https://doi.org/10.20965/jdr.2017.p1151

Paper:

The Importance of Seismic Death Risk Assessment of Households in the Kumamoto Earthquake of 2016

Tadayoshi Nakashima[†], **Shigeyuki Okada, and Akane Shinoda**

Hokkaido University
Kita 13 Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan
[†]Corresponding author, E-mail: nakashima@eng.hokudai.ac.jp

[Received July 28, 2017; accepted October 31, 2017]

This paper discusses the reduction effect of a foreshock on casualties during the mainshock of people who evacuated to shelters and their private cars during the 2016 Kumamoto earthquake. In the first part of this paper, we discuss the number of human casualties caused by the collapse of wooden buildings. The characteristics of casualties in the Kumamoto earthquake are classified as household attributes and building damage caused by the foreshock and mainshock. In the second part, we apply equations (Nakashima and Okada 2008 and Okada and Nakashima 2015) to the Masiki area to determine the total number of casualties with a focus on deaths. The number of deaths due to total building damage from the foreshock and the mainshock in the case of 0 evacuees was estimated as 147. We then estimated the reduction effect on the number of casualties caused by the foreshock by using the survey data of the mainshock and foreshock. We found that evacuation during the mainshock decreased the death toll by 128 people. Moreover, the number of injured people decreased by 657. Generally, most people who evacuate tend to return home over time. As a result, many people die at the time of a subsequent mainshock. It is important to provide death risk information to each household to support their decision-making regarding appropriate evacuation.

Keywords: 2016 Kumamoto earthquake, foreshock, mainshock, casualty, evacuation

1. Introduction

The series of seismic activities of the 2016 Kumamoto earthquake started with the foreshock that occurred at 9:26 PM on April 14, 2016. This was followed by the mainshock on April 16 in Mashiki Town of Kumamoto Prefecture. The maximum index number, i.e. 7 was measured twice on the Japanese seismic intensity scale. In total, 8,647 buildings were destroyed and 236 victims killed (including related deaths) throughout Kumamoto Prefecture in the series of shocks [1]. In Mashiki Town, 20 people were killed [1]: 19 were crushed by or suffocated in collapsed buildings (one was killed by a block wall); 7 were killed in the foreshock on April 14; and 12 were killed in the mainshock on April 16. The fact that more people were killed in their house due to the subsequent earthquake suggest other risks of evacuation to one's own house that has been recommended to prevent related deaths from the experience of the 2004 Niigata Chuetsu earthquake.

Important is the effects of evacuation after the foreshock on human injury in the subsequent mainshock. To understand this, the damage caused by the foreshock and mainshock must be evaluated separately.

Regarding building damage, field surveys targeting only central Mashiki Town indicated that many houses collapsed after the mainshock. In addition, Sugino et al. [2] evaluated building damage in the foreshock and mainshock using aerial photographs. Their study demonstrated the accuracy of evaluating damage based on photographs. Moreover, field surveys on building damage after the earthquake have been conducted. However, few studies have examined the highest priority of various damages, namely human damage. Although Ushiyama et al. [3] investigated human damage, they did not evaluate the difference between deaths due to the foreshock and mainshock in relation to building collapse as the main factor. In addition, they researched evacuation after the earthquake; however, more important information on which to judge evacuation clearance after the foreshock is not cleared. In principle, the rapid screening of buildings damaged that determines whether a house in the affected region can be used is based on conditions after the damage done, and does not guarantee safety against subsequent shocks. Possibly, a house with poor seismic resistance undergoes no to little damage during the first shock; however, such a house cannot always withstand subsequent larger shocks. In fact, many houses with minor damage during the foreshock collapse after the mainshock [4].

Based on the above, in this research, a literature study on damage caused by the series of activities of the Kumamoto earthquake was performed and field surveys conducted to clarify residents' evacuation actions and their significance (how residents' evacuation affected deaths in the subsequent shocks) based on the relationship between the degree of building damage and death rate. Furthermore, in this paper, methods to reduce deaths are examined by investigating what information can be provided to individual households based on conventional damage prediction equations to reduce deaths due to the mainshock. The degree of damage is an index defined by the level of building damage [0, 1.0] using the pattern chart proposed by Okada and Takai [5]. The applicability of the human injury function based on death rate data from the 1995 South Hyogo earthquake [6] to other earthquakes in other areas is confirmed by comparing the relationship between building damage and the death rate in Kumamoto City due to the earthquake using this function. Finally, the effect of outdoor evacuation immediately after the foreshock is removed by applying the human body damage function in the inverse to the number of totally collapsed buildings and deaths. The purpose is to estimate the deaths due to the mainshock in a case when the foreshock does not occur. This operation clarifies the reduction effect of the foreshock on the number of deaths during the mainshock. Currently, there is little information available on which to judge outdoor evacuation after an earthquake to avoid damage. In risk assessment (building vulnerability assessment) on houses where victims were killed in Mashiki Town, information that can currently be offered is investigated.

2. Kumamoto Earthquake Study

2.1. Death Toll and Location

Mashiki Town in Kumamoto Prefecture is located in the west of Kumamoto City and has a population of 34,229. Literature and field surveys were conducted to clarify the degree of building damage and the locations where the 19 victims in the town had died. The name, age, and address at the district level of victims were obtained based on information released by the National Police Agency [7]. Next, seven researchers performed a field survey on May 13, 2016 and identified the locations of the destroyed houses of the 19 victims and the housing conditions of 18 victims using the pattern chart. This was after assuming the locations of their deaths based on the resident map [8] and victims' names. In addition, the house of the victim not identified in the field survey was identified afterwards. **Fig. 1** shows the death distribution in Mashiki Town obtained from the survey. The open circles show the death distribution for April 14, and the solid ones for April 16. On April 14, people were killed in congested urban areas, while in the mainshock on April 16, people were killed in the south of Mashiki town. **Fig. 2** shows the population distribution represented by 500 meshes for Mashiki Town. People were killed in the central, more populated areas on April 14, and in sparsely populated areas on April 16.

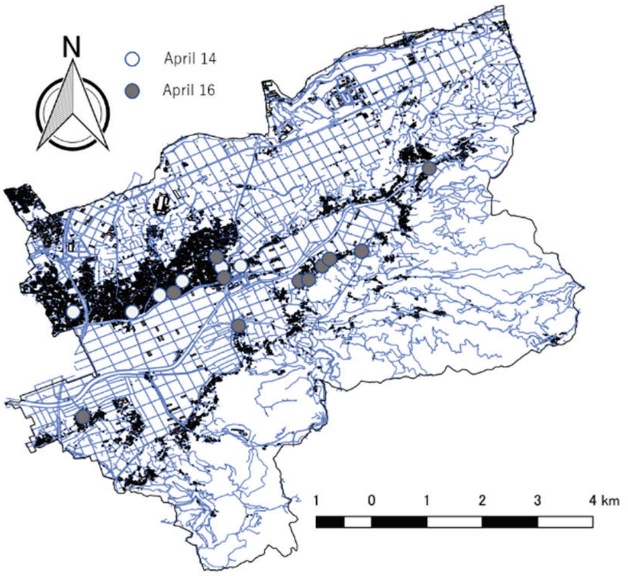


Fig. 1. Death distribution.

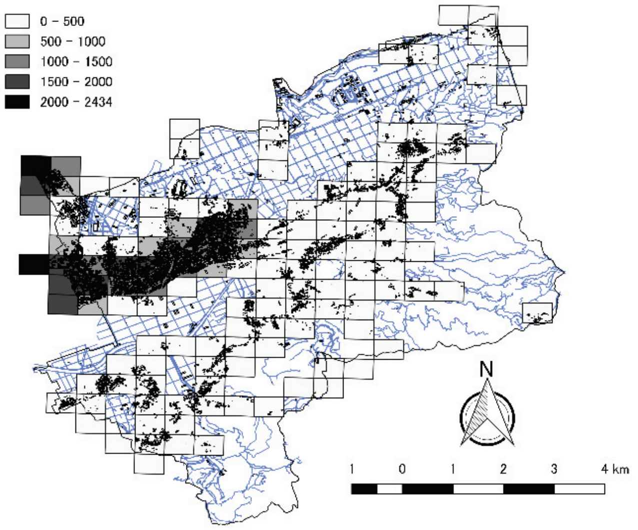


Fig. 2. Population distribution of Mashiki Town.

2.2. Damage Pattern of Houses Where Victims Were Killed

The death toll is shown in **Table 1** according to the damage to houses where victims were killed based on the field survey (on six scales ranging from D1 to D6). The level of damage to affected buildings was determined using the damage pattern chart [5] in **Fig. 3** in the field survey. The results are provided in **Table 1**. In all cases, the victims were killed in wooden houses. In total, 7 and 2 people were killed at D5 and D6 after the foreshock, respectively, and 11 and 2 people were killed at D5 and D6 after the mainshock, respectively. No one was killed at D4 after the foreshock and mainshock, although many people died at D5. This means that most deaths occurred on the first floor, similar to the case of the South Hyogo Earthquake, which had a high death rate.

2.3. Death Rate

Compared to the average age of 45 years of the total population of Mashiki Town in 2010, the average age of those who died after the foreshock and mainshock was

Table 1. Death toll according to level of damage.

	D4	D5	D6
foreshock	0	5	2
mainshock	0	11	1

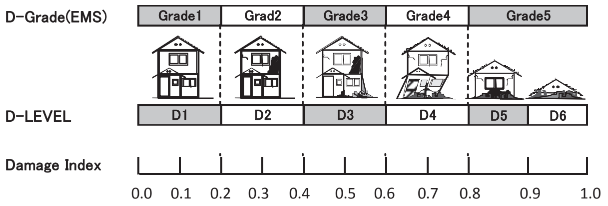


Fig. 3. Damage pattern chart [5].

Table 2. Average age of victims who died in the foreshock and mainshock.

	Mashiki(2010)	foreshock	mainshock
Average age	45	71.1	75.8

71.1 and 75.8 years respectively. Of the 19 victims, 16 were elderly citizens in their 60s or older. According to newspaper reports and the results of the field survey, the average age of those who were on the first floor and for whom information on age was available was 70.5 years. Furthermore, they lived in houses with poor seismic resistance, which may have caused the deaths of the elderly citizens.

In addition, people were killed on the first floors of collapsed buildings in the Kumamoto earthquake, similar to the victims of past earthquakes. Note that those who evacuated immediately after the foreshock returned to their houses, which had poor seismic resistance, before the mainshock. Of the 12 victims who died on day 16, 11 had returned to their houses after they evacuated to cars or local community centers. As the average age of those killed after the mainshock is older than that of those killed after the foreshock, it seems that elderly people tend to return to their houses.

3. Inverse Analysis of the Number of Evacuees

3.1. Death Rate According to the Level of Damage in Mashiki Town

The death rate according to the level of damage in Mashiki Town was calculated. The number of buildings according to level of damage and the death toll of the foreshock not affected by evacuation after the earthquake were used in the evaluation. Note that the released research results (e.g., the inventory survey by the Architectural Institute of Japan [9]) were the sum of damage caused in the foreshock and mainshock and as such could not be employed directly. Therefore, this study reevaluated the level of building damage using 132 angled pictures taken immediately after the foreshock by the Geospatial Information Authority of Japan [10]. The death rate was evaluated for each 250-m mesh. An example aerial photo (**Fig. 4**) and judgment results are shown in **Fig. 5**. The results of the building damage evaluation are provided in **Fig. 6** using 132 pictures, including the example. Damage due to the foreshock is concentrated along prefectural road No. 28. Next, to calculate the number of residents who were in their houses, the population

Fig. 4. Aerial picture [10].

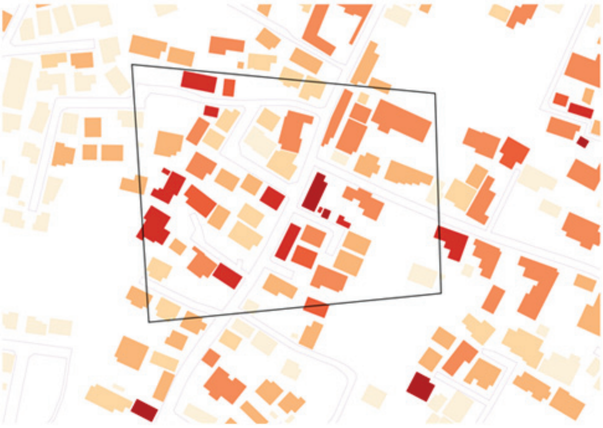


Fig. 5. Read results.

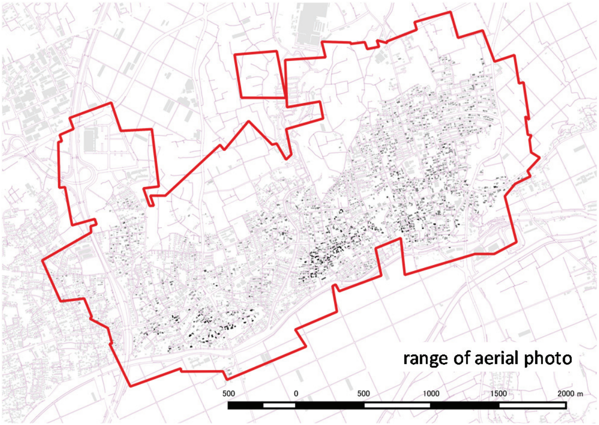


Fig. 6. Distribution of level of damage after the foreshock based on aerial pictures.

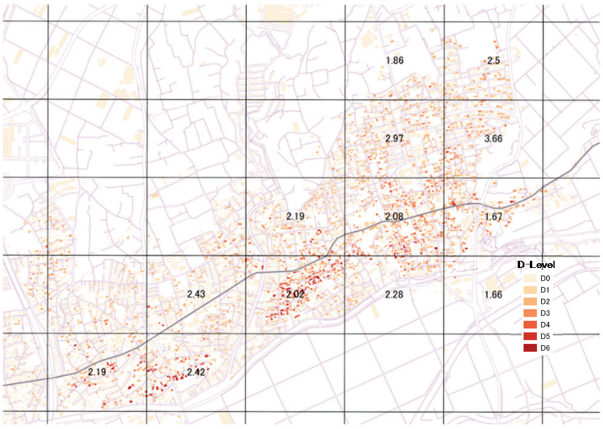


Fig. 7. Population of each building for each mesh.

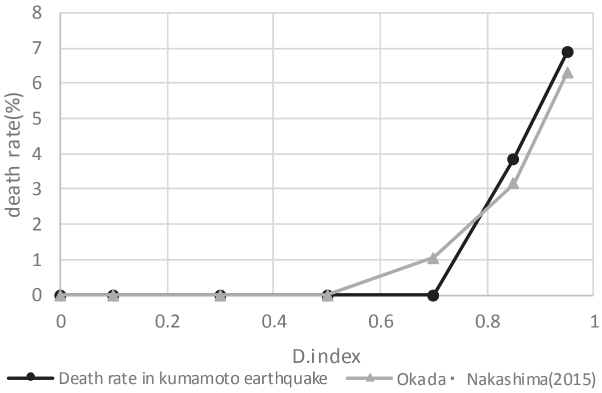


Fig. 8. Comparison of death risk in kumamoto earthquake and seismic death risk function.

of one building was estimated based on the relationship between the number of buildings in a mesh and the population using local mesh data (500-m mesh) of the census population in 2010 [11]. The number of people staying in a building (building population) was estimated using the following equation.

$$Ph_j = \frac{p_j}{h_j}, \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

where Ph_i is the population per building for each mesh, h_j is the number of buildings for mesh j, and P_j is the mesh population for mesh j. **Fig. 7** shows the calculated population distribution. By applying the obtained population for each mesh to each house, the death rate according to the level of damage was calculated as follows using $P_n(x)_i$ with the building population according to damage level, and $D_n(x)_i$, the death toll according to the level of damage obtained in the field survey.

$$D_r(x) = \frac{\sum_{i=1}^{N_m} D_n(x)_i}{E_r \sum_{i=1}^{N_m} P_n(x)_i}, \quad \dots\dots\dots\dots \quad (2)$$

where N_m is the number of buildings in a mesh, and E_r is the rate of those who were at home. This study used 81.7% (the national average value) [12] for the day of the foreshock, according to the social research results of The NHK Broadcasting Culture Research Institute. **Fig. 8** compares the building death rate in Mashiki Town calculated using Eq. (2) and data from Okada and Nakashima (2015) [6] using the South Hyogo earthquake data. The human body damage function reproduced the actual conditions at D5 and D6. Based on this, it is considered that the level of building damage and deaths in Mashiki Town were the same as those in the South Hyogo earthquake. However, deaths caused by furniture can probably be included in the value for the South Hyogo earthquake, which affected a wide area and therefore decreased the rescue rate. This is considered the reason why the death rate for the South Hyogo earthquake is higher than that in the Mashiki Town case. On the other hand, non-structural materials including furniture were not the main factor in the deaths in the Kumamoto earthquake. Therefore, according to Saeki et al. [13], the death estimation results for the South Hyogo earthquake using this method is 4,601, although the actual death toll was 4,984. The death toll for the Kumamoto earthquake was overestimated as 442, although the actual death toll was 193. Saeki et al. reported that this method produces estimation results more similar to the actual conditions compared to the death estimation equation of the Cabinet Office (1215) and Tokyo Metropolitan Government (962) [13]. In addition, because this method can evaluate injured people according to the level of building damage in addition to the death evaluation, this study evaluated the effect of the foreshock on casualties after the mainshock by conducting an inverse analysis of the actual death toll using the equation by Okada and Nakashima (2015). The difference at D4 is an issue for a future study.

3.2. Calculation Flow of the Death Reduction Effect of the Foreshock

In Mashiki Town, 7 and 12 victims were killed by collapsing buildings after the foreshock and mainshock, respectively. The victims were located in small communities in the south of Mashiki Town after the mainshock, not in the urban area where the foreshock wrought more serious damage. The smaller number of deaths in the central urban area after the mainshock is attributed to the reduced rate of those who were at home, because of the first evacuation after the foreshock. In this study, it is considered possible that the relationship between the level of building damage and death rate of a past earthquake (the South Hyogo earthquake) can be applied to that of Mashiki Town, as discussed in the previous section. The study examines the evacuation rate after the mainshock by applying the human body damage function proposed by Okada and Nakashima (2015) [6] to 3,026 buildings, derived from the house damage research results in Mashiki Town and comparing this to the actual death toll. The flow is described in more detail as follows. The calculation flow is shown in **Fig. 9**. This approach determines

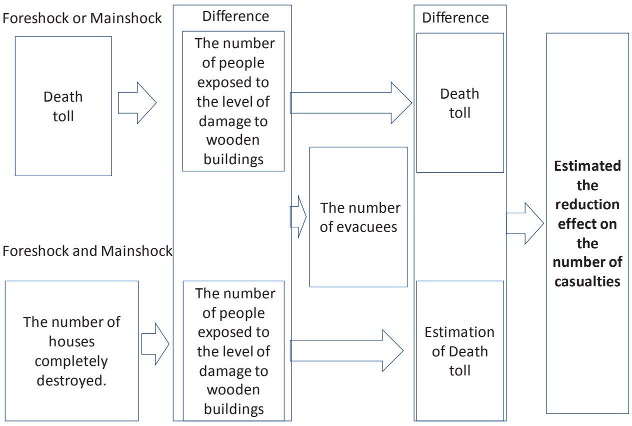


Fig. 9. Calculation flow of the number of evacuees.

the rate of those who were at home to inversely explain the actual death toll to normal death estimation processes.

(1) The population exposed to damage to wooden buildings is calculated after calculating the death toll of seven after the mainshock by applying the human body damage function of Okada and Nakashima (2015) [6].

(2) Next, the population exposed to damage to wooden buildings is calculated when the death toll of 12 is calculated by applying the human body damage function.

(3) The number of evacuees after the foreshock is estimated using the number of totally collapsed buildings after the foreshock and mainshock and the number of those living in such buildings based on the data released by Kumamoto Prefecture [1] to estimate the death toll if they had been at home.

(4) The death reduction effect of evacuation after the foreshock is clarified by determining the difference between the estimated death toll based on the number of totally collapsed buildings after the foreshock and mainshock and the actual death toll after the foreshock and mainshock.

(5) Using the number of totally collapsed buildings in (3), the reduced number of injured people due to building collapse is calculated.

3.3. Estimation of the Number of Those at Home According to the Level of Damage During the Earthquake

Available data in this study were the number of victims killed in the foreshock, number of victims killed in the mainshock, number of damaged buildings after the foreshock and mainshock, and the locations of these incidents. The death toll after the mainshock was estimated using the number of damaged buildings. The death rate D_θ during the earthquake was calculated using the Okada and Nakashima function (2015) [6] by determining the death toll after the mainshock. D_θ is expressed as follows:

$$D_\theta = \int_0^{75} M_{ISS}(\theta)\times d(\theta)\times K(\gamma)\cdot d\theta, \quad . \; . \; . \quad (3)$$

where $M_{ISS}(\theta)$ is the distribution of human body damage level θ according to the level of building damage, $d(\theta)$ is the death rate based on the ISS value according to age, and $K(\gamma)$ is the death rate coefficient. To express injuries according to the level of damage as a probability density (domain of [0, 1]), ISS, namely the human severity θ, is converted as follows with a focus on the domain of ISS ([0, 75]).

$$\theta = I_{ss}/75. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

The following equation is an outline of $M_{ISS}(\theta)$. Please refer to Okada and Nakashima (2015) [6] for further information.

$$M_{ISS}(\theta) = \sum_{\Delta x=0.6}^{1.0}\sum_{I=0}^{I=7.4} k_{\Delta x}\cdot {f''}_{\Delta x}(\theta), \quad . \; . \; . \; . \quad (5)$$

where, $k_\Delta x$ is the internal loss population according to the damage level Δx. This and can be obtained as follows: Population The population in the loss space according to the level of damage to wooden house damage levelhouses was is calculated by multiplying exposure the exposed population to the intensity $M_f(I)$ by the building damage level function $P(I,\Delta x)$ and internal space loss rate W. Here, W represents space loss: at D4 or less $(\Delta x \leq 0.6)$, where no space loss occurred, $W\Delta x = 0$, at D4 $(0.6 < \Delta x \leq 0.8)$, $W\Delta x = 0.23$, at D5 $(0.8 < \Delta x \leq 0.9)$, $W\Delta x = 0.47$, and at D6 $(0.9 < \Delta x \leq 1.0)$, $W\Delta x = 0.78$. Moreover, the human damage level function is multiplied for each damage level $(\Delta x = D4, D5, D6)$ and summed for intensity I and building damage level Δx, as shown in the following equation. By doing so, the internal loss population $k\Delta x$ according to the level of damage to wooden building damage level buildings can be obtained.

$$k_{\Delta x} = \sum_{\Delta x=0.6}^{1.0}\sum_{I=0}^{7.4} M_f(I)\times P(I,\Delta x)\times W_{\Delta x}. \quad . \; . \; . \quad (6)$$

Here, the seismic resistance grade distribution $g(q,s)$ for each age based on the theory by Nakashima and Okada (2008) [14] is multiplied by the building rate for each age according to evaluation unit $T(q)$ to calculate the emergency probability $g(s)$ of seismic resistance grade s. In addition, deterioration function $F(t')$ for the evaluation year is also considered. Then, the resistance distribution for each age is expressed as follows. Damage probability according to the damage level can be obtained using the following equation.

$$P(I,x) = \int_0^s \sum_q \left(g(q,s)\times T(q)\times F(t')\right)ds \quad . \; . \quad (7)$$

Here, seismic resistance grade s can be determined as follows:

$$s = \left\{\left(I - a(x)\right)/b(x)\right\}^{1/c(x)} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

Table 6. Coefficient according to level of damage based on the seismic resistance grade evaluation Eq. (5) [14].

x	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
a	1.59	1.28	0.93	0.49	-0.05	-0.89	-2.16	-4.72	-14.48
b	4.48	5.07	5.61	6.19	6.86	7.81	9.18	11.88	21.80
c	0.21	0.17	0.14	0.12	0.11	0.09	0.07	0.05	0.02

Table 7. Coefficient according to building age [14].

	-1950	1951 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991-	All
μ	-1.097	-0.760	-0.585	-0.402	-0.186	-0.030	-0.368
σ	0.823	0.705	0.558	0.534	0.513	0.481	0.597

where s is the seismic resistance grade, and a, b, and c are parameters depending on damage level x as shown in **Table 6**.

In addition, the resistance distribution of wooden houses is as follows:

$$g(q,s,t') = \frac{1}{\sqrt{2\pi} s\sigma} \exp\left(-\frac{(\ln(s)-\mu)^2}{2\sigma^2}\right) \times F(t'). \quad (9)$$

The average resistance distribution and standard deviation are provided in **Table 7**.

In addition, $F(t')$ is expressed by the following equation. As 12 years have passed since 2004, 12 was used for t'.

$$\begin{aligned} F(t') &= -0.00021 \times t' + 1 \\ t' &= q_0 - q + t. \end{aligned} \quad \dots\dots\dots (10)$$

Using the above Eq. (9), the resistance distribution of wooden houses is shown in **Fig. 10** using the building age distribution of the 2013 residence and land statistics [15]. The building age distribution of the residence and land statistics is shown in **Table 8**.

Next, the human body damage function is expressed by the following equation.

$$f_{\Delta x}(\theta) = \int_{-\infty}^{\infty} \frac{f''_{\Lambda}(\lambda)}{\sqrt{2\pi}\zeta\theta} exp\left[-\frac{1}{2}\left(\frac{\ln(\theta)-\lambda}{\zeta}\right)^2\right] d\lambda . (11)$$

Here, $f'_{\Delta x}(\theta)$ is the non-normal distribution determined by using the following equation.

$$f''_{\Lambda}(\lambda) = \frac{1}{\sqrt{2\pi}\sigma} exp\left[-\frac{1}{2}\left(\frac{\lambda-\mu}{\sigma}\right)^2\right] \quad \dots\dots (12)$$

Here, average μ and standard deviation σ are shown in **Table 9**. The death rate according to the human body damage level $(d(\theta))(k(\gamma))$ is the death rate coefficient, which is expressed as follows using the totally collapsed rate γ. The parameters vary depending on age v, but were fixed for the purposes of this study as follows:

$$K(\gamma) = \left\{ \left(\gamma - a(v)\right) / b(v) \right\}^{1/c(v)} . \quad \dots\dots (13)$$

The number of those who were in wooden houses when the foreshock occurred was calculated. Seven (death toll after the foreshock) and 12 (death toll after the mainshock) were substituted for D_θ and an inverse analysis was performed using the rate of those who were at home to calculate the population according to the level of damage to wooden houses. It was assumed that 585.4 victims were in totally collapsed houses during the foreshock, and 980.7 were in totally collapsed houses during the mainshock. **Fig. 11** shows the number of population exposed to totally collapsed buildings estimated from the death toll. The ground motion and number of totally collapsed houses for the mainshock are greater than those for the foreshock for all levels of damage. The greater number of those who were at home resulted in the greater death toll, even when considering evacuation after the foreshock.

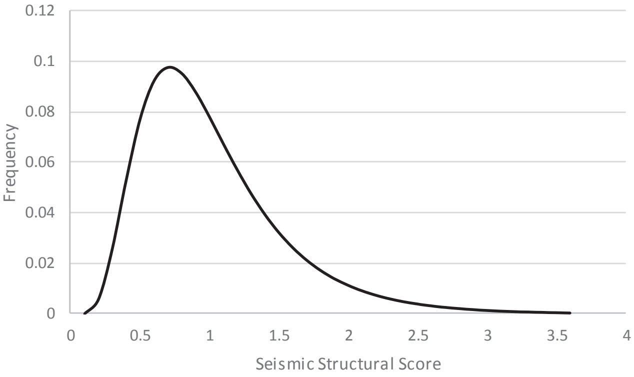


Fig. 10. Seismic resistance grade distribution.

Table 8. Fragment of building age [15].

	-1970	1971-1980	1981-1990	1991-
Ratio	0.11	0.13	0.17	0.58

Table 9. Average and standard deviation of non-normal distribution [6].

	D4	D5	D6
μ	-3.05	-2.42	-2.27
σ	0.38	0.21	0.39

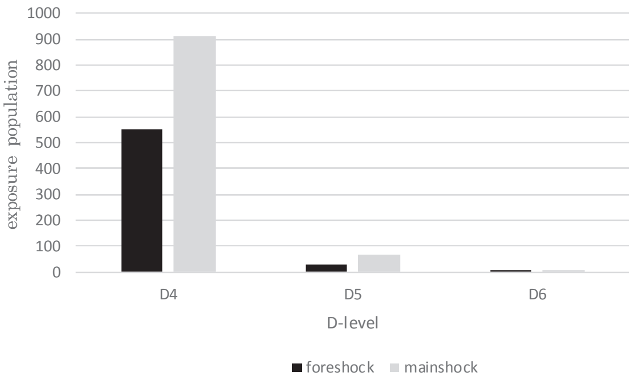


Fig. 11. Number of people exposed to the level of damage to wooden buildings.

Table 10. Number of actual and estimated deaths.

	foreshock	mainshock	no evacuation
Death toll	7	12	147

Table 11. Number of population exposed to totally collapsed buildings.

	foreshock	mainshock	mainshock (no evacuation)
Population exposed to totally collapsed buildings	585	980	8461

3.4. Evaluation of Death Toll in the Case of No Evacuation

Next, the death toll for the foreshock and mainshock was estimated. In this study, it was assumed that 8,461 victims were exposed to totally collapsed buildings based on materials published by Kumamoto Prefecture [1] to calculate the number of those exposed to each level of damage. Following this, the death toll was estimated by substituting the obtained values in Eq. (5). The death toll for the foreshock, mainshock, and foreshock plus mainshock is shown in **Table 10**. The estimated death toll in the case of no evacuation was 147, approximately 8 times higher than the actual death toll of 19. This suggests that the rate of those who were at home was reduced because of evacuation, resulting in a decrease of 128 deaths. The foreshock led to the evacuation of those who lived in houses with poor seismic resistance, significantly reducing human damage during the mainshock. Considering that there were three related deaths in Mashiki Town, as shown in the damage report of Kumamoto Prefecture, the evacuation effectively reduced human damage.

3.5. Estimation of Evacuation Rate and Number of Evacuees

The death toll in **Table 10** indicates the evacuation rate of those who lived in totally collapsed houses and would have been killed. Next, the number of evacuees can be estimated using the following equation based on the relationship between the actual and estimated death toll.

$$N_e = M_p - M_{pa} \quad \text{. . . . .} \quad (14)$$

where M_p is the population exposed to totally collapsed buildings, M_{pa} is the population actually exposed to totally collapsed buildings, and N_e is the number of evacuees. **Table 11** shows the estimation results for the number of evacuees. It is deemed that 6,896 of the 8,461 victims who could have been exposed to totally collapsed buildings after the foreshock evacuated their houses.

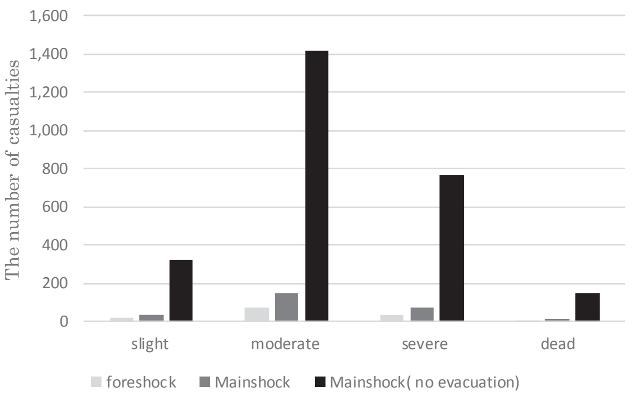


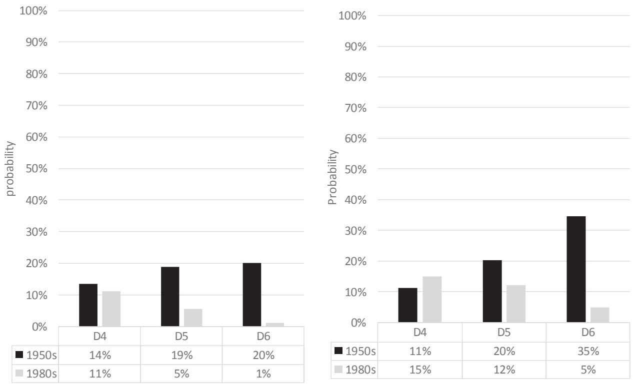
Fig. 12. Estimated number of victims who were injured victims.

3.6. Reduction Effect on the Number of Injured Victims

The human body damage function shown as Eq. (3) can estimate the number of injured victims. **Fig. 12** shows the number of injured victims reduced by the foreshock. The number of seriously injured people is estimated to be 100.8 for the foreshock plus mainshock. The damage research report of Kumamoto Prefecture indicates that the number of seriously injured people is 134 [1], indicating high estimation accuracy. Next, the number of casualties and seriously injured victims is estimated to be 2,647 and 766, respectively, using the number of totally collapsed houses for the mainshock. The results are approximately 8 times higher than those of the mainshock. In addition, the difference between the estimated number of seriously injured victims and actual number of seriously injured victims for the foreshock plus mainshock is 657. The results indicate that the evacuation reduced the number of injured victims and deaths.

4. Risk Evaluation of Individual Households

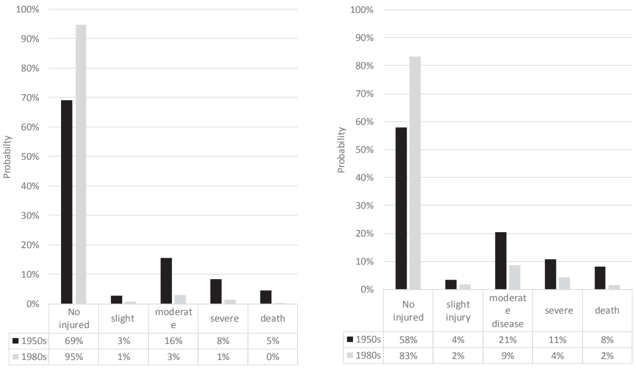
It was demonstrated that continuous evacuation effectively reduces damage, and the judgment on returning home significantly affects deaths in cases with two large shocks such as the Kumamoto Earthquake. To make proper decisions, some organizations judge the level of a structure's damage through an emergency risk judgment, and provide important information based on continuous availability. However, emergency risk judgment evaluates temporal conditions and not safety against future shocks. When serious shocks successively occur as in the Kumamoto earthquake, safety judgment information after the foreshock (before the mainshock) suggests that houses can be used, inducing an early return to homes from shelters and inducing an early return to homes from shelters and there is a possibility of increasing the human damage during the serious subsequent earthquake. A lesson from the Kumamoto earthquake is that ground motion scenarios with continuous serious earthquakes must be assumed, requiring measures by disaster prevention admin-



a) Foreshock
(6.61 in Intensity scale)

b) Mainshock
(6.77 in Intensity scale)

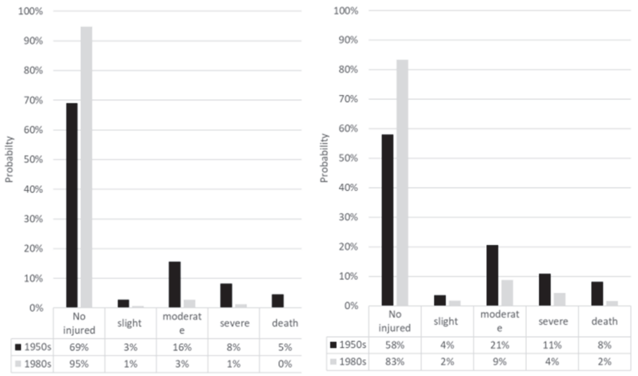
Fig. 13. Building damage rate estimated according to the year of construction.



a) Foreshock
(6.61 in Intensity scale)

b) Mainshock
(6.77 in Intensity scale)

Fig. 14. Probability of human damage estimated according to year of construction.



a) Foreshock
(6.61 in Intensity scale)

b) Mainshock
(6.77 in Intensity scale)

Fig. 15. Casualty rate according to seismic resistance grade.

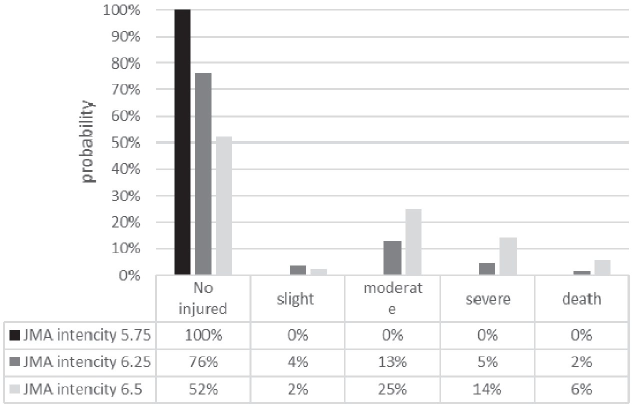


Fig. 16. Casualty rate according to intensity.

istrative agencies. Specifically, extended waiting time at shelters considering the decreasing aftershocks and emergency risk judgment is required, in addition to providing information using a method to confirm safety from subsequent earthquakes based on a risk assessment of houses' seismic resistance grade. The easiest method (e.g., calculation method of grades based on area ages) is desired, rather than a precise seismic resistance evaluation, which considers the situation immediately after a disaster. In the following section, the risk information on building vulnerability provided through existing methods was studied. As above, the equations proposed by Nakashima and Okada (2008) [14] and Okada and Nakashima (2015) were used [6].

4.1. Comparison of Ground Motions

In Mashiki Town, seismic intensities of 6.61 and 6.77 were measured by Mashiki Town for the foreshock and mainshock, respectively. The probability of damage to the wooden houses built in the 1950s and 1980s was evaluated using the method of Nakashima and Okada (2008), as shown in **Fig. 13**. The total collapse rate was 53% and 67% for the 1950s and 17% and 32% for the 1980s, indicating a significant difference in the rate and a small difference in intensity. Among the houses that did not totally collapse during the foreshock, after the mainshock, 28% and 18% of houses built in the 1950s and 1980s totally collapsed respectively.

Next, the estimation results for human damage are shown in **Fig. 14**. For house from the 1950s, the injury rate increased from 22% to 45%, while the death rate increased from 3% to 9%. For those from the 1980s, the injury rate increased from 5% to 19%, and the death risk increased from 0% to 5%. The seismic risks for the foreshock and mainshock significantly differ depending on the year of construction. In addition, it is highly probable that houses not affected by the foreshock can be affected by the mainshock. Such information can be provided if the year of construction is available.

4.2. Difference in Seismic Resistance Grade

The seismic resistance performance index for each building is required to more accurately evaluate risk. Recently, a seismic resistance renovation promotion plan has become effective; therefore, a seismic resistance evaluation costs less if evaluation funds are used in communities. For evaluated houses, a more detailed risk evaluation is available. For the foreshock, the probability of human damage is 48% for seismic resistance grade 0.3, while it is almost 0% for 0.7. For the mainshock, it is 78% at grade 0.3 and 24% at 0.7. The risk significantly increases for the mainshock. at intensity 6 upper and 7, respectively. Thus, for the old wooden houses in communities in the south of Mashiki Town, seismic resistance is low and the rate of human damage significantly increases at the high intensity of the mainshock, even if they did not collapse after the foreshock. These cases are overlooked in emergency risk judgments, indicating the importance of evaluating the seismic risk of individual houses and an evacuation study.

5. Conclusion

This paper analyzed houses where victims died in Mashiki Town, which was affected by the 2016 Kumamoto earthquake. Furthermore, it clarified the death reduction effect of the foreshock on the mainshock by employing existing human damage prediction equations. Although this study was based on the differences using existing equations and includes many assumptions, the death reduction effect of evacuation after the foreshock is certain.

(1) Locations of deaths
The victims died around prefectural road No. 28 on day 14, and south of the urban area on day 16.

(2) Relationship between the number of building collapses and deaths
The victims died along prefectural road No. 28 on day 14. Outside central Mashiki Town, more victims died in relation to the number of collapsed buildings. This seems to have been affected by evacuation in the central urban areas after the foreshock.

(3) Characteristics of victims who died
Most victims who died were elderly citizens. They tend to live in vulnerable old buildings and have less physical strength. Almost all households including those of the victims who died evacuated once and returned to their homes, because they could not endure life as evacuees. Returning home after an earthquake to a house with poor seismic resistance must be reconsidered. Some of the victims who died required nursing assistance and could not live in shelters. As such, the quality of living as an evacuee must be enhanced.

(4) Death reduction effect of the foreshock
The death reduction effect of the foreshock was estimated by comparing the number of deaths in this earthquake to that in a past earthquake. It was indicated that the death toll might have been 147 if the number of evacuees had not increased.

(5) Number of evacuees
It was estimated that 6,896 victims who lived in houses that totally collapsed in the earthquake evacuated. The foreshock triggered the evacuation and reduced the number of injured victims by 657 people.

(6) Individual seismic risk assessment
Individual household evacuation is important for judging evacuation. As a case study, individual households were evaluated in this study. The results indicate that the mainshock was risky, the threshold value for damage differs depending on the seismic resistance performance of a house, and a house with poor resistance can withstand a foreshock, but suffer in subsequent shocks. This information can be valuable when considering the evacuation of each household.

(7) Future issues
Regional difference of evacuation is possible because victims died in marginal areas instead of urban areas with more affected houses. The victims of this earthquake were almost all elderly citizens. The current human damage prediction equation cannot precisely evaluate human damage according to age group. It is important to formulate a prediction equation by studying the house tax list and Basic Resident Register.

Acknowledgements
Aerial photographs of the Geospatial Information Authority of Japan were used in this study. Students of the urban disaster prevention laboratory at Hokkaido University helped in conducting the field survey. This study was funded by the JSPS scientific grant 17K13003, 16H03141. The authors wish to express their sincere thanks.

References:
[1] Kumamoto Prefecture, "Preliminary Reconnaissance Report of Damages by the Kumamoto Earthquake (247^{th} Report)," Jul. 13, 2017 (in Japanese).

[2] M. Sugino, R. Yamamuro, S. Kobayashi, S. Murase, S. Ohmura, and Y. Hayashi, "Analyses of Building Damages in Mashiki Town in the 2016 Kumamoto Earthquake," J. of Japan Association for Earthquake Engineering, Vol.16, No.10, pp. 69-83, 2016 (in Japanese with English abstract).

[3] M. Ushiyama, Y. Saki and K. Sugimura, "Characteristics of victims of the 2016 Kumamoto Earthquake," J. of Japan society for natural disaster science, Vol.35, No.3, 2016 (in Japanese with English abstract).

[4] National Institute for Land and Infrastructure Management Ministry of Land, Infrastructure, Transport and Tourism, Japan and Building Research Institute National Research and Development Agency, Japan, "Quick Report of the Field Survey on the Building Damage by the 2016 Kumamoto Earthquake," Sep. 2016 (in Japanese).

[5] S. Okada and T. Nobuo, "Classifications of Structural Types and Damage Patterns of Buildings for Earthquake Field Investigation," J. of structural and construction engineering, Trans. of AIJ 524, pp. 65-72, 1999 (in Japanese with English abstract).

[6] S. Okada and T. Nakashima, "A New Causality Model for Evaluating the Probability of Human Damage from Injury to Death Associated with Building Collapse," in K. Ohtsuka (Ed.), "Health and Labour Sciences Research Grant report," pp. 147-161, 2015 (in Japanese).

[7] National Police Agency, "Information on Killed Victims by the 2016 Kumamoto Earthquake," announced in Apr., pp. 15-16, 2016 (in Japanese).

[8] ZENRIN, "Residential Maps in Mashiki Town," Nov. 2014 (in Japanese).

[9] K. Kenji and K. Tanaka, "Complete Enumeration in Urban Area of Mashiki Town," Disaster Investigation Report Meeting, pp. 83-93, Aug. 2016 (in Japanese).

[10] Geographical Survey Institute of Japan, "Information on the Kumamoto Earthquake of 2016," (in Japanese), http://www.gsi.go.jp/BOUSAI/H27-kumamoto-earthquake-index.html#2 [accessed Jul. 27, 2017]

[11] Statistic Bureau, Ministry of Internal Affairs and Communications, "Census Data in 2010," (Grid Square Statistics) (in Japanese).

[12] NHK Broadcasting Culture Research Institute, "Report on Time Use Research in 2015," Feb. 2016 (in Japanese).

[13] S. Takuma, H. Fujiwara, K. Sakamoto, and N. Yoshii, "A Consideration about Estimation of the Number of Dead by an Earthquake using Damage Information which Paid Attention to Structural Damage in Buildings," Summaries of Technical Papers of Annual Meeting, pp. 481-482, 2017 (in Japanese).

[14] T. Nakashima and S. Okada, "Seismic Strengthening Strategy for Wood Frame Dwellings Targeting to Minimize the Death Toll from a View Point of Temporal Variation – Case Study for Tokai Region, Japan, in the Forthcoming Tokai-Tohnankai Earthquake –," J. of Structural and Construction Engineering, Vol.73, No.623, pp. 79-86, 2008 (in Japanese with English abstract).

[15] Statistic Bureau, Ministry of Internal Affairs and Communications, "The 2013 Residence and Land Statistics," (in Japanese).

Name:
Tadayoshi Nakashima

Affiliation:
Assistant Professor, Dr. Eng., Faculty of Engineering, Hokkaido University

Address:
N13W8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan

Brief Career:
2009-2012 Researcher, Tono Research Institute of Earthquake Science
2012- Assistant Professor, Faculty of Engineering, Hokkaido University

Selected Publications:
- T. Nakashima, S. Okada, and K. Okuda, "Seismic 3D Indoor Risk Assessment for Inhabitants Using the Method of Human Body and Funiture-overturned Detection," J. of Social Safety Science, Vol.27, pp. 257-265, 2015.

Academic Societies & Scientific Organizations:
- Architectural Institute of Japan (AIJ)
- Institute of Social Safety Science (ISSS)
- Japanese Society for Artificial Intelligence (JSAI)

Name:
Shigeyuki Okada

Affiliation:
Professor, Dr. Eng., Faculty of Engineering, Hokkaido University

Address:
N13W8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan

Brief Career:
1979-1990 Assistant Professor, Faculty of Engineering, Hokkaido University
1990-2004 Associate Professor, Faculty of Engineering, Hokkaido University
2004-2010 Professor, Faculty of Engineering, Nagoya Institute of Technology
2008-2017 Visiting Professor (Concurrent responsibilities), Disaster Control Research Center, Tohoku University
2010- Professor, Faculty of Engineering, Hokkaido University

Selected Publications:
- S. Okada et al.,"Development of Active Evacuation System through Computer Vision Technology – As a Part of Multi-countermeasures for Reducing Seismic Casualties in Dwellings –," J. Social Safety Science, No.13, pp. 213-221, Nov., 2010 (in Japanese).
- S. Okada et al., "A New Causality Model for Evaluating the Probability of Human Damage from Injury to Death in Collapsed Buildings," 16th World, Conf. on Earthquake Engineering, Paper No.2938, pp. 1-10, Santiago Chile, Jan., 2017.

Academic Societies & Scientific Organizations:
- Architectural Institute of Japan (AIJ)
- Institute of Social Safety Science (ISSS)
- Japan Society for Natural Disaster Science (JSNDS)

Name:
Akane Shinoda

Affiliation:
Graduate Student, Hokkaido University

Address:
N13W8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan

Brief Career:
2017- Graduate Student, Hokkaido University