Seismic Fragility Curve Update Based on Empirical Fragility Estimates Employing Automated ERGO Platform

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ABSTRACT: In this study, a new method for efficiently updating the seismic fragility curves of structures based on actual fragility data is proposed. A seismic fragility curve is typically represented by the two parameters of a lognormal distribution, a logarithmic mean and a logarithmic standard deviation. To simulate seismic losses with distribution parameters and find the optimal values, this study employs ERGO, which is a seismic risk assessment platform. However, ERGO comprises a graphic user interface (GUI), which makes it difficult to run ERGO repeatedly and automatically during optimization analysis. Hence, an automated ERGO platform that enables GUI-based ERGO analysis through macro control in MATLAB is developed for updating the distribution parameters of seismic fragility curves. Using the automated platform, optimization is performed to obtain the optimal values of parameters of a seismic fragility curve based on actual fragility estimates. To test the proposed method, it was applied to update the seismic fragility curves of building structures in the Republic of Korea. Based on actual building damage, the fragility curve for a certain building type was successfully updated, and the updated fragility curve contains smaller errors with respect to the actual damage probabilities than the original fragility curve.

1. INTRODUCTION

An earthquakes often affects a large area and results in significant physical and socioeconomic losses. Thus, seismic risk assessment is essential to reduce such losses caused by earthquakes, and accurate seismic fragility curves are known to be key to reliable seismic risk assessment (Yoon et al., 2018). A seismic fragility curve is typically defined as a probabilistic distribution in which a structure will be damaged at a certain level by an intensity measure and is commonly used to indicate the vulnerability of a structure to an earthquake. Mathematically, a seismic fragility curve is represented by the two parameters of a lognormal distribution, a logarithmic mean and a logarithmic standard deviation. Moreover, seismic fragility curves are broadly used in earthquake loss estimation and seismic risk assessment software packages such as HAZUS (FEMA, 2013) and ERGO, previously known as MAEviz (Elnashai et al., 2008). Such software packages essentially use seismic fragility curves to estimate the post-earthquake losses of various structures. Among various software packages for seismic loss estimation, ERGO has a visual-based interface with a user-friendly and open-source platform (Hosseinpour et al., 2021). Another advantage of ERGO is that it is publicly accessible. Ergo allows decision-makers plan to mitigate post-earthquake losses. In this context, deriving an accurate seismic fragility curve is essential for efficient seismic risk assessment and disaster mitigation strategy.

Researchers have developed different seismic fragility curves for various structures, and some researchers have attempted to improve seismic fragility curves based on empirical damage to derive more accurate seismic fragility curves (Lee et al., 2021). However, a simple and efficient updating method must be identified. In this study, a new method to efficiently update the seismic fragility curve of a structure is proposed based on actual earthquake damage. To update a seismic fragility curve based on actual fragility data, a specific earthquake must be simulated and the optimal parameters of a seismic fragility curve that approximate the actual damage must be identified. For the task, ERGO, geographic information system (GIS)-based seismic risk assessment software jointly developed by the Mid America Earthquake (MAE) Center and the National Center for Supercomputing at the University of Illinois, is used to simulate and estimate earthquake losses.

Although ERGO has been used to predict seismic damage in target area given earthquake scenarios, its graphic user interface (GUI) makes it difficult to run the software repeatedly and automatically during optimization analysis. Hence, the proposed method is devised for an automated ERGO platform that allows the distribution parameters to be updated via GUI-based ERGO analysis using an automatic mouse and keyboard control in MATLAB. This automation platform is suitable for iterative analysis tasks, and optimization is performed using this platform to obtain the optimal values of the distribution parameters of a seismic fragility curve based on actual fragility estimates. This process, which can be used to manage different structure types, allows seismic fragility curves to be updated.

The proposed method comprises three steps: 1) input data preprocessing of ERGO, 2) analysis of estimated earthquake damage using the ERGO automation platform, and 3) optimization analysis and derivation of an optimal seismic fragility curve. The proposed method and its application are described in more detail in the following sections.

2. PROPOSED METHOD FOR UPDATING FRAGILITY CURVE

2.1. Input data preprocessing of ERGO

Preprocessing is required for the data used as the input for ERGO. The main input data of ERGO can be categorized into four types: structural inventory, seismic hazard information, seismic fragility curves, and seismic fragility mapping information.

First, structural inventory data means the characteristic information of a structure. For example, building inventory means the building type and location, the number of floors, and the year of construction. Among them, the most important information is the structure location, which comprises the latitude and longitude coordinate data of the WGS84 coordinate system. This is because the ground acceleration calculated from the seismic hazard information can be input only when the location information is available and the seismic damage probability of a structure is critically dependent with the structural location.

Second, seismic hazard information is necessary because ERGO needs to create a scenario earthquake based on the information. In detail, a ground attenuation law, the latitude and longitude coordinate data of the epicenter, the focal depth, and the magnitude are necessary for the earthquake scenario generation. ERGO provide various built-in attenuation laws, and users can specify the fault type, azimuth, dip angle, etc. based on the characteristics of each attenuation.

Third, seismic fragility curves are required to calculate the damage probabilities of structures given the ground motion intensities. A seismic fragility curve is typically represented by the two parameters of a lognormal distribution, a logarithmic mean and a logarithmic standard deviation.

Last, the structural inventory and fragility curves must be matched through seismic mapping. In the case of buildings, the main variables of seismic fragility mapping are structure type, number of floors, and the year of construction. After mapping the structure and fragility curves using these variables, the failure probability is calculated at a specific ground acceleration.

2.2. Proposed Method

ERGO performs seismic loss analysis based on a GUI environment, which allows users to execute the analysis intuitively and more easily compared with constructing the source code. However, when iterative analysis must be performed, an individual analysis of the earthquake scenario becomes difficult. Hence, the ERGO automated platform was constructed with a GUI control module using the robot class of Java supported by MATLAB.

The robot class is typically used to generate system input events for applications that require mouse and keyboard control. The automated ERGO platform utilizes the robot class function to perform software operation and seismic damage simulation using mouse and keyboard control commands, among the GUI control modules. Thus, the platform can automatically perform iterative seismic simulation analysis and various damage probabilities can be estimated for structures in the target area.

Using the GUI control module, optimization was performed using the results of the estimated failure probability calculated in ERGO for each structure. The optimization was analyzed by defining the objective function, i.e., the mean absolute error (MAE), expressed in Equation (1) below.

$$f(\boldsymbol{\theta}) = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i| \qquad (1)$$

where $\boldsymbol{\theta}$ is the vector of the distribution parameters (i.e., logarithmic mean and logarithmic standard deviation) of the lognormal distribution that represents the seismic fragility curve; n is the number of earthquake-damaged areas; y_i is the number of actual damaged building in the ith area; and $\hat{y}_i$ is the estimated number of damaged buildings in the ith area, which is obtained by multiplying the damage probability obtained from the ERGO analysis by the number of total buildings in the target area.

Subsequently, an optimal seismic fragility curve can be derived using the Nelder–Mead simplex algorithm provided by an optimization toolbox in MATLAB (Lagarias et al., 1998). To perform this optimization, the number of actual damaged buildings in the target area to be used as an actual value (e.g., the number of total and seismically damaged structures in each area) must be investigated in advance.

The flowchart of the proposed method is shown in Figure 1. The invariable input information in ERGO analysis is inventory, hazard, fragility, and mapping. These information should be entered based on parameters subject to continuous updating in the proposed method as design variables of the seismic fragility curve. A user cannot easily change the parameters of the seismic fragility curve directly (i.e., probability distribution parameters) and proceed with the ERGO analysis accordingly during the iterative process of optimization; therefore, the automated ERGO analysis platform was adopted, in which optimization analysis is executed based on the estimated damage probabilities multiplied by the total building number in the target area of a structure. Subsequently, the optimal parameter value for reducing error is identified, and the optimal seismic fragility curve is obtained.

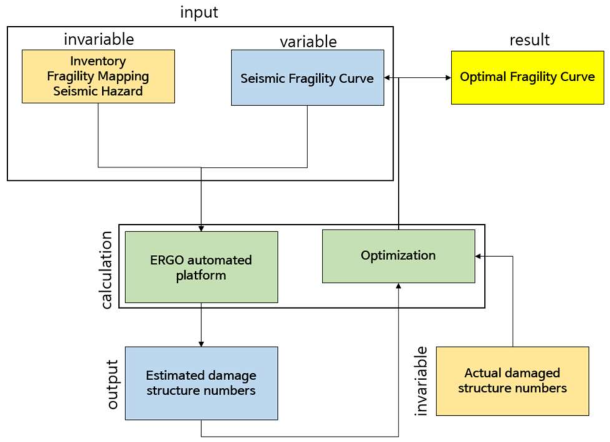

Figure 1: Flowchart of proposed method

3. APPLICATION EXAMPLE

To illustrate the proposed method, the 2017 Pohang earthquake damage data were applied to a case. Among the post-earthquake reconnaissance data, the concrete moment frame with shear wall (C4L2) building type was selected. The number of damaged buildings was considered for each 2 km × 2 km grid corresponding to Pohang City, as shown in Table 1 and Figure 2.

Table 1: Number of total and damaged C4L2 buildings.

Grid number	SA	Number of buildings	Number of damaged buildings
1	0.2982	2	0
2	0.3493	0	0
3	0.4274	6	0
4	0.3602	17	0
5	0.3196	10	1
6	0.3438	0	0
7	0.4540	0	0
8	0.4738	11	0
9	0.4505	0	0
10	0.4022	6	0
11	0.3602	0	0
12	0.3914	2	0
13	0.4792	0	0
14	0.4370	3	0
15	0.4010	36	19
16	0.3317	3	0
17	0.4279	0	0
18	0.4759	3	0
19	0.4603	96	15
20	0.4170	45	11
21	0.3101	0	0
22	0.3461	1	0
23	0.3994	4	0
24	0.4309	43	8
25	0.3894	10	4

Spectral acceleration (SA) was calculated from the observation data of the Korea Meteorological Administration and the seismic disaster response system of the Ministry of Public Administration and Security in the Republic of Korea. In addition, the total number of buildings and the number of damaged buildings were aggregated based on a field survey (Kim et al., 2020). To visualize the grid and area, the Pohang area and 2 km × 2 km grids with a GIS map of scale 1:20000 are illustrated in Figure 2.

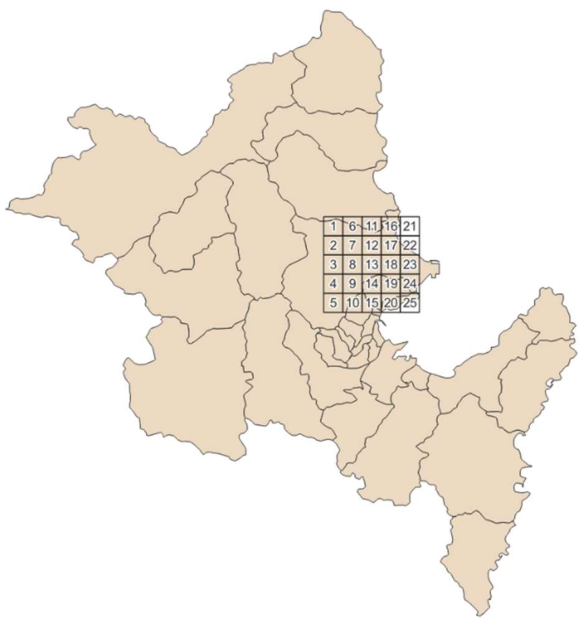

Figure 2: 2 km × 2 km grid in target area.

As the location of all C4L2 structures could not be observed, the inventory was idealized as central points of 25 grids, and the failure probabilities calculated at each central point were multiplied by the total number of buildings in the grid.

Meanwhile, the seismic hazard information used by Spudich et al. (1999), which is predefined in ERGO, was used, and other information such as the magnitude and epicenter was set based on the 2017 Pohang earthquake. For the seismic fragility curve, the C4L2 type was used, and the seismic fragility mapping was set to allow substitution between the inventory and fragility curve such that analysis in ERGO was realizable.

As mentioned in Section 2, the Nelder–Mead simplex algorithm was executed using the above-mentioned input data and MAE as an objective function. At this time, iterative ERGO analysis was required; therefore, analysis was performed in the ERGO automated.

Figure 3 shows the result of the updated seismic fragility curve based on the actual fragility data for C4L2. In Figure 3, the blue dots indicate the actual damage probability, which is the damaged C4L2 number divided by the total C4L2 number shown in Table 1, and the thick dots indicate the probability of more than 10 damaged C4L2. Although the probability definition is restricted owing to the few numbers of aggregated C4L2, it was defined as the probability to express the fragility curve.

The original fragility curve shows a relatively large error with respect to the actual damaged building number; however, the probability number approached by the updated fragility curve based on the proposed method was similar to the empirical probability.

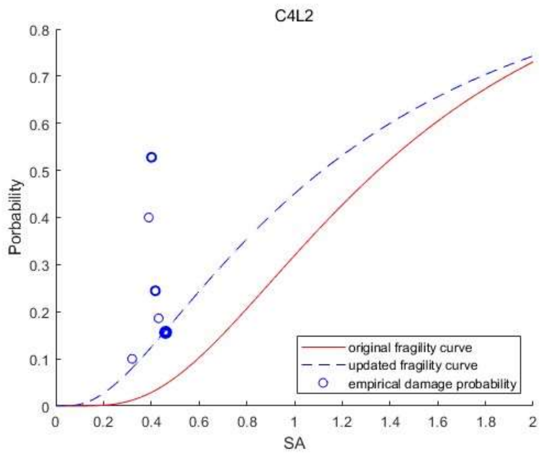

Figure 3: Seismic fragility curve update results for C4L2.

This shows that the proposed method successfully updated the seismic fragility curve by reflecting the actual data. If various actual damage data (i.e., the number of damaged structures) for various building types can be obtained in the future, then it can be analyzed. Consequently, multiple seismic fragility curves can be simultaneously updated.

4. CONCLUSIONS

In this study, a new method for efficiently updating the seismic fragility curve of a structure based on actual fragility data was proposed. A seismic fragility curve is generally modeled as a lognormal distribution, which requires the determination of two distribution parameters: the logarithmic mean and logarithmic standard deviation. The proposed method comprises three phases: 1) input data preprocessing of ERGO, 2) analysis of estimated earthquake damage using the ERGO automation platform, and 3) optimization analysis and derivation of an optimal seismic fragility curve. The automated ERGO platform, which enables controlling the GUI of ERGO to automatically update distribution parameters through macro control in MATLAB, was implemented. Using the automated platform, optimization was performed to obtain the optimal values of the distribution parameters of a seismic fragility curve based on actual earthquake damage.

To illustrate the proposed method, it was applied to the seismic fragility curve of the C4L2 building structure in the Republic of Korea based on the 2017 Pohang earthquake. The seismic fragility curve for the C4L2 building type was successfully updated, and the updated fragility curve indicated less errors with respect to the actual damage probabilities than the original fragility curve. In this study, only one seismic fragility curve was updated. However, if more actual damage data are obtained, then multiple seismic fragility curves can be updated simultaneously.

5. ACKNOWLEDGEMENT

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