A Failure Estimation Considering the Thickness of Steel Pipe Elbows under In-plane Cyclic Loading

Sung-Jin Chang [a*], Sung-Wan Kim [a], Bub-Gyu Jeon [a], Dae-Gi Hahm [b]
[a] *Seismic Simulation Test Center, Pusan National University, Busandaehak-ro 49, Mulgeum, Yangsan, Kyungnam 50612, Republic of Korea*
[b] *Korea Atomic Energy Research Institute, Daedeok-Daero 989-111, Yuseong-Gu, Daejeon*
[*] *Corresponding author: sjchang@pusan.ac.kr*

1. Introduction

In 2011, there was a Fukushima Nuclear Power Plant accident in Japan and since 2016, frequent earthquakes have happened in Korea. For this reason, a social concern about safety of nuclear power plants is highly growing.

Piping system is an important component of a nuclear power plant, but it has been screened out, as it was recognized to be safe enough. But after the Great East Japan earthquake, studies for proving a failure of a pipe quantitatively began to be conducted in order to evaluate safety from beyond-design earthquakes.

A failure of a pipe by seismic loading is defined as a low-frequency fatigue failure by many researchers. If the pipe connects two structures, the relative displacement between the two supports may be large due to the difference in the natural frequency of the structure. The relative displacement may increase even more when the isolation device is applied. But it is considerably difficult to quantitatively define a failure of a pipe by SAM(Seismic Anchor Motions), that is, a low-frequency fatigue failure.

Therefore, an experimental study was carried out to quantitatively define a failure of a pipe by this low-frequency fatigue failure. A damage index of the load-displacement relation was obtained from the experiment in the Elbow, which is a weak part of a pipe and the damage index was used to prove a failure of a pipe quantitatively.

2. Component Tests

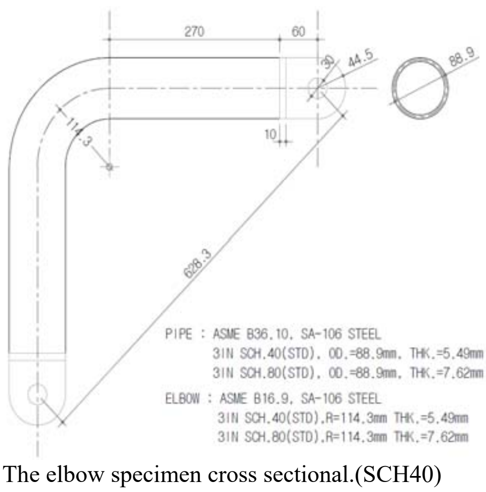

Fig. 1. The elbow specimen cross sectional.(SCH40)

Fig. 2. Cyclic loading test photo

Table I: Test loading description

Schedule No.	Constant cyclic loading amplitude(mm)
40	±20, ±30, ±40, ±50, ±60, ±70, ±80, ±90, ±100
80	±20, ±40, ±60, ±80

To identify the uniform load-displacement relation of the Elbow, an experiment was conducted using a specimen shown in Fig. 1. For observing the change depending on the thickness of a pipe, two kinds of thickness(Sch. 40, Sch. 80) were applied. As presented in Fig. 2, a Static Cyclic Loading Test was performed using Dynamic UTM of the Seismic Simulation Test Center of Pusan National University.

The experiment was performed under the loading condition in Table 1. The static cyclic loading test was carried out until a through crack occurred. Displacement and load were measured using a measurement sensor installed in the UTM.

After the test, a load-displacement curve was obtained as shown in Fig. 3 and Fig. 4. Fig. 3 indicates a load-displacement curve of Sch.40 and Fig. 4 indicates a load-displacement curve of Sch.80. Sch.80 needed a bigger load than Sch. 40 under the same displacement condition. It was also revealed that for creating a cracks, Sch. 80 had to receive more cyclic loadings than Sch. 40. Therefore, it is considered that a larger external force and a lot of cyclic loadings are necessary for creating a creak of the thick Elbow.

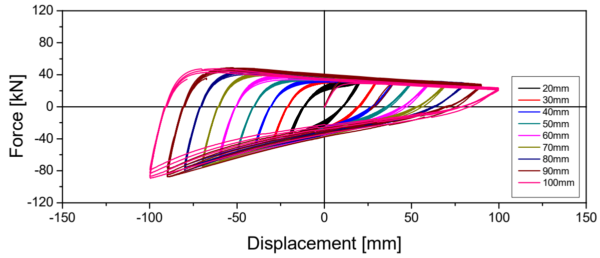

Fig. 3. Force-displacement relationship (Sch. 40)

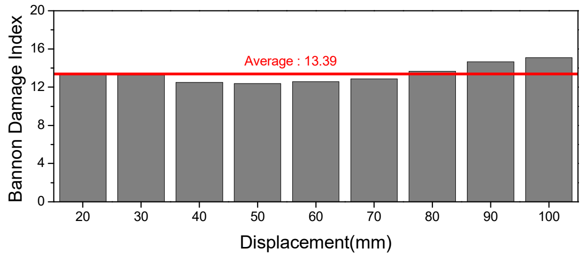

Fig. 5. Damage Index for Sch. 40 pipe elbow specimens

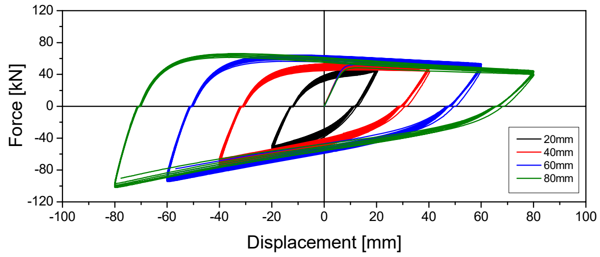

Fig. 4. Force-displacement relationship (Sch. 80)

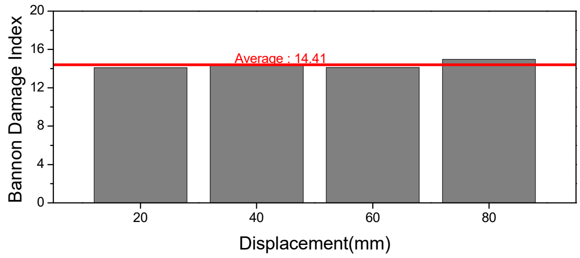

Fig. 6. Damage Index for Sch. 80 pipe elbow specimens

3. Damage Index

In order to suggest a failure criterion, Banon's[1] research finding was used. Equation (1) is the damage index of Banon. Here, D_y and F_y are yield displacement and yield force, and D_i and E_i are displacement amplitude and dissipated energy of the i th cycle. The c and d values in Equation (1) are constant values. From the results of Castiglioni, 1.1 and 0.38 are considered to be the best values for steel structures [2]. However, in the case of steel piping, 3.3 and 0.21 were found to be the optimum coefficients [3].

$$D = \sqrt{\left(\max\left(\frac{D_i}{D_y} - 1\right)\right)^2 + \left(\sum_{i=1}^{N} c\left(2\frac{E_i}{F_y D_y}\right)^d\right)^2} \qquad (1)$$

Yield displacement and yield force of the Elbow were derived using Jelka's method[4]. Yield displacement and yield load of a pipe with a thickness of Sch. 40 are 9mm and 32kN. Also, the yield displacement of pipe 80 is 7.98mm and the yield load is 46.47kN.

As indicated in Fig. 5 and Fig. 6, Bannon damage index fo Sch. 40 was 13.39 and Bannon damage index of Sch. 80 was 14.41. Log-normal standard deviation of Sch. 40 and Sch. 80 were 0.03 and 0.012 respectively that are not big. Therefore, it is supposed that the mean value could be used as a representative value of the failure. When damage indices of pipes of different thickness were compared in this experiment, a thicker pipe had a large damage index.

4. Conclusions

Static cyclic loading tests were performed to confirm the safety of piping. The performance according to pipe diameter and operating displacement was confirmed.

The damage index of 3in pipe was acquired by using Bannon 's damage index based on dissipated energy of load - displacement relation. When damage indices of pipes of different thickness(Sch.40, Sch.80) were compared, a thick pipe had a large damage index. This demonstrates that by the measured damage index of the elbow, which is a weak part of a pipe can be used in analyzing fragility of pipes in future.

4. Acknowledgements

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