*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 17-18, 2018*

# A Study of the Failure Criterion for the Steel Pipe Components Under Seismic Loading Condition

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## 1. Introduction

For a nuclear power plant, safety is the most important factor as it is a facility handling hazardous materials. Nuclear power plant consists of pipes transporting fluid and gas. Thus, piping wholesomeness is a very important element for safety of a nuclear power plant.

The piping system of a nuclear power plant is composed of straight pipes and connection pipes of different forms(Elbow, Tee, etc.). When an external load like an earthquake is applied to a pipe, stress is concentrated in the Elbow and Tee pipes that are connections of a pipe rather than in the straight pipe. In this case, a pipe may be damaged. Therefore, there is a need to understand behavior characteristics of loading for safety of connection pipes. In this study, a damage index was obtained from the load-displacement relation of the Elbow and Tee pipe in the connection pipe.

## 2. Test Set Up and Results

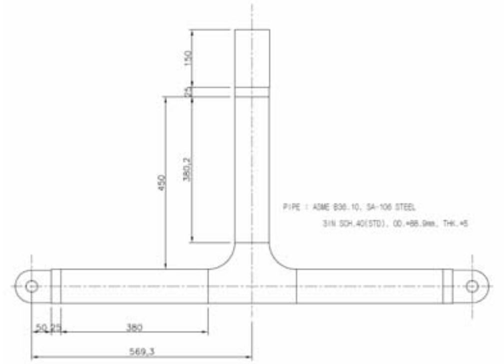


Fig. 1. The tee specimen cross sectional.

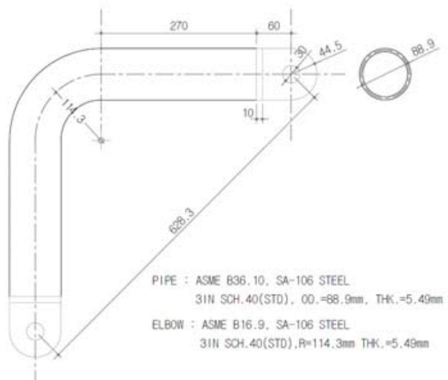


Fig. 2. The elbow specimen cross sectional.

To comprehend the load-displacement relation of the Elbow and Tee, an experiment was used using specimens shown in Fig. 1 and Fig. 2. Also, a pipe with a diameter of 3in and a thickness of Sch. 40 was used. For the static cyclic loading test, Dynamic UTM of the Seismic Simulation Test Center of Pusan National University was applied as presented in Fig. 3.

The experiment was conducted under the loading condition like Table 1 to identify performance of a connection pipe. The static cyclic loading tests were performed until a through crack occurred. Displacement and load were measured using a measurement sensor installed in the UTM.

Fig. 3. Cyclic loading test photo.

Table I: Test loading description

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

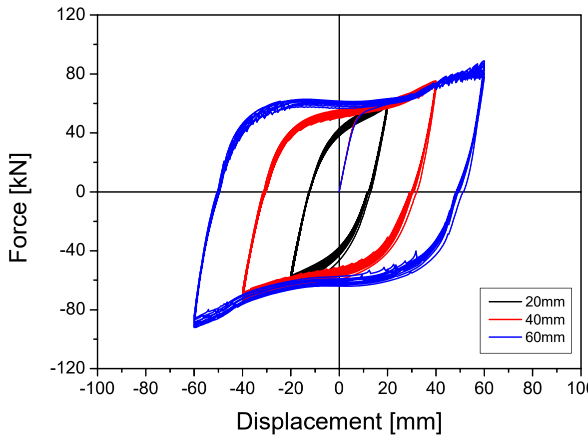


Fig. 4. Force-displacement relationship (Tee pipe)

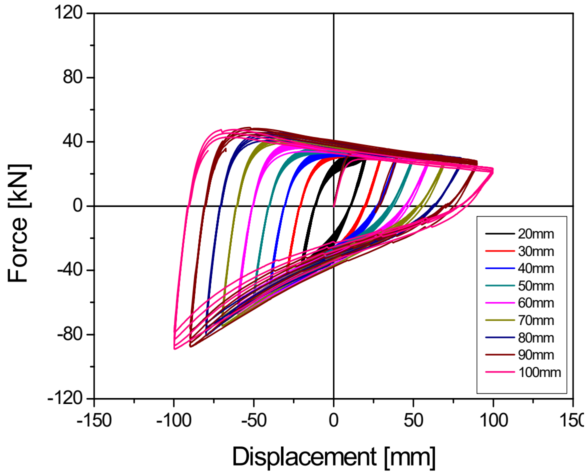


Fig. 5. . Force-displacement relationship (Elbow pipe)

After the experiment, a load-displacement curve was obtained as presented in Fig. 4 and Fig. 5. It was found that as loading amplitude grew, there was a decrease in the frequency of cyclic loading until a through crack occurred.

### 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].

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

Yield displacement and yield force of the Elbow were derived using Jelka's method[4]. Yield displacement and yield load of a Tee pipe are 8.6mm and 52kN. Also, the yield displacement of Elbow pipe is 9mm and the yield load is 32kN.

As indicated in Fig. 6 and Fig. 7, Bannon damage index fo Tee pipe was 13.74 and Bannon damage index of Elbow pipe was 13.39. Log-normal standard deviation of Tee pipe and Elbow pipe were 0.0046 and 0.03 respectively. Therefore, it is supposed that the mean value could be used as a representative value of the failure. It was also revealed that there was a 2.6% difference of damage index between the Tee pipe and the Elbow pipe, which means the pipes had similar values.

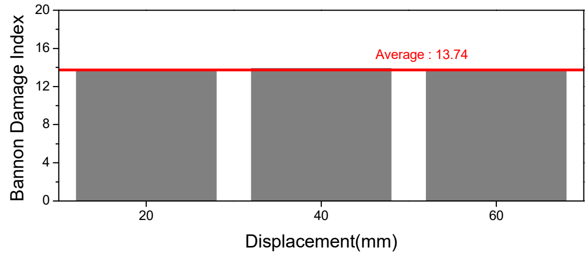


Fig. 6. Damage Index for tee specimens

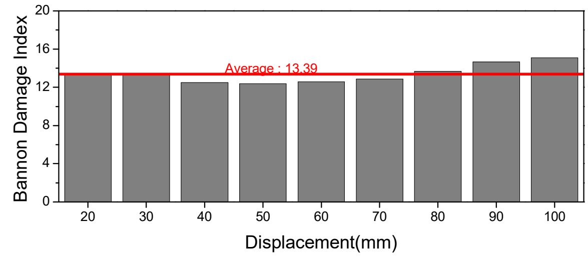


Fig. 7. Damage Index for elbow specimens

### 3. Conclusions

In order to verify safety of pipes, the static cyclic loading test of the Elbow pipe and the Tee pipe was performed and performances were measured depending on the forms and displacements of pipes.

Damage indices of pipes were acquired using damage index of Bannon, based on dissipation energy of the load-displacement relation. There was a 2.6% difference of damage index between the Tee pipe and the Elbow, which means the pipes had similar values.

It is considered that the measured damage indices of the Elbow pipe and the Tee pipe that are weak parts of a piping system can be used in analyzing fragility of pipes in future.

### 4. Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (NRF-2017M2A8A4039749). Moreover, the authors would like to thank the KOCED Seismic Simulation Test Center for their assistance with the test equipment.

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