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DAMAGE TO REINFORCED CONCRETE SCHOOL BUILDINGS BY 2016 KUMAMOTO EARTHQUAKE

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Abstract

On April 16, 2016, a Mw7.0 earthquake struck Kumamoto in Japan following a Mw6.2 earthquake on April 14. It heavily damaged not only many wooden houses but also some reinforced concrete (RC) buildings such as residential buildings, commercial buildings, and school buildings. The Architectural Institute of Japan (AIJ) received a request from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to investigate damage to school buildings. This paper shows an outline of damage and the damage rates of reinforced concrete school buildings.

1) The surveyed school buildings are designed with a current seismic code (constructed after 1981) or with an old seismic code (constructed before 1981). In the latter case, most had been seismically evaluated or retrofitted to have earthquake resistance equivalent to the current seismic code. In these school buildings, almost no major damage such as collapse occurred. On the other hand, in school buildings which do not meet the current seismic code, some structural members were severely damaged, such as column shear failure and axial collapse.

2) Buildings built after 1981 and designed with the current seismic code or buildings which are seismically evaluated or retrofitted to have earthquake resistance equivalent to the current seismic code suffered a certain amount of damage such as moderate or minor damage that hinders continued use of the building. The main structural damages include shear cracks in shear walls, shear cracks or shear failure in RC non-structural walls, shear cracks in columns (with side walls), and cracks in beam-column joints.

3) In composite structures with steel structures such as gymnasiums or public halls with large span, the cover concrete is peeled off or collapsed/cracked at the joints of steel to concrete such as anchorage of roof beams. These damages were also found in buildings constructed after 1981 as well. The ratios of the damaged buildings which were not functional in continuous use after the earthquake were generally much higher in the steel or steel-composite gymnasiums than in the reinforced concrete school buildings.

4) Buildings that had been seismically retrofitted were prevented from collapsing and the effectiveness of retrofit was confirmed. However, even if they were retrofitted, the damage level was moderately damaged in some of the retrofitted buildings. In addition, there was an example where a building (walking corridor) that satisfied criteria of the seismic evaluation suffered heavy damage near collapse.

5) Some buildings could not be used continuously due to the falling of ceiling and the destruction of non-structural members such as partition walls and outer walls. These were also found in relatively new buildings designed with the current seismic code.

6) Subsidence and inclination of the foundation of the building, which is estimated to be caused by piles, ground deformation, liquefaction, and faults (cracking) that appeared on the ground surface, were observed. These were also seen in relatively new buildings designed with the current seismic code, and in buildings where the superstructure was seismically retrofitted. In some cases, the superstructure was seismically reinforced, but it had to be demolished and rebuilt due to the heavy damage caused by the foundation ground.

Keywords: damage rate; retrofit; composite structure; continuous use; foundation

1. Introduction

On April 14, 2016, a Mw6.2 earthquake occurred in Kumamoto Prefecture, Japan. Two days after, on the 16th, another Mw7.0 earthquake occurred in Kumamoto Prefecture. The largest level of Japanese seismic intensity of 7 (Shindo 7) was observed for each earthquake. It was the first time in Japan's observation history that seismic intensity 7 earthquakes were observed twice in succession. These series of earthquakes are named 2016 Kumamoto earthquake. Due to these earthquakes, many wooden houses were damaged in Kumamoto Prefecture, such as collapses, as well as reinforced concrete buildings and steel buildings. The school building made of reinforced concrete was also severely damaged. Therefore, the Architectural Institute of Japan Academic Committee Educational Facilities Subcommittee established the Kumamoto Earthquake School Building Damage Assessment WG (Chief of Toshimi Kabeyasawa). The WG judged the damage level of the damaged educational facilities at the request of the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) and conducted an academic damage survey (hereinafter "WG survey"). This survey is not an inventory survey but is conducted on some of buildings, most of which had relatively large structural damage based on the quickinspection by the administrators. In this paper, the characteristics of damage to RC school buildings and especially the results of the damage rate estimation are summarized from the WG survey report [1] on behalf of AIJ WG members.

2. Outline of survey

2.1 Surveyed buildings

The facilities surveyed included schools and social education facilities that had been requested by the establishers through the MEXT to determine the damage level, and the schools that were not requested to determine the damage level but had reported a certain amount of damage, for which the WG had requested a survey. Most of these facilities have multiple buildings and often have different structural types. Therefore, members of the WG who specializes in reinforced concrete structures (RC staffs) investigated mainly for facilities that have determined that there could be a damaged RC building based on the damage summary of each facility collected prior to the site survey.

The number of facilities surveyed was 79 for establisher's request and 32 for WG requests, for a total of 111 facilities. Table 1 shows the number of these facilities by municipality. The table also shows the total number of elementary schools, junior high schools, high schools, kindergartens, and special schools [2] and the ratio of the number of surveyed facilities to the total number (survey rate). Fig.1 shows the geographical distribution of these facilities. Looking at the survey rates for elementary schools, junior high schools, and high schools, the survey rates are high in Mashiki town and Nishihara village, which have been severely damaged by the earthquake, but are generally around 10-30% in other areas. Schools for which the establisher was able to judge the damage level independently were not included in the request facilities, and schools that did not make a budget request for restoration were not included in the survey requests from the WG because their damage could not be grasped. Therefore, it cannot be said that all facilities where structural damage was observed in RC buildings were covered in this survey. However, even if the damage is minor, most establishers usually tend to request determining the damage level and request a restoration budget. Therefore, it is estimated that the damage to most of the unsurveyed buildings is very small or almost undamaged. For this reason, the survey rate could be indirectly reflecting the percentage of facilities where damage was observed to a certain degree, although each municipality is in a different situation.

If there are multiple buildings in the surveyed facility, RC staffs investigated the establisher's request buildings unsurveyed by the WG members other than RC staffs, and buildings which RC staffs judged necessary to investigate. Therefore, the buildings surveyed by the RC staff include buildings of structural types other than RC structures. This paper deals with buildings whose main structures are reinforced concrete, concrete-steel composite, and concrete block although almost all buildings are reinforced concrete structure. As a result, the study covers 312 buildings. Table 2 shows the number of these survey buildings classified according to the construction year and the implementation status of seismic evaluation and retrofit. Here, "Retrofitted" means the seismic evaluation and retrofit have completed, "No retrofit required" means the seismic evaluation has completed and retrofit has not been required, and "Current code" means the structure was designed according to 1981 seismic code. These are generally considered earthquake-resistant buildings. "Retrofit required" means the seismic evaluation has completed and retrofit was required but has not completed yet, which is not considered earthquake-resistant building. "Unevaluated" means the seismic evaluation has not completed. This table shows that approximately 40% of the buildings are designed with the 1981 seismic code, approximately 40% are designed with the old seismic code after 1971 when regulation for column hoop spacing became strict, and approximately 20% are buildings before 1971. It also shows that buildings that are earthquake-resistant account for about 85%, and buildings that are not earthquake-resistant or whose seismic resistance is unknown account for about 15%. Most of the latter buildings are private school buildings, connecting corridors, social education facilities, simple buildings with small floor space, and buildings that were to be demolished in near future. Almost all public-school buildings were earthquake-resistant when the earthquake occurs.

2.2 Survey method

The on-site survey began in late May, each RC staff with a few investigators surveying about 2-3 facilities per day. The survey was conducted by a total of 23 RC staffs, and almost all surveys had been completed by early June.

In the field survey, a visual survey of the exterior and interior of the building was performed to record the outline of the damage to the building and to judge the damage level of the building.

Based on residual seismic performance, *R*, which was calculated according to the Japan Building Disaster Prevention Association's standard [4] for judgement of the damage level of RC buildings, the damage level of the buildings was judged.

Table 1 – Number of facilities surveyed

Location	Elementary school*1	Junior high school*2	High school*3	Kinder -garten	Special school	Univ.	Social facility	Subtotal (*1-3)	Total
Kumamoto	22/96(23%)	19/53(36%)	11/27(41%)	2/33(6%)	0/5(0%)	0	11	52/176(30%)	65
Mashiki	4/5(80%)	2/2(100%)	0/0(-)	1/1(100%)	0/0(-)	1	2	6/7(86%)	10
Aso	1/9(11%)	0/3(0%)	0/1(0%)	0/2(0%)	0/0(-)	0	0	1/13(8%)	1
Minami-aso	0/5(0%)	0/3(0%)	0/0(-)	0/0(-)	0/0(-)	1	2	0/8(0%)	3
Nishihara	1/2(50%)	1/1(100%)	0/0(-)	0/0(-)	0/0(-)	0	0	2/3(67%)	2
Oozu	1/7(14%)	0/2(0%)	0/2(0%)	0/2(0%)	1/1(100%)	0	0	1/11(9%)	2
Kikuyo	4/6(67%)	1/2(50%)	0/0(-)	0/2(0%)	0/0(-)	0	1	5/8(63%)	6
Kikuchi	0/10(0%)	1/5(20%)	0/3(0%)	0/2(0%)	0/0(-)	0	0	1/18(6%)	1
Koshi	0/7(0%)	1/3(33%)	0/0(-)	0/3(0%)	0/3(0%)	0	0	1/10(10%)	1
Mifune	1/6(17%)	0/1(0%)	1/1(100%)	0/1(0%)	0/0(-)	0	0	2/8(25%)	2
Kashima	0/2(0%)	1/1(100%)	0/0(-)	0/0(-)	0/0(-)	0	0	1/3(33%)	1
Kosa	1/4(25%)	0/1(0%)	0/1(0%)	0/0(-)	0/0(-)	0	0	1/6(17%)	1
Misato	1/3(33%)	0/2(0%)	0/0(-)	0/1(0%)	0/0(-)	0	0	1/5(20%)	1
Uto	0/7(0%)	0/4(0%)	1/1(100%)	0/0(-)	0/0(-)	0	0	1/12(8%)	1
Uki	2/13(15%)	0/5(0%)	1/2(50%)	0/2(0%)	2/3(67%)	0	3	3/20(15%)	8
Yatsushiro	2/27(7%)	3/16(19%)	0/8(0%)	0/4(0%)	0/1(0%)	0	0	5/51(10%)	5
Nagomi	0/5(0%)	1/2(50%)	0/0(-)	0/1(0%)	0/0(-)	0	0	1/7(14%)	1
Total	40/214(19%)	30/106(28%)	14/46(30%)	3/54(6%)	3/13(23%)	2	19	84/366(23%)	111

The fraction notation indicates the number of surveyed subjects / total number. The ratio is shown in parentheses.

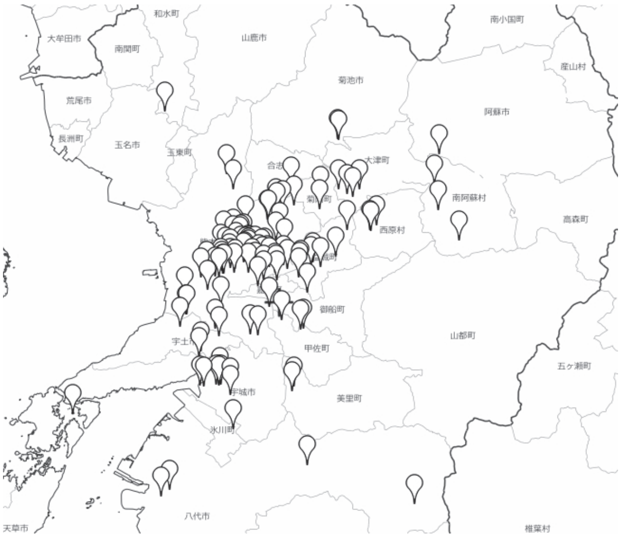


Fig. 1 – Distribution of surveyed facilities

(Created based on the Geographical Survey Institute's blank map [3])

Table 2 – Number of buildings surveyed

Status	Construction year				Total
	- 1971	1972 - 81	1982 -	Unknown	
Retrofitted	54	42	0	0	96
No retrofit required	1	65	2	0	68
Current code	0	0	117	0	117
Subtotal	55	107	119	0	281
Retrofit required	5	4	0	0	9
Unevaluated	3	6	0	2	11
Unknown	3	8	0	0	11
Subtotal	11	18	0	2	31
Total	66	125	119	2	312

In this standard, the damage level of the superstructure is determined as follows. The damage levels of vertical members (columns and walls) are classified into 0 to V, and their residual shear capacity are determined corresponding their damage levels. Then, the vertical members are classified into 8 categories according to their shape and failure mode; (1) shear column, (2) bending shear column, (3) bending column, (4) beam-controlled shear column, (5) beam-controlled bending column, (6) wall without column, (7) wall with an end column and (8) wall with both end columns. The ratio of the residual shear capacity to the original shear capacity of the vertical members with damage level from 0 to V is assumed 1, 0.95, 0.6, 0.3, 0 and 0 for categories (1), (6), (7) and (8), 1, 0.95, 0.7, 0.4, 0.1 and 0 for categories (2) and (4), and 1, 0.95, 0.75, 0.5, 0.2 and 0 for categories (3) and (5), respectively. The ratio of shear capacity of each member is assumed 1, 1, 1, 1, 1, 1, 2 and 6 for categories (1) to (8) respectively. Based on these assumptions, the residual seismic performance, R, is calculated as the ratio of the total residual shear capacity to original capacity of all members for each floor and direction. The damage level are judged to be no damage for $R = 100\%$, slight damage for $95\% \leq R < 100\%$, minor damage for $80\% \leq R < 95\%$, moderate damage for $60\% \leq R < 80\%$, major damage for $R < 60\%$, and collapse for $R \approx 0\%$.

The damage level of foundations is determined based on the settlement amount and inclination of the foundation, based on Table 3 (a) for pile foundations and Table 3 (b) for spread foundations.

Table 3 – Damage level of foundations

(a) Pile foundation

		Settlement (m)			
		- 0	0 - 0.1	0.1 - 0.3	0.3 -
Inclination (rad)	- 1/300	No damage	Minor	Moderate	N/A
	1/300 - 1/150	Minor	Moderate	Major	Major
	1/150 - 1/75	Moderate	Moderate	Major	Major
	1/75 -	Major	Major	Major	Major

(b) Spread foundation

		Settlement (m)			
		- 0.05	0.05 - 0.1	0.1 - 0.3	0.3 -
Inclination (rad)	- 1/150	No damage	Minor	N/A	N/A
	1/150 - 1/75	Minor	Moderate	Major	N/A
	1/75 - 1/30	Moderate	Moderate	Major	Major
	1/30 -	Major	Major	Major	Major

3. Characteristic of damage

3.1 Major damage / Collapse

Some buildings were judged to need demolished and rebuilt due to major damages or collapse, and some of moderate or minor damaged buildings required limited entry. Many of them were the buildings constructed before 1981, and particularly severe damage was observed in buildings which was constructed before 1971 and had not been retrofitted. Such damage was limited in public schools and somewhat noticeable in private schools. Most of the structural damage is shear failure of columns (Photos 1 (a) and (b)) and flexural failure (Photo 1 (c)), or damage to foundations or ground (Photo 1 (d)).

These damages are mainly due to insufficient amount of shear reinforcement of columns in old buildings. It is also presumed that the ground deformation directly affected the response of the superstructure. Furthermore, since the ground motion near the hypocenter greatly exceeded the expected ground motion, even some buildings with enough ductility and strength caused severe damage close to collapse. (Photo 1 (c)).

3.2 Damage that hinders continued use

Some buildings constructed after 1982 (designed with 1981 seismic code) or some buildings that did not require retrofit as a result of seismic evaluation showed moderate damage or minor damage that hinder continuous use of the buildings. The main structural damages shown were shear cracks in shear walls (Photo 2 (a)), shear cracks and shear failure of RC non-structural walls (Photo 2 (b)), and shear cracks in columns (with side walls) (Photo 2 (c)) and cracks in the beam-column joint (Photo 2 (d)).

In the current Japanese Building Standard Law and the Japanese standard of seismic evaluation and retrofit, the goal of structural performance of buildings against extremely rare earthquakes is to ensure safety, and prevention of damage is not considered. Therefore, in general, buildings designed with the current seismic code can be damaged to the extent that they need to be repaired even in the case of the expected earthquake in the seismic design. Further, even in a retrofitted building, some brittle members may cause shear failure or shear cracking.

3.3 Composite structure

In composite structures of RC columns and steel beams, such as large-span structures (gymnasiums or public halls), spalling, collapse and cracking of cover concrete were found at the joints of RC columns and steel beams due to insufficient beam end anchoring (Photos 3 (a) and (b)).

(a) Shear failure of columns

(b) Shear failure of a column with wing-walls

(c) Flexural failure of columns

(d) Damage due to settlement

Photo. 2 – Major damage

Even buildings designed with the current seismic code have suffered such damage, and there is a possibility that the current seismic design method of the RC column-steel beam joint may have problems.

3.4 Seismic retrofit

Many buildings with seismic retrofits had only minor damage levels, and collapse was prevented, confirming the effectiveness of the retrofit for life safety. However, moderate or major damage except for the retrofitted part was observed in some retrofitted buildings. In addition, there were a few cases where the buildings that were retrofitted and buildings that almost satisfied the criteria in the seismic evaluation suffered severe damage.

In Kumamoto City, almost all public elementary and junior high schools had achieved to be earthquake-resistant before Kumamoto earthquake occurred. It is probable that private schools caused significant damage to buildings, some of which had not yet retrofitted, while public schools suffered relatively less damage owing to the accomplishment of seismic evaluation and retrofit.

3.5 Non-structural members

Some buildings could not be used continuously due to the falling of ceiling materials and destruction of non-structural members such as partition walls. These were also found in relatively new buildings designed with the current seismic code.

Since damage control of non-structural walls and finishing materials and prevention of collapse of non-structural members such as ceiling materials are not guaranteed by the current seismic design, it is probable that such damage was observed a lot. However, in the gymnasium of a public school in Kumamoto City, the ceiling had been removed in principle as a measure against earthquakes, so no damage was seen from the ceiling falling.

(a) Shear cracks in shear walls


(b) Shear failure of non-structural walls

(c) Shear cracks in columns with side walls


(d) Cracks in beam-column joints

Photo.2 Damage that hinders continued use


(a) Damage to RC column at joint with steel beam


(b) Damage to RC wall at joint with steel beam

Photo.3 Damage to composite structure

3.6 Foundation and ground

Settlement or inclination of the foundation of the building, which is presumed to be caused by pile and ground deformation, liquefaction, and a fault (ground crack) that appeared on the ground surface, was observed. These were also seen in relatively new buildings designed with the current seismic code and buildings with superstructures retrofitted.

In most buildings, piles and ground are not designed to be safe against extremely rare earthquake, so brittle fractures can occur at the pile head. Furthermore, since the effect of the fault appeared as a ground deformation on the ground surface directly at the Kumamoto earthquake, it is estimated that the direct influence of the ground deformation caused differential settlement and inclination of the superstructure.

(a) Falling of ceiling material

(b) ALC board collapse

Photo.4 Damage to non-structural members

(a) Building damage due to ground deformation

(b) Vertical cracks in beams due to fault displacement

Photo.5 Damage to foundation and ground

4. Damage level of the surveyed buildings

For the surveyed building, the residual seismic performance, R, was calculated and the amount of settlement was measured to determine the damage level of the superstructure and the foundation based on the standard [4]. However, if the damage level could be classified as slight or no damage by quick inspection, the damage level was determined without calculating and measuring specific values.

Table 4 shows the number of buildings by the damage level of the superstructure, classified by construction year and earthquake resistance. This table shows that there are 16 major damaged buildings. Half of them, 8 buildings, are connecting corridors. Four of the corridors were designed with the 1981 seismic code, two are buildings that need not to be retrofitted as a result of seismic evaluation, and two are not seismic evaluated. They were severely damaged regardless of whether they were earthquake-resistant at the time of the disaster. Four of the 16 major damaged buildings are private schools that had not been retrofitted although their seismic performance index, Is, was 0.2 - 0.4 which did not satisfy the criteria, Is <= 0.6. The remaining four major damaged buildings are a school building which has a severely damaged penthouse with few walls, a school building that was severely damaged by the displacement of a fault beneath, a school building whose seismic resistance was unknown constructed in 1967, and a school building which needs not to be retrofitted because of Is = 0.72.

Table 5 shows the number of buildings according to the damage level of the foundation, classified by construction year. There were 10 severely damaged buildings, most of which were built near the location where the fault appeared on the ground, or in areas where the ground seems to be soft near lakes and rivers.

These buildings were either spread foundations or pile foundations, and the damage was not concentrated only on one type of foundation.

Table 4 – Number of buildings by superstructure damage level

Damage level	- 1971				1972 - 81				1982 -				Unknown				Total
	Earthquake resistance			Sub total	Earthquake resistance			Sub total	Earthquake resistance			Sub total	Earthquake resistance			Sub total	
	Yes	No	N/A		Yes	No	N/A		Yes	No	N/A		Yes	No	N/A		
No damage	1	0	0	1	7	0	0	7	6	0	0	6	0	0	0	0	14
Slight	20	1	2	23	63	2	6	71	74	0	0	74	0	0	0	0	168
Minor	20	1	2	23	20	0	5	25	24	0	0	24	0	0	0	0	72
Moderate	13	0	1	14	13	1	3	17	7	0	0	7	0	0	0	0	38
Major	1	3	1	5	4	1	0	5	4	0	0	4	0	0	2	2	16
Not investigated	0	0	0	0	0	0	0	0	4	0	0	4	0	0	0	0	4
Total	55	5	6	66	107	4	14	125	119	0	0	119	0	0	2	2	312

Table 5 – Number of buildings by foundation damage level

Damage level	Construction year				Total
	- 1971	1972 - 81	1982 -	Unknown	
No damage	38	74	77	0	189
Slight	0	0	2	0	2
Minor	1	4	10	0	15
Moderate	5	7	5	0	17
Major	1	1	8	0	10
Not investigated	21	39	17	2	79
Total	66	125	119	2	312

5. Damage rate of superstructure

5.1 Method fo estimating damage rate

The MEXT facility ledger manages all building information for public elementary schools, junior high schools, and high schools. Therefore, the damage rate of the superstructure was estimated for these public schools. The study areas were Kumamoto city where the epicenter located, and Mashiki town where seismic intensity 7 was observed twice and large building damage was observed. The building to be surveyed was a RC school building, and the RC gymnasium was excluded from the survey here because the frame type is different from the school building. The numbers of buildings surveyed were 1,045 in Kumamoto city and 45 in Mashiki town. As shown in Chapter 4, major damages were seen in some connecting corridors and private school buildings, but they were not included because they were not on the MEXT facility ledger.

In buildings where the damage level of the superstructure was determined in the WG survey, the determined damage level was used as it was. There were 116 buildings in Kumamoto city and 16 buildings in Mashiki town, which accounted for 10% and 36% of the total, respectively.

As for buildings where the damage level of the superstructure was not determined by the WG survey, the damage level was estimated based on the damage photographs and damage maps in the restoration cost assessment materials submitted to MEXT by school establishers. Specifically, the maximum damage level of columns and walls that can be confirmed from the damage photographs and maps was determined, the ratio of the number of members corresponding to each damage level to the number of members of the entire building was estimated, and the damage level was estimated from Table 6. In addition, when the damage levels estimated from the damage level of the columns and the walls were different, the larger damage level was selected. Buildings that did not apply to this table were estimated to be slight damage. All school buildings for which no assessment materials were submitted were estimated to be no damage.

Table 6 – Damage estimation method

		Percentage of damaged parts	
		10 - 50%	50% -
Maximum damage of column	III	Minor	Moderate
	IV	Moderate	Major
	V	Major	Major
Maximum damage of wall	II	Minor	Moderate
	III	Moderate	Major
	IV / V	Major	Major

5.2 Damage rate in Kumamoto City

Figure 2 shows the damage rates of the superstructure of the public school in Kumamoto. (a) to (d) show the estimated damage rates by total and construction year, and (e) shows the damage rate by the WG survey. According to (a) and (e), most buildings that were not surveyed in the WG survey were undamaged or minor damaged, and some were minor or moderate damaged. That shows the buildings which were surveyed in the WG survey were relatively severe damaged building. The estimated minor or more damage rate for all the buildings is 10%, but the damage rate varies depending on the construction year. The older the construction year, the higher the damage rate.

As mentioned above, connecting corridors and private school buildings were not included in the damage rate calculation here. In Kumamoto City, there were two corridors and four private school buildings which were major damaged. These are equivalent to about 0.6% of the number of the surveyed buildings.

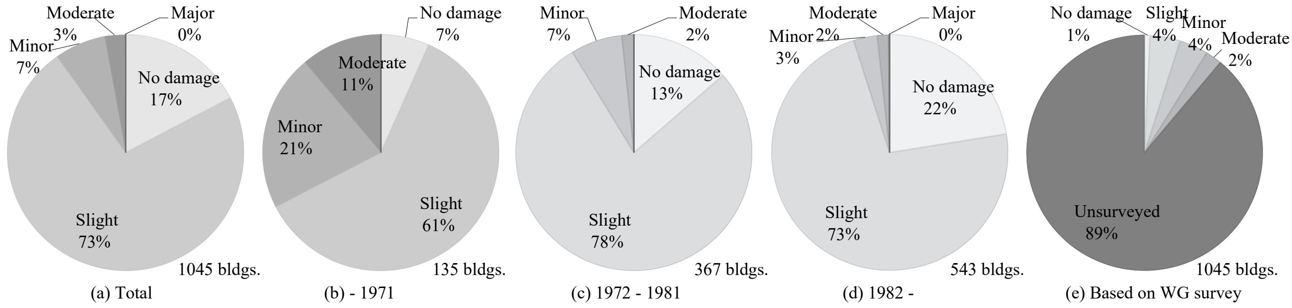


Fig. 2 – Damage rate in Kumamoto city ((a)-(d) are estimated damage rates)

5.3 Damage rate in Mashiki town

Figure 3 shows the damage rate in Mashiki town. The damage rate for minor or more damage is 29%, which is more than Kumamoto City. In Mashiki town, Japanese seismic intensity of 7 was observed, and many wooden houses collapsed, RC school building was relatively damaged as well. In addition, as in Kumamoto City, most of the damages of uninvestigated buildings were slight or less, and the older the building was, the higher the damage rate.

Connecting corridors were not included in the damage rate calculation as in Kumamoto city. In Mashiki town, there were two major damaged corridors, which correspond to about 4% of the number of surveyed buildings.

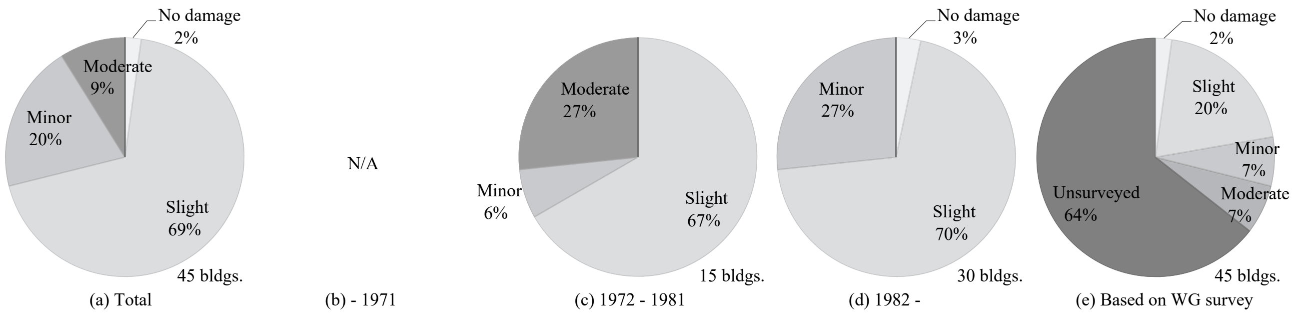


Fig. 3 – Damage rate in Mashiki town ((a)-(d) are estimated damage rates)

5.4 Damage rate of retrofitted buildings

Figures 4 and 5 show the damage rates of retrofitted buildings and buildings that had been constructed before 1981 and judged as unnecessary for retrofit by seismic evaluation for Kumamoto City and Mashiki Town, respectively. Although almost all of public schools in Kumamoto City and Mashiki Town was earthquake resistant, the number of buildings constructed before 1981 does not match the number of buildings seismic evaluated in Figs. 2 to 4. This is because Fig.4 includes small buildings that were not subject to seismic evaluation. There is a big difference between the damage rate of retrofitted buildings and those without retrofit. Focusing on Kumamoto city which has much more buildings than Mashiki town, retrofitted buildings has higher damage rate of minor and moderate damage than those without retrofit. Fig.5 is the numbers of public schools in Kumamoto city by seismic performance index and damage level. This figure shows the retrofitted buildings tend to have lower seismic performance than the buildings without retrofit. That may be because most retrofitted buildings are designed to meet barely the criteria for retrofit. That is considered to be one of the causes of the higher damage rate of minor and moderate damage in retrofitted buildings.

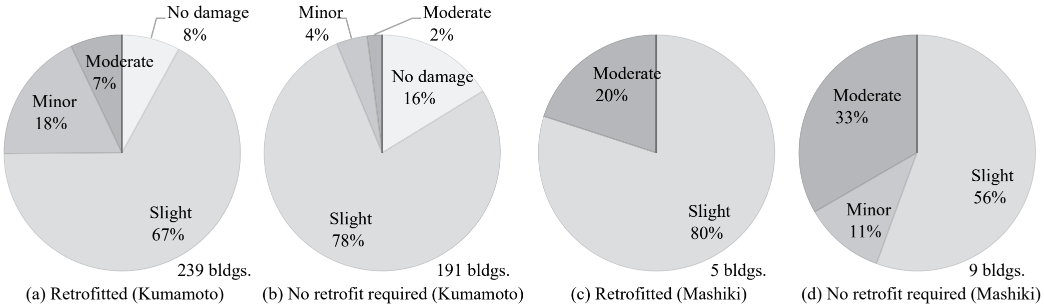
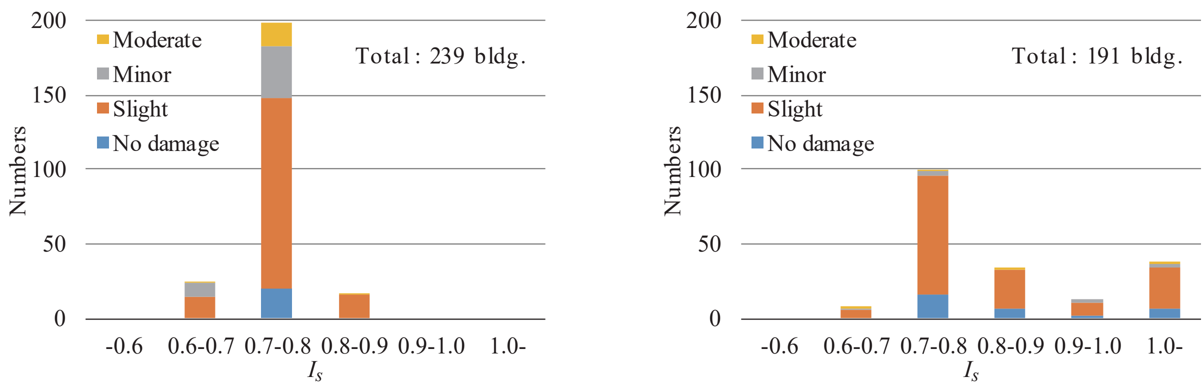


Fig. 4 – Damage rate of retrofitted buildings and buildings that do not require retrofit



(a) Retrofitted (b) No retrofit required

Fig. 5 – The numbers of buildings by seismic performance index and damage level

6. Conclusion

In this paper, we reported the outline, characteristics, and damage rate of RC school buildings due to the 2016 Kumamoto earthquake.

(1) Severe damage such as major damage was found mainly in old buildings constructed before 1981. Such severe damage was limited for buildings constructed after 1982, buildings that had been confirmed to be safe by seismic evaluation, and buildings that had been retrofitted, however, damage that hinders continuous use occurred in some of those.

(2) Damage to the joint between RC and steel structures, damage to non-structural members such as ceilings and partition walls, and damage to the foundation and ground were observed. These damages were seen even in buildings designed with the current seismic code. The current design code does not require to prevent such damage or is inadequate, then the current design method needs to be revised.

(3) Damage rate of RC school buildings at public schools in Kumamoto city and Mashiki town due to the 2016 Kumamoto earthquake was estimated. The damage rate for minor or more was 10% in Kumamoto city and 29% in Mashiki town. The older the construction year, the higher the damage rate. In addition, the damage rate of minor and moderate in the retrofitted buildings was higher than those in buildings that had been constructed before 1981 and judged as unnecessary for retrofit by seismic evaluation.

7. Acknowledgements

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8. References

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