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Sensitivity Analysis on Elbow Piping Components in Seismically Isolated NPP under Seismic Loading

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1. Introduction

In nuclear power plants (NPPs), piping system plays an important role to maintain the plant serviceability. Failure of a pipeline containing coolant cause a reactor failure in the worst case, in which severe consequence are expected. Meanwhile, it has been years since base isolation concept is introduced to increase the seismic capability of NPP. However, it is well known that not all components in the NPP become safer with the introduction of base isolation. Pipelines are representative of them because they could undergo larger displacements when they are supported on both isolated and non-isolated structures simultaneously [1]. Especially elbows are critical components of pipes under severed loading conditions such as earthquake action because strain is accumulated on them during the repeated bending of the pipe [2]. Therefore, seismic performance of pipe elbow components should be examined thoroughly based on the fragility analysis. Fragility assessment of interface pipe should take different sources of uncertainty into account. However, selection of important sources and repeated tests with many random input values are very time consuming and expensive, so numerical analysis is commonly used.

In the present study, finite element (FE) model of elbow component will be validated using the dynamic test results of elbow components. Using the verified model, sensitivity analysis will be implemented as a preliminary process of seismic fragility of piping system. Several important input parameters are selected and how the uncertainty of them are apportioned to the uncertainty of the elbow response is to be studied.

2. FE model validation

2.1. Test on the elbow component specimen

Material test was performed before the dynamic loading to estimate the mechanical properties for the numerical model. Modulus of elasticity and inelastic behavior of the steel were determined as shown in the Fig. 2 and 3.

Cyclic loading tests on the elbow component specimen were performed under various test conditions. Different diameters of elbows (3 in. and 6 in.), loading types (sinusoidal wave and earthquake), amplitude (40 mm-160mm), and internal pressure (2.0-5.0MPa) were applied at the test. Tests were conducted until the elbows fail to leak the water inside.

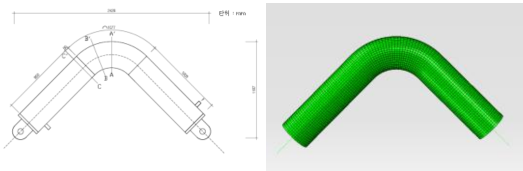

Fig. 1. Test specimen and FE model of elbow

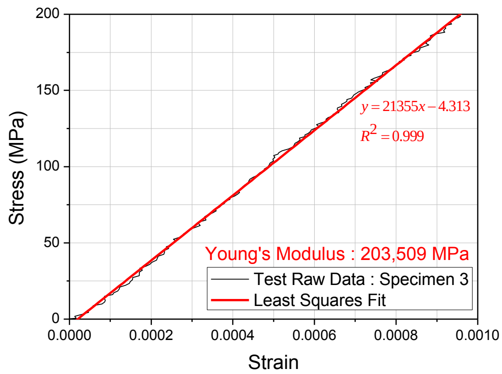

Fig. 2. Estimation of modulus of elasticity

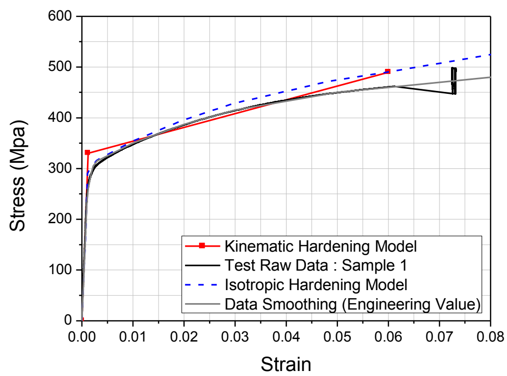

Fig. 3. Inelastic behavior of steel

2.2. Comparison of results between FE model and test specimen

Finite element program ABAQUS is employed for analysis of piping elbow in this study. FE model of the elbow is presented in the Fig. 1. The model is made of an elbow part and two straight segments using shell elements. Two end supports are made of rigid beam, one of which represent hinged support and the other moves freely along the horizontal direction allowing the in-plane bending movement of the piping elbow.

The shell thickness is uniform along the pipeline and equals to 2.72mm. The initial bend angle is 90 degree and the bend radius equals to 120.65mm. Length of two straight arms equal to 243.88mm and 217.48mm each, and the former is the hinged part. Material density, elastic modulus, and Poisson's ratio equal to 7.85 g/cm^3, 200 MPa, and 0.27 for each. Also, kinematic hardening model is used to represent the inelastic behavior (Fig. 3.)

Numerical and test results were compared in the Fig. 4. FE elbow model tends to predict force-displacement behavior similar to the specimen. The elbow component FE model is decided to be suitable for sensitivity analysis.

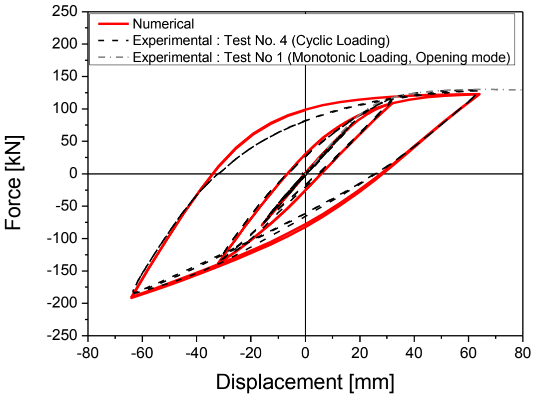

Fig. 4. Result comparison between numerical analysis and test under cyclic loading

3. Sensitivity Analysis

3.1. Parameter selection

Several parameters are selected as effective parameters for the analysis. Uncertainty sources are largely attributed to the manufacturing process of elbow components. Material properties like mass density, elastic modulus, and stress-strain curve can differ from specimen to specimen. For example, yield stress or plastic strain hardening curve varies as shown in the Fig. 5. The variation will make the model exhibit different results. Also the geometrical property like shell thickness and the internal pressure would be the effective parameter.

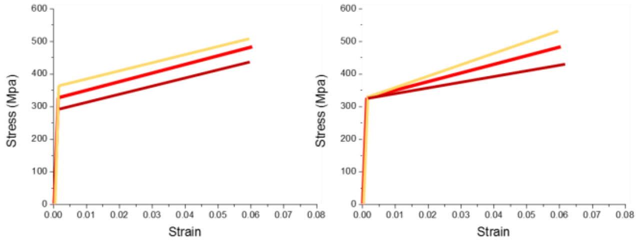

Fig. 5. Variation of kinematic hardening model

Piping models with input parameter value variations are used for sensitivity analysis for the response of elbow components under cyclic loading. Sinusoidal wave motions are used as input motion. In-plane closing and opening of elbows get to have force-displacement hysteresis, and the dissipated energy calculated from the hysteresis is used as the output of interest for the sensitivity analysis. The dissipated energy was proposed from [3] and expressed as in the equation (1).

$$D = \max\left(\frac{D_i}{D_y}\right) + b\sum_{i=1}^{N}\left(\frac{E_i}{F_y D_y}\right) \qquad (1)$$

3.2. Parameter ranges and simulation

Most of parameters corresponding to material properties or any other measurement properties are normally or log-normally distributed. In the present study the parameter values are simply assumed to be vary by 20 percent from the nominal value.

3. Conclusion

Piping elbows are critical components under cyclic loading conditions as they are subjected large displacement. In a seismically isolated NPP, seismic capacity of piping system should be evaluated with caution. Seismic fragility assessment preliminarily needs parameter sensitivity analysis about the output of interest with different input parameter values. In this study, the FE model is verified using specimen test results and simulation with parameter variations are conducted. Effective parameters will randomly sampled and used as input values for simulations to be applied to the fragility analysis.

Acknowledgement

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