Seismic Capacity Estimation of Steel Piping Elbow under Low-cycle Fatigue Loading

Bub Gyu Jeon [a], Sung Wan Kim [b], Hyoung Suk Choi [a], Dae gi Hahm [c], Nam Sik Kim [d*]
[a] *KOCED Seismic Simulation Test, Pusan National University, Yangsan*
[b] *Research Institute of Industrial Technology, Pusan National University, Busan*
[c] *Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, Daejeon*
[d] *Department of Civil and Environmental Engineering, Pusan National University, Busan*
[*] *Corresponding author: nskim@pusan.ac.kr*

1. Introduction

Generally, an isolation system for a facility in nuclear power plants can causes a large relative displacement under seismic condition. In some cases, this large relative displacement can increase seismic risk of the isolated facility. Especially, a inelastic behavior of crossover piping system to connect base isolated building and fixed base building can caused by a large relative displacement. Therefore, seismic capacity estimation for isolated piping system is needed to increase safety of nuclear power plant under seismic condition.

Dynamic behavior analysis of piping system under seismic condition using shake table tests was performed by Touboul et al in 1995. In accordance with their study, plastic behavior could be occurred at pipe elbow under seismic condition [1]. Experimental researches for dynamic behavior of typical piping system in nuclear power plant have been performed for several years by JNES(Japan Nuclear Energy Safety Organization) and NUPEC(Nuclear Power Engineering Corporation) [2]. A low cycle ratcheting fatigue test was performed with scaled model of elbow which is a weakest component in piping system by Mizuno et al. [3].

In this study, in-plane cyclic loading test is performed for evaluating seismic capacity of a internal pressured piping elbow under seismic condition. In the test, critical component of piping system is the elbow. And failure was defined as leakage. As a result, A fatigue curve for 3 inch steel piping elbow was estimated from test results. and a numerical analysis of piping elbow was performed and the results was compared with test results.

2. Component Test and Test Results

Test specimens were made in accordance with ASME B36.10. The material is SA-106 steel, outer diameter and thickness are 88.9 mm and 5.49 mm respectively. 270 mm straight pipe was welded each end of elbow to make inelastic behavior in elbow part.

Fig 1(a) shows the test experimental configuration. Test specimen was filled with water and 3MPa internal pressured by using air booster. In-plane loading was performed by displacement control. loading amplitude was controlled from ±20 mm to ±100 mm at intervals of ±10 mm. As shown in Fig. 2(b), through crack occurred on the near crown in piping elbow. Those cracks grew up in axial direction.

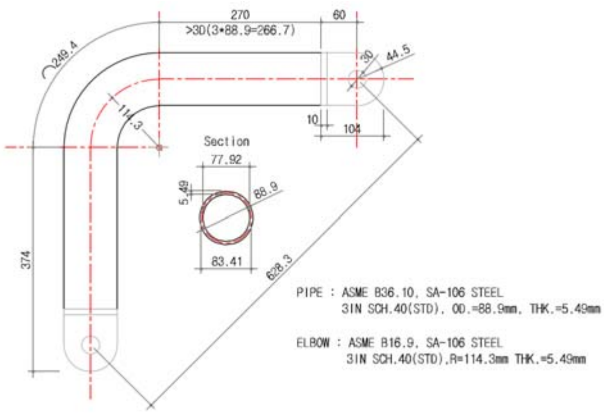
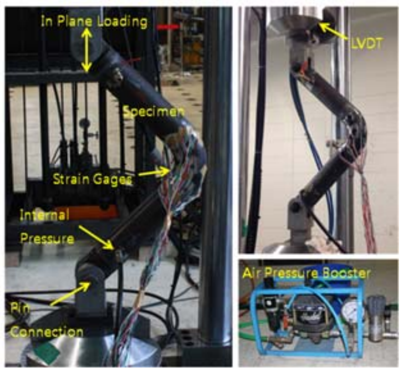
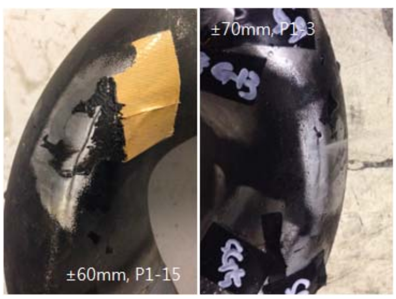


Fig. 1. Description of test specimen

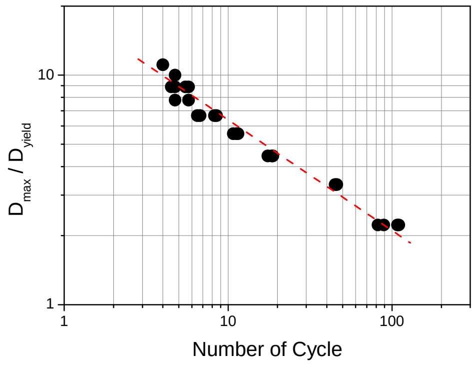


(a) Experimental configuration

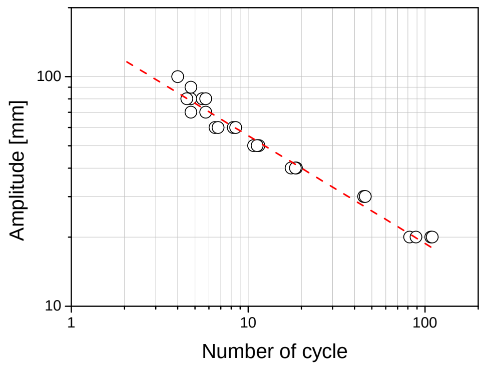


(b) Leakage point
Fig. 2. Description of component test

The fatigue curve was estimated from test results as shown in Fig. 3. Figure 3(a) is the fatigue curve of the ratio of D_{max} to D_{yield}. Here, D_{max} is the loading amplitude, D_{yield} is the yield displacement. Fatigue curve based on relationship between loading amplitude and number of cycles is as shown in Fig 3(b).

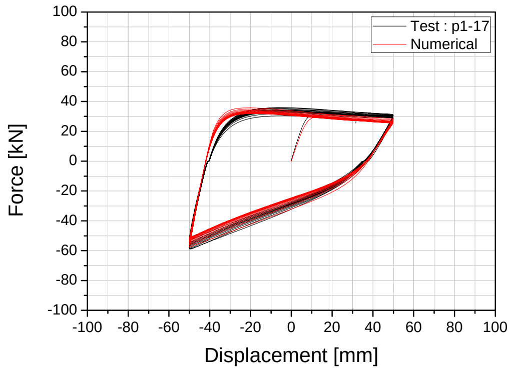


(a) Fatigue curve of the ratio of loading amplitude to yield displacement

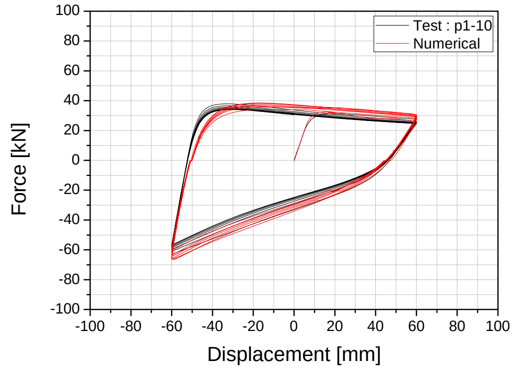


(b) Fatigue curve based on the loading amplitude
Fig. 3. Fatigue curve of 3in. piping elbow

A numerical model of piping elbow was built by using results of coupon test. And it was updated with cyclic loading test results. Fig. 4 shows the results from test and numerical analysis. The relationships between displacement and force from tests and numerical analysis was well matched.



(a) 50mm force-displacement relationship



(b) 60mm force-displacement relationship
Fig. 4. Comparison of test and analysis results

3. Conclusions

In-plane cyclic loading tests under internal pressure condition were performed to evaluate the seismic capacity of the steel piping elbow—a weak component in a piping system under seismic condition.

Leakage phenomenon occurred on and near the crown in piping elbow. Those cracks grew up in axial direction.

The fatigue curve was estimated from test results. In the fatigue curve, loading amplitude exponentially decreased as the number of cycles increased.

A FEM model of piping elbow was modified with test results. The relationships between displacement and force from tests and numerical analysis was well matched. Therefore, failure of piping elbow can be predicted based on numerical analysis.

ACKNOWLEDGMENTS

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 2014151010170C)

REFERENCES

[1] F. Touboul, P. Sollogoub and N. Blay, Seismic behaviour of piping systems with and without detect : experimental and numerical evaluations. Journal of Nuclear Engineering and Design, Vol. 192, pp.243-260, 1999.
[2] T. Zhang, F.W. Brust, D.J. Shim, G. Wikowski, J. Nie and C. Hofmayer, Analysis of JNES Seismic Tests on Degraded Piping. NUREG/CR-7015, BNL-NUREG -91346-2010, 2010.
[3] K. Mizuno, H. Shimizu, M. Jimbo, N. Oritani and S. Onishi, Development of an Evaluation Method for Seismic Isolation Systems of Nuclear Power Facilities (Part 5) Fatigue Test of The Crossover Piping, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference PVP2014, Anaheim, California, USA, 2014.