Relationship between the conditions of collapsed wooden buildings and rescue operations in the 2016 Kumamoto earthquakes

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Abstract

In Japan, earthquakes occur often; therefore, improving the authorities' ability to rescue victims trapped under collapsed wooden buildings is paramount to preserving public safety. As part of their disaster relief responsibilities, police and fire department rescue teams adopt a pyramid architecture with respect to operation types: ordinary, advanced, and especially advanced; the selection depends on the equipment and skill levels involved. An accurate assessment of the associated difficulties on-site and appropriate allocation of teams according to skill level facilitate their efficient operation when an earthquake occurs. Therefore, it is essential to study the actual challenges rescue operations encounter regarding conditions of collapsed wooden buildings and to accumulate such knowledge for future reference.

This work presents a case study from Japan, where earthquakes frequently occur, to supply data on the 2016 Kumamoto earthquakes to those involved in disaster response practices and educational research. Using empirical data collected by the National Police Agency, we focused on the collapsed wooden structures and analyzed the relationship between the duration of rescue operations and site conditions, e.g., the grade of building damage, depths of trapped victims, and separation between the collapsed structure and victims, if any.

The duration of rescue operations was not considerably affected by most site conditions; however, operations that freed victims bearing some weight from the collapsed structure challenged the teams and required the most time; operations that freed victims supported by pliable materials required the least amount of time.

The results of this study 1) illustrate the factors that should be considered when judging the level of difficulty of rescue operations and 2) reveal the risks associated with arriving at judgments, based solely on outside observation, on collapsed buildings. These results can also inform the methods for safely, quickly, and accurately performing difficult rescue operations at collapsed wooden building sites and can identify the materials and equipment required to arrange and plan for training. Internationally, the elucidation of factors that result in increased rescue operation difficulty is receiving more attention. Therefore, analyses based on actual rescue cases and their corresponding results can be used to ensure more efficient rescue team allocation and training.

Keywords: 2016 Kumamoto earthquakes, collapsed wooden buildings, victim entrapment, confined space rescue safety, confined space medicine (CSM)

1. Introduction

Earthquakes often occur in Japan; therefore, improving the ability and capacity to rescue victims trapped under collapsed wooden buildings is essential. The chances of survival substantially increase if rescue occurs within 24 hours. To make effective use of this limited window of time, rescue organizers must utilize resources as efficiently as possible. Rescue teams, such as the police and fire departments who are responsible for disaster relief operations, have adopted a pyramid architecture consisting of three tiers: *ordinary*, *advanced*, and *especially advanced* (Fig. 1); team selection is dependent on the equipment and skill levels involved. Accurate assessment of the difficulties at a site and the appropriate allocation of rescue teams according to skill level facilitates their efficient operation when an earthquake occurs. However, empirical data and analyses of past disasters, by comparing building collapse site conditions with the difficulty of rescue, are rare.

After a major earthquake is detected in Japan, a specialist from the Disaster Command Center, defined within the administrative agencies, directs and coordinates the assignment and operation of each rescue team [1]. However, as mentioned above, accurately using empirical data to estimate a rescue operation's degree of difficulty at a collapsed building site requires more data and analysis as input; currently, rescue team allocation is often based on personal experience and subjectivity. Rescue teams with the wrong equipment and expertise may therefore be allocated to disaster sites, resulting in inefficient and sometimes dangerous operations.

In this study, we analyzed empirical data from rescue operations involving collapsed wooden buildings in the 2016 Kumamoto earthquakes; this was done to a) determine how the different types of collapse site affected the difficulty of rescue operations and b) to organize the indicators used by disaster specialists to estimate the difficulty of rescue operations. In addition, we have been conducting studies on rescue activities at collapsed building sites for many years [2-12]. This paper represents one milestone, based on these studies; beyond disaster response practices, this work presents data for the purpose of educational research.

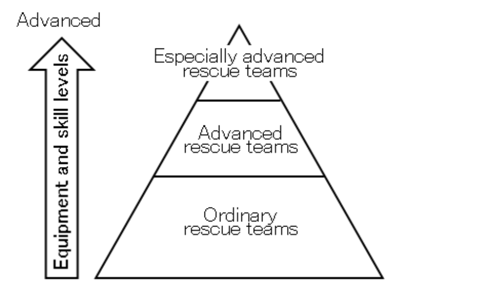

Figure 1 – Disaster rescue team structure in Japan

2. Materials & methods

In the 2016 Kumamoto Earthquakes, many wooden buildings collapsed during the foreshock on April 14, and the main shock on April 16; many victims within these buildings were trapped. The National Police Agency of Japan surveyed the rescue operations of the police for this disaster and collected various data: e.g., detailed data on the conditions at sites of collapsed wooden buildings, implementation status of rescue operations, and the duration of rescue operations by activity. The results are published on the agency website [1].

In general, the difficulty of a rescue operation will affect its duration, for rescue teams in the same tier. We speculate that the factors that increase or decrease duration can be estimated by better understanding these factors. Therefore, we analyze the relationship between conditions of the building collapse sites (Table 1) and the duration of rescue operations by using actual data from the National Police Agency. In this study, the duration of a rescue operation for a victim is the sum of the durations of four steps: conducting a search at the site of the collapsed building, approaching the victim, releasing pinch-pressure (including on-site collaboration with a medical specialist), and transporting the victim from the building. We did not include the durations of other operations e.g., interviewing people on site (such as family members of the victims) and hazard investigation; the data for these were not included by the National Police Agency.

We used the classification of police rescue operations conducted during the 2016 Kumamoto Earthquakes (Fig. 2) to define the target cases of this study: rescue operations for victims (18 sites, 24 victims (alive)) performed by the police, either as part of the especially advanced or advanced rescue teams, deployed during the 2016 Kumamoto earthquakes. In addition, rescue operations for victims in cardiopulmonary arrest, at the time of contact, are likely to have different characteristics: priority was given to stabilization, rather than

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speed, when life-threatening health concerns arose; therefore, these were excluded from this study. Figure 3 shows the time, the number of sites, and the number of victims for which the target cases of this study were implemented.

Table 1 – Definition of data used to analyze the relationship between the difficulty and duration of rescue operations

1. Classification of building damage
2. Depths at which victims were trapped (the horizontal distance from the entry point of the collapsed building to trapped victims)
3. Extent of spaces in which victims became trapped (the distance from the top of the victim to the collapsed structure)
4. Extent of spaces in which victims became trapped (the number of rescuers who were able to work simultaneously in the confinement spaces)
5. Conditions of victim entrapment and whether CSM was implemented or not
6. Configurations under the pinched victims and pressure release methods

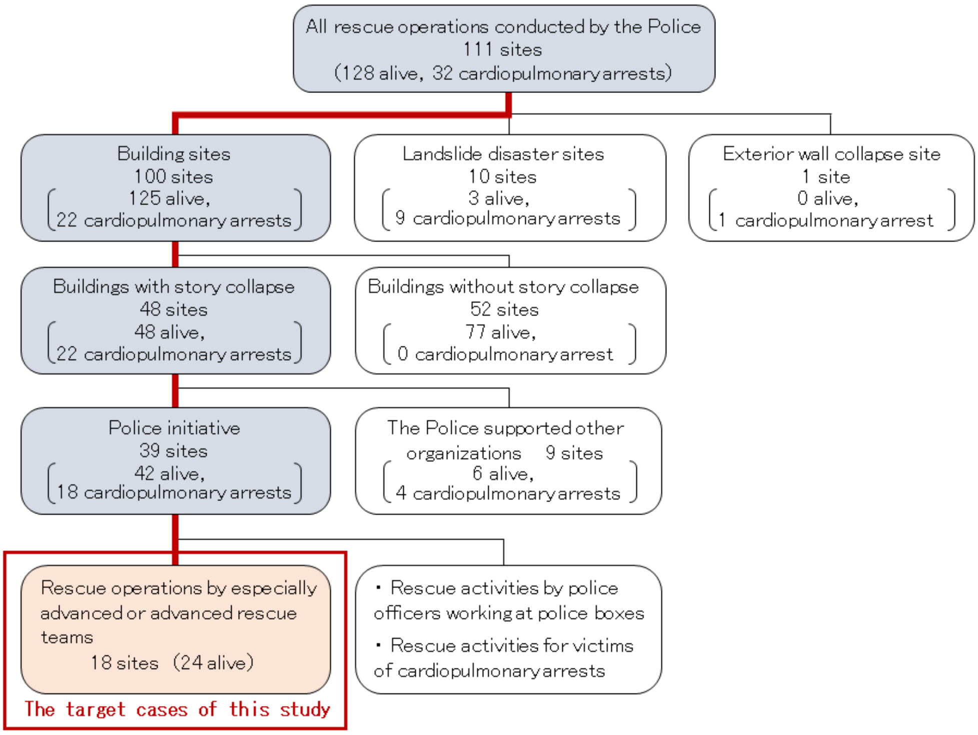

Figure 2 – Classification of rescue operations conducted by the police for the 2016 Kumamoto earthquakes, and the target cases of this study

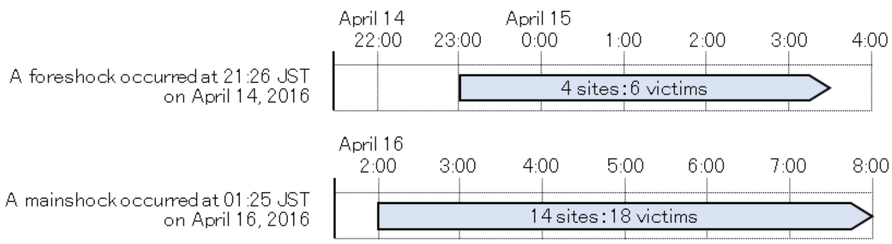

Figure 3 – Time, number of sites, and number of victims for rescue operations conducted for the target cases

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3. Result

3.1 The relationship between the grade of the building damage and the duration of rescue operations

The actual data released by the National Police Agency included a survey of the damage grade for the target building using a pattern chart developed by Okada and Takai [13]: if the building is a two-story wooden building, the damage grade increases in the order of Gd5- → Gd5+ → Cd6- → Cd6+ (Fig. 4). However, the damage grade was Gd5- for the instance that involved the longest duration of rescue (380 min), while the damage grade was Cd6- for the shortest (7 min). Thus, the damage grade of the target building did not significantly affect the duration of rescue operations.

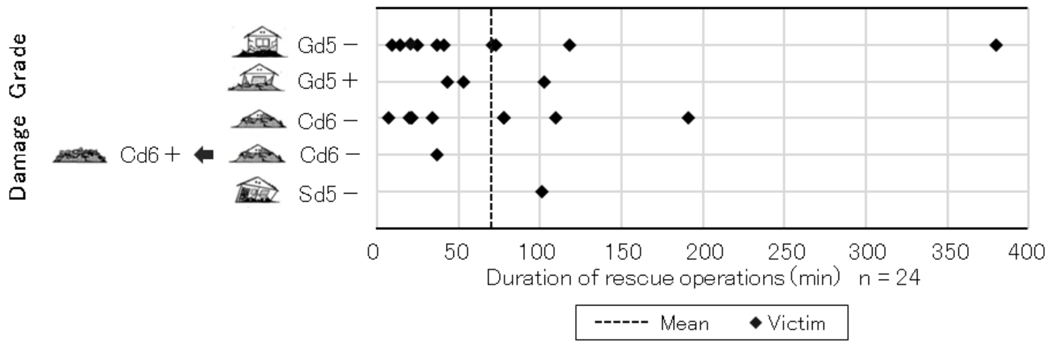

Figure 4 – Relationship between grade of building damage and duration of rescue operations

3.2 The relationship between the depth of trapped victims and the duration of rescue operations

The data released by the National Police Agency included a survey of the depth of the confinement position, based on the horizontal distance from the entry point of the collapsed building to the trapped victim (Fig. 5). A depth of 8 m (the longest in this case study) was observed in the case where the duration of the rescue operation was only 9 min (the second shortest duration in this study). However, the depth ranged from 1 m to 2 m in cases where rescue operation durations exceeded the mean (70 min). Thus, the depth of the confinement position did not correlate with the duration of rescue operations.

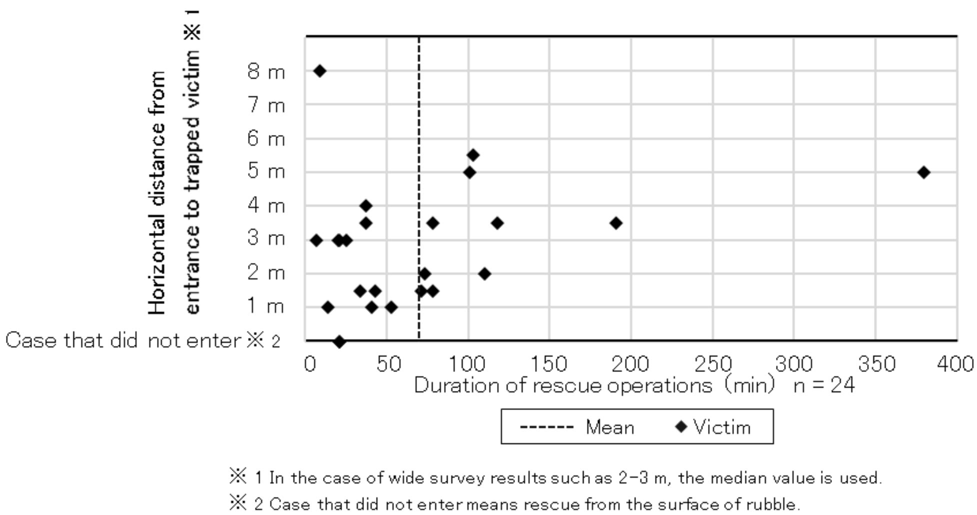

Figure 5 – Relationship between depths at which victims were trapped and duration of rescue operations

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3.3 Relationship between the size of spaces in which victims were trapped and duration of rescue operations

The data released by the National Police Agency included a survey of the confined space; the pattern chart we developed, and the number of rescuers who could simultaneously inhabit this space to indicate its size. Figure 6 shows the relationship between the distance from the top of the victim to the collapsed structure and the duration of rescue operations, while Figure 7 shows the relationship between the number of rescuers who were able to work simultaneously in the confinement space and the duration of rescue operations. In the case where the highest point of the victim was 175 cm or more, the duration of the rescue operation was 191 min, which was much higher than the mean (70 min). Furthermore, when three or four rescuers could simultaneously work in a relatively large confinement space, the duration of rescue operations was 380 min (the maximum value in the case study). Alternatively, there were several cases where only one rescuer could work and yet the duration of rescue operations was below the mean. These results show that the size of the confinement space did not correlate with the duration of rescue operations.

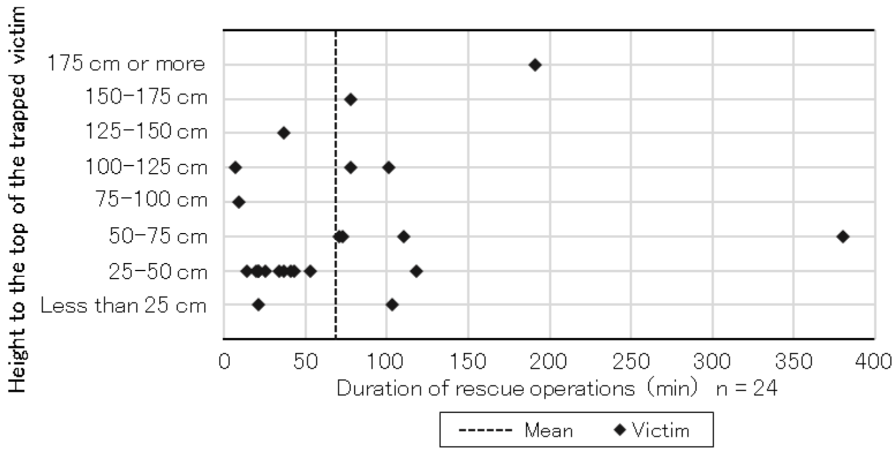

Figure 6 – Relationship between the distance at which victims were trapped (distance to the highest point of the victim) and the duration of rescue operations

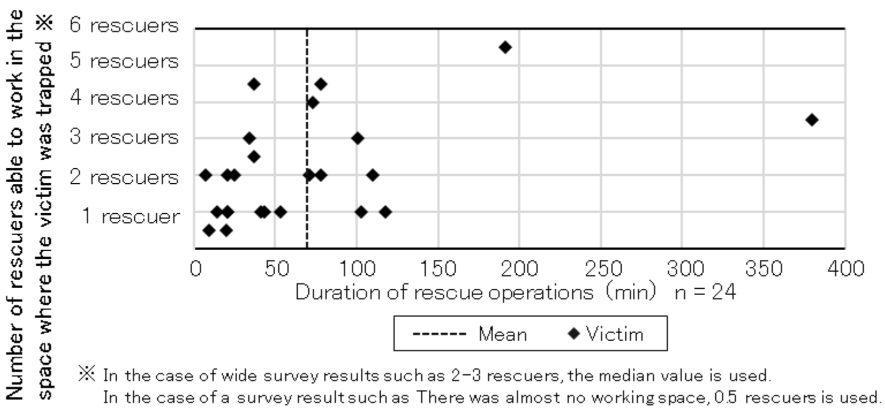

Figure 7 – Relationship between the size of the space in which victims were trapped (number of rescuers who were able to work simultaneously within the confined space) and the duration of rescue operations

3.4 Relationship between pinched victims, whether confined space medicine (CSM) was implemented or not, and the duration of rescue operations

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Instances of pinching were recorded by the National Police Agency for all victims; for victims subjected to pinching by collapsed structure elements, the data included supplemental survey information: the body part under pressure, and the type of object pressing the victim (e.g., beams). Furthermore, the data recorded whether medical specialists entered a collapsed building and performed treatments such as infusion, which is a CSM used to avoid the occurrence of crush syndrome. This syndrome is a systemic disorder that occurs when muscles are pinched for a long time and the compression they are subjected to is relieved. The muscle cell material that has died from this compression is released into the blood upon decompression, and can cause acute renal or heart failure.

Figure 8 shows the relationship between the pinched part (including cases when there was none), whether CSM was implemented or not, and the duration of rescue operations. First, for the cases where no pinching occurred, the mean rescue operation time was 25 min, the standard deviation was 15 min, the minimum was 7 min, and the maximum was 53 min. For cases that had pinching (all body part rows), the mean rescue operation time was 102 min, the standard deviation was 88 min, the minimum was 21 min, and the maximum was 380 min. Comparing these two results, the mean for the cases with pinching was four times that of the no pinching cases. Furthermore, in the cases with pinching, the numerical value dispersion was larger than that in the cases with no pinching. Next, compression objects were roughly classified into beams, ceilings, and rubble. In cases where beams exerted pressure, the duration of rescue operations tended to be longer. There were also various types of compression, such as compression of the whole body and compression of parts of the body: e.g., the shoulder. CSM was implemented in four cases where pressure was exerted on various parts of the body: one for below the waist, one for the abdomen, and two for the thigh (one leg). In these four cases, the duration of rescue operations had increased partially because the mean time between the request for medical specialists and their arrival and subsequent cooperation was 39 min, while the minimum time was 20 min, and the maximum time was 60 min. In addition, all cases involving CSM occurred after the main shock.

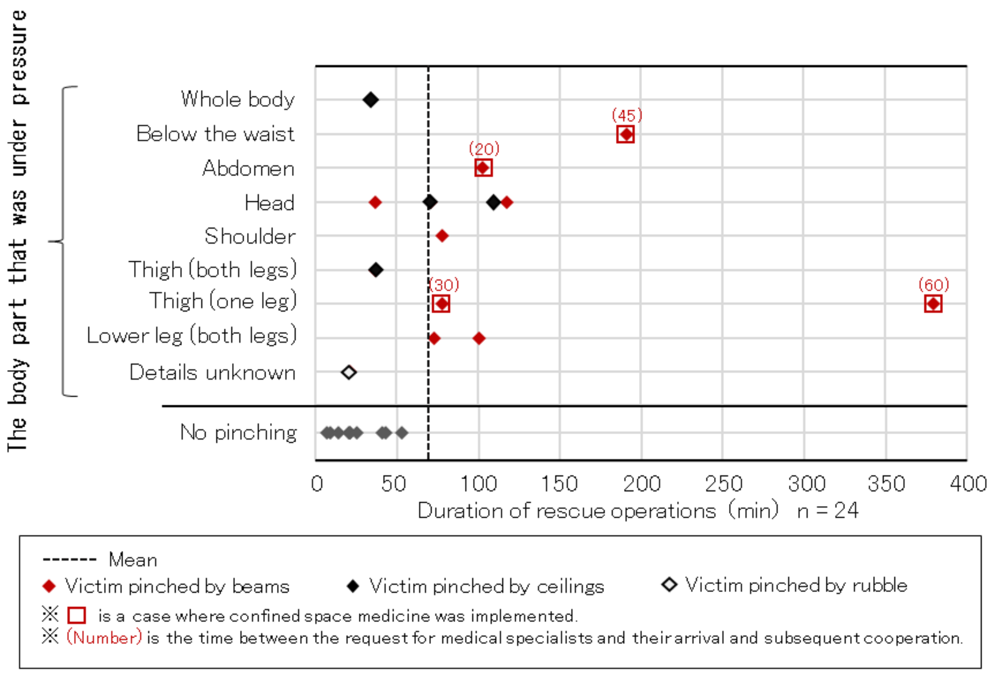

Figure 8 – Relationship between the pinched part (including the case when there was no pinching), whether CSM was implemented or not, and the duration of rescue operations

3.5 Relationship between the configurations under the pinched victims, pressure release methods, and the duration of rescue operations

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Figure 9 shows the relationship between the configurations under the pinched victims, pressure relief methods, and the duration of rescue operations; there were 14 such victims. In cases where a bed or sofa was under the victims, the duration of rescue operations tended to be shorter than in cases where flooring, a tatami, a futon, or the ground was underneath. In those same cases where a bed or sofa was under the victims, pinching was often relieved by establishing a space below the victim; when using that method, the duration of rescue operations tended to be shorter than what was observed when the object was lifted or cut. In addition, the National Police Agency released an investigation report that details via an image diagram the work situation for cases where the pinching was released by establishing a space below the victim [1] (Chapter 2, p.26, p.29, p.38). Figure 10 shows an excerpt from the image diagrams.

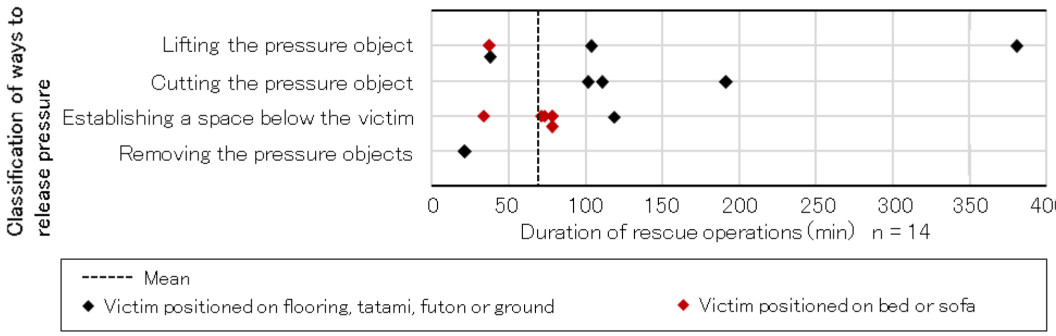

Figure 9 – Relationship between configurations under the pinched victims, pressure release methods, and duration of rescue operations

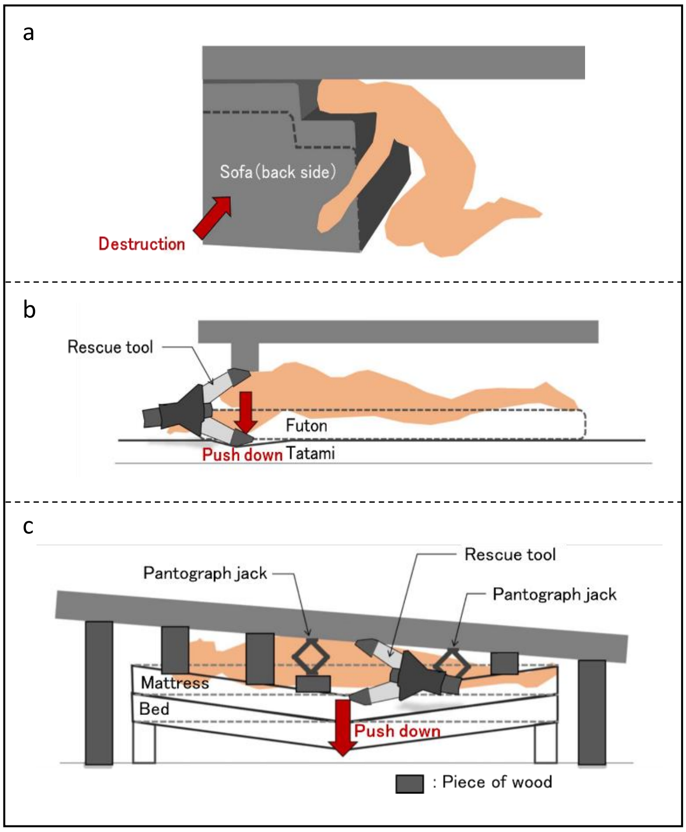

Figure 10 – Image diagrams for a case where pinching was relieved by establishing a space below the victim

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4. Discussions

The grade of building damage, the depths at which the victims were trapped, and the size and extent of spaces in which victims became trapped were thought to have some effect on the duration of rescue operations; however, these show no correlation (Figs. 4–7). As shown in Figs. 8 and 9, the pinched body part of the victim and configurations under the victims did trend with the duration of rescue operations, however.

To aid the discussion, we created a diagram of the various stages of rescue operations (Fig. 11), based on the investigation report by the National Police Agency.

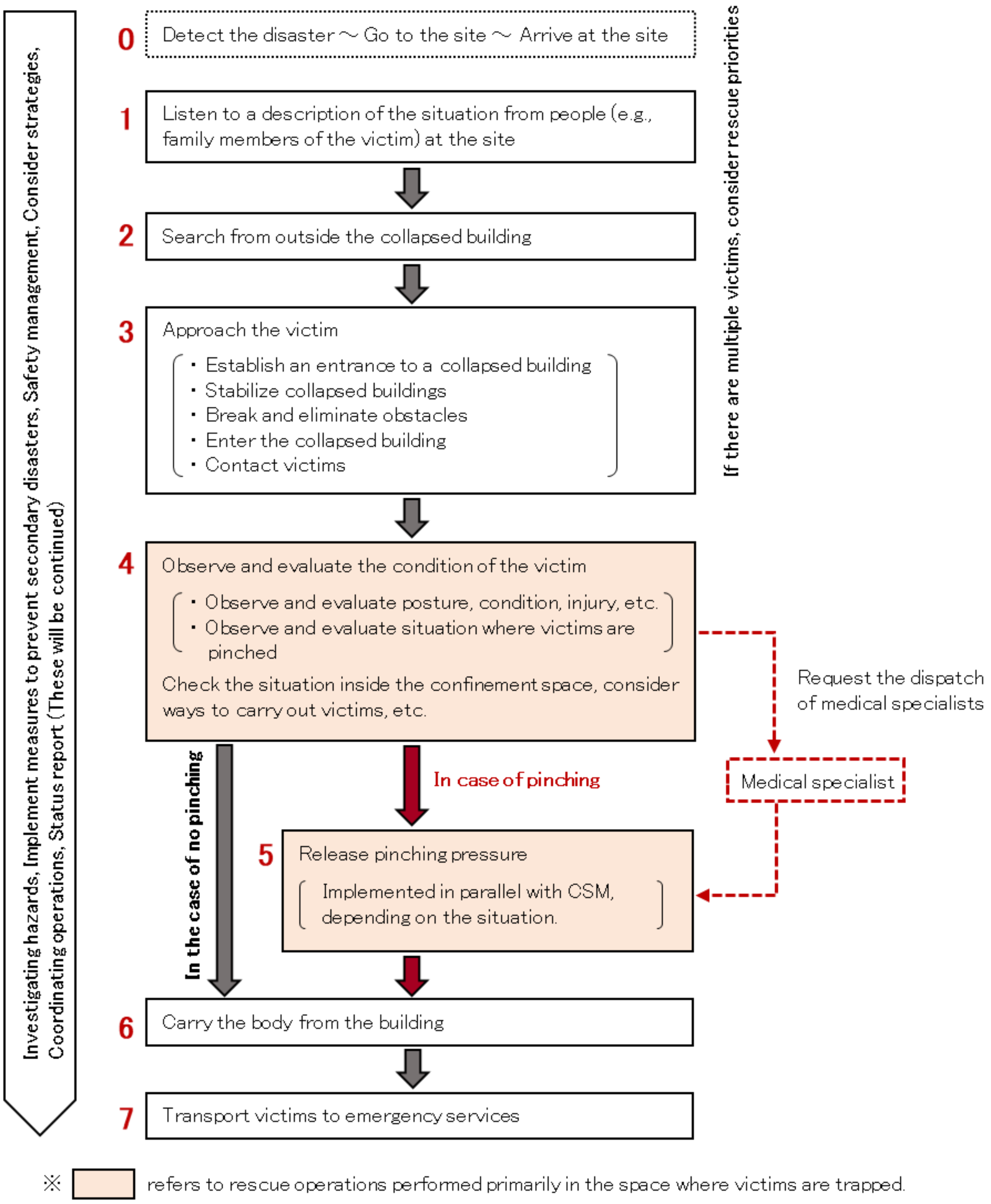

Figure 11 – Stages of rescue operations for victims in collapsed wooden buildings

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4.1 Situations where victims were pinched

The duration of rescue operations in cases where there was no pinching was relatively short (Fig. 8). This short duration is to be expected, because these cases do not require application of any pressure release methods (see the gray arrow from box 4 to 6 in Fig. 11). From Fig. 8, the average rescue duration for cases with pinching is four times greater than for cases with none; whether the victim was pinched or not is a significant factor that affected the difficulty of rescue operations. For cases where pinching was involved, the duration of rescue varied widely, from 20 min to 380 min. This result indicates that the level of difficulty varied substantially among cases; rescuers are required to evaluate the situation carefully when the victim is pinched. We discuss this in more detail in the following sections.

4.2 Body part of the victims that was pinched

As shown in Fig. 8, in many cases where the rescue duration was notably long, CSM was often implemented to avoid crush syndrome. In these circumstances, the pinched body parts varied: below the waist, abdomen, and thigh (one leg); it is assumed that a broader range of muscles was pinched than in the other cases where the head, shoulder, lower leg (both legs) were pinched; the broader range caused the mean rescue time to be exceeded. When a broad range of muscles is pinched, the risk of developing crush syndrome increases. Therefore, it is presumed that the rescue team attended to this situation, requested the dispatch of medical specialists, and performed rescue operations in parallel with CSM (refer to the transition from box 4 to 5 in Fig. 11). CSM is a specialized medical practice performed in dangerous or less than optimal environments. Therefore, CSM implementation requires a high degree of competence from both rescuers and medical specialists [14]. When estimating the degree of difficulty in rescue operations, it is necessary to accurately detect the body part that is under pressure and to evaluate the probability of crush syndrome occurrence. In addition, as shown in Section 4 of Chapter 3, all four cases where CSM was implemented occurred after the main shock, and the time required to start on-site cooperation with the medical specialist in these cases averaged 39 min. The 2016 Kumamoto earthquakes were an extraordinary disaster with the main shock occurring just 28 hours after the foreshock. Therefore, we speculate that when the main shock occurred, many emergency medical teams already serviced the affected area following the foreshock; these emergency medical teams were immediately allocated on site. This immediacy is a rare case. Therefore, it should be noted that the times before the start of cooperation with medical specialist in this survey are not necessarily representative of what is observed for standard disasters.

4.3 Compression objects

The duration of rescue operations was longer in cases where there were beams pressing on the victim (Fig. 8). First, the beam is a main structural member of the building, and the load of the collapsed building is likely to add to the compression significantly. Because of this, we speculate it was difficult to lift the mass or that it was time consuming to stabilize the building and to prevent the progression of destruction that can be caused by cutting.

In light of these considerations, it is assumed that advanced lifting or cutting skills will be required if the compression object is a beam. When estimating the degree of difficulty for rescue activities involving this type of compression object, it is necessary to take the building structure into account and determine whether the compression object is a beam, the weight of the load on the beam, and the risk of secondary disaster occurrence.

4.4 Compression objects and pressure release methods

The configurations under the victims affected the duration of rescue operations. If a beam is exerting a considerable load as described above and if the object under the victim can be safely destroyed or further compressed like a bed or sofa (a and c in the image diagram of Fig. 10), the pinching pressure can probably be relieved in a relatively short time. In the case where the object below the victim is a futon or tatami (Fig. 10-b), pinching can be relieved by securing a small space below the victim if the rescue team has the appropriate

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rescue tools. More research is needed to determine the required tool kits and skillsets. Owing to the limited number of cases, further research is also needed to validate the results, but the configurations under the victims may be a useful indicator for estimating the difficulty of rescue operations.

5. Conclusions

The National Police Agency collected survey data based on rescue operations performed at collapsed wooden building sites during the 2016 Kumamoto earthquakes. Using this data, we analyzed the relationship between the duration of rescue operations and site conditions, and we organized the indicators used by disaster responders to estimate the difficulty of rescue operations. The following two points have been revealed in this study.

1. Rescue operation difficulty was affected by three factors: whether the victims were pinched, the mass of or pressure exerted by the collapsed structure element (beam, etc.) on the victim, and the configuration under the victims.

2. Contrary to expectations, the grade of the building damage, depth at which victims became trapped, and extent of the confinement space did not affect the difficulty of operations.

It is worth noting that the limited number of cases analyzed in this study and restrictions to accessing rescue operations by police rescue teams mean that the results of this study may not be a complete reflection of the entire disaster recovery situation.

Because it is challenging to estimate rescue operation difficulty for a collapsed wooden building by using only exterior observation, it is necessary to confirm the condition of victims in internal confined spaces.

In the future, a method that will provide a) more secure, prompt, and accurate confirmation of whether the victims are pinched, b) the mass or pressure exerted by the collapsed structure element (beam, etc.) on the victim, and c) the configuration under the victims must be determined. Furthermore, the matching efficiency of the levels of site difficulty with the levels of rescue teams, equipment, and skills must be examined. It is also important to consider how to safely, promptly, and accurately proceed with rescue operations for difficult cases. The results of this study are also useful for examining what kind of personnel and equipment should be deployed and for determining what training should be planned.

Finally, in this study, we effectively analyzed the actual data described in the investigation report by the National Police Agency. It is important to accumulate the same data and, for future disasters, to proceed with a study that adopts viewpoints from multiple disciplines such as rescue, disaster medicine, and building engineering.

6. Acknowledgements

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