Application of Bayesian Updating to Seismic Fragility Analysis of Piping System

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1. Introduction

In this study, based on the existing seismic fragility method, so-called as an EPRI Separation of Variables (SOV) method [1], we intend to propose a piping seismic fragility method using Bayesian updating technique. In order to prove the effectiveness of the proposed method, it is verified by being compared with the existing method based on the building-piping coupled structural model.

2. Proposed approach

In this study, based on the existing piping seismic fragility method, the EPRI SOV method, a Bayesian updating concept is introduced to propose a method for calculating a relatively accurate piping seismic fragility curve (see Fig. 1). In detail, first, a numerical analysis model of the building-piping coupled system is created. Besides, a single design earthquake ground motion input that matches the design-basis intensity is defined at the building foundation. A dynamic seismic response analysis is performed on the basis of the constituted building-piping coupled numerical model and the defined ground motion input. Based on the numerical analysis results calculated as above, the first step is to derive a prior seismic fragility curve of the piping system using the EPRI SOV seismic fragility method. The next step is to select and define the additional required seismic intensity to improve the accuracy of the prior seismic fragility curve. Based on the selected seismic intensity, several earthquake ground motions are scaled, and nonlinear time history analyses (NTHA) are repeatedly performed based on the scaled seismic input. Based on the numerical analysis results, a conditional failure probability is calculated from each selected seismic intensity. Lastly, based on the calculated conditional failure probabilities at the selected seismic intensities, the failure probability information of the prior piping seismic fragility curve is re-evaluated using the Bayesian updating technique to derive the posterior seismic fragility curve. Consequently, the proposed approach can improve the accuracy of the seismic fragility curve obtained from the existing EPRI SOV method through additional nonlinear seismic response analyses. Here, the EPRI SOV method utilized in the proposed method adopted the coupled-seismic analysis instead of the decoupled approach.

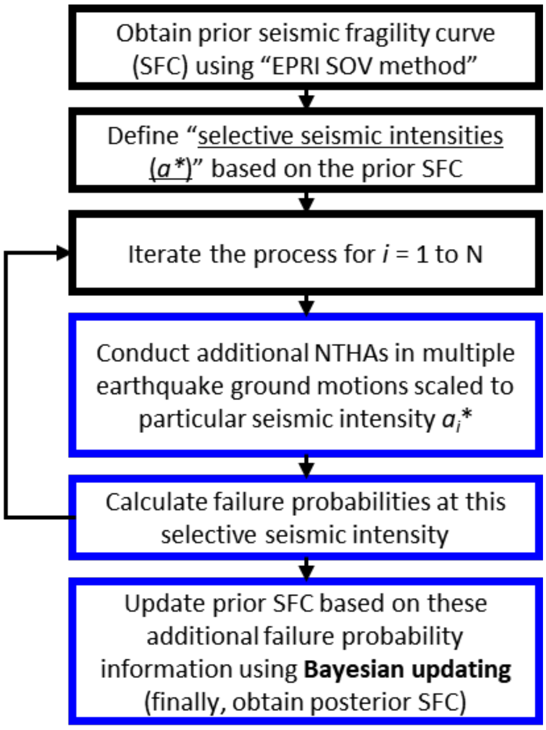

Fig. 1. Application of Bayesian updating to seismic fragility analysis

3. Results

The numerical model of the building-piping coupled system used in this study was developed with the OPENSEES (The Open System for Earthquake Engineering Simulation) code, as shown in Fig. 2. The major seismic fragile location of the piping system was defined as the T-joint portion (T104) of the 2-inch pipe where the leakage was observed in the piping dynamic test [2]. When applying the EPRI SOV method, A_{DBE}, which is the design seismic intensity introduced into the building foundation, was assumed to be 0.2g in consideration of the seismic design regulations for building structures. Based on the design ground motion input corresponding to the A_{DBE}, the seismic response analysis was performed on the numerical model of the building-piping coupled system, and the maximum rotation angle response of T104 was evaluated to be 0.003 radian. Considering the calculated maximum rotation angle response and the limit rotation angle of 0.0135 radian of the 2-inch pipe T joint, the safety factor F value can be determined as "4.5". In addition, if

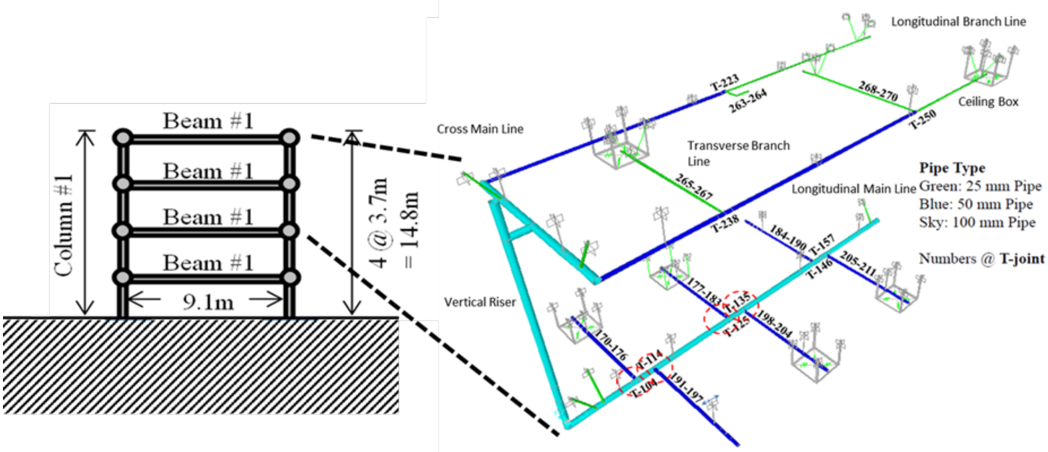

Fig. 2. Building-piping coupled numerical model

the uncertainty related to the piping system is assumed to be the log-standard deviation value of 0.3 using the existing piping fragility study results, the final seismic fragility curve can be represented by the "blue dashed line" graph in Fig. 3 (A_m = 0.9 g, β_c = 0.3). Here, several factors such as characteristics of the piping itself or any other assumptions which can affect fragility result can be incorporated into the safety factor if needed.

Since the EPRI SOV method does not reflect the nonlinear dynamic behavior characteristics of the piping system as the seismic intensity increases, it is impossible to derive an accurate seismic fragility curve. Accordingly, the method proposed in this study was applied to the seismic fragility analysis of the target piping system. Based on the seismic fragility curve of the EPRI SOV method, additional NTHAs were performed at seismic intensities of 0.6g and 1.2g to further improve the accuracy of this prior curve and based on this conditional failure probability information was calculated at these seismic intensities. Finally, based on the Bayesian inference, the probability distribution of key variables of the seismic fragility curve obtained from the EPRI SOV method was updated using the newly obtained conditional failure probability information. Fig. 3 compares the seismic fragility curves from different approaches. As can be seen in the Figure, the accuracy of the seismic fragility curve of the EPRI SOV method is improved by the Bayesian updating technique.

4. Summary and conclusions

In this study, based on the existing EPRI SOV seismic fragility analysis method, we proposed an approach to calculate the piping seismic fragility curve using the Bayesian updating concept. In order to verify the validity of the proposed method, it was applied to an example of a coupled structural system of a building and piping to calculate the seismic fragility curve of the piping system. As a result, it was seen that the proposed method improved the accuracy by using the Bayesian updating concept compared to the existing method.

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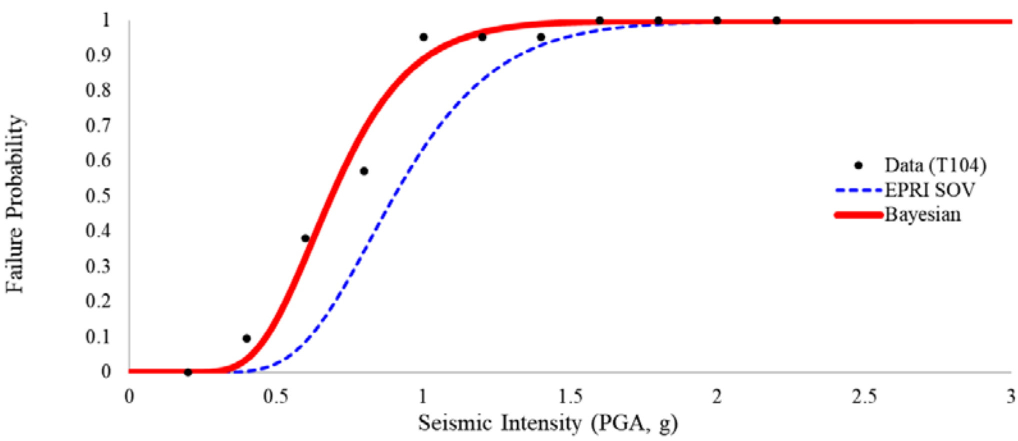

Fig. 3. Piping seismic fragility curves regarding T104