Analysis of building damage mapping technique using seismic fragility funtions: A case study of the 2016 Mw 7.0 Kumamoto earthquake

Luis MOYA* Erick MAS‡
INTERNATIONAL RESEARCH INSTITUTE OF DISASTER SCIENCE (IRIDeS), TOHOKU UNIVERSITY, JAPAN

1. Introduction

Soon after an earthquake disaster, the distribution of building damage is crucial to disaster management. Damage mapping can be performed using remote sensing technologies (Yamazaki and Matsuoka, 2007) or based on statistical analysis from previous earthquakes, such as vulnerability matrices, vulnerability curves (i.e., fragility curves) or vulnerability indicators. The Mashiki town in Japan, was hit by two big earthquakes within 28 hours. The first earthquake, known as the foreshock, occurred on April 14, 2016, while the second event ocurred at April 16, 2016, hereafter referred as the mainshock. The mainshock produced a large amount of damage on buildings and casualties.

This paper evaluates the performance of the estimation of building damage distribution based on fragility curves by comparing with actual data obtained from a field survey.

2. Study area and data set

The building damage inventory was obtained from the field survey conducted by Integral Corporation, available in web (`http://jutaku.homeskun.com/taishin/jishin/2016_kumamoto_eq.html`). The survey was performed within the Mashiki town. Figure 1 shows the buildings that were surveyed, which were classified into three groups: no damage on the exterior (外観上被害無): 321 buildings, partial damage (半壊): 223 buildings, and complete collapse (全壊): 280 buildings.

Additionaly, historical aerial images are available from the Geospatial Information Authority of Japan (GSI). We used eight aerial images taken on 1956, 1964, 1975, 1982, 1992, 2003, 2008, and 2016 to estimate the construction year of each building. For instance, the aerial images shown in Figure 1, which were taken on 1964 and 2003, depict clearly the urban growth. Several areas were modified from agriculture field to urban areas including parts of the surveyed area. The following section shows the importance of this information.

3. Methodology

The estimation of damage level is based on empirical fragility functions proposed by Yamazaki and Murao (2000). A fragility function provides the likelihood that an element would experience or exceed a certain level of damage under a given engineering demand parameter (EDP) (Porter et al., 2007). In general for risk analyis, fragility curves are expressed

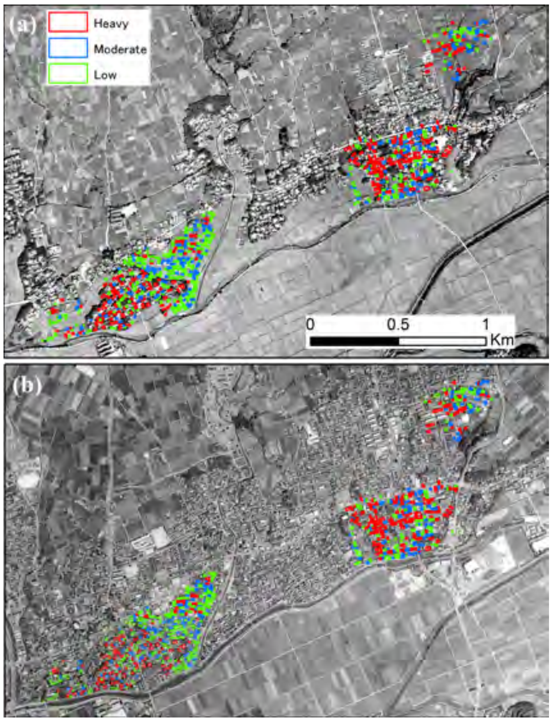

Figure 1: Aerial photos of the study area taken on 1964 (a) and 2003 (b)

as a logarithmic cumulative distribution function:

$$F_{dm}(edp) = P[DM \geq dm | EDP = edp] \quad (1)$$

$$F_{dm}(edp) = \Phi(\frac{\ln\left(edp/x_m\right)}{\beta}) \quad (2)$$

where Φ refers to the normal cumulative distribution function, x_m denotes the median value of the distribution, β is the logarithmic standar deviation, edp denots a specific value of EDP, and dm a specific damage state. Yamazaki and Murao (2000) used the building damage inventory collected after the 1995 Hyogoken-Nanbu (Kobe) earthquake and proposed a set of empirical fragility functions for four structural types: wood-frame, reinforced concrete, steel, and light gauge steel. Here, we use the fragility curves for wood-frame, which was divided in five construction periods: -1951, 1952-61, 1962-71, 1972-81, and 1982-94. For each construction period, three level of damage (heavy, moderate and slight/no damage) was stablished. In their study, the peak ground velocity (PGV) is used as EDP.

Figure 2 depicts the fragility curves for buildings with construction period of 1972-81.The set of fragility curves for each construction period clearly delimits the region of each damage states. For instance from Figure 2, a building with a demand of 100 cm/s as PGV has a probability of 0.18, 0.45,

*Resarcher, Laboratory of Remote Sensing and Geoinformatics for Disaster Management, IRIDeS, Tohoku University
†Associate Professor, Laboratory of Remote Sensing and Geoinformatics for Disaster Management, IRIDeS, Tohoku University
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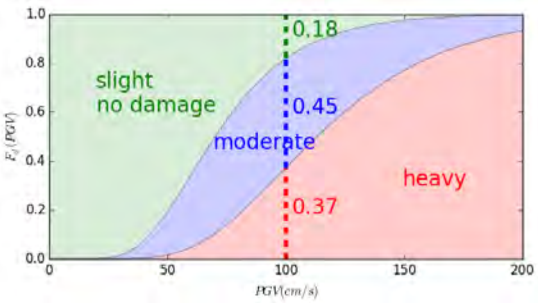

Figure 2: Fragility functions for wooden house

and 0.37 for slight/no damage, moderate, and heavy damage, respectively. Recall that when the demand (PGV) increases, the probability of heavy damage increases, while the probability of slight/no damage reduces.

The methodology applied here is based on an aleatory simulation in which the damage of each building is estimated from a random selection out of three possible outcomes (slight/no damage, moderate, or heavy). The random selection is performed using probabilities associated with each option, which is the probability of damage calculated from the fragility curves. Furthermore, the demand parameter (PGV) is provided by the framework QuiQuake (`https://gbank.gsj.jp/QuiQuake/index.en.html`) which calculated the spatial distribution based on simple kriging interpolation considering an attenuation law of the strong-motion networks of the National Research Institute for Earth Science and Disaster Prevention (NIED)(Figure 3). Another issue to be faced is the construction period. The years in which the aerial images were taken does not match perfectly with the construction periods of the fragility curves. Thus, two possible construction periods were associated for each building in most of the cases and when it was not clear because of the low resolution of the photos, three construction periods were associated in some cases.

4. Simulation

Three set of simulations based on the associated construction period of each building was performed: considering the oldest construction period (Figure 4a), an aleatory selection of the construction period (Figure 4b), and the newest construction period (Figure 4c). Each set consist of 500 simulations and the ratio of the damage states is recorded for each simulation.

5. Discussion and Conclusions

In general, the results show an overestimation of the heavy damage buildings; thus, the performance of the method is conservative. Additionally, the results show high sensitivity with the construction period and the results from the third set are the closest to the actual data. Therefore, with accurate information of building data inventory, this method can provide a first estimation of building damage distribution on real time.

Few words are necessary on behalf of our assumptions. Indeed epistemic uncertainties are presented in this study. The unavailability of fragility curves for buildings with construction buildings greater than 1995 and the lack of precise information of construction building are such examples. However, some conclusion can be extracted. Recall that new buildings have better seismic performance and thus it is expected a less amount of heavy damage buildings. The results of this preliminary evaluation is going to be updated when building data inventory of the affected area is released.

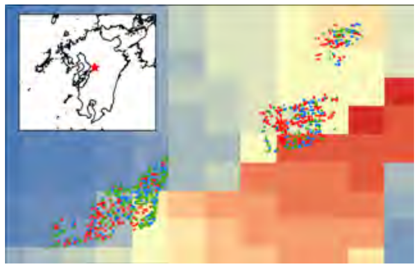

Figure 3: Spatial distribution of PGV

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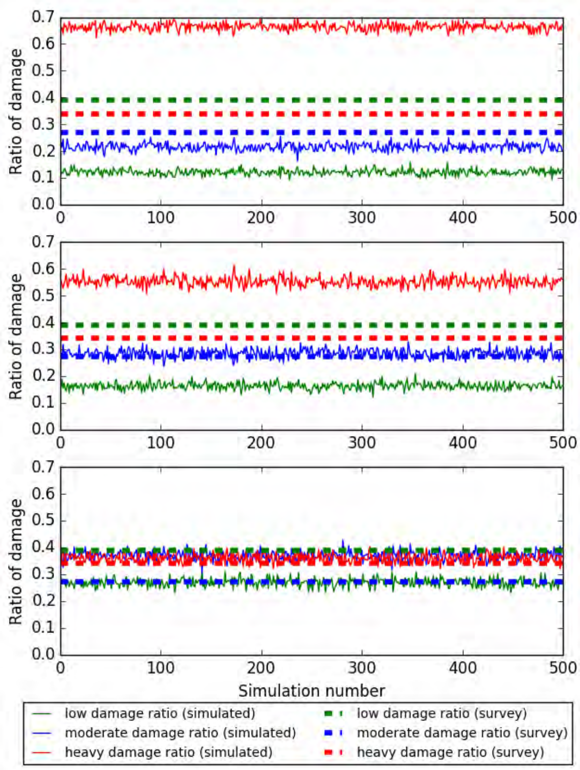

Figure 4: Ratio of damage calculated from the simulations