Simulations of damage on architectural structures due to unexpectedly great earthquakes

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SUMMARY
The purpose of this paper is to predict damage on architectural structures due to unexpectedly great earthquakes. We consider the Nankai earthquake and damage induced in Hyogo prefecture as an example. Given the Nankai earthquake model, we generate unexpectedly large earthquake vibrations by changing moment magnitude with keeping fault parameters. The simulations are performed on 250 meter grids in the Hyogo area. The peak bedrock velocity is estimated from the given magnitude and distance from the seismic center based on an attenuation relation, and the peak ground velocity is obtained by multiplying the peak bedrock velocity with an amplification factor depending on a geological condition of the surface. Based on the seismic intensity distribution obtained from the simulation, we estimate damage using a damage function and facility data. We report a summary of damage situation caused by ground motions of an unexpectedly great Nankai earthquake.

Keywords: Damage estimate, Nankai earthquake, Geographic information system

1. INTRODUCTION

In this study, using the ground tremors (seismic motion) from the Nankai earthquake, we calculate earthquake scale distribution within Hyogo prefecture through simulation. Using those results, we estimate the number of collapsed buildings due to seismic motion.

Following the Great Kobe Earthquake of 1995, approximately 30,000 temporary emergency dwellings were constructed. The Tohoku Earthquake of March 11th, 2011 was a massive earthquake of a magnitude of 9 (hereafter abbreviated to M9.0), and caused an extensive range of both human injury and building damage due to the seismic motion and the tsunami. In 58 municipalities and 913 districts in Iwate, Miyagi, Fukushima, Ibaraki, Tochigi, Chiba and Nagano, approximately 53,000 temporary emergency dwellings have been constructed. (Ministry of Land, Infrastructure, Transport and Tourism Housing Bureau documents, current as of 10am, April 2nd, 2012.) Following the occurrence of a large-scale earthquake, there is a requirement to extensively construct a great number of temporary emergency dwellings, and for the construction of temporary dwellings, it is important not only to prepare construction material, but also to prepare the selection of a site in advance.

This article consists of the following. In section 2, we conduct a simulation of seismic motion using an occurrence of the Nankai earthquake, and seek earthquake scale distribution for Hyogo prefecture. For the hypothetical earthquake magnitude, we carry out calculations for 3 cases; M8.4, M8.6 and M9.0. In section 3, using the earthquake scale distribution calculated in section 2, we tally the building damage using Geographic information System (GIS) software. For the building damage, we establish a ratio (called building damage function) that shows what degree of damage will be received based on the earthquake scale, and calculate through multiplying it with the counted whole building number. We believe that information related to general building damage circumstances is important for the sake of selecting a temporary emergency dwelling construction site, so we sort by buildings that exceed 6m and buildings under 6m, and carry out sum total. This is because we hypothesize that buildings under 6m are wooden buildings, and buildings that exceed 6m are buildings made of something other than wood (for example robust buildings made of reinforced concrete, etc). In section 4, for the conclusion, we vary the Earthquake scale to magnitudes of 8.4, 8.6 and 9.0 for the fault parameters from the 1854 (Ansei era) Nankai earthquake, and calculate the number of destroyed buildings corresponding to the earthquake scale, in scale with the seismic motion in Hyogo prefecture.

2. EARTHQUAKE SIMULATION

2.1. A Hypothesised Large-Scale Earthquake

Earthquakes can be largely divided into two types: near-field and interplate. For interplate earthquakes, because energy is accumulated in the faults through the movement of the plates, the earthquakes occur somewhat periodically, depending on the speed of the plate movement. In the Kansai and Shikoku regions, which includes Hyogo prefecture, the Nankai earthquake is an interplate earthquake which occurs periodically. According to records, large scale earthquakes have occurred in the past on a roughly 100 to 150 year cycle, in 1605 (Keicho era, M7.9-8.0), 1707 (Hoei era, M8.4), 1854 (Ansei era, M8.4), and 1946 (Showa era, M8.0), so it can be assumed that a large earthquake will occur once again in the near future.

In this article, in order to predict the building damage caused by the seismic motion and tsunami caused by a large-scale earthquake, we performed a simulation using the 1854 Nankai earthquake as a model. When performing the simulation of the seismic motion, it was necessary to determine the data for the fault that would cause the earthquake to occur, and the energy (moment magnitude) by which the earthquake would be unleashed. For earthquakes that have occurred in the past, this information is already known. Fig. 2.1 shows the parameters of the 1854 Nankai earthquake fault model. In addition, the fault location is shown in Fig. 2.1. The fault is subducted to the north. Next, for the simulation of the explained seismic motion and tsunami, we performed an earthquake simulation of differing magnitudes by modifying the released energy, using the parameters from Table 2.1 (Sato 1989).

Table 2.1. Fault parameters of 1854 Ansei-Nankai earthquake (M8.4)

Latitude [degree]	Longitude [degree]	Length [km]	Width [km]	Depth [km]	Strike [degree]	Dip [degree]	Slip [degree]	Dislocation [m]
32.7	134.74	150	120	1	250	20	117	6.3
33.41	136.15	150	70	10	250	10	127	4.7

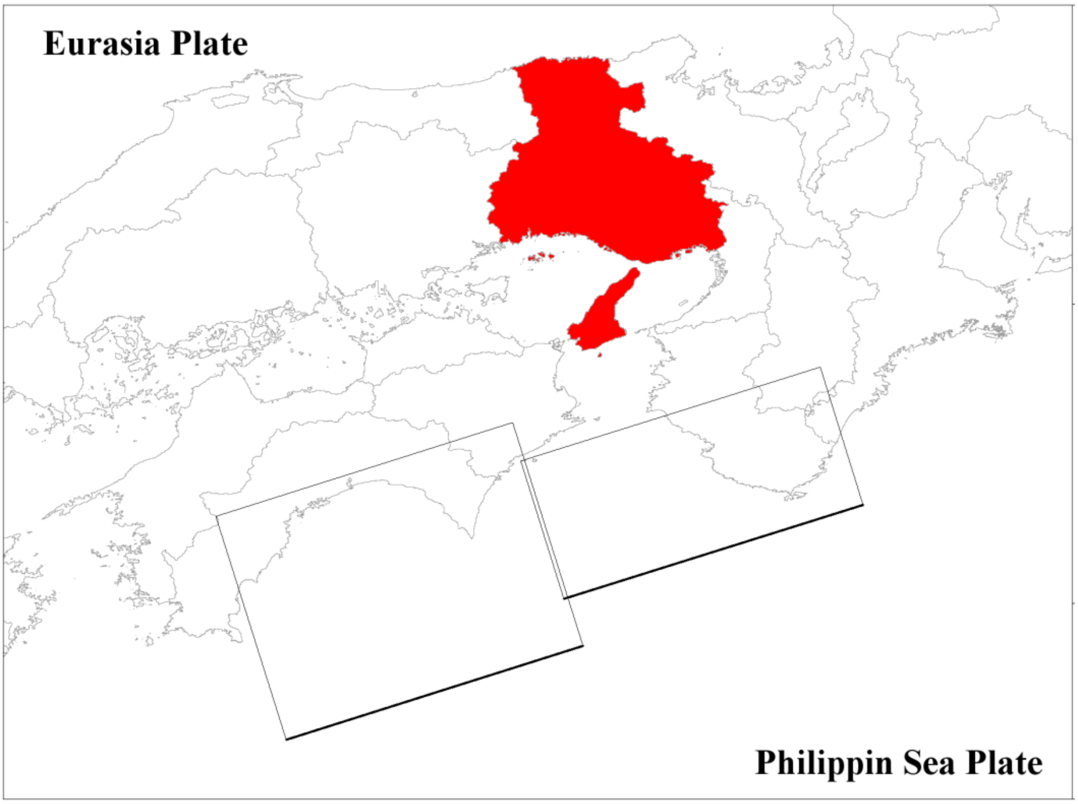

Figure 2.1. Model faults positions of 1854 Ansei-Nankai earthquake. Faults are modelled by two squares mapped on the western Japan. The red area shows the target analysis area (Hyogo prefecture).

2.2. Earthquake Simulation Results

For the earthquake model described in Sec. 2.1, we performed seismic meter calculations for in Hyogo prefecture, using the earthquake disaster prevention information system QUIET-J (KOZO KEIKAKU ENGINEERING Inc. 2004). With QUIET-J, it is possible to directly specify the scale of the earthquake as the "magnitude". Figures 2.2 to 2.4 show each respective case for M8.4, M8.6 and M9.0 of the earthquake scale distribution under Hyogo prefecture.

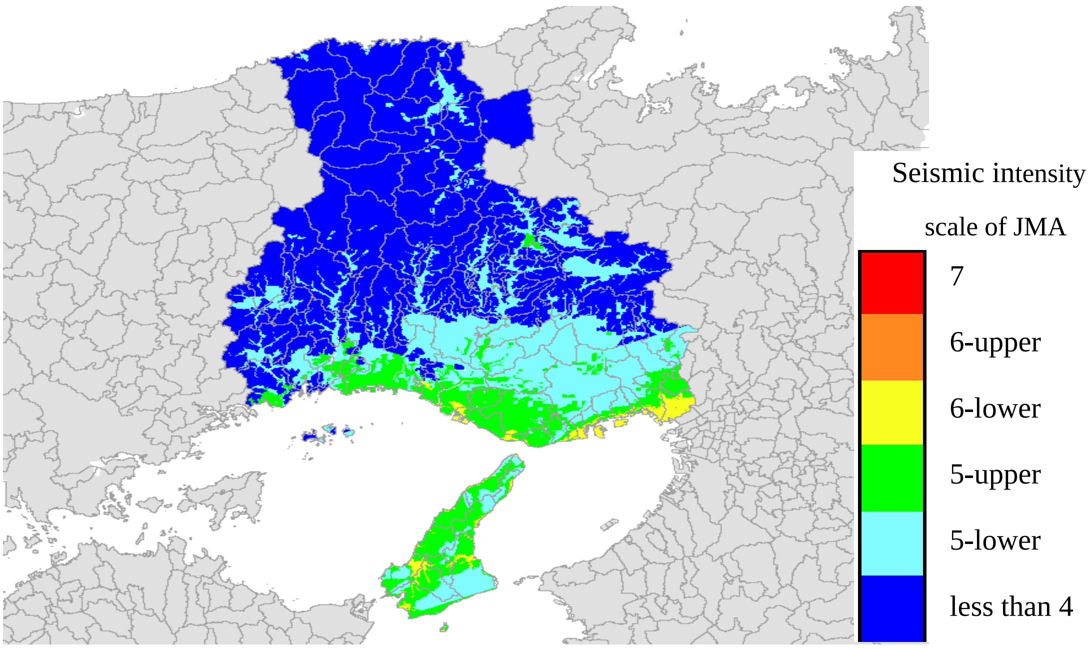

Figure 2.2. Seismic intensity distribution due to a Nankai earthquake (M8.4)

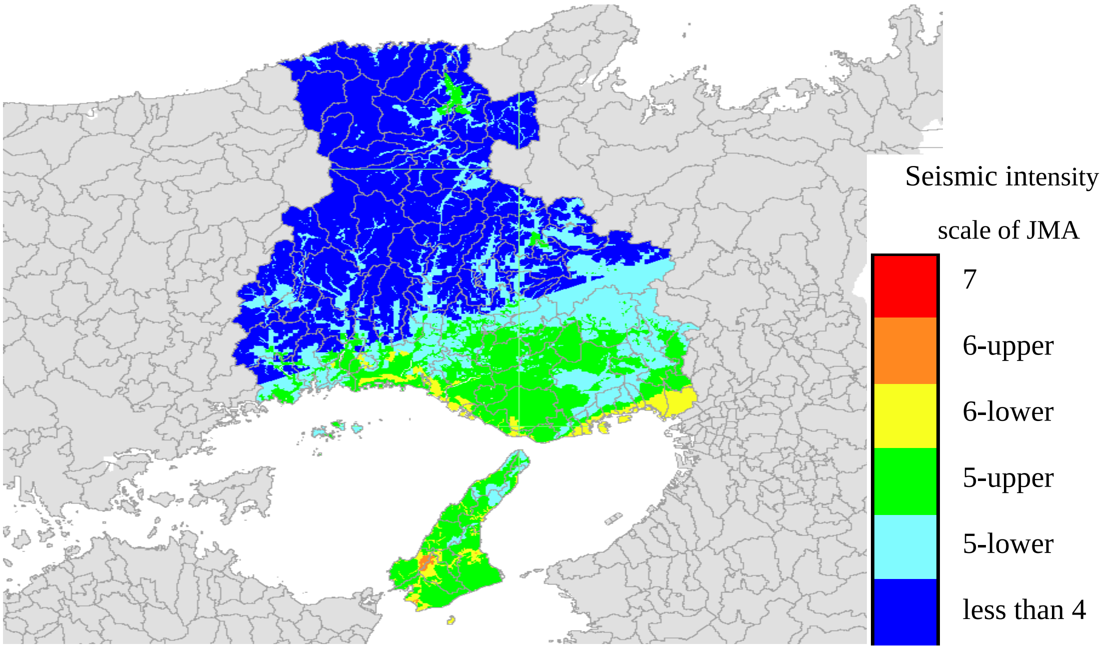

Figure 2.3. Seismic intensity distribution due to a Nankai earthquake (M8.6)

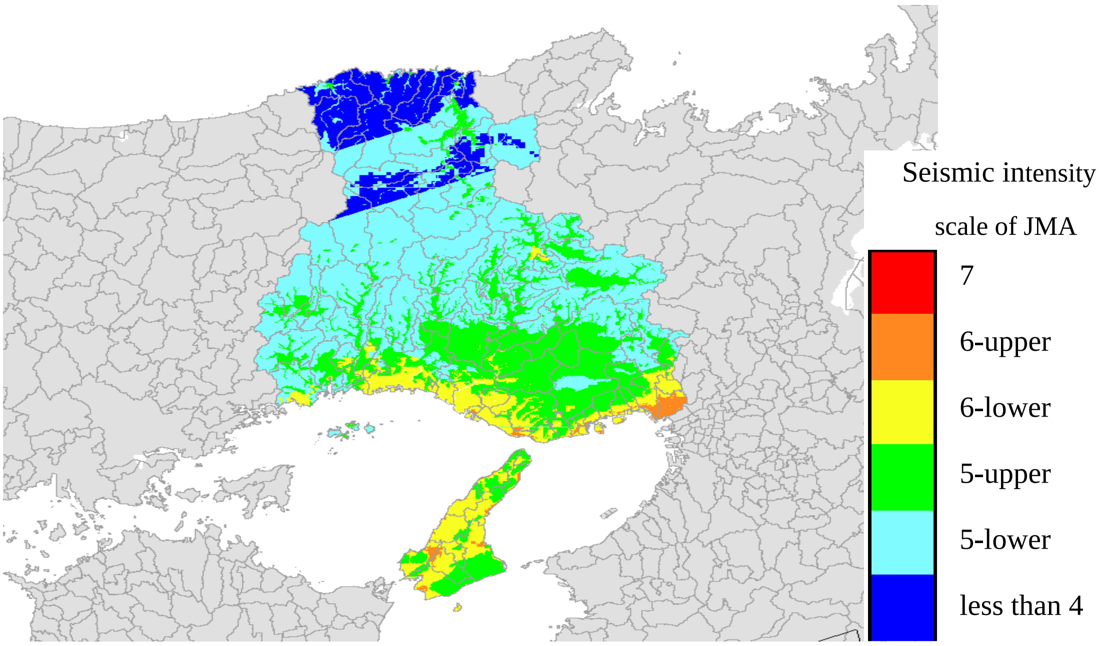

Figure 2.4. Seismic intensity distribution due to a Nankai earthquake (M9.0)

2.3. Simulation Results Conclusion

The earthquake scale is primarily decided by the distance from the fault and the data for the ground. In the simulation results, the area where seismic intensity is large would be the Osaka-Kobe area (in particular, Amagasaki and Nishinomiya) as well as Awaji Island (Miharagunseidanchou, Nandanchou), etc, and in the case of M8.4 would be on a seismic intensity scale of JMA 6-lower; in the case of M9.0 would be on a seismic intensity scale of JMA 6-upper.

3. DAMAGE ESTIMATE ON ARCHITECTURAL STRUCTURES

Using the seismic motion from the Nankai earthquake estimated in Sec. 2 as a base, we carried out a prediction of building damage within Hyogo prefecture. Using Geographic Information System software, we conducted the number of buildings for each scale of earthquake according to seismic motion, and then established a damage function for the seismic motion, and predicted building damage. To avoid double counting of damage due to earthquake motion and tsunami, we exclude the number of architectural structures which are marked as destroyed from the total number of them. (See Numata *et al*. (2012) for damage estimate due to tsunami.)

3.1. Building Damage Prediction by Seismic Motion

Fig. 3.1 shows the building damage function for wooden buildings, while Fig. 3.2 shows the building damage function for non-wooden buildings. The building damage ratio taken from these figures is summarized in Table 3.1.

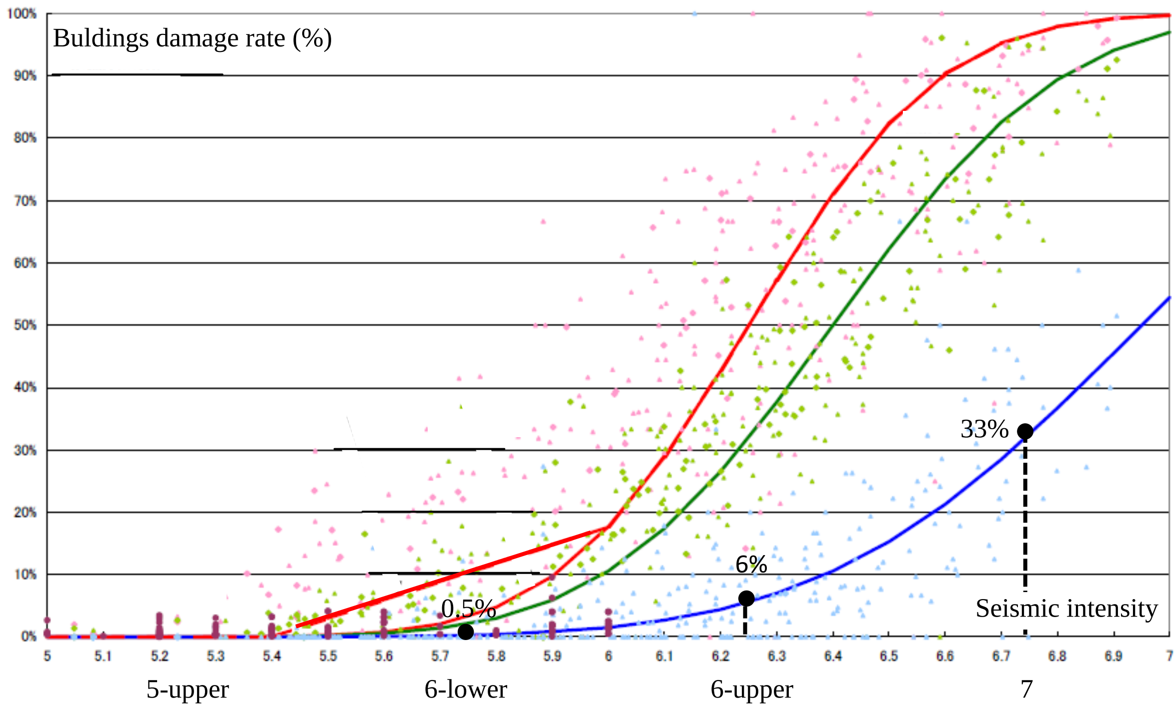

Figure 3.1. Functions of building damage rate corresponding to the seismic intensity（Completely destruction rate of wooden houses）: Blue line was adopted.

Table 3.1. Building damage rate corresponding to the seismic intensity (%)

Seismic intensity scale of JMA					
less than 4	5-lower	5-upper	6-lower	6-upper	7
0	0	0	0.5	6	33

Table 3.2. Estimate of damages on architectural structures

Magnitude	Seismic intensity scale of JMA					
	less than 4	5-lower	5-upper	6-lower	6-upper	7
M8.4	0	0	0	759	0	0
M8.6	0	0	0	1,412	229	0
M9.0	0	0	0	3,418	6,459	0

For the earthquake scale distribution obtained in Sec. 2, we counted the number of buildings for the corresponding area, and by multiplying these building damage functions, we predicted the number of buildings damaged. In addition, for houses made of wood, we divided them according to year of construction (prior to 1960, after 1981) and then established a damage function. However, in this current study, for the building damage number estimation, all wooden houses (less than 6m) were considered to be newly constructed. Table 3.2 shows the results of the number of buildings that received seismic motion damage from the earthquake for the 3 cases of earthquake scale distribution gained from the simulation. For the Nankai earthquake, we paid particular attention to the 3 areas assumed to show a particularly large scale of damage – the Osaka-Kobe area, Awaji Island, and the Himeji region – and the summarized results of wooden building damage distribution are shown in Figures 3.2 to 3.10. The yellow dots correspond to a single house that received damage. In addition, these figures only represent the damage distribution as dots; it must be noted that they are not showing that the building in that location will definitely receive damage.

3.2. Building Damage Prediction Results

Using seismic motion and tsunami hypothesised from the Nankai earthquake, we summarized the predicted results of the number of buildings that would receive damage. In this report, buildings were classified by their height of either over or under 6m, and buildings under 6m were deemed general buildings, and the number of general buildings damaged was counted. The number of damaged buildings due to seismic motion is shown in Table 3.3.

Table 3.3. Estimate of damages on architectural structures

Magnitude	total
M8.4	759
M8.6	1,641
M9.0	9,877

4. CONCLUSION

Using the fault parameters of the 1854 (Ansei era) Nankai earthquake, and varying the earthquake scale to magnitudes of 8.4, 8.6 and 9.0, we calculated the earthquake scale distribution corresponding to the seismic motion in Hyogo prefecture via simulation.

We hypothesised that buildings with a height under 6m are wooden buildings, and from a building damage function corresponding to the earthquake scale, we used a Geographic Information System (ArcGIS), and calculated the number of destroyed buildings. The results, for earthquakes on a scale of M8.4, M8.6 and M9.0 respectively, were 759 houses, 1,641 houses, and 9,877 houses.

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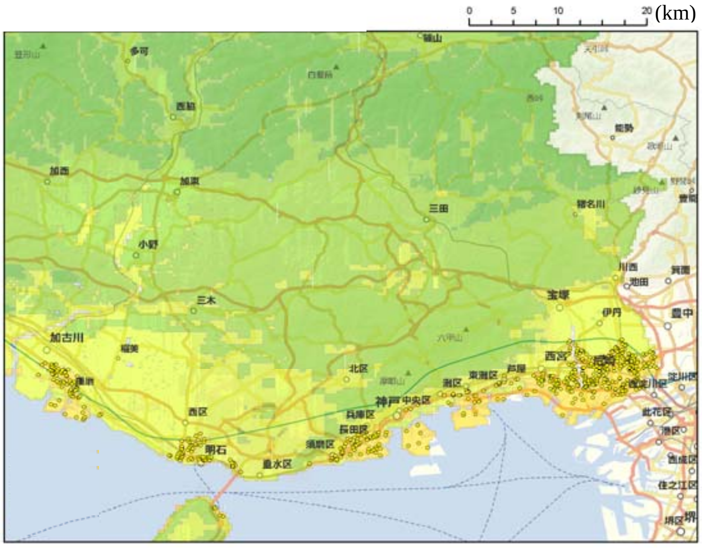

Figure 3.2. Building damage distribution in Hanshin area (M8.4)

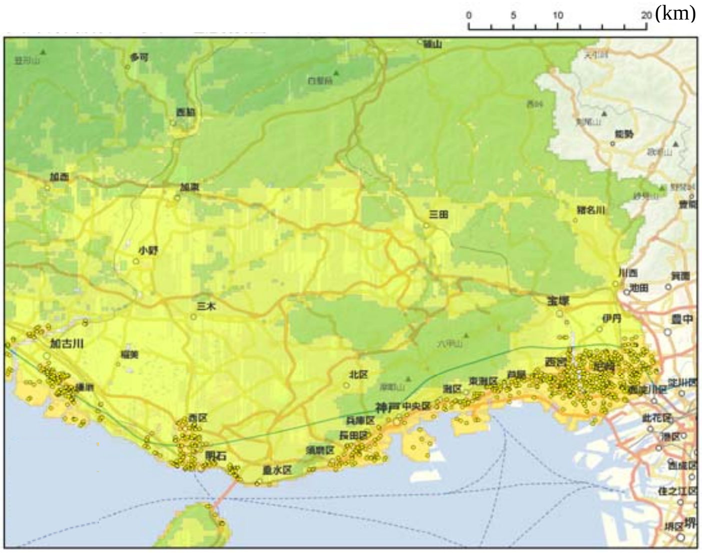

Figure 3.3. Building damage distribution in Hanshin area (M8.6)

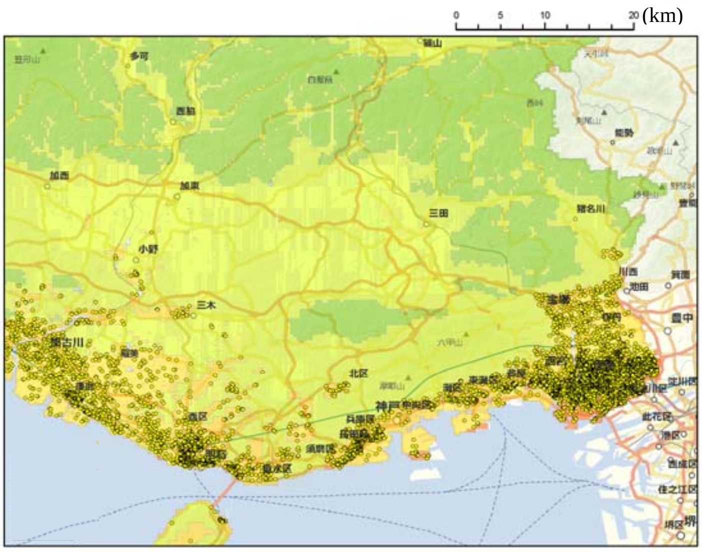

Figure 3.4. Building damage distribution in Hanshin area (M9.0)

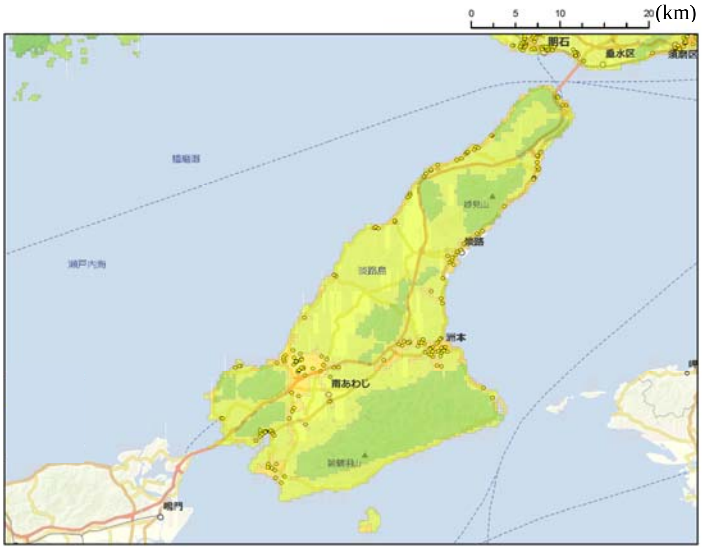

Figure 3.5. Building damage distribution in Awaji area (M8.4)

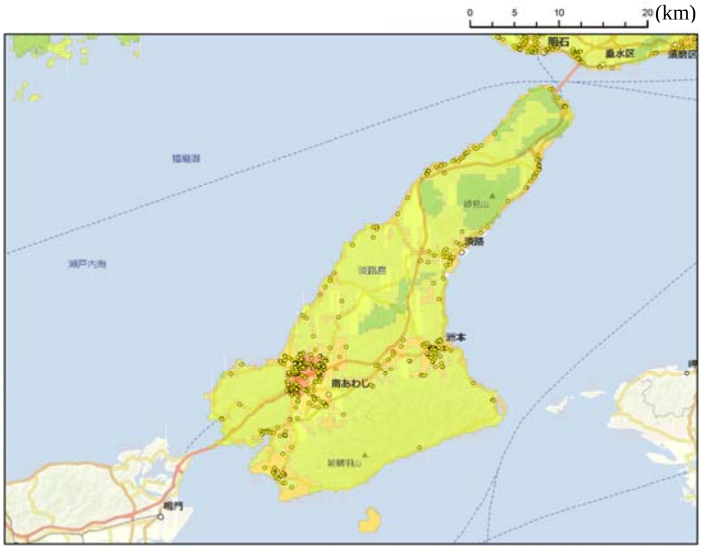

Figure 3.6. Building damage distribution in Awaji area (M8.6)

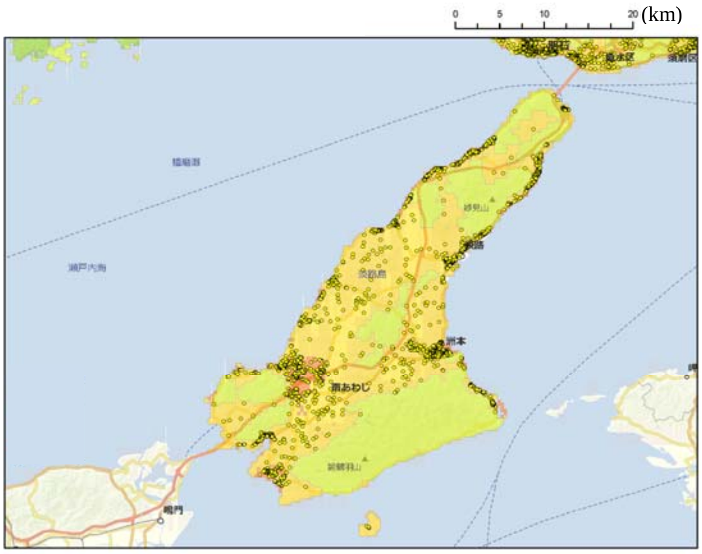

Figure 3.7. Building damage distribution in Awaji area (M9.0)

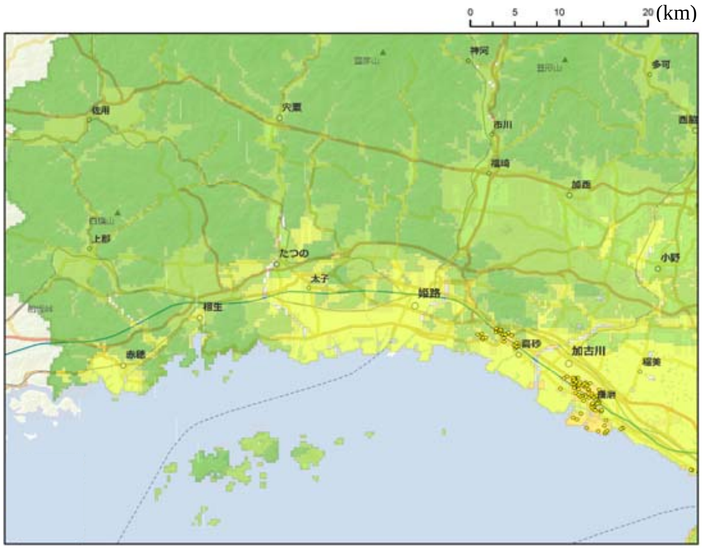

Figure 3.8. Building damage distribution in Himeji area (M8.4)

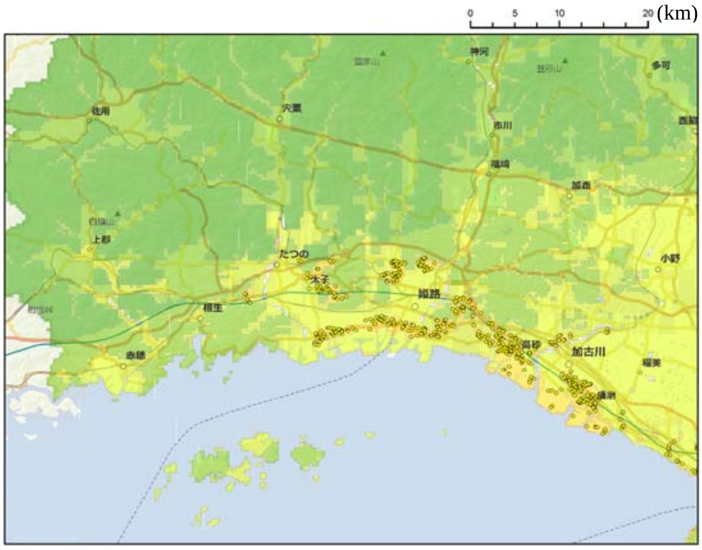

Figure 3.9. Building damage distribution in Himeji area (M8.6)

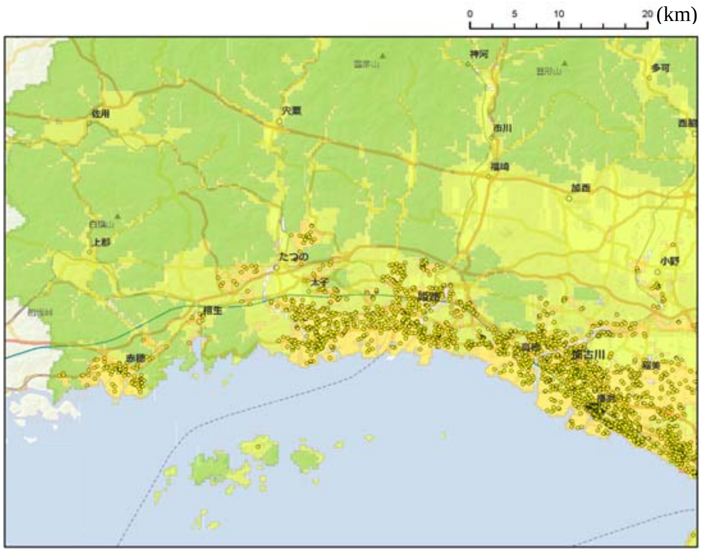

Figure 3.10. Building damage distribution in Himeji area (M9.0)