dynamic motion.

5. Conclusions

This paper discusses on the response control of piping structures using elasto-plastic damper as one of preventive technologies against severe accident of piping system in the NPP. SCD is recommended to control the dynamic response of NPP piping system for a huge earthquake exceeding DBE. This paper introduced the design method of elasto-plastic damper, mechanical characteristics through loading test, and analytical study. Then, this study suggests an analytical model to represent vibration characteristics of the elasto-plastic SCD.

The actual piping system with and without SCD were modeled by finite element analysis program. The experimental modal identification was also performed to validate the analytical model. The performance of the SCD was proven by analyses. The controlled responses of the piping system model were compared with its uncontrolled responses. From the dynamic analysis results, it is confirmed that the SCD can effectively reduce the vibration of the piping system under dynamic motion. Applying the elasto-plastic support proposed in this study to the piping system can control the elastic response of the piping, and it is possible to control the thermal expansion during normal operation, and when the earthquake excursion exceeding the design base earthquake is input to the nuclear installation piping and the safety in the last state can be ensured.

ACKNOWLEDGEMENT

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