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Characterization of the Nonlinear Behavior of the piping T-joints by Experiment and Finite Element Analysis

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1. Introduction

This study has developed a formulation that can represent the nonlinear behavior of a T-joints as a function of geometrical properties of the pipe. This formulation accounts for degradation mechanism of stiffness of the piping joints. The formulation is the version of the closed form solution for moment-curvature developed by Gupta et al. (2016) for a straight pipe to the case of a T-joint and represent the moment-rotation relationship. This study identified the points on the pinching model curve.

2. Pinching Model of T-joint

The pinching behavior can be represented by using 8 points as shown in Fig. 1. This study developed a closed-form relationship for moment-rotation in a T-joint subjected to pure bending. This relationship is used for characterizing the points on the curve of the Pinching model.

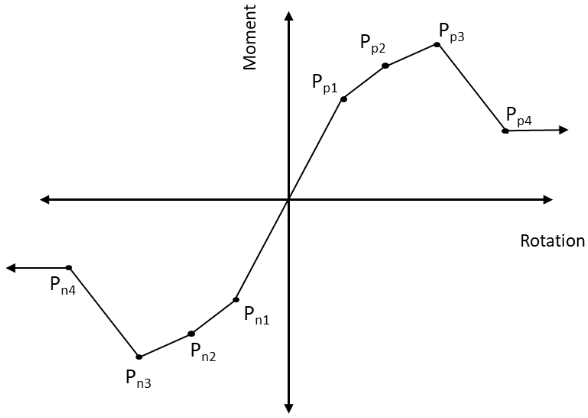

Fig. 1. Pinching Model of piping T-joints

Fig. 2 shows the configuration of the T-shaped piping and its deformation under cyclic loading at the T-joint. As shown in this figure, the flange of the T-joint and the two straight pipes connected to the either side of the T-joint together undergo a deformation that is dominated by bending deformation. Figure 3 shows a pipe having thickness *t* and radius *R*, which is subjected to a pure bending moment *M*.

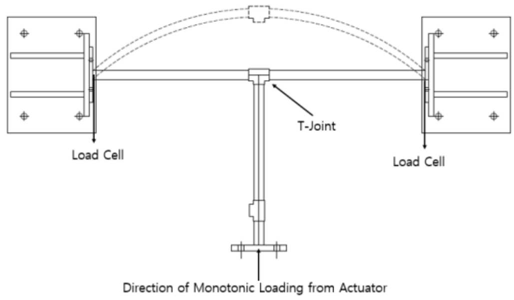

Fig. 2. Configuration of piping T-joints and deformed shape

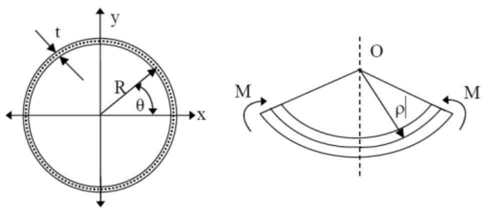

Fig. 3. Pipe subjected to bending.

The material is considered to have modulus of E, yield stress S_y, and yield strain ε_y, with bilinear kinematic hardening. The strain hardening parameter, which specifies the ratio of post yield to initial elastic tangent, is denoted by λ. Let θ_y be the angle measured from the horizontal to the elastic-plastic boundary surface. At the yield point, $\theta = \theta_y$.

$$\theta_y = \sin^{-1}\left(\frac{\varepsilon_y}{\kappa\ R}\right) \tag{1}$$

Where, $\kappa = 1/\rho$ is the curvature (rotation/length). The moment-curvature relationship was derived as Equation (2).

$$M = 4\ t\ R^2\ S_y \left[\left(\frac{\kappa R}{2\varepsilon_y}\right)\left\{\theta_y - \frac{\sin(2\ \theta_y)}{2}\right\} + \cos\left(\frac{\theta_y}{\kappa R}\right) + \left(\frac{\lambda\ \kappa\ R}{\varepsilon_y}\right)\left(\left(\frac{\pi}{4} - \frac{1}{2}\ \ \theta_y\right) + \frac{\sin(2\ \theta_y)}{2}\right) \right] \tag{2}$$

Fig. 4 compares the results obtained from simulation and experiment. A reasonable reconciliation between the experiment and simulation results was achieved.

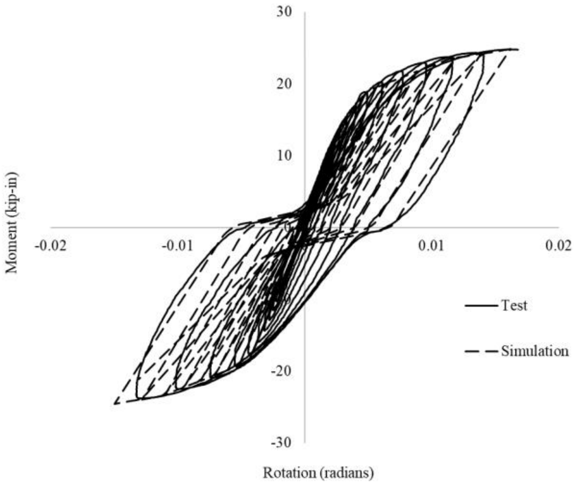

Fig. 4. Comparison of test and simulation results

3. Monotonic Loading Test

Next, a set of experiment have been performed to investigate the monotonic moment-rotation behavior of T-joint for both end hinge condition. The LVDT (Linear Variable Differential Transformer) and the load cell are used to measure physical load and displacement for the pipe behavior.

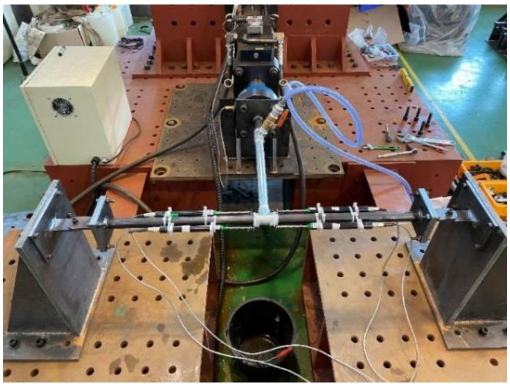

Fig. 5. Test Setup for Hinged Support Condition

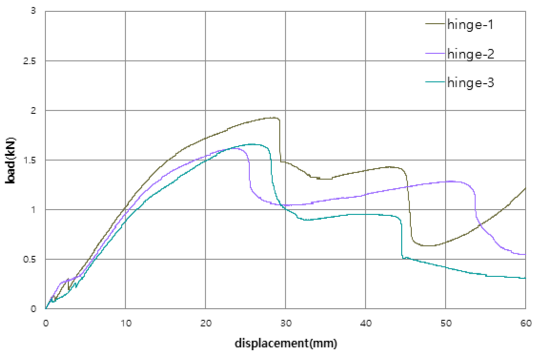

Fig. 6. Monotonic Loading Test of T-Joint

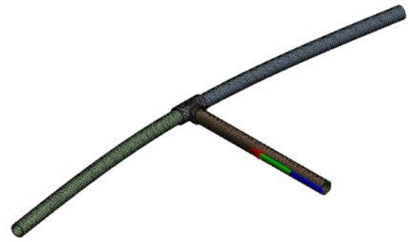

Fig. 7. Deformed Shape Obtained from FE Analysis

In addition, Finite element analyses were performed to estimate the behavior of T-joint under cyclic loading in the transverse direction. The results of experiment and finite element analysis were compared to investigate the behavior at hinged support condition and the moment-rotation relationship and to validate the closed-form formulation.

4. Conclusions

This paper presents a closed-form formulation that generates the monotonic and cyclic moment-rotation response of T-joint of piing system. From the experimental and FE analytical study, the results are compared to the developed closed-form formulation the monotonic moment-rotation response of T-joints. In the future, it is necessary to develop a predictive formulation considering the effects of different boundary conditions of the piping system.

Acknowledgements

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