Cumulative Damage Indices in a Carbon Steel Pipe Elbow under Cyclic Loading

Sung-Wan Kim [a*], Da-Woon Yun [a], Bub-Gyu Jeon [a], Dae-Gi Hahm [b], Min-Kyu Kim [b]
[a] *Seismic Research and Test Center, Pusan National University, Yangsan, Korea*
[b] *Smart Structural Safety & Prognosis Division, Korea Atomic Energy Research Institute, Daejeon, Korea*
[*] *Corresponding author: swkim09@pusan.ac.kr*

1. Introduction

When a base isolation system is installed in a nuclear power plant, larger displacement is expected to occur compared to before the installation because the system deals with seismic loads. Larger displacement may increase the seismic risk of some facilities. In particular, the seismic risk of the crossover piping system that connects base-isolated structures to general structures is expected to significantly increase. In this study, the in-plane cyclic loading test was conducted on a test specimen composed of a 3-inch pipe elbow and 3-inch straight pipes, which are mainly used in the piping of nuclear power plants, through displacement control. The test was conducted using constant amplitudes of various sizes until leakage, which is the limit state of the test specimen, occurred. From the test results, the limit state in which leakage occurred in the test specimen was quantitatively expressed using the damage indices based on the force–displacement relationship. Park and Ang's damage index and Banon's damage index, which can express cumulative damage, were used.

2. Methods and Results

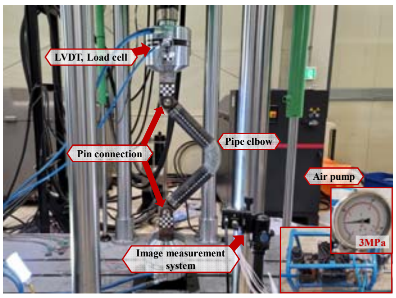

Fig. 1. Experimental setup

The in-plane cyclic loading test was conducted after filling the inside of the test specimen with water and applying an internal pressure of 3 MPa using an air booster, as shown in Fig. 1. The test specimen was fabricated by welding straight pipes to both ends of a 90° long pipe elbow with a radius of curvature of 114.3 mm. The straight pipes, whose lengths were approximately three times their outer diameter, were welded to the ends of the pipe elbow. The length from the center of the pin to the end of the pipe elbow was approximately 3.8 times the outer diameter, or 88.9 mm. The straight pipes were 3-inch ASME B36.10 SA106 Grade B SCH 40 (5.49 mm), and the pipe elbow was a 3-inch ASME A234 WPB SCH40 90° long pipe elbow. In the in-plane cyclic loading test, the loading amplitude increased by ±10 mm from ±20 mm to ±100 mm. For the force and displacement, the displacement response measured through the load cell and the linear variable differential transformer installed inside the universal testing machine was used (Fig. 1).

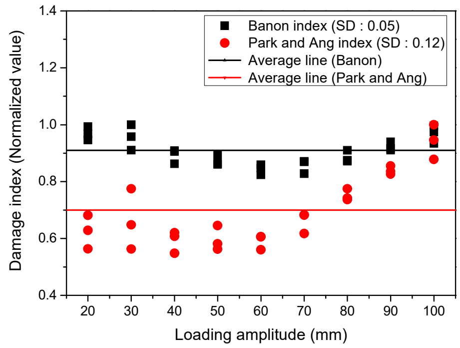

Fig. 2. Damage indices

Fig. 2 shows the normalized values of the damage indices for each loading amplitude. In this study, the failure mode of the test specimen was defined as the leakage caused by through-wall cracks. Therefore, the damage index for the failure mode must be similar for all loading amplitudes. The standard deviation of Banon's damage index was 0.05, and that of Park and Ang's damage index was 0.12. These indicate that Banon's damage index is more appropriate to use than Park and Ang's damage index to quantitatively express the limit state of the test specimen.

3. Conclusions

In this study, the failure mode of the test specimen was defined as the leakage caused by through-wall cracks. In the limit state, damage indices must be distributed with a small standard deviation from the average value. Therefore, it was found that the use of Banon's damage index is more appropriate to use than Park and Ang's damage index to express the limit state of the test specimen.

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