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Ultimate Failure Criteria Evaluation of Elbow Components by using Dynamic Cyclic Loading Tests

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1. Introduction

Seismic isolation system can be an effective alternative to protect the nuclear power plants (NPPs) against to the strong seismic events. Therefore, some research activities to adopt the seismic isolation concept to the design of the next generation NPPs have been progressed for last few years in Korea. If seismic isolation devices are installed in nuclear power plant for seismic stability, safety against seismic load of power plant may be improved. But in some equipment, the seismic fragility capacity may decrease because the relative displacements may become larger compared to the non-isolated case. It is well known that the interface pipes between isolated & non-isolated structures will become the most critical component when the seismic isolation system will be introduced [1]. Therefore, seismic performance of such interface pipes should be evaluated comprehensively especially in terms of the seismic fragility capacity. To evaluate the seismic capacity of interface pipes in the isolated NPP, firstly, we should define the failure mode and failure criteria of critical pipe components. Hence, in this study, we performed the dynamic tests of elbow components which were installed in an actual NPPs, and evaluated the ultimate failure mode and failure criteria by using the test results.

2. Methods and Results

When seismic event occurs, plastic deformation and failure occur in the elbow of piping system [2, 3]. Therefore, we manufactured the elbow component specimens and performed cyclic loading tests under the internal pressure condition. The figure of the elbow specimens of ASME B36.10M SA53, Grade A, SCH 40 [4] shown in Fig. 1. Straight pipes with sufficient length were attached to the ends of elbows by welding to generate plastic behavior in the elbow section of the specimen.

To ensure the straight movement of the actuator, we produced a special zig. A CAD drawing and a picture of the zig are illustrated in Fig. 2. Also, to prevent the play of the hinge, we introduced high-precision hinge components to the ends of elbow specimen (Fig. 3). In Fig. 4, the total configuration of the dynamic test is presented. For the dynamic test, a 250 kN dynamic actuator and a MTS FlexTest controller are used.

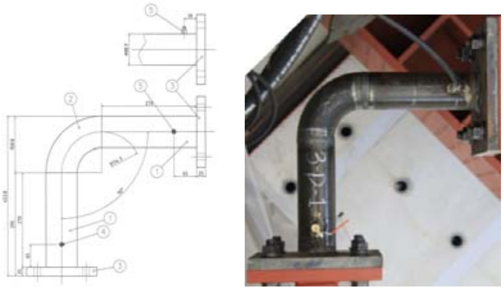

Fig. 1. Elbow test specimen.

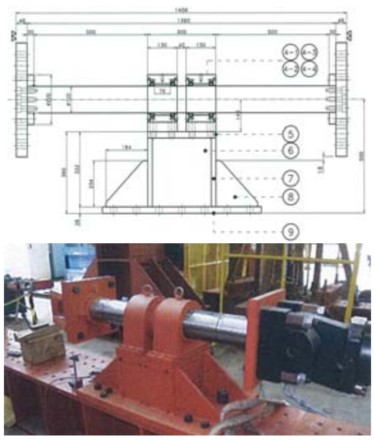

Fig. 2. A special zig to ensure the straight movement of actuator.

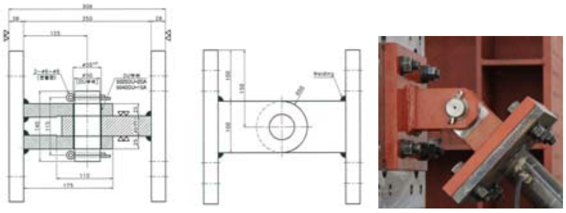

Fig. 3. A high-precision hinge component to prevent the play at the hinge element.

Fig. 4. Dynamic test setup configuration using straight moving zig, hinge elements, and elbow specimen.

With the dynamic test to evaluate the ultimate failure mode and failure criteria, we also tried to verify the effects of many variation parameters, such as the internal pressure, loading amplitude, loading type, and the size of elbow specimens. In Table 1, the test plans are summarized. We used sinusoidal input wave with amplitudes of 60, 80, and 100 mm, and also earthquake input motions which has maximum displacements between the elbow arms of 40 to 160 mm. In Fig. 5, the force-displacement hysteresis curves for specimens of 3-A and 3-B are illustrated. From the figure, it can be seen that the each of three hysteresis curves shows a good consistencies in the shape of loops. From all of the 24 elbow component specimens, the penetration cracks and leakage of waters were captured as the ultimate failure mode of pipes. Fig. 6 depicts one of the ultimate failure states of elbow specimens.

Table 1. Test plans for the dynamic cyclic loading test to evaluate the failure mode & failure criteria.

Specimen #	Diameter (in)	Amp.(±mm)	Loading Type	Internal Prs.(MPa)
3-A	3.0	60.0	Sine	2.0
3-C				5.0
3-B		80.0		2.0
3-D-1		40.0	EQ	
3-D-2		60.0		
3-D-3		80.0		
3-D-4		120.0		
3-D-5		140.0		
3-D-6		160.0		
3-E		100.0	Sine	
6-A	6.0	160.0		
6-B		120.0		

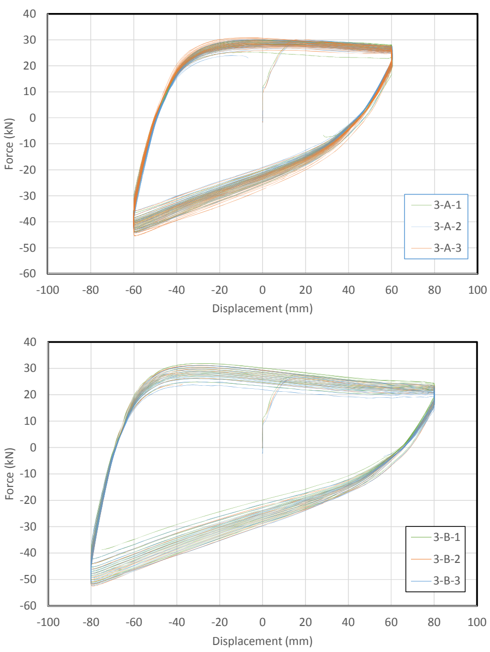

Fig. 5. Force-displacement hysteresis curves for specimens of 3-A and 3-B

Fig. 6. Ultimate failure state of elbow specimen: penetration crack & leakage of water at the crown of elbow.

In Table 2, the results of ultimate failure criteria are listed in terms of the number of cyclic loading counts required to occur the ultimate failure. From the results, we found that the increase of the internal pressure will slightly increase the failure criteria. Tested elbow components had a very good sustainability against to the earthquake loading since that more than 34 times of 0.5g earthquakes (in this case, 40 mm amplitude case) were required to make a penetration crack at the tested pipes.

Table 2. Test results: ultimate failure criteria in terms of the number of cyclic loadings.

Specimen #	Amp.(±mm)	Internal Prs.(MPa)	# of Cycles to Failure	Maximum Loading (kN)
3-A	60.0	2.0	18.3	44.2
3-C		5.0	21.0	47.2
3-B	80.0	2.0	10.2	51.9
3-D-1	40.0		34.5	49.8
3-D-2	60.0		15.0	56.6
3-D-3	80.0		8.0	71.5
3-D-4	120.0		3.0	91.7
3-D-5	140.0		2.0	97.4
3-D-6	160.0		1.5	104.4
3-E	100.0		8.0	62.6
6-A	160.0		6.5	194.3
6-B	120.0		11.9	151.4

3. Conclusions

The dynamic tests were performed for the elbow components which were installed in an actual NPPs, and the ultimate failure mode and failure criteria were also evaluated by using the test results. From the results, we found that the tested elbow specimens sustained healthiness against to the earthquakes stronger than 1.0 g scale. Even under the 4 times larger amplitude of earthquake compared to the 0.5 g scale earthquake, the penetration crack was not occurred in the tested specimen.

ACKNOWLEDGEMENT

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