Failure Behaviors of Pipe Elbows under a Large Amplitude Cyclic Loads

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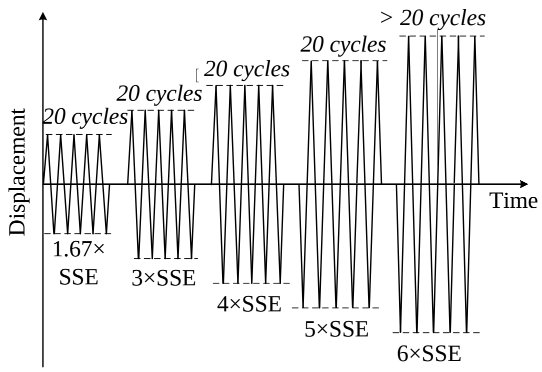
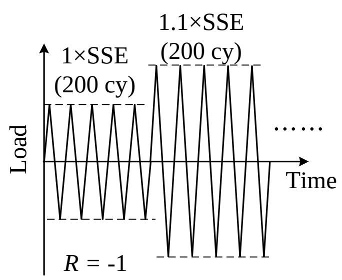
1. Introduction

The elbow in the piping systems of nuclear power plants (NPPs) is vulnerable component subject to large amplitude cyclic loads during the seismic event. Thus, understanding the deformation and failure behaviors of pipe elbows under large amplitude cyclic loads is important to develop the evaluation procedure for structural integrity of piping systems under excessive seismic loads beyond the design basis. In this context, a number of experimental and numerical studies have been conducted [1-2]. However, most of the existing experimental studies were conducted using thin-walled pipe specimens under displacement controlled cyclic loading with high internal pressure exceeding operating pressure. This study conducts failure tests on elbow specimens of different thickness and material types under displacement- and load-controlled cyclic loads with and without internal pressure at room temperature (RT). From the results, the effects of large amplitude displacement- and load-controlled cyclic loads and internal pressure on failure cycles and failure mode of the pipe elbows are investigated.



(a) Displacement-control



(b) Load-control

Fig. 1 Loading types used for failure tests

2. Experiment

2.1. Elbow specimens

Three types of 90º and long radius pipe elbows were used in the tests; *i.e.*, SA234 WPB carbon steel (CS) elbow with a nominal dimension of 4-inch, Sch.40 and SA403 WP316 stainless steel (SS) elbow with a nominal dimension of 4-inch, Sch.40 and Sch.160. The nominal outer diameter (D_o) and thickness (t_n) of the 4-inch, Sch.40 elbow are 114.3mm and 6.0mm, respectively. For the 4-inch, Sch.160 elbow, D_o and t_n are 114.3mm and 13.5mm, respectively. The specimens were made by welding straight pipes to both ends of the elbow.

2.2. Test conditions and procedure

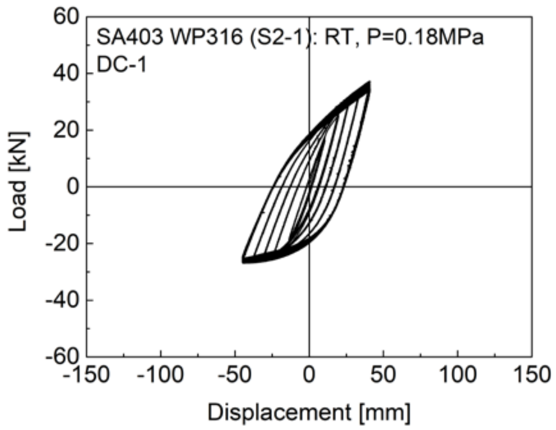
Four types of loading were considered in the tests; displacement- and load-controlled cyclic loads with and without internal pressure. As internal pressure, operating pressure for each pipe elbow were regarded; 4.8MPa was applied to the Sch.40 elbow specimens and 16MPa was applied to the Sch.160 elbow specimens. In the displacement-controlled cyclic test, as shown in Fig. 1(a), multiple sets of fully reversed cyclic displacements were applied while increasing the displacement amplitude until the specimen failed. One set of cyclic displacements consists of 20 cycles. If the specimen did not fail until the displacement amplitude corresponding to 6×SSE (safe shutdown earthquake), the set of cyclic displacement at this level was repeated until the

Fig. 2 Setup of failure tests on elbow specimen

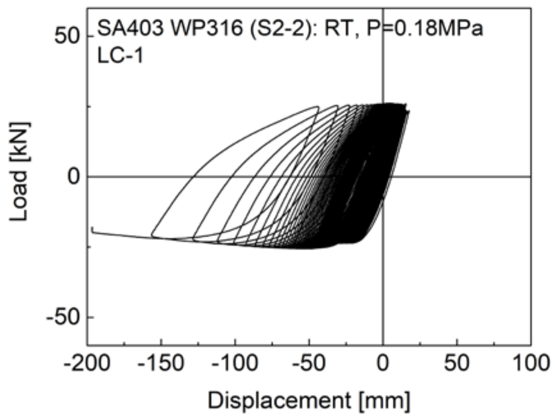
specimens failed. For the load-controlled cyclic tests, a fully reversed cyclic load corresponding to the SSE was applied until the specimen failed. If the specimen did not fail by 200 cycles, the amplitude of cyclic load increased to 110% of the previous amplitude (see Fig. 1(b)). In the tests, failure of specimen was defined by crack penetration or collapse. All tests were conducted under quasi-static rate at RT, and a servo-hydraulic UTM with a 250 kN load cell was used. During the tests, load, displacement, LVDT, pressure, and strains were monitored. Fig. 2 shows setup for cyclic elbow tests.

3. Results and Conclusions

The failure tests were conducted on three types of elbow specimens under displacement- and load controlled cyclic loads with and without internal pressure. Fig. 3 presents a sample of load-displacement curves obtained from tests under displacement- and load-controlled cyclic loads. The test results showed that the elbow has sufficient margin for failure under displacement- and load-controlled cyclic loads with amplitudes exceeding the design basis earthquake. Under displacement-controlled cyclic load, all elbow specimens failed due to cracking, and the location and pattern of crack depended on the elbow schedule (*i.e*., thickness of the elbow). However, most of the elbow specimens were failed due to ratcheting collapse under load-controlled cyclic loads, except for the case of SA234 WPB CS elbow with internal pressure of 4.8 MPa. That is, under cyclic loads, the failure mode of the elbow depended on the level of internal pressure and thickness and material type of the elbow. This is different from the existing observations that elbow failed under cyclic loads by cracking at the crown [1-5]. Also, it can be seen that as increasing internal pressure, the failure cycles reduced under displacement-controlled cyclic loads, but increased under load-controlled cyclic loads. The SA403 WP316 SS elbows were more resistance to failure than the SA234 WPB CS elbow, regardless of the types of cyclic load.



(a) Displacement-controlled



(b) Load-controlled

Fig. 3 Load-displacement curves under displacement- and load-controlled cyclic loads

Acknowledgements

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