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Procedia Engineering 14 (2011) 227–232

Procedia Engineering

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The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction

Reevaluation Method of Fragility Curves of Wooden House Based on Collected Damage Information

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Abstract

The distribution of earthquake damage plays an important role in the rescue operation and the restoration work in the aftermath of a seismic event. Immediately after an earthquake, the building damage ratios are estimated using ground motion indices and fragility curves constructed from the prior earthquake damage information. However, it should be noted that the fragility curves may sometimes provide less accurate estimations for recent earthquakes. On the other hand, some researchers are focusing efforts on collecting the actual damage information efficiently soon after an earthquake has occurred. The increased attention to collecting the actual damage information is expected to improve the efficiency in the near future and become increasingly helpful for a rapid disaster assessment. In this study, a method for data synthesis to restructure fragility curves is proposed, with respect to the actual gathered damage information. Either the mean or the standard deviation of the prior fragility curve is updated based on collected building damage datasets after recent earthquakes. As a result, the restructured fragility curves with the updated mean values show better estimations than the original ones.

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Keywords: Type your keywords here, separated by semicolons ;

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1877–7058 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2011.07.027

1. Introduction

The distribution of earthquake ground motion is used for the disaster prevention system to predict damage distribution and emergency decision process. Since the actual damage information could not be obtained in the immediate aftermath of the 1995 Kobe earthquake, the rescue operation and the restoration work were delayed (Yamazaki 2001a).

Thereafter, seismometer networks are deployed by various institutions in Japan. Many of the earthquake disaster prevention systems predict building damage levels based on ground motion indices monitored by these systems. The building damage ratios are estimated using fragility curves constructed from the prior earthquake damage information. It should be noted that the fragility curves can sometimes provide some inaccuracies in estimations for the recent earthquakes.

On the other hand, some researchers have placed greater focus on the efficiency of collection of actual damage information after an earthquake has occurred (Shimizu *et al*. 2006). The remote sensing technology, mobile terminal combined with GIS and GPS and other systems are utilized to obtain the actual damage information (Yamazaki 2001b; Nojima and Sugito 2004). The actual damage ratios collected by these systems can be helpful to restructure fragility curves to improve the accuracy of estimations.

In this study, a method for data synthesis to restructure fragility curves is proposed with respect to actual collected damage information. First, a series of numerical simulations based on the methodology proposed by Nojima *et al.* (2003) are performed using the actual building damage ratios after the recent earthquakes in Japan. Then, as a proposed method of this study, either the mean or the standard deviation of the fragility curves constructed after the 1995 Kobe earthquake is updated based on actual damage datasets. The accuracy of estimations given by the proposed method is discussed by comparing the damage ratios after the 1995 Kobe earthquake with those after the 2004 Mid-Niigata earthquake.

2. Numerical Simulation Following the Previous Research

Nojima *et al*. (2003) proposed a methodology to re-evaluate building damage ratios with the aid of the actual damage information obtained by field surveys soon after an earthquake. In the study, damage levels are classified into two groupings, damaged and non-damaged, and the number of damaged buildings, denoted by n, is assumed to follow the binomial distribution with the damage probability p. In addition to that, the damage probability p is estimated from fragility curves using monitored seismic indices from a disaster prevention system. The mean and the standard deviation of the estimated damage probability p are defined as μ_p and σ_p, respectively.

Assuming that the number of damaged buildings is n_0 out of M_0 samples collected in a field survey, the updated mean of damage probability, μ_p', and the associated standard deviation, σ_p', are derived as

$$\mu'_p = \frac{n_0 + n'_0 + 1}{M_0 + M'_0 + 2} \tag{1}$$

$$\sigma'_p = \sqrt{\frac{(M_0 + M'_0 - n_0 - n'_0 + 1)(n_0 + n'_0 + 1)}{(M_0 + M'_0 + 2)^2 (M_0 + M'_0 + 3)}} \tag{2}$$

where

$$M'_0 = \frac{\mu_p (1 - \mu_p)}{\sigma_p^{\,2}} - 3 \tag{3}$$

$$n'_0 = \mu_p \left[\frac{\mu_p (1-\mu_p)}{\sigma_p^{\ 2}} - 1 \right] - 1 \tag{4}$$

According to the study by Nojima *et al.* (2003), to estimate the damage probability from the fragility curves is interpreted to find n_0’ damage buildings out of M_0’ samples in a field survey.

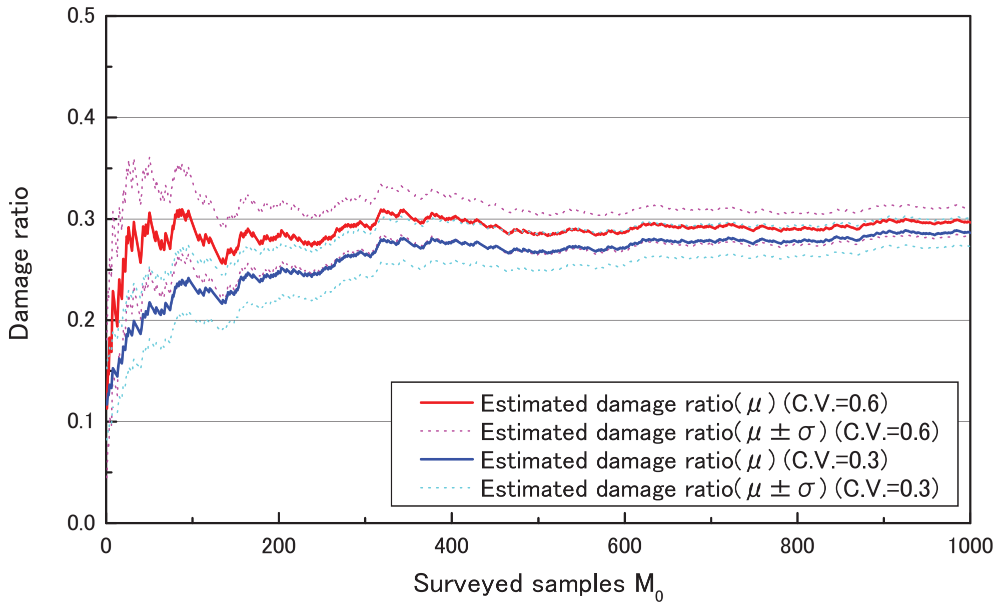

Figure 1: The reevaluated damage ratios with respect to the number of surveyed samples when the actual damage ratio is 0.3 and the coefficients of variation (C.V.) are set to be 0.6 and 0.3.

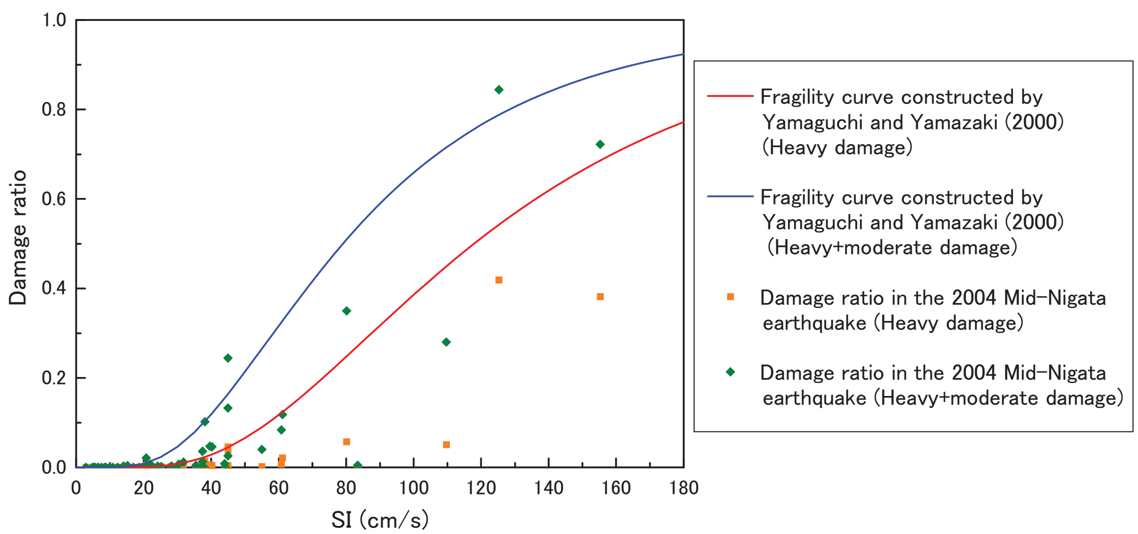

Figure 2: Comparison of the fragility curves constructed by Yamaguchi and Yamazaki (2000) and the actual damage ratios after the 2004 Mid-Niigata earthquake

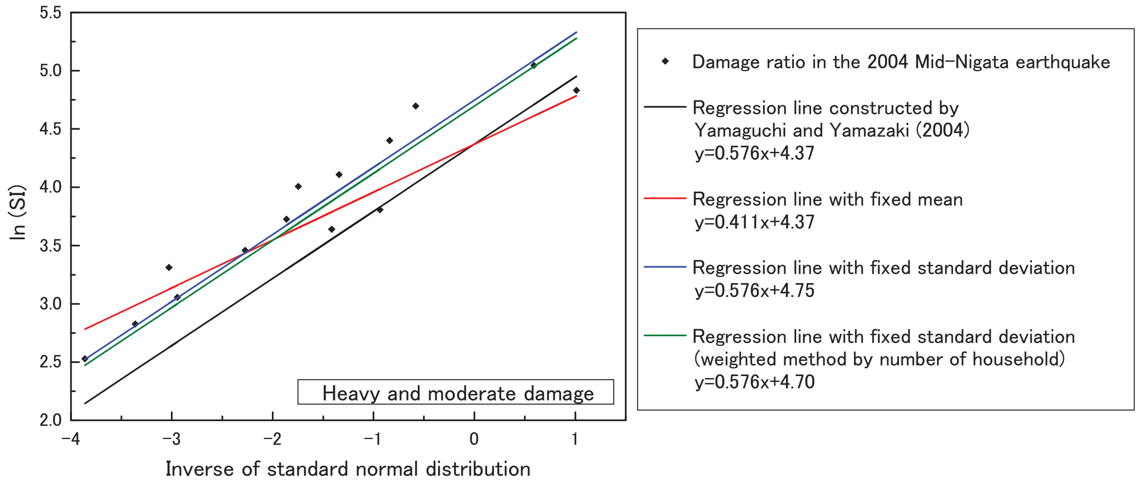

Figure 3: Regression analysis on the probability paper using the damage dataset after the 2004 Mid-Niigata earthquake.

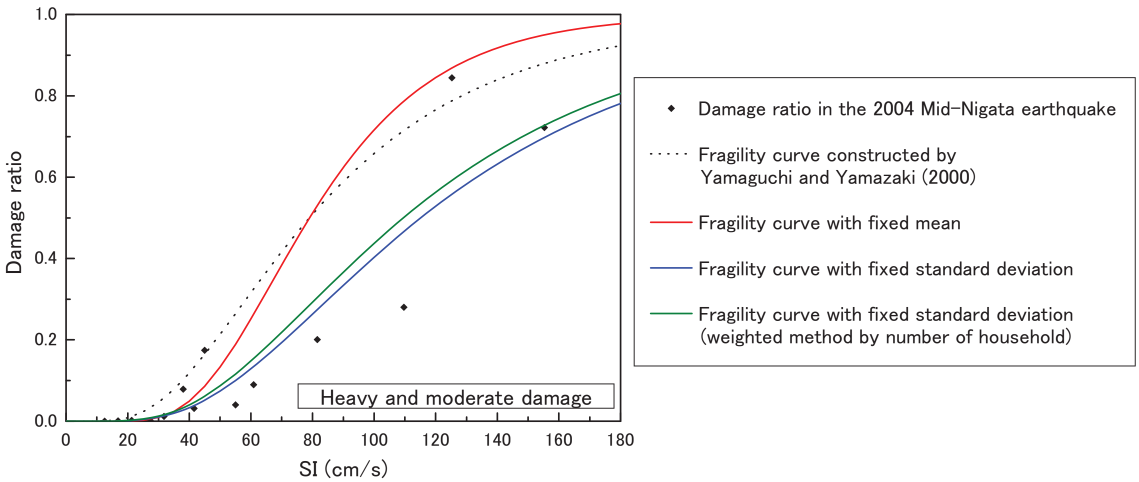

Figure 4: Reconstructed fragility curves to adjust the damage ratios in the 2004 Mid-Niigata earthquake. (Heavy and moderate damage ratios)

Figure 1 shows the result of numerical simulation supposing that the actual damage information for wooden houses is being collected. Here, the fragility curve to estimate the damage ratio of wooden houses just after an earthquake was constructed by Yamaguchi and Yamazaki (2000), which is shown in Eq. (5). The function is formulated with respect to the spectral intensity (SI) and the damage ratios are considered to follow the log-normal distribution.

$$P(SI) = \Phi((\ln SI - \lambda)/\zeta) \tag{5}$$

where Φ(x) is the cumulative distribution function of the standard normal distribution. For the totally or partially collapsed buildings, the mean, λ, and the standard deviation, ζ, of ln *SI* are set to be 4.37 and 0.576, respectively.

Supposing that the monitored SI is 40 cm/s, the mean of the damage ratio, μ_p, is 0.119 based on Eq. (5). The standard deviation, σ_p, is assumed to be 0.0711 when the coefficient of variation is 0.6. In the case, M_0' and n_0' are derived as 17.66 and 1.33, respectively, using Eqs. (3) and (4). If the actual damage ratio of wooden houses is assumed to be 0.3, the re-evaluated damage ratios with respect to the number of surveyed samples, M_0, are drawn red lines in Fig. 1. The renewed damage ratio reaches the actual one (= 0.3) when M_0 is almost equal to M_0'. If the coefficient of variation is set to be 0.3, the re-evaluated damage ratios are obtained as blue lines in Fig. 1. In this case, M_0' and n_0' are calculated as 79.65 and 8.68, respectively. Since the M_0' shows larger value than the coefficient of variation is set to be 0.3 as shown red lines in Fig. 1, the renewed damage ratio does not attain the actual damage ratio so soon.

3. Reconstruction of Fragility Curve Considering Actual Damage Ratio

The methodology introduced in the previous chapter is utilized to update the damage ratio associated with a sole seismic intensity. In this study, the fragility curve itself is adjusted to give estimations with respect to the actual damage ratio.

Figure 2 compares the fragility curves constructed by Yamaguchi and Yamazaki (2000) after the 1995 Kobe earthquake and the actual damage ratios for wooden houses in the 2004 Mid-Niigata earthquake. The damage dataset was compiled by Niigata Prefecture (2010). The two patterns of damage incidents, heavy and moderate, are considered in Fig. 2. According to the figure, the fragility curves overestimate the actual damage ratio. Since the characteristics of input ground motions differ from event to event and the seismic capacity of wooden houses differ from region to region, the empirical fragility curves sometimes may not provide the best fit.

Table 1: Coefficients of determination of regression analysis on the probability paper.

Damage level	Yamaguchi and Yamazaki (2000)	Fixed mean	Fixed standard deviation	Fixed standard deviation (Weighted)
Heavy damage	0.230	0.746	0.823	0.772
Heavy and moderate damage	0.626	0.856	0.894	0.889

To determine the two parameters of the fragility curve, λ and ζ, a detailed building damage dataset should be compiled. However, understandably it is difficult to prepare the dataset soon after an earthquake. Therefore, either the mean, λ, or the standard deviation, ζ, is adjusted by a regression analysis using the actual damage information of the 2004 Mid-Niigata earthquake (Fig. 3). One parameter is set to be the same as the previous study (Yamaguchi and Yamazaki 2000) while the other is obtained through the regression analysis. The weighted least squares method is considered in Fig. 3.

Figure 4 shows the reconstructed fragility curves to fit the damage ratios after the 2004 Mid-Niigata earthquake. According to the figure, the renewed fragility curves with fixed standard deviation show better estimations. The coefficients of determination on the probability paper (Table 1) indicate the same tendency. Hence, the parameter to be adjusted following the actual damage dataset should be the mean value, λ. However, it is difficult to judge whether the weighted least square method is better based on the results of this study alone. To draw a solid conclusion, the damage datasets from other earthquakes need to be analyzed.

4. Conclusion

In this study, empirical fragility curves were deformed to give better estimations by changing only one parameter assuming that actual damage ratios are available soon after an earthquake. The fragility curves have two parameters, the mean and the standard deviation; however, a detailed damage dataset is required to obtain them. Hence, either the mean or the standard deviation was determined by a regression analysis using immediately collected damage data.

As a result, the fragility curve with the renewed mean value shows better estimation than that with the renewed standard deviation. It is recommended that the mean value should be adjusted to the actual damage ratio; however, the suitable type of regression analysis is difficult to determine from the result of this study alone. To draw a solid conclusion, the damage datasets from other earthquakes should be analyzed to obtain a more accurate fit.

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