A Study on Failure Mode & Limit Strain Range of Crossover Piping in Seismically Isolated Nuclear Power Plants

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1. Introduction

Recently, to design the nuclear power plants (NPPs) more efficiently and safely against the strong seismic load, many researchers focus on the seismic isolation system. For the adoption of seismic isolation system to the NPPs, the seismic performance of isolation devices, structures, and components should be guaranteed firstly. Hence, some researches were performed to determine the seismic performance of such items [1,2]. For the crossover piping system between isolated structure and non-isolated structure, the seismic capacity should be carefully estimated since that the required displacement absorption capacity will be increased significantly by the adoption of the seismic isolation system. Hence, in the recent NUREG report emphasize that the probabilistic seismic performance of such a crossover piping system under beyond design basis earthquake should be verified. The probabilistic seismic capacity of piping system in isolated NPP is determined by the seismic response and the ultimate limit state of a piping system or piping components. Hence, in this study, we developed the failure mode & limit strain range of crossover piping by using the experimental methods.

2. Methods and Results

To define the failure mode & limit strain range of crossover piping by using the experimental methods, we performed the quasi-static and dynamic seismic performance test of elbow piping components.

2.1 Model of elbow components

When seismic occurs, plastic deformation and failure occur in the elbow of piping system. Therefore, an elbow specimen was manufactured and numerical model was made. Loading and internal pressure tests were performed. In addition, the numerical model was updated using test results to improve reliability of the numerical model.

In this study, an elbow specimen of ASME B36.10M SA53, Grade A, SCH 40 shown in Table 1 was manufactured. A straight pipe with sufficient length was attached to the elbow by welding to generate plastic behavior in the elbow section of the specimen. Fig. 1 is the drawing of the elbow specimen.

Table 1. Description of elbow specimen

Outer diameter	323.85mm	
Thickness	9.5mm	
Elbow radius	457.2mm	
Length of straight pipe	Part 1	950mm
Length of straight pipe	Part 2	1000mm

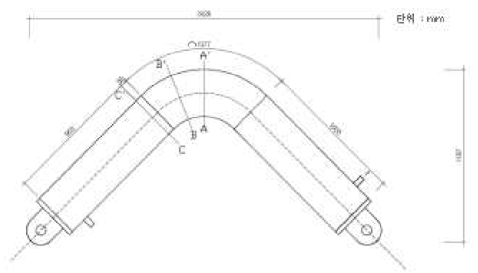

Fig. 1. Elbow specimen drawing

Material tension test was performed to determine physical properties of the numerical model. Modulus of elasticity estimated from the result of material tension test was 203,509 MPa.

Shell element is known to express ovalization and warping, characteristics of pipe, well. Accordingly, the numerical model of the specimen was prepared using shell element as in Fig. 2, and the jig connected to UTM was prepared as beam element.

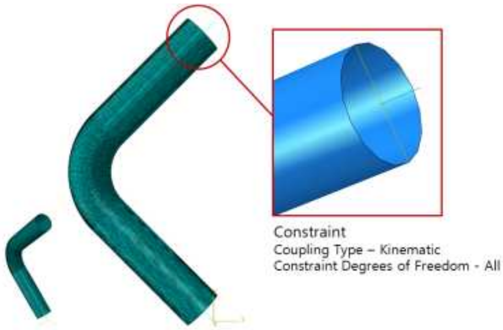

Fig. 2. Numerical model of elbow component

2.2 Ultimate performance test of elbow components

Experimental ultimate seismic performance test of elbow components were performed for the test sets for various loading conditions of elbows which described in Table 2. Fig. 3 depicts the failure modes and limit state of each elbow component specimen. We determined that the ultimate failure mode of elbow components is the leakage through the penetration crack of pipes. In each case of test, the leakage failure modes are captured under the specific hysterical loading cycles. Fig. 4 shows the examples of hysteresis force-displacements curves of some test components.

Table 2. Description of elbow specimen

Test Specimen	P1-10	P1-1	P1-2	P1-3	P1-4	P1-5
Mode	Cyclic mode	Cyclic mode	Cyclic mode	Cyclic mode	Cyclic mode	Cyclic mode
Velocity (mm/s)	12	12	16	16	16	16
Amplitude	±60mm x 7cycle	±60mm x 7cycle	±50mm 12cycle	±70mm 5cycle	±40mm x 18cycle	±80mm x 6cycle
Pressure	3MPa	3MPa	3MPa	3MPa	3MPa	3MPa

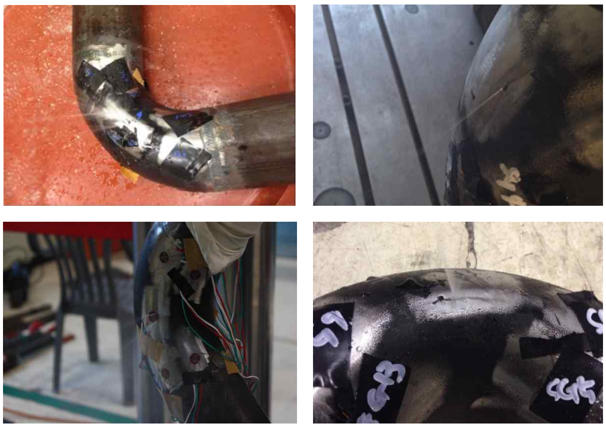

Fig. 3. Failure mode ultimate state of each elbow.

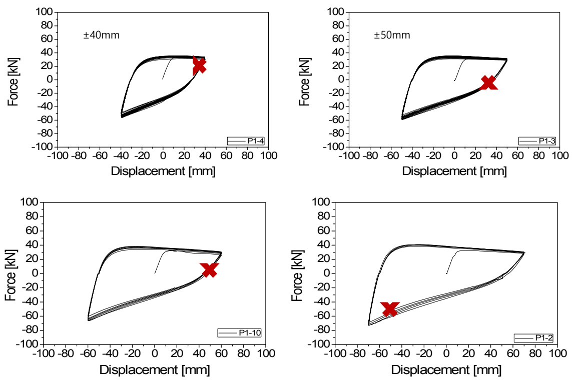

Fig. 4. Examples of hysteresis force-displacements curves of some test components.

From the seismic capacity test of specimen, we modified the finite element component model, and performed numerical analysis to determine the limit strain range of each model. Fig. 5 is one of the finite element analysis results of components.

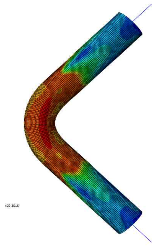

Fig. 5. Finite element analysis result example.

From the test & numerical results, we defined the limit state failure range of crossover piping system in the seismically isolated NPPs.

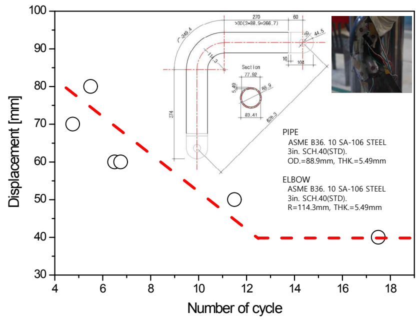

Fig. 6. Limit state failure range of crossover piping component

3. Conclusions

In this study, we developed the failure mode & limit strain range of crossover piping by using the experimental methods. The limit strain range of piping components determined in this study, can be used for the ultimate seismic capacity evaluation of crossover piping systems in the seismically isolated NPPs.

Acknowledgement

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