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Estimation of the Damage Index for a Nuclear Power Plant Piping System

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1. Introduction

To secure the seismic safety of base-isolated nuclear power plants, it is necessary to verify the seismic performance of the crossover piping system where large relative displacement is expected to occur. In general, the crossover piping system is composed of straight pipes and fittings such as elbows and tees. It was found that the failure mode of the crossover piping system under seismic loads is low-cycle fatigue failure accompanied by ratcheting, and that elements that fail due to the concentration of nonlinear behavior are fittings. This study aimed to quantitatively define the failure criteria for the pipe elbow, which is an element vulnerable to seismic loads in the crossover piping system of a base-isolated nuclear power plant, using Banon's damage index. The limit state of the pipe elbow was quantitatively expressed using the damage index based on the force–displacement (P–D) relationship, and the damage index based on the moment–relative deformation angle (M–R) relationship.

2. Methods and Results

In this study, a test specimen was fabricated and installed in a universal testing machine (UTM) to evaluate the limit state of the pipe elbow, a fitting in the crossover piping system, under low cycle fatigue as shown in Fig. 1. For the test specimen, the straight pipes were ASME 6-inch SCH40 SA 106 Gr.b, and the pipe elbow was a ASME 6-inch SCH40 A234 WPB. The length from the center of the pin to the weld zone of the pipe elbow was approximately 3.8 times the outer diameter (D). The moment ($M = p \cdot d$) was calculated using the load (p) measured through the load cell of UTM and the distance between the center of the pin and the center of the pipe elbow (d). The deformation angle was calculated using the relationship between the center of the pipe elbow and the symmetrical pin connections. The loading amplitude in the in-plane cyclic loading test was increased by ±20 mm, from ±20 mm to ±120 mm.

Fig. 2 shows the average damage index calculated at each loading amplitude. It was found that the average damage indices calculated using the M–R relationship were located between ±2σ of the average damage indices calculated using the P–D relationship. This indicates that the average damage indices calculated using the P–D and M–R relationships are highly correlated. Therefore, it was confirmed that the average damage indices calculated using the P–D and M–R relationships can quantitatively express the limit state of the test specimen.

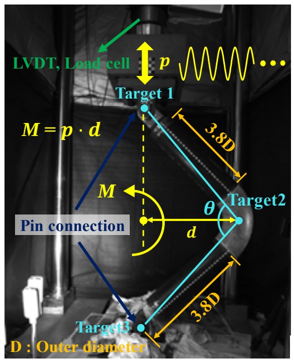

Fig. 1. Experimental setup

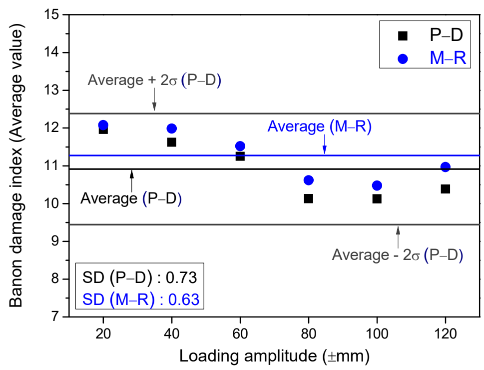

Fig. 2. Damage index for P–D and M–R

3. Conclusions

In this study, the standard deviations of the average damage indices calculated using the P–D and M–R relationships in the crossover piping system of a nuclear power plant were found to be less than 0.8. This confirmed that the average damage indices calculated using the P–D and M–R relationships can quantitatively express the failure criteria for the limit state of the test specimen.

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