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Seismic Analysis of the Piping System with Shaking Table Test

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1. Introduction

The nonlinear behavior of the nuclear power plant (NPP) piping system due to plastic deformation cannot be ignored under the beyond design basis earthquake. Therefore, here is active research on predicting failure behaviors in the piping system using finite element (FE) analysis [1-3]. Our research team aims to construct an FE model that can accurately represent the acceleration and strain responses of a piping system experiment conducted by Chosun University in 2022. Furthermore, this study aims to provide guidelines for FE analysis methods that can simulate the dynamic responses under considering material nonlinearities.

Fig. 1. Experimental set up for shaking table test consisting stainless steel specimen.

2. Experiments set-up for the Elasto-plastic analysis

For the experimental design, as shown in Fig. 1, the target piping system consists of 8 elbows and a straight tee component is placed between two shaking tables. The shaking table on the left side of Fig. 1 remains fixed, while the one on the right side is only excited.

The input for the elasto-plastic analysis is the displacement at the point where the piping system and the jig are connected. In this case, the experimental piping system is a specimen that simulate the Safety Injection System of APR1400, and the acceleration time history used as input for the experiment corresponds to an artificial earthquake wave generated based on the floor response spectra of the corresponding height level as shown in Fig. 2. In addition, it consisted of a total of two cases, including the case with the maximum input acceleration level of the shaking table to confirm the failure behavior through the experiment.

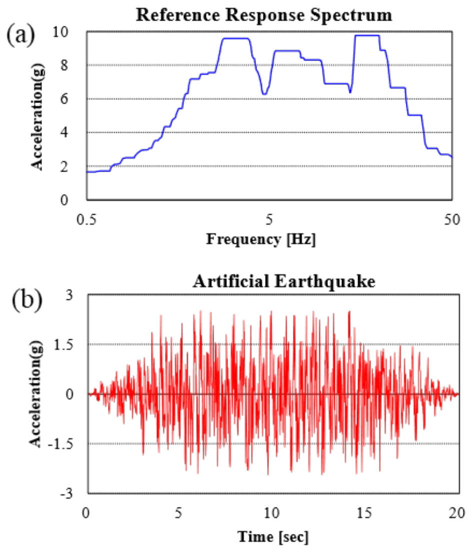

Fig. 2. Input for this experiment, (a) Floor response spectrum of target piping system under BDBE condition and (b) generated time-historical acceleration.

The pipe specimen is a 4-inch sch40, with straight pipes made of SA312 TP316, and SA403 WP316 on both elbows and a tee. To improve dynamic response and accelerate damage on the elbow specimen, 400kg and 300kg weights were attached at two locations.

3. FE model Construction

Through the white noise excitation where plastic behavior does not occur, the first and second natural frequencies in the excitation directions are derived at 3.09 Hz and 4.70 Hz, respectively, and these have a strong earthquake motion in the input spectrum. In addition, based on FEM, which consists only of solid elements containing the jig of the experiment, the Young's modulus of material properties was tuned to within 10%, and a model that matches the error of each of the first and second natural frequencies within 0.48% was constructed. In addition, FE analysis was performed based on the hybrid (Solid and pipe) element considering the computational load.

Rayleigh model was applied for the damping input. Alpha and beta coefficients were selected as targets for the 21 Hz mode, where the primary natural frequency and pipe response were prominent, and the attenuation ratio of the 1st natural frequency was 0.30% calculated from the free vibration responses under elastic behavior.

Previous studies considering the nonlinear behavior of tees, which are nuclear piping components, do not provide specific guidelines for the shape of tees and specific elemental constructions [4]. This study would deals with the construction of FEMs that can simulate nonlinear behavior characteristics through sensitivity analysis for tee components whose shape information has been determined, and it is meaningful that the actual response of nuclear power plant piping system under the BDBE, also including the shaking table test, can be derived.

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