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Failure Estimation of Pressurized Carbon Steel Pipe Tee Junction by Experimental and Numerical Study

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1. Introduction

This study presents the experimental and numerical studies of failure estimation in carbon steel pipe tee junction under internal pressure and cyclic loading. Low-cycle fatigue tests are performed on 3 inch pressurized tee junction made of carbon steel of grade SA106 Gr B. Failure mode of carbon steel pipe is leakage by through crack. Tests are carried out using cyclic loading by displacement control till failure. Numerical analysis was performed by ABAQUS 6.14. The finite element analysis (FEM) of pipe tee junction are modeled by shell elements. Material properties are estimated by coupon tests and bi-linear nonlinear model was used for numerical analysis. Numerical analysis results are compared with test results by using damage index and the details are given in this paper.

2. Test Specimens

Fig. 1 shows the carbon steel pipe tee junction for the low-cycle fatigue tests. A pipe specification was as shown in Table I. The experimental verification for the tests is shown in Fig. 2. The specimen was filled with water and an internal pressure of 3MPa was applied. The static cyclic loading tests were performed until a leakage occurred. Displacement and load responses were measured using a sensor installed in the UTM and two load cells at the ends of the straight pipes. Tests were performed as in Table II.

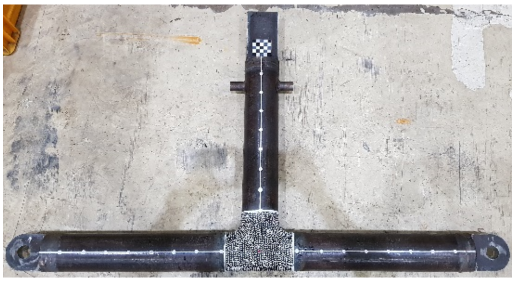

Fig. 1. Test specimen: Carbon steel pipe tee junction

Table I: Test specimen specification

Material	SA-106 Gr B
Sch.	40
Outer diameter	83.41 mm
Thickness	5.49 mm
Length of straight pipe	380 mm

Tests are conducted with various displacement amplitudes in the in-plane of piping direction. All specimens were subjected to displacement control.

Table II: Case of the low-cycle fatigue tests

Test No.	Pressure (MPa)	Loading amplitude (mm)	Leakage cycle (Number of cycle)
1	3	±10	252, 306
2	3	±20	86, 81
3	3	±40	26, 19, 21
4	3	±60	9, 10

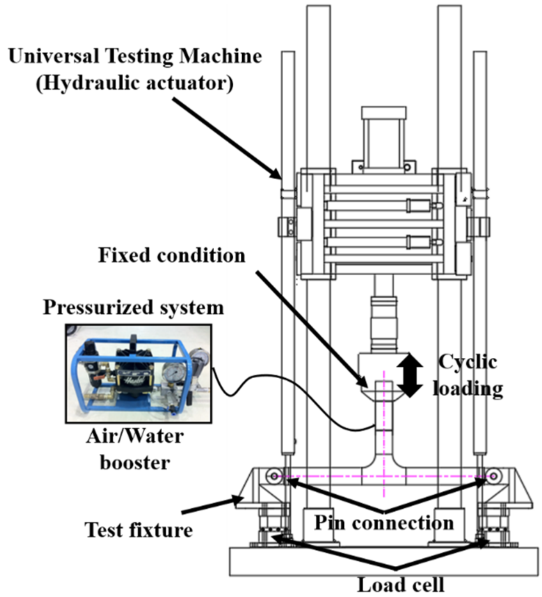

Fig. 2. Test configuration.

3. Numerical Analysis

Shell elements are known to express ovalization and warping, characteristics of pipe. Accordingly, the FEM model of the specimen was prepared using shell element(S4R). The jig connected to UTM was prepared as beam element(B32)[1]. Fig. 3 shows the model of the specimen. The shell element and the beam element are constrained by the coupling. Modulus of elasticity estimated from the result of coupon test was 205GPa, and inelastic behavior is as shown in Fig. 4.

The numerical procedure is divided into two steps. In step 1, the internal pressure is pressurized. The same test conditions are simulated by the displacement control in step 2. Table III shows the numerical analysis methods.

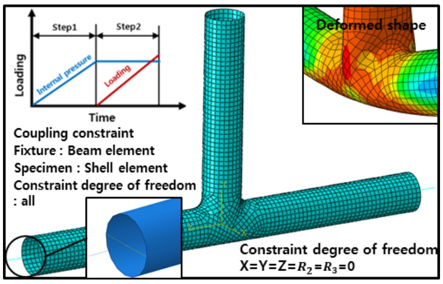

Fig. 3. Numerical analysis for internal pressured pipe tee junction under in-plane cyclic loading

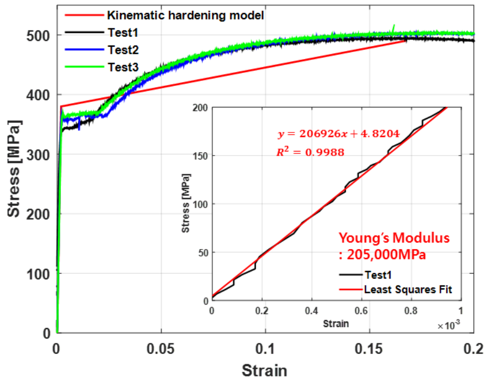

Fig. 4. Inelastic behavior.

Table III: Case of the low-cycle fatigue tests

		Step 1	Step 2
Load type	Internal pressure	Created	Propagated
	Cyclic loading		Created

4. Comparison of Test Results and Analysis Results

The results of the comparison of the load-displacement curves through experimental and numerical methods are shown in Fig. 5. The estimation result by the damage index is calculated [2] according to Equation (1), and the percent error of the average value is 1.32%, as shown in Fig. 6. Therefore, it seems that the numerical results represents well matched with the test results.

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

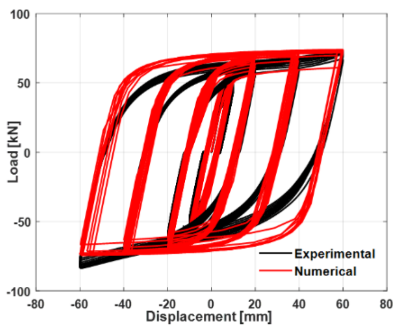

Fig. 5. Comparison of load-displacement relationship

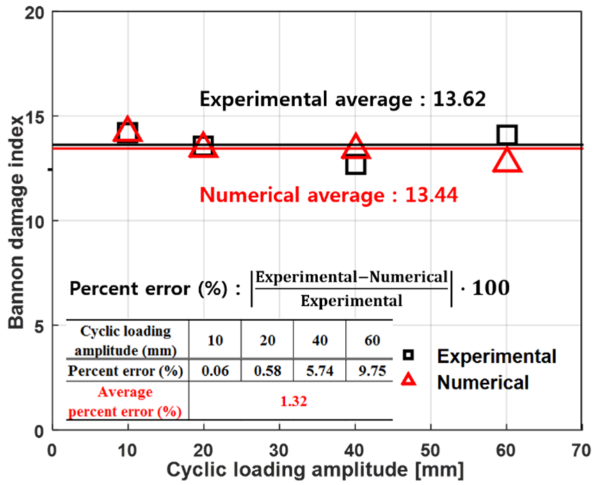

Fig. 6. Comparison of damage index by each methods

5. Concluding Remarks

This study presents the experimental and numerical studies of failure estimation in pressurized carbon steel pipe tee junction under cyclic loading. In the load-displacement relationship, the numerical analysis result shows that the load is somewhat different from the test result. However, the percent error is small when the damage is evaluated. Therefore, it is considered that the damage of the pipe could be sufficiently simulated analytically. This result could be applied as a failure criterion for the seismic fragility analysis of nuclear piping.

Acknowledgment

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