

Case Study of the 2016 Kumamoto Earthquake: The Disaster Response Capability of Kumamoto Compact City, Japan

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Abstract. Compact cities are widely used in urban planning in Japan due to the following benefits: efficient land use, reduction in the transport network and reliance on mass transport, low emissions, etc. However, Compactness often means high density. In disaster-resistant Japan, whether the compact city form can effectively respond to disasters is needed further discussion. In the Kumamoto City Master Plan, 15 local hubs have been planned to promote the development of the compact city. In this study, 15 local hubs are selected as the research objects. Moreover, the entropy method was chosen to evaluate the disaster prevention capability. The results show that disaster risk is high and the disaster prevention ability is weak in the central urban area, which is likely to cause greater losses when the disaster occurs. The local hubs that are far away from the city centre also have the weak disaster prevention due to the lack of disaster prevention facilities, while some hub areas are more capable of disaster prevention despite the high risk of disasters. Therefore, in the post-disaster reconstruction plan, it is recommended making a focus on the low-risk and disaster resistant areas. At the same time, the cancellation of hubs with high risk and weak disaster prevention needs to be further discussed.

1 Introduction

In Japan, in order to improve the city's disaster prevention performance, it is seeking to build a compact urban structure. In many cities around the world, with the rapid popularization of automobiles, cities have become low density and sprawl. As many traffic behaviors depend on cars, when large-scale disasters occur, the emergency response problem is worrying. For example, serious congestion occurred around the disaster area after the Great Hanshin-Awaji Earthquake[1], which is an important obstacle to emergency response. In addition, there have been many problems in the Great East Japan earthquake in 2011, such as the delay of emergency response due to lack of gasoline supply. Since the daily activities of the city as a whole are overly dependent on cars, it is inevitable that excessive dependence on cars during disasters. One of the goals of a compact city are to

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reduce its dependence on the car, which may improve the emergency response capability of a disaster.

However, the disaster prevention ability of compact city is also questionable. For example, compact cities tend to be high-density. If the population is excessively concentrated in disasters, it may cause confusion and cause more losses. The effective emergency response is worrying.

Therefore, in Japan, a country with frequent disasters, the development of compact cities should take its disaster prevention performance into consideration. Based on the 2016 Kumamoto earthquake, this study discusses the disaster prevention capability of compact urban structures, and clarifies the gaps and improvement directions of disaster prevention capabilities in various regions of the city, hoping to provide a reference for the development of other similar regions.

2 Study areas

2.1 2016 Kumamoto earthquake and disaster risk

In April 2016, two earthquakes struck Kumamoto with the first quake, a 6.4 magnitude quake (April 14 foreshock), followed one day later with a bigger tremor hitting a wider area and measuring 7.3 (April 16 main shock) on the Richter scale. [2]

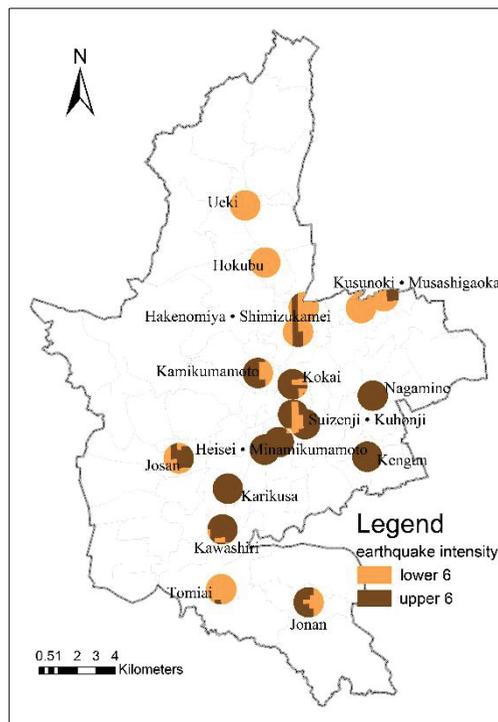


Fig. 1. The distribution of seismic earthquake intensity in 15 local hubs.

The total number of fatalities caused by the earthquakes is reported being 69, while the total number of casualties was 1747. The earthquakes destroyed 8050 houses and 24,147 buildings suffered major damage. Historically, there have been devastating earthquakes in Kumamoto area, but this was the most devastating one in this area ever recorded [2].

2.2 Kumamoto compact city

In the city of Kumamoto, "Secondary Kumamoto City Urban Master Plan -- Regional Structure" was formulated in 2014, among which the goal of urban development is to make the multinucleated interlocking city which central urban areas and regional bases are connected by public transport and cooperate with each other.

At that time, the purpose of this plan was to cope with a decrease in population and rapid aging of society. The problem of disaster prevention was not considered too much.

After 2016 Kumamoto Earthquake, based on the experience of the damage, Kumamoto City has reviewed the Master Plan and Regional Disaster Prevention Plan at the Urban Master Plan Formulation Committee and disaster prevention meeting. Various issues such as "Strengthening civil, regional and administrative disaster response capabilities", "Reinforcement and strengthening of the establishment and operation of evacuation shelters etc.", "Review of supply system", "Earthquake resistance of infrastructure and public facilities" were revealed. In addition, in order to realize the multinucleated interlocking city with high disaster prevention capability, it is mainly to carry out revisions of disaster prevention and mitigation.

Under the multinucleated interlocking community concept, the city government assumes three types of core areas [3] (Fig. 2):

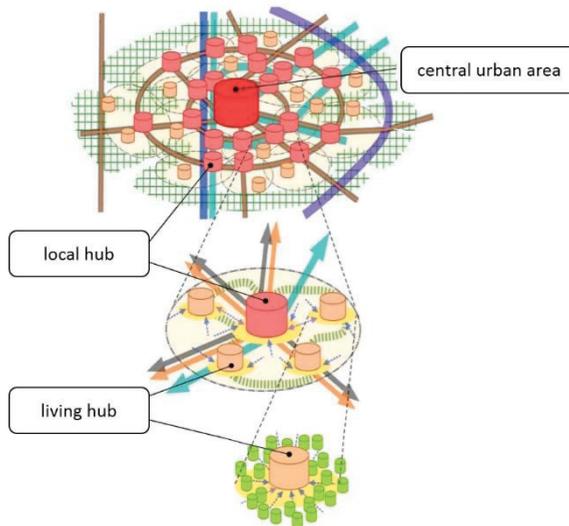


Fig. 2. The multinucleated interlocking community concept of Kumamoto City.

- The central urban area where Kumamoto Castle, a symbol of the city, and advanced city functions, such as commercial districts, financial institutions, and broadcasting bases, are concentrated.
- Some local hubs where service functions needed for daily life, such as commercial and medical functions, are concentrated. According to the Kumamoto Master Plan, there are 15 local hubs in Kumamoto City.
- Many living hubs where housing is mainly located.

The local hubs and the living hubs will form "local living centres," with the central urban area and local hubs connected by public transport networks such as streetcars and buses. The local hub consists of living hub, showing the characteristics of a compact city that gathers population and facilities.

However, gathering the population and facilities in a certain area, when the disaster occurred, is really good for disaster prevention? It needs to be further discussed.

In this study, taking April 16 main shock as a case and 15 local hubs as the study area, we analyse the distribution of seismic earthquake intensity in 15 local hubs, and take the seismic intensity distribution as the disaster risk standard.

3 Evaluation index system and methods

3.1 Construction of evaluation index system

By analysing and summarizing the previous studies [4-5], from the perspective of "easy to evacuate", "hard to be destroyed", "high recovery ability", we divided the evaluation field into "accommodation ability," "supply ability," "health care," "convenience," and "security", "Resilience". A total of 17 items (Table 1) were selected to construct an evaluation index system for the disaster prevention capability of Kumamoto City.

Table 1. Evaluation index system

Evaluation field	Evaluation item	Correlation
Accommodation ability	Per capita area of shelters(m ²)	+
	The number of seating capacity	+
	The number of parks (excluding shelters)	+
	The number of schools (excluding shelters)	+
	Elderly people	-
Supply ability	The number of companies wells in disasters	+
	Disaster prevention warehouse	+
	The number of convenience stores	+
	The number of free Wi-Fi facilities	+
Healthcare	The number of hospitals	+
	The number of welfare facilities	+
Convenience	Emergency road length	+
	Percentage of roads with width of 12 m or more	+
	Percentage of roads with width less than 4 m	-
Security	Construction damage rate	-
	Percentage of wooden houses	-
Resilience	The number of public housing	+

Facilities such as shelters are an important indicator of disaster prevention. With regard to accommodation ability, we evaluated the per capita area of shelters, the number of

seating capacity, parks (excluding shelters), schools (excluding shelters), and elderly people. Since the area of each local hub and population are different, we investigated the per capita area of shelters. In Kumamoto City, most of the shelters are school sports venues, playgrounds, etc., and some are parks. However, not every school is a designated shelter. Therefore, while analysing the accommodation ability of existing shelters, the number of schools and parks (excluding shelters) in each local hub is evaluated. These are potential resources that can be used as shelters when disasters occur.

During the 2016 Kumamoto Earthquake, the Japanese government announced on April 17 that 700,000 meals will be delivered to convenience stores in the disaster area. When a disaster occurs, convenience stores can serve as an important base to help a wide range from neighbouring residents to victims on their way home. The Kumamoto Earthquake also confirmed that convenience stores have indeed become an important part of its disaster prevention. After the earthquake, water breaks often occur. Therefore, wells are important facilities to ensure water supply during disasters.

As for healthcare, we investigated the number of hospitals and welfare facilities at each hub. If the number of hospitals and welfare facilities is large, it is considered that disaster prevention capability is high.

When the width of the road is narrow, the road blockage rate is high and evacuation cannot be secured. If we can secure a certain road or roadside space, it is considered that a "safe evacuation route" can be secured.

When the construction damage rate is high, it is considered that the disaster prevention ability is low, so the damage rate of the building is analyzed. Moreover, it was found that the wooden buildings suffered the most damage after the earthquake. Therefore, we investigated the proportion of wooden buildings in each hub.

Disaster Public Housing (municipal and prefectural housing) is a construction project based on the Public Housing Law to allow local governments to reside in houses damaged by disasters and to rent themselves to those who are difficult to rebuild their houses on their own. Municipal and prefectural houses are temporarily furnished with housing when disasters occur. It can ensure a stable life and improve the resilience of local disasters.

3.2 Entropy method

Shannon[6] first introduced the application of entropy which describes the uncertainty. In information theory, entropy is a measure of the degree of disorder of the system. The greater the variability of the indicator value of an indicator, the smaller the information. The larger the amount of information provided by the indicator, the greater the weight of the indicator. Conversely, the weight of the indicator is smaller. The entropy method calculation steps[7-8] are:

Step 1: Create a data matrix X :

$$X = X(i,j)_{m \times n} \tag{1}$$

The data matrix X is created by numerical values of evaluation items. i ($i = 1, 2, \dots, m$) is the number of local hubs, and j ($j = 1, 2, \dots, n$) is the evaluation item.

Step 2: Normalize the decision matrix:

$$Y_{ij} = X_{ij} / \sum_{i=1}^m X_{ij} \tag{2}$$

Step 3: Calculate entropy :

$$e_j = -K \sum_{i=1}^m (Y_{ij} * \ln Y_{ij}) \tag{3}$$

Where K is the entropy constant and is equal to $1/\ln(m)$.

Step 4: Calculate the degree of divergence:

$$d_j = 1 - e_j \tag{4}$$

Step 5: Weighting of evaluation item:

$$W_j = d_j / \sum_{j=1}^n d_j \tag{5}$$

where W_j is the degree of importance of attribute j .

Step 6: Calculation of evaluation score:

$$S_i = \sum_{j=1}^n (W_j * X_{ij}) \tag{6}$$

3.3 Data Sources

The original data and relevant calculations are mainly based on the Kumamoto 2012 basic survey data and National Land Numeral Information, part of the data comes from our investigation and calculation.

3.3.1 The number of seating capacity

When referring to calculation standards such as Himeji City, Uozu City, Ise City, Tottori Prefecture, it is considered that 2 people per 3.3m² in the case of long-term evacuation and 4 people per 3.3m² in the case of temporary evacuation. However, this standard does not take into account factors such as household belongings, aisles.

In addition, in the case of the actual evacuation, in addition to the living space of the asylum, it is necessary to ensure the space for the care of the weak, the provision of medical care, and the space used by the meeting, so each refugee should have the best of about 6m² (of which an effective building area is about 3m²).

For the above reasons, the calculation method of the number of people to be evacuated is as follows.

$$\text{Seating capacity} = \text{total floor area} / \text{per capita demand area}$$

3.3.2 Construction damage rate

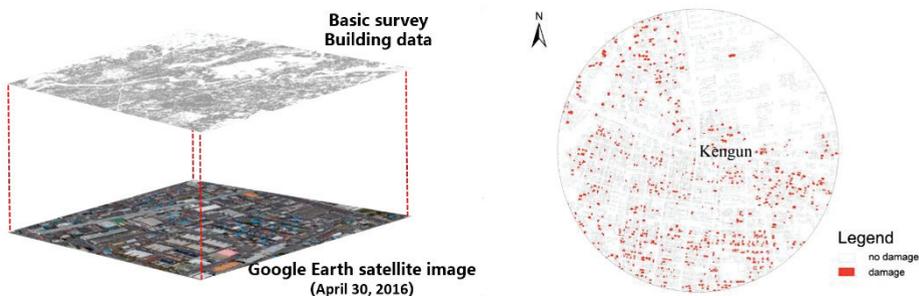


Fig. 3. The method of visual interpretation.

According to Google earth data (April 30, 2016) and building data from the 2012 basic survey of Kumamoto city, the damage status of buildings after the 2016 Kumamoto earthquake was investigated. Using the method of visual interpretation [9-10], the damage condition of each building in the local hubs of Kumamoto city was evaluated. The interpretation of building damage this time was divided into two stages of damage and no damage. Damage is that the building collapsed, the outer shape of the building remained but the outer wall collapsed, the majority or part of the roof tile dropped. No damage is minor damage that is not damaged or cannot be confirmed by photograph reading.

4 Results

According to the above data and calculation steps, the data of 17 evaluation items of 15 local hubs in Kumamoto City were processed, and the score of disaster prevention ability of each local hub was calculated (Table 2).

Table 2. Evaluation score

Number	Local hubs	Score
6	Nagamine	3.49
15	Kamikumamoto	3.11
8	Kengun	3.10
5	Kokai	2.86
14	Josan	2.73
1	Ueki	2.72
12	Jonan	2.66
2	Hokubu	2.49
10	Karikusa	2.49
11	Tomiai	2.43
4	Hakenomiya • Shimizukamei	2.38
13	Kawashiri	2.15
7	Suizenji • Kuhonji	2.09
9	Heisei • Minamikumamoto	2.09
3	Kusunoki • Musashigaoka	1.98

It is not difficult to see from Table 2 that the disaster prevention capability of the 15 local hubs in Kumamoto has obvious spatial differences, the higher the score in this study, the weaker the disaster prevention capability, and vice versa. Nagamine, which has the

weakest disaster prevention capability, has a comprehensive disaster prevention capability score of 3.49, which is equivalent to 1.8 times that of Kusunoki · Musashigaoka, which ranks the highest in disaster prevention capability. In order to facilitate the overall understanding of the spatial differentiation characteristics of the city's disaster prevention capabilities, SPSS19.0 was used to systematically cluster 15 local hubs according to the comprehensive score of disaster prevention capability, and the cluster pedigree of 15 local hubs in Kumamoto City was obtained.

According to the clustering results, 15 local hubs in Kumamoto City are divided into 3 types: areas with medium disaster prevention capability and areas with weak disaster prevention capability, areas with high disaster prevention capability (Fig.4).

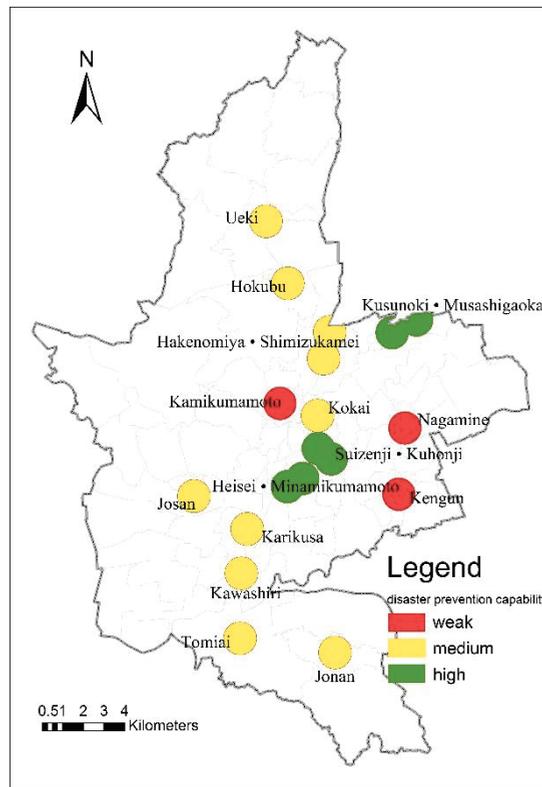


Fig. 4. The disaster prevention capability in 15 local hubs.

4.1 Areas with weak disaster prevention capability

Areas with low disaster prevention capacity include Nagamine, Kamikumamoto, and Kengun, with comprehensive scores of more than 3.10.

Nagamine area is close to the earthquake centre and has been seriously affected by the earthquake. It is one of the areas with the highest damage rate of buildings. Therefore, the risk of earthquake disasters is high. In terms of disaster prevention capacity, the distribution of disaster prevention infrastructure in this region is not balanced. The per capita shelter area is only 0.66m², which is the lowest among the 15 local hubs. Therefore, the number of seating capacity of the shelter is relatively poor. To make matters worse, there are also shortages of facilities such as schools and parks for disaster evacuation. At the same time, the proportion of roads less than 4 meters in this region are relatively large, which also

causes certain difficulties for the evacuation during disasters. However, this area is one of the more concentrated areas of public housing in Kumamoto City. It provides a guarantee for post-disaster recovery and reconstruction after the disaster.

Kamikumamoto area is far away from the earthquake centre, but it has been affected more seriously, and it is one of the areas with high a damage rate of buildings. The narrow road and the small number of public housing are all the factors that lead to its weak disaster prevention ability. At the same time, the more important reason for its weak disaster prevention capability is that it is closer to the city centre, and it is likely to cause more serious impacts during disasters.

Kengun area is one of the closest areas to the earthquake centre. High risk of disaster, coupled with weak disaster prevention capacity, resulting in more serious losses. In the 2016 Kumamoto earthquake, the construction of buildings in the Kengun area was the highest.

4.2 Areas with medium disaster prevention capability

The number of local hubs with the medium disaster prevention capacity is more than half of the total number of hubs. In addition to Kokai area, most of these areas are far from the city centre, and the distribution of disaster prevention facilities is relatively balanced, which can better meet the needs of local people in disaster prevention. Among them, the Kokai area is a region with weak disaster prevention ability in this group, mainly because of the large number of elderly people and old buildings.

4.3 Areas with high disaster prevention capability

The areas with high disaster prevention capacity include Kusunoki · Musashigaoka, Heisei · Minamikumamoto, Suizenji · Kuhonji, Kawashiri, which are closer to the city centre. The comprehensive score is between 1.98~2.15.

Among them, Kusunoki Musashigaoka area, which is located on the northeast of Kumamoto City, has the highest disaster prevention ability. Although the number of elderly population in this area is large, the ability of disaster prevention is relatively high due to the balanced distribution of urban disaster prevention facilities. Therefore, in the post-disaster recovery planning proposal, this area should have higher utilization value and higher priority.

The other three areas, especially the Heisei · Minamikumamoto and Suizenji · Kuhonji, are close to the city centre, and the layout of various disaster prevention facilities is relatively reasonable. Meanwhile, the earthquake resistance of buildings is relatively high, which makes these areas have higher disaster prevention capability.

5 Discussion and conclusion

The assessment of disaster prevention capability is a complex project involving economic, social, demographic, resource, and environmental aspects. At present, there are relatively few related studies on the assessment of disaster prevention capability in compact city. This study extracts 17 related indicators from the perspectives of "easy to evacuate", "hard to be destroyed", "high recovery ability", and attempts to evaluate the earthquake disaster prevention capability of the Kumamoto compact city. In the evaluation, the entropy method is used to determine the index weight, which can not only overcome the randomness and the disconnection problem that the subjective weighting method can't avoid, but also avoid

the overlap of information between multiple index variables, which has strong practicability.

The disaster prevention capabilities of the 15 regional bases in Kumamoto City show significant spatial differences. The disaster prevention capabilities of the 15 local hubs in Kumamoto City show significant spatial differences. Overall, areas closer to the city centre have a weaker disaster prevention capability. The areas outside the city are with medium disaster prevention capability, and the risk of disasters is not high. For areas closer to the city centre, there are also differences in disaster prevention capabilities, such as the weak disaster prevention ability of Kamikumamoto and the high disaster prevention ability of the Suizenji · Kuhonji and Heisei · Minamikumamoto. Therefore, in the post-disaster reconstruction plan, the feasibility of 15 local hubs should be further explored. It is suggested that the site selection of the 15 existing areas should be revised. Furthermore, it is recommended making focus on the low-risk and disaster resistant areas. While for those with poor resilience and high risk, it is necessary to further explore the rationality of their location.

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