Probabilistic seismic risk assessment of buildings in Thailand based on proper orthogonal decomposition

Junxian LI[1], Hidekazu USAMI[2], Shuji MORIGUCHI[3], Kenjiro TERADA[4],
[1]Member of JSCE, Dept. of Civil Eng., Tohoku University
[2]Member of JSCE, Dept. of Civil Eng., Tohoku University
[3]Member of JSCE, Associate Professor, IRIDeS., Tohoku University
[4]Member of JSCE, Professor, IRIDeS, Tohoku University
FAX: 022-752-2133, E-mail: li.junxian.s4@dc.tohoku.ac.jp

This study presents a new framework for probabilistic risk assessment of buildings under seismic conditions. A part of Chiang Mai city (Thailand) is selected as a target area, and a building damage evaluation method developed in HAZUS is employed in the numerical simulations. We prepared simulated results with a variety of situations by changing locations of earthquake sources and their magnitudes. Based on the obtained results, the seismic risk of buildings in Chiang Mai is analyzed. The proposed framework can provide an efficient approach to the probabilistic seismic risk analysis, and it has a high potential for disaster risk assessment.

1. INTRODUCTION

At the present day, with the rapid development of numerical analysis technology, it is possible to simulate earthquake damage. However, it is generally essential to consider many uncertain factors in the damage analysis; that is, a large number of calculation cases are required. This leads to an increase in calculation costs. In this study, we propose a low-cost real-time risk assessment method by extracting data features from the results of numerical simulations. Specifically, we apply the Proper Orthogonal Decomposition (POD) to the spatial distribution of a simulated building damage rate in a part of Chiang Mai city and extract the principal spatial modes. The spatial modes enable us to create a surrogate model that can predict the spatial distribution of building damage with low calculation cost. The past earthquake data in the target area show that earthquakes frequently occurred, even the magnitude is small. It is necessary to assess the damage that may arise. By applying the proposed method to the risk analysis in the target area, its performance is validated.

2. DAMAGE ANALYSIS AND MODE DECOMPOSITION

(1) A method of building damage analysis

A numerical analysis based on the Capacity Spectrum Method (CSM)[1)] and HAZUS[2)] methodology is employed to evaluate the seismic damage of buildings. Buildings in Chiang Mai Municipality were classified and placed in a Geographic Information System (GIS) database based on the results of a field survey. There are 80,290 buildings in Chiang Mai Municipality, which can be classified by the HAZUS methodology into eight types[3)]. Then, building damage to the Chiang Mai Municipality was analyzed with possible earthquake scenarios.

(2) Mode decomposition

POD is employed to extract spatial modes from the results of the numerical analysis. Given a data matrix $\boldsymbol{X}$ with N cases in simulated results $\boldsymbol{x}_i$. A covariance matrix can be obtained as the product of $\boldsymbol{X}$ and its transpose matrix $\boldsymbol{X}^{\boldsymbol{T}}$.

$$\boldsymbol{C} = \boldsymbol{X}^{\boldsymbol{T}}\boldsymbol{X} \tag{1}$$

By applying the eigenvalue decomposition to the covariance matrix, the eigenvalues λ_j and eigenvectors $\boldsymbol{v}_j$ can be obtained. On the other hand, based on the theory of singular value decomposition, $\boldsymbol{X}$ can be decomposed as below.

$$\boldsymbol{X} = \boldsymbol{U\Sigma V}^{\boldsymbol{T}} \tag{2}$$

$\boldsymbol{V}$ is the matrix of the eigenvectors, $\boldsymbol{\Sigma}$ is a diagonal matrix in which diagonal components are square of the eigenvalues, and $\boldsymbol{U}$ is the matrix of the spatial modes. Because $\boldsymbol{U}$ can be calculated, the data matrix $\boldsymbol{X}$ is expressed as a linear combination of the spatial modes with POD coefficients α as below.

$$\boldsymbol{x}_i = \sum_{j=1}^{N}(\sqrt{\lambda_j}v_{ij})\boldsymbol{u}_j = \sum_{j=1}^{N}\alpha_{ij}\boldsymbol{u}_j \tag{3}$$

Because the number of spatial modes that have significant physical meaning is limited, the above equation can be rewritten by reducing the number of spatial modes. Furthermore, a surrogate model of the numerical analysis is obtained by expressing the POD coefficients as functions of a set of input parameters $\boldsymbol{\theta}$ used in the numerical analysis.

$$\hat{\boldsymbol{x}}_i = \sum_{j=1}^{r} f_j(\boldsymbol{\theta})\boldsymbol{u}_j \tag{4}$$

where $\hat{\boldsymbol{x}}$ is a result of building damage rate calculated from the surrogate model, and f is an interpolation function.

3. PROBABILISTIC ANALYSIS THROUGH SURROGATE MODEL

Five different epicenter locations (see Figure 1) with magnitudes ranging from 4.0 to 6.0 varying by 0.25 are considered to cover the possible earthquake scenarios. Hence a total of 45 cases were analyzed. The POD coefficient α is expressed as a function A_j of the magnitude ($\boldsymbol{M}$) and the epicenter position (1-dimensional distance l_e measured along the fault from epicenter E), and through linear coupling to obtain a surrogate model of building damage rate, $\hat{x}$ can be created.

$$\hat{x}(l_e, \boldsymbol{M}) = \sum_{j=1}^{r} A_j(l_e, \boldsymbol{M})\boldsymbol{u}_j \tag{4}$$

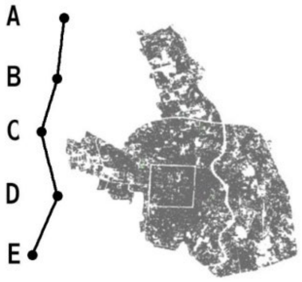

Fig. 1 The positional relationship between the target area and fault

Figures 2 and 3 show the damage rate maps obtained from the numerical analysis and the surrogate model, respectively. These results are obtained in the condition of magnitude 5.2 with the epicenter at midpoint between B and C. This indicates that the calculation case is not used to obtain the surrogate model. Although the result of the surrogate model is in good agreement with the simulated result qualitatively, we checked an error between two results. The error can be estimated by following equation.

$$e_{ij} = \frac{|x_{ij} - \hat{x}_{ij}|}{x_{ij}} \times 100 \tag{5}$$

where x_{ij} is the result of numerical analysis of the damage rate of building j in scheme i. $\hat{x}_{ij}$ is the result obtained by building the surrogate model in scheme i. According to calculated error, the error is usually less than 5%.

4. PROBABILISTIC ANALYSIS

Because the surrogate model can estimate distribution of building damage rate with low calculation cost, the model enables us to perform the Monte Carlo Simulation (MCS). The normal distribution and the uniform distribution were employed for distribution function of the magnitude and epicenter. Figure 4 shows an example of exceedance probability map in case that the damage rate is 0.3. As can be seen from the figure, proposed framework provides efficient probabilistic risk approach based on numerical simulations.

5. CONCLUSION

In this study, we proposed a new framework which enables us to perform probabilistic risk assessment of seismic building damage. A part of Chiang Mai city is selected as a target area, and the surrogate model of numerical analysis developed in HAZUS was built. Then, MCS was performed to discuss the risk based on probabilistic approach. The proposed framework can provide an efficient approach to the probabilistic seismic risk analysis, and it has a high potential for disaster risk assessment.

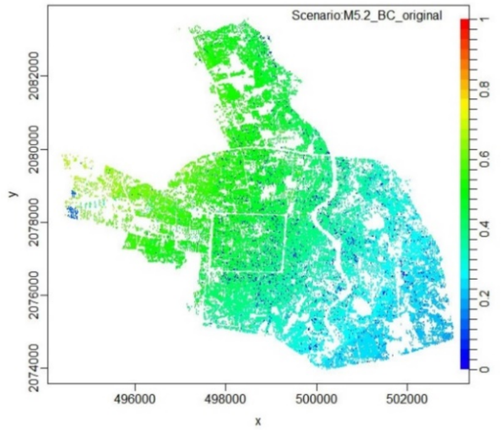

Fig.2 Damage rate map obtained from numerical analysis

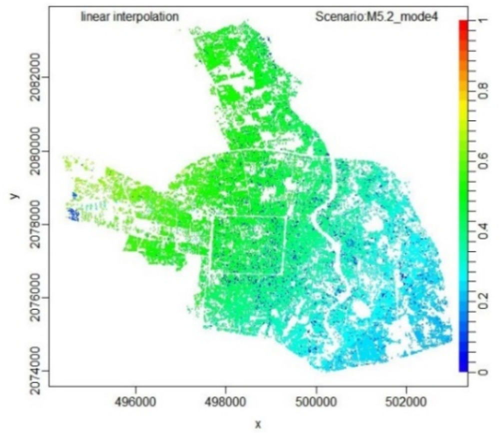

Fig.3 Damage rate map obtained from surrogate model

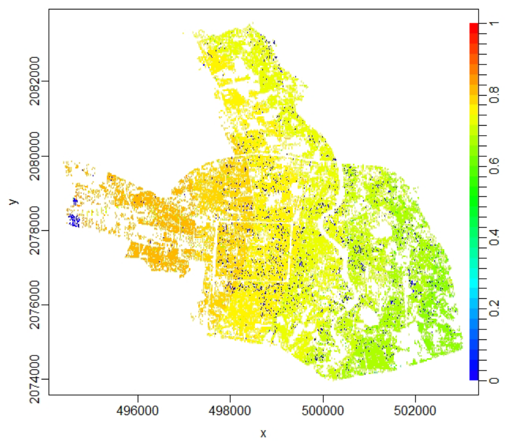

Fig.4 Exceedance probability map (damage rate 0.3)

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