Piping Component Tests under Simulated Excessive Seismic Loads

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1. Introduction

Piping system in nuclear power plants(NPPs) is designed to maintain the integrity under design basis earthquake (DBE)[1]. However, the elbow in the piping system, which is designed to absorb the energy by plastic deformation under an excessive external load, may be vulnerable to cyclic deformation and related damage during beyond design basis earthquake (BDBE) events [2]. Recently, it is also required to ensure the integrity of safety related nuclear system, structure, and components (SSCs) under BDBE as well as DBE conditions [3]. Thus, the development of the best estimation procedure for structural integrity of the piping system under excessive seismic load is needed. To this end, it is necessary to understand the deformation and failure behaviors of pipe elbows under large amplitude cyclic loads. Therefore, our previous study conducted cyclic failure tests on elbow specimens under large amplitude load- and displacement-controlled cyclic loads of quasi-static rate at room temperature [4]. In the same line of the study, the present study performs excitation test on elbow specimen using shaking table under input acceleration simulating excessive seismic loading. From the results, the effect of excessive seismic loads on the cyclic deformation and failure behavior of pipe elbows.

2. Experiment

2.1 Elbow specimen

The elbow specimen was made by attaching the straight pipes to both ends of the elbow. Two types of 90° and long radius pipe elbow were used in the test; SA234 WPB carbon steel (CS) and SA403 WP316 stainless steel (SS) elbows of 4-inch, Sch.40. The nominal outer diameter (D_o), thickness(t_n), and bend radius(R_b) of the 4-inch, Sch.40 elbow are 114.3mm, 6.0mm, and 152mm, respectively. The straight pipe is the same grade as the corresponding elbow and has the same nominal size. That is, SA106 Gr.B CS pipe was attached to the SA234 WPB CS elbow and SA312 TP316 SS pipe was attached to the SA403 WP316 SS elbow.

2.2 Test conditions and procedure

As shown in Fig. 1, the elbow specimen was subjected to a dynamic moment generated by the acceleration of the weight (300kg) attached to the end of the connecting pipe during the excitation. The specimen was excited uniaxially to cause in-plane bending using shaking table. Seven specimens were tested: three SA234 WPB CS elbow specimens and four SA403 WP316 SS elbow specimens. As shown in Fig. 2, two waveforms were considered as an input acceleration; sinusoidal waveform (SW-1) and random waveform (RW-1). SW-1 consisted of 20 steady amplitude cycle part and 10 transient amplitude cycle parts at the beginning and ending. RW-1 was obtained by adjusting the maximum amplitude of the time-acceleration data given from the seismic analysis of the containment building to 1.2g. Pressured and unpressured conditions were considered in the test. SA234 WPB CS elbow specimens were pressurized to 4.8 MPa and SA403 WP316 SS elbow specimens were pressurized to 4.8 and 9.6 MPa.

In all tests under SW-1 input acceleration, the dominant natural frequency of the specimen was determined by inputting a wide-band random wave, and then the specimen was excited by the SW-1 input whose frequency was set to the dominant natural frequency of the specimen. The excitation was applied until the specimen failed while increasing the amplitude of input acceleration to 1.2g. If the specimen didn't fail up to the input of 1.2g, the excitation was repeated with the same input level until the specimen failed. When applying RW-1 input, the same waveform with frequency of 2.93Hz (Fig. 2(b)) was repeated until the specimen failed. In this test, the failure was defined as crack formation and plastic collapse of the specimen.

During the test, displacement of weight, closing and opening displacement of elbow, internal pressure, and response acceleration and strain at various locations were monitored.

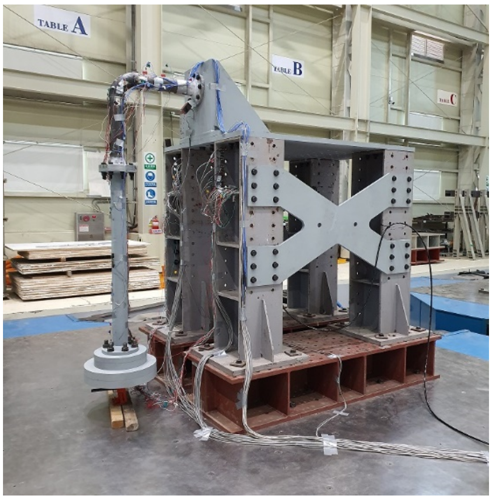
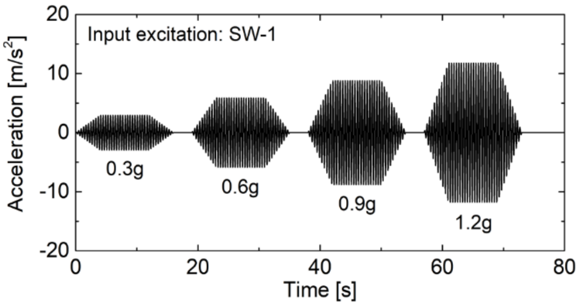
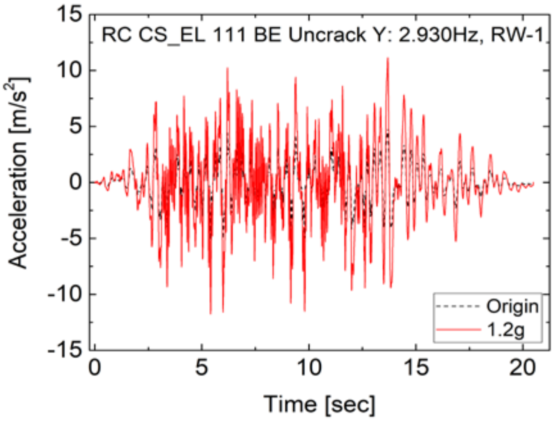


Fig.1 Setup of excitation test using shaking table



(a)



(b)

Fig.2 Input excitation wave: (a) Sinusoidal wave (SW-1) and (b) Random wave (RW-1)

3. Results and Conclusions

As results of the experiment, the response acceleration at bottom of the shaking table and the connection point between the elbow specimen and the support was found to be amplified about 1.7 to 1.8 times compared to the input acceleration regardless of waveform. Thus, the acceleration level acting on the elbow specimen in the test was higher than the input acceleration.

The results of the SW-1 input condition showed that, as the level of input acceleration increased, the response acceleration at the weight increased almost linearly up to 0.9g, but the increase rate showed a tendency to decrease at the input acceleration level above 0.9g. In addition, as the same input acceleration with amplitude of 1.2g was repeated, the response acceleration decreased. A similar behavior was also observed in the moment imposed to the elbow calculated from the response acceleration. This is associated with the loss of stiffness induced by plastic deformation of the elbow specimen. The moment applied to the elbow increased with increasing internal pressure and it was higher for the SA234 WPB CS than for the SA403 WP316 SS elbow specimen. Regardless of the type of waveform, the circumferential strains at the crown increased considerably as the input acceleration level increased and the number of cycles increased.

Regardless of type of elbow material, input waveform, and internal pressure, all elbow specimens showed the same failure mode; *i.e.*, an axial crack was formed at the crown of elbow. Such failure mode is the same as that observed from the previous tests on the pipe elbow under seismic loading condition [4-6]. Also, it is agreement with the fact that the mean and amplitude of the circumferential strain were predominantly increased with increasing number of excitations. Under the same level of input acceleration, the failure cycle of the SA403 WP316 SS elbow specimen was longer than that of the SA234 WPB CS elbow specimen. That is, the SA403 WP316 SS elbow has better failure resistance than the SA234 WPB CS elbow under seismic loading conditions. Such material dependence of the failure cycles has been also reported from the existing experimental investigation [6]. This is associated with the larger ductility of the SA403 WP316 SS compared to the SA403 WP316 SS elbow material. As the internal pressure increased, also, the failure cycle decreased for the SA234 WPB CS elbow. However, compared with the unpressurized condition, the failure cycle of the SA403 WP316 SS elbow specimen increased at 4.8MPa and decreased at 9.6MPa. Thus, the effect of internal pressure on the failure cycle depends on the elbow material and further investigation is needed to reach a definitive conclusion.

Acknowledgements

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REFERENCES

[1] ASME, Rules for Construction of Nuclear Facility Components, ASME B&PV Code, Sec. III, 2007.

[2] I. Nakamura and N. Kasahara, Excitation Tests on Elbow Pipe Specimens to Investigate Failure Behavior Under Excessive Seismic Loads, PVP Conference, *J. Pres. Ves. Tech.*, Vol. 139, 061802, 2017.

[3] IAEA, Consideration of the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants, *IAEA TECDOC–1791*, 2016.

[4] S.E. Kim, J.N. Kim, J.W. Kim, D.Y. Lee, and H.B. Park, Failure Behaviors of Pipe Elbows under a Large Amplitude Cyclic Loads, *Trans. KNS Autumn met*., 2020.

[5] G. E.Varelis, S. A. Karamanos, A.M. Gresnigt, Pipe Elbow Under Strong Cyclic Loading, *J. Pres. Ves. Tech.*, Vol. 135, 011207, 2013.

[6] K.Yahiaoui, D.G.Moffat, and D.N.Moreton, Response and Cyclic Strain Accumulation of Pressurized Piping Elbows under Dynamic In-plane Bending, *J. of Strain Anal*., Vol. 31, No. 2, pp.135-151, 1996.