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STRUCTURAL TYPE AND DAMAGE CLASS OF DEMOLISHED BUILDINGS IN MASHIKI AFTER THE 2016 KUMAMOTO EARTHQUAKE

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Abstract

After a large-scale disaster, many damaged buildings are demolished and treated as disaster waste not only to prevent the occurrence of secondary damage but also to rebuild the living environment. As Kumamoto Prefecture administrative office reported that approximately 210000 buildings in Kumamoto prefecture and 15300 buildings in Mashiki town were damaged and many buildings needed to be demolished. It is necessary to properly estimate a weight of disaster waste for the purpose of disaster waste disposal implementation. Though the weight of disaster waste was estimated two months after the 2016 earthquake in Kumamoto, Japan, the estimated weight was significantly different from the result when the disaster waste disposal was completed in March 2018. The amount of disaster waste generated is able to be estimated by equation by multiplying the total number of major damaged and partially moderate damaged buildings by the coefficient of generated weight per building. We consider that the total volume of disaster waste disposal depends on the actual number of demolished buildings, the floor area of buildings, and the typologies of building structures, such as wood and concrete construction. In past research, however, demolished buildings were not individually identified, and the percentage of damaged buildings that were demolished, the total floor area, and the proportions of structure typologies were not clarified. Yamazaki et al. (2019) studied relationship damage class and structural typologies based on survey data of Mashiki municipality [1]. But buildings demolished were not related to the survey data. Therefore, it is necessary to create a dataset to identify demolished and remaining buildings. We used OpenStreetMap (OSM) data as base data and classified demolished buildings from satellite images. We made a time series geographic information system (GIS) dataset with labels of demolished and remaining buildings in Mashiki in the two years following the Kumamoto earthquake. In this study, we classify structure typologies and stories of each building by image analysis, field survey, and visual interpretation through Google Street View. And we combine the structure typologies with the GIS dataset which has the label of the demolished and remaining building. We further investigate the relationship between structure typologies of buildings, damage class, and demolished buildings in the GIS dataset in order to improve estimation for the disaster waste generation.

Keywords: building structure typologies, disaster waste, GIS, recovery, satellite image

1. Introduction

In the 2016 Kumamoto disaster, two large earthquakes of M6.5 on 14 April and M7.3 on 16 April occurred near Mashiki town, causing major damage to many buildings. Kumamoto Prefecture reported that approximately 210000 buildings in Kumamoto prefecture and 16590 buildings in Mashiki Town were damaged, including both residential and non-residential houses, due to the 2016 Kumamoto earthquake [2]. As Mashiki town was close to the epicenters, around 30% of the damaged buildings were severely damaged and many buildings needed to be demolished. Demolished buildings are generally treated as disaster waste disposal. In order to smoothly implement disaster waste disposal, it is necessary to estimate the amount of disaster waste disposal and draw up an implementation plan that includes schedules, securing of a temporary site, equipment, and team organization. The Kumamoto Prefectural government estimated that the amount of disaster waste disposal would be 1 to 1.3 million tons on 18 May 2016 prior to the completion of the survey of the damaged buildings. On 1 June 2016, the Kumamoto Prefectural government reported the number of majorly and moderately damaged buildings and estimated again that the amount of disaster waste generated would be about 2 million tons [2]. At the completion of its disposal, the Kumamoto Prefectural government reported that the amount of disaster waste in Kumamoto prefecture was approximately 3 million tons and that of Mashiki town was 337629 tons [3], which were significantly different from the amount estimated in initial phase.

Hirayama and Kawata et al. [4, 5] investigated total amount of disaster waste disposed and the total number of damaged buildings in the past disasters, so that estimation equations for the amount of generated disaster waste was determined by a regression analysis. Based on the past researches, the equation (1) for estimating the amount of disaster waste generated from number of damaged buildings as below;

$$\text{Amount of disaster waste} = N_1 \times I_1 + N_2 \times I_2, \tag{1}$$

where N_1 is a number of majorly damaged buildings and N_2 is a number of moderately damaged buildings. And I_1 and I_2 are the disaster waste disposal generation intensity for majorly damaged building and moderately damaged building respectively [6]. However, compared to the estimated value of June 2016, the final value of March 2018 was 1.6 times greater. It is necessary to improve the accuracy of the estimation method.

In the past research, demolished buildings were not individually identified, and the percentage of damaged buildings that were demolished, the total floor area, and the proportions of structure typologies were not clarified. Therefore, it is necessary to create a dataset to identify demolished and remaining buildings.

In addition, according to the report of the Mashiki municipality [3], 5702 buildings were demolished as of the end of March 2018, however, more than 700 buildings of them were not certified for the disaster damage. Therefore, it is necessary to clarify demolished buildings, floor area, and structures by other method than registry book and the disaster certification. Yamazaki et al. [1] classified the damage grades of wooden buildings on a field survey and investigated the damage ratio with respect to the construction year. It was found that the ratio of larger damage grade was smaller as the construction year was newer. Kushiyama and Matsuoka [7] created a Mashiki map dataset using OpenStreetMap (OSM) data as base data and time series SPOT images observed during the two years following the Kumamoto earthquake to label all demolished and remaining buildings in Mashiki town.

We tried to make a relationship the Mashiki map dataset that has the labels of demolished and remaining buildings with the structure and construction year in order to create a database for a more accurate estimation of disaster waste generation.

2. Methodology of relation between Mashiki map dataset and field survey data

In this study, three input data were used to associate demolished / remaining identification, damage grade, and building structure with the Mashiki town building. Input data 1, Mashiki map dataset were 16107 building footprints that consisted of building map data extracted from OSM and manually traced outline on buildings in satellite image. We treated the input data 1 as base data, because they had all building footprints in Mashiki town with the labels of 5701 demolished and 10406 remaining buildings. Input data 2 were 19497 points data included damage grade, the latitude and longitude as a field survey position. However, some points were overlapped at same position or surveyed to the same building from different directions. It was necessary to be filtered by the geolocation and the damage grades and so on. Input data 3 were 13718 point data that Yamazaki et al. [1] had correlated with the location information of input data 2 and the address of the house registry book of the Mashiki municipality. The input data 3 included not only geolocation and damage grade but also building information such as structure, floor area, and construction year etc.

The flow to make the relationships among the input data are shown in Fig.1.

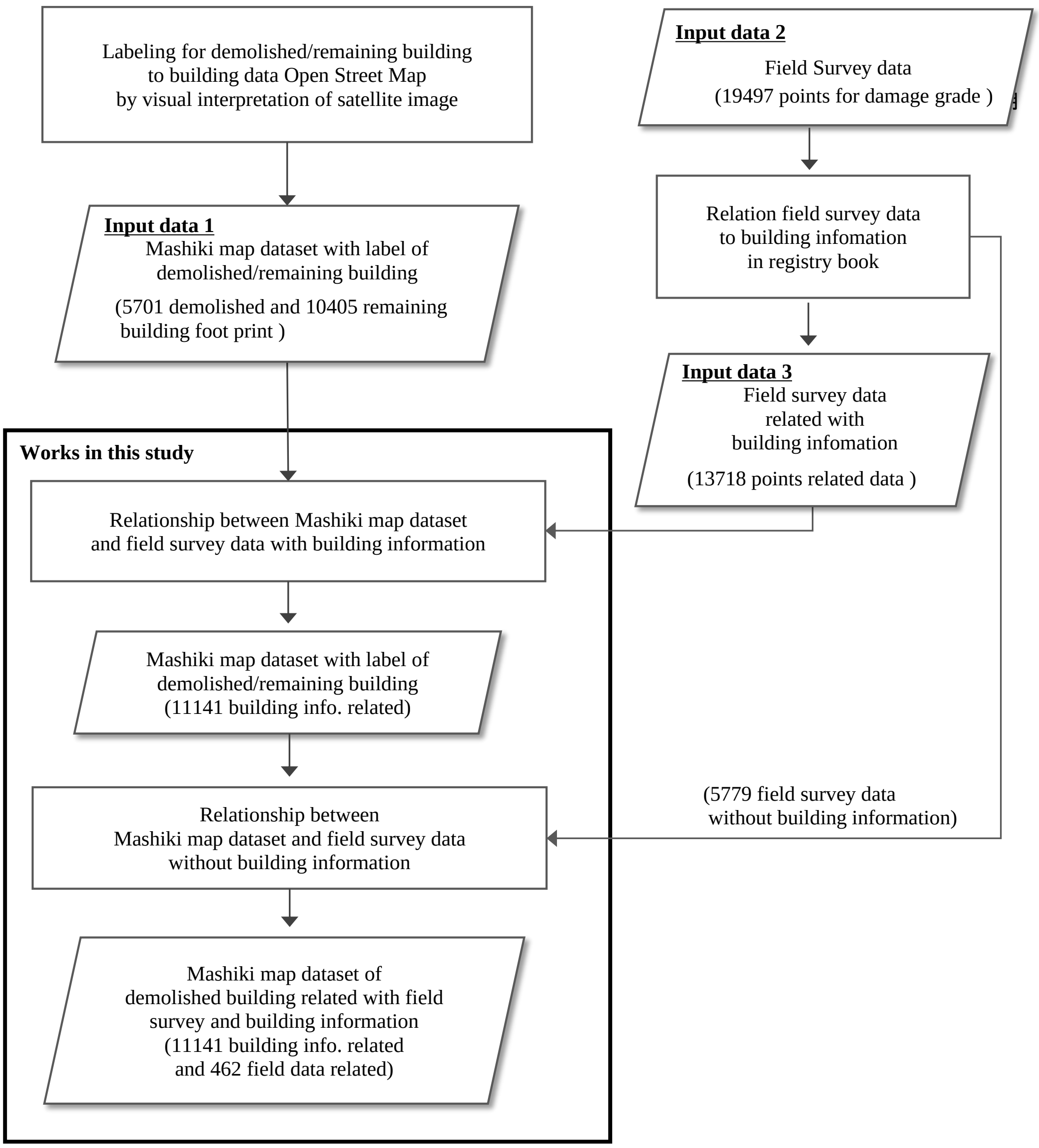
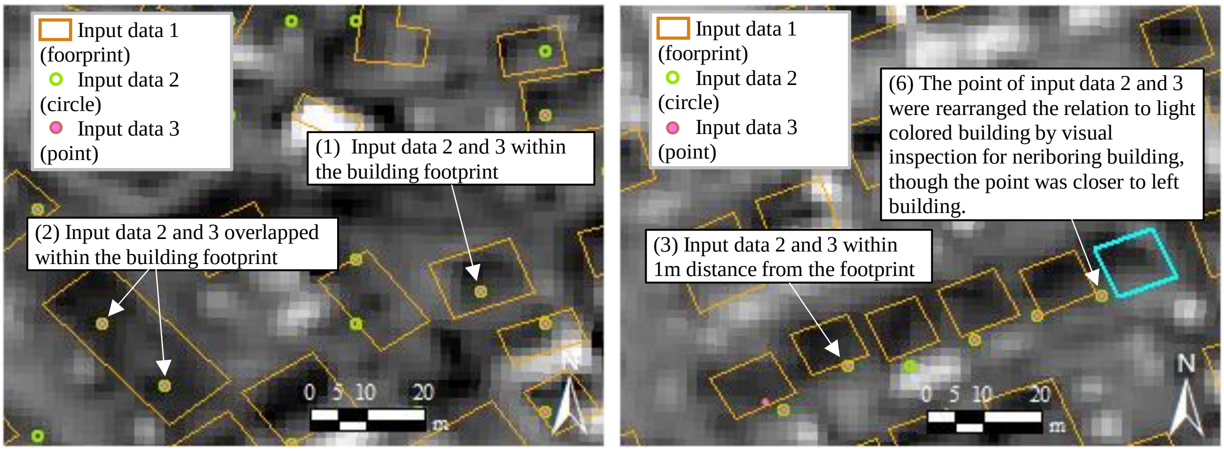


Fig. 1 – Work flow for the development of relationship between Mashiki map dataset of buildings, field survey data, and building information

Firstly, we made the relationship between the input data 1 and the input data 3 through the following steps:

(1) We made geospatial relations of the point of the input data 3 within the building footprint. (Fig.2 (a))
(2) We selected only one geolocation point to one building by manual operation, if two or more geolocation points were overlapped. (Fig.2 (a))
(3) We made the geospatial relations, if the rest points of input data 3 within 1m distance from buildings. (Fig.2 (b))
(4) We repeated the geospatial relations to the input data 3 within 5m distance from buildings.
(5) We made the geospatial relations by visual interpretation, if there were more than 5m distance from buildings.
(6) We rearranged the relations by visual inspection for geospatial position among neighboring buildings. (Fig.2 (b))
11141 points of the input data 3 were related to the input data 1 included 4485 demolished and 6656 remaining building. Next, we made associate the rest input data 1 with the input data 2 that were other points than input data 3 as same as steps (1) to (6).



(a) (b)

Fig. 2 –Examples of the relations between the points of input data 2/3 and input data1 (building footprint) overlaid on SPOT image on 20 March 2016

3. Result

As a result of relation between the input data 1, input data 2, and input data 3, Mashiki map dataset were classified into three relation groups. Number of data in the groups (Gr1, Gr2, Gr3) and relation patterns between building footprint, demolished/remaining, damage grade, and building information are shown in Table 1.

The numbers of demolished and remaining buildings in the groups are shown in Fig.2. As Gr1 and Gr2 that included 11603 building data were related to the damage grades, the numbers of demolished and remaining buildings with respect to the damage grades were shown in Fig.3. We investigated the demolished and remaining buildings in the relationship for building structure, construction year, number of stories, and floor area to the damage grades from Gr1 and Gr2. The numbers are shown in Table 2, Table 3, Table 4, and Table 5 respectively.

Table 1 – Number of related data in groups and relation pattern on Mashiki map dataset

Relation group	Footprint	Damage grade	Building information	Subtotal*
Gr1	Y	Y	Y	11141 (4485, 6656)
Gr2	Y	Y	-	462 (443, 19)
Gr3	Y	-	-	4503 (773, 3730)
Total				16106 (5701, 10406)

Y: The data were related.
*: Number of data in each group and the numbers of demolished and remaining buildings in the groups are shown in the blankets.

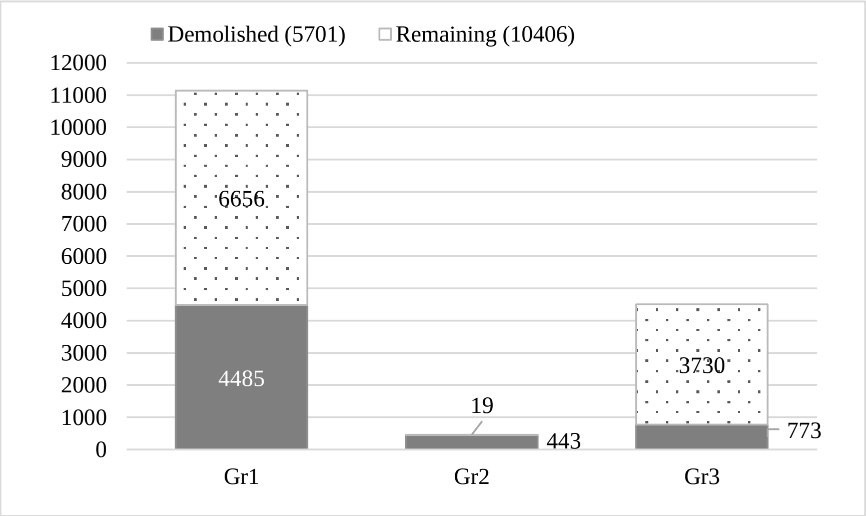


Fig.3 –Number of demolished and remaining buildings in groups

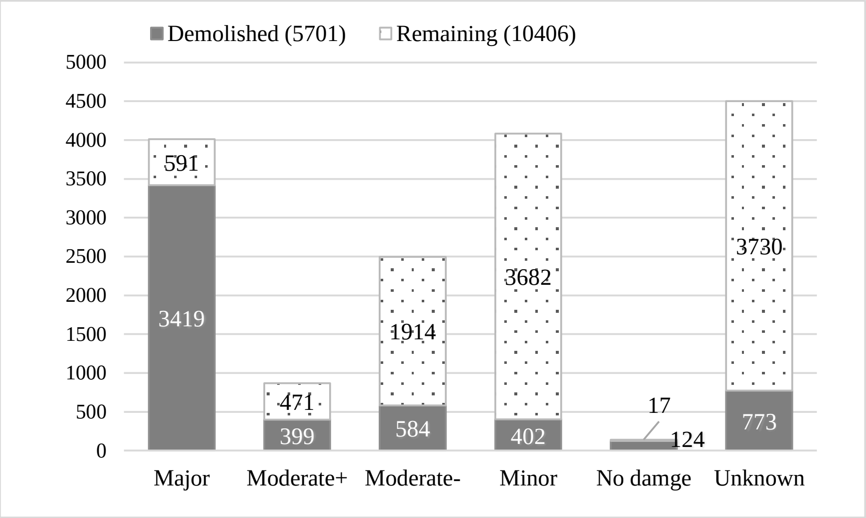


Fig.4 –Number of demolished and remaining buildings in damage grades

Table 2 – Number of buildings in relationship between structure type and damage grades

Structure	Major		Moderate+		Moderate-		Minor		No damage		Sum
	D	R	D	R	D	R	D	R	D	R	
Wooden	3067	527	374	439	502	1749	251	2777	5	8	9699
LS	67	40	5	13	32	96	59	500	0	2	814
Steel	42	17	5	17	16	51	32	301	0	1	482
SRC	0	0	0	0	0	0	0	1	0	0	1
RC	5	3	2	0	5	10	3	88	0	0	116
CB	4	1	0	0	4	3	3	9	0	0	24
Other	1	0	0	1	1	0	0	2	0	0	5
Unknown	233	3	13	1	24	5	54	4	119	6	462
Sub total	3419	591	399	471	584	1914	402	3682	124	17	11603

D: Number of demolished buildings. R: Number of remaining buildings

Table 3 – Number of buildings in relationship between construction year and damage grades

Structure	Major		Moderate+		Moderate-		Minor		No damage		Sum
	D	R	D	R	D	R	D	R	D	R	
-1951	834	115	55	56	80	101	54	131	2	0	1428
1952-61	268	35	24	20	25	41	10	46	0	1	470
1962-71	396	48	35	29	51	89	40	100	0	0	788
1972-81	765	140	119	87	150	404	63	397	0	2	2127
1982-90	402	68	79	112	113	444	44	579	2	0	1843
1991-00	274	99	43	113	84	520	60	1162	1	3	2359
2001-16	76	66	12	34	25	224	62	1121	0	3	1623
Unknown	404	20	32	20	56	91	69	146	119	8	965
Sub total	3419	591	399	471	584	1914	402	3682	124	17	11603

D: Number of demolished buildings. R: Number of remaining buildings

Table 4 – Number of buildings in relationship between number of stories and damage grade

Structure	Major		Moderate+		Moderate-		Minor		No damage		Sum
	D	R	D	R	D	R	D	R	D	R	
2-stories	1907	355	244	336	312	1357	124	2537	2	3	7177
1-story	1438	221	152	130	266	541	269	1085	59	12	4173
Others	62	9	3	5	6	16	9	59	63	2	234
Unknown	12	6	0	0	0	0	0	1	0	0	19
Sub total	3419	591	399	471	584	1914	402	3682	124	17	11603

D: Number of demolished buildings. R: Number of remaining buildings

Table 5 – Number of buildings in relationship between floor area and damage grade

Floor Area(m^2)	Major		Moderate+		Moderate-		Minor		No damage		Sum
	D	R	D	R	D	R	D	R	D	R	
0-20	85	21	11	5	22	19	39	68	1	2	273
20-60	691	100	65	39	110	170	124	331	2	1	1633
60-100	875	138	114	116	161	459	62	600	0	3	2528
100-150	926	175	135	187	183	849	78	1724	1	4	4262
150-200	395	97	41	90	55	288	27	490	1	1	1485
>200	214	57	20	33	29	124	18	465	0	0	960
Unknown	233	3	13	1	24	5	54	4	119	6	462
Sub total	3419	591	399	471	584	1914	402	3682	124	17	11603

D: Number of demolished buildings. R: Number of remaining buildings

4. Discussion

We could develop the three relationship groups as shown in Table 1. Gr1 including 11141 footprint data in Mashiki map dataset was able to be related to the building information and the damage grades. Gr2 including 461 data was related to the damage grades. Gr3 including 4503 data could not be related to the building information and the damage grade. There were 773 demolished building data without relation to the damage grades in the Gr3, it was almost close to the number of demolished buildings without damage certification as written in the report of the Mashiki municipality [3]. We calculated the ratio of demolished building in the major, moderate+, and moderate- damage grades from Fig.4: 85.3%, 45.9%, and 23.4% respectively. In the past investigation [6], the ratio of demolished building in the moderate damage was estimated as more or less 20%. But we found that the larger number of moderate damage buildings had been demolished in this study. On the other hand, we thought that all major damage buildings were demolished according to the conventional method, however 14.7% of the major damage building remained. We looked at the numbers and characteristics of the demolished and remaining buildings with regards to the structure type, the construction year, number of stories, and floor area. It is known that a typical structure type of the buildings in Mashiki town is a wooden structure. The number of the demolished buildings that had wooden structure was 4199 and the ratio was 93.6% of Gr1, as they were calculated from Table 2. There were not many RC and CB buildings in Mashiki Town. Table 2 also shows that there were 15 demolished and 101 remaining RC buildings as well as 11 demolished and 13 remaining CB buildings. We found that RC structure buildings classified as the major and moderate+ damage were demolished quite less than the wooden demolished buildings in the same damage grades. We considered the relationship between construction year, building damage, and demolished buildings from Table 3. It is well known that the building is less damaged as the construction year of building is newer. Table 3 shows that the ratio of demolished building was higher as the construction year was older. There were 1428 buildings constructed before 1951 and 1025 buildings of them were demolished. 115 buildings were classified as major damage; nevertheless they remained. We particularly noticed that 175 demolished buildings were constructed from 2001 to 2016 and 62 demolished buildings of them were classified as minor damage. It is needed to research further to decide the demolition in spite of the minor damage. Table 4 shows that the numbers of demolished buildings and remaining buildings that had 2-stories were 2589 and 4588 and the percentages of them were more or less 45% to the demolished buildings and remaining buildings. With regarding to the floor area of building, Table 5 shows that 50% of demolished buildings with 20m^2 floor area were classified as major damage. The percentage of major damage became higher as the floor area is larger.

We investigated the relationship between the damage grades, the structure types, the year, the number of stories, and floor area of demolished and remaining buildings in Gr1. We continue to study the building structures and floor areas of buildings in Gr2 and Gr3, consequently it is possible to obtain a precise disaster waste disposal generation intensity as well as to develop the proposed equation as below;

$$\text{Amount of disaster waste} = Nw_1 \times Dw_1 \times Iw + Nw_2 \times Dw_2 \times Iw + Nx_1 \times Dx_1 \times Ix + Nx_2 \times Dx_2 \times Ix, \quad (2)$$

where Nw_1 and Nw_2 are numbers of majorly damaged buildings and moderately damaged buildings that have wooden structure. Dw_1 and Dw_2 are the ratios of demolished buildings to the majorly damaged wooden buildings and moderately damaged wooden buildings. And Iw is a disaster waste disposal generation intensity for wooden structure building has an average floor area. In addition, Nx_1 and Nx_2 are numbers of majorly damaged and moderately damaged buildings that are based on non-wooden structure such as RC and CB etc. Dx_1 and Dx_2 are the ratios of demolished buildings in the majorly damaged non-wooden buildings and moderately damaged non-wooden buildings. And Ix is a disaster waste disposal generation intensity for non-wooden structure building.

5. Conclusion

We could make the relationship of the Mashiki map dataset with labels of the demolished and remaining buildings to the damage grades and building information such as the structure typologies, the construction year, the number of stories, and floor area in order to improve the estimation equation for the disaster waste generation. 4485 demolished and 6656 remaining buildings were able to be related to building information and damage grades. 443 demolished and 19 remaining buildings were related to only damage grades. 773 demolished and 3730 remaining buildings were related to neither building information nor damage grades. We found that the higher ratio of moderate buildings was demolished as compared with the past study as well as 14.7% of the major damage building remained. We will continue to research a past inventory and photography and analyze the individual building information that were not able to be related in this study. It is possible to develop more accurate equation to estimate the disaster waste disposal.

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7. References

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