ANALYSIS OF BUILDING DAMAGE IN ABIRA TOWN DUE TO THE 2018 HOKKAIDO EASTERN IBURI EARTHQUAKE, JAPAN

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Abstract

Building damage due to strong seismic motion is a major cause of human causalities and it also induces large economic losses. To reduce building damage risk, it is important to clarify the causes of damage and accelerate measures to enhance seismic capacity of buildings. When a building is damaged by a disaster in Japan, local governments carry out building damage assessment to issue disaster-victim certificates based on the extent of each victim's housing damage. This certificate is required to receive most of the individual assistance measures for livelihood reconstruction of disaster-victims. The damage statuses are classified into five levels; no damage, minor damage, moderate damage (-), moderate damage (+), and major damage.

An M_J 6.7 earthquake occurred with its epicenter in the middle-east of Iburi sub-prefecture, Hokkaido island, Japan on September 6, 2018 at 3:07 (JST). In Abira Town, many buildings were damaged due to strong seismic motion. The Abira Town government conducted building damage assessment in the entire town area and a total of 7,011 damage certificates is issued using the comprehensive disaster victim support system. The system enables to manage a set of processes and data involving the building damage assessment, the issuance of certificates, and the support activities for each victim. The system provided the Abira Town government with a standardized workflow and an effective training procedure for the building damage assessment based on the unified loss evaluation method by the Cabinet Office of Japan, resulting in easy and high-quality investigation even by general officials without sufficient building expertise.

This paper aims to reveal the building damage in Abira Town. Firstly, the distribution of seismic ground motion in the affected area is estimated by collecting a total of 629 strong motion records. Secondary, the building damage assessment process and method by the Abira Town government is introduced. The result of damage assessment provided by Abira Town is used to analyze from the viewpoints of structural material and construction period. The spatial distribution of damaged buildings is further investigated with their location information on GIS. Finally, the analysis results are compared with building damage situations due to other past earthquakes in Japan.

As the result, it is found that the structural material and construction period are seen to be significant factors to determine damage grades of buildings. The damage ratio of wooden houses gets smaller as the construction period becomes newer. Especially, it is clearly observed that the damage ratio is greatly reduced for new wooden houses within the construction period after 1982, corresponding to the new seismic code in Japan. Although the major damage ratio in Abira Town is much lower than that of the 1995 Kobe earthquake and the 2016 Kumamoto earthquake, it is almost the same level as that of the 2007 Niigata-Chuetsu-Oki earthquake. It is also revealed that the damage ratio of wooden houses tends to become higher as the peak ground velocity (PGV) increases. The result of this study will be used in the development of fragility curves to assess building damage risk in Japan.

Keywords: the 2018 Hokkaido Eastern Iburi earthquake, damage assessment, damage ratio, building attribute

1. Introduction

In Japan, many damage estimations for scenario future earthquakes have been published by the national and local governments in order to take appropriate and effective measures against damaging earthquakes such as the Tokyo Inland Earthquake and the Nankai-Trough Earthquake. Building fragility curves are an efficient tool to estimate building damage. Most of the present fragility curves have been developed based on the empirical analysis of building damage due to the 1995 Kobe earthquake [1, 2]. It is because there were not enough data of building damage due to past several earthquakes after the Kobe earthquake to construct the fragility curves.

In the recent years, earthquakes intensity of magnitude-7 level, such as the 2016 Kumamoto earthquake and the 2018 Hokkaido Eastern Iburi earthquake, occurred and many buildings were damaged. The seismic performance of buildings changes due to the advancement of building design and construction technologies and aging deterioration of seismic resistance. Therefore, in order to enhance the reliability of damage estimation, it is necessary to develop building fragility curves based on such recent damage data. From this viewpoint, several fragility curves have been proposed based on analysis of building damage due to the Kumamoto earthquake [3, 4].

Toward the reconstruction of building fragility curves, in this paper, we analyze the building damage due to the 2018 Hokkaido Eastern Iburi earthquake. Seismic motion is estimated with high accuracy in 250-m grid by collecting a large number of strong motion records. The result of damage assessment in Abira Town, Hokkaido, Japan, where strong seismic motion was observed, is analyzed. Because the results of building damage assessment conducted by local governments to issue disaster victim certificates are used as source data for developing fragility curves in the damage estimation by the national and local governments. The tendency of building damage in Abira Town is also considered in comparison with the results of damage assessment conducted by other local governments in the past earthquakes in Japan.

2. 2018 Hokkaido Eastern Iburi Earthquake and Storong Motion in Abira Town

An M_J 6.7 earthquake occurred with its epicenter in the middle-east of Iburi Sub-prefecture, Hokkaido island, Japan on September 6, 2018 at 3:07 (JST). In Hokkaido, strong motions with the JMA seismic intensity scale of 7 were observed in Atsuma Town, and 6 upper in Abira Town and Mukawa Town [5] as shown in Fig.1. In Abira Town, a large number of buildings were damaged due to strong seismic motion with the maximum acceleration by three-component composition of 1,796 cm/s^2 at K-NET Oiwake (HKD127) station. The earthquake caused damage, including 42 deaths, 762 injuries, 462 major-damaged houses, and 1,570 moderate-damaged houses [6].

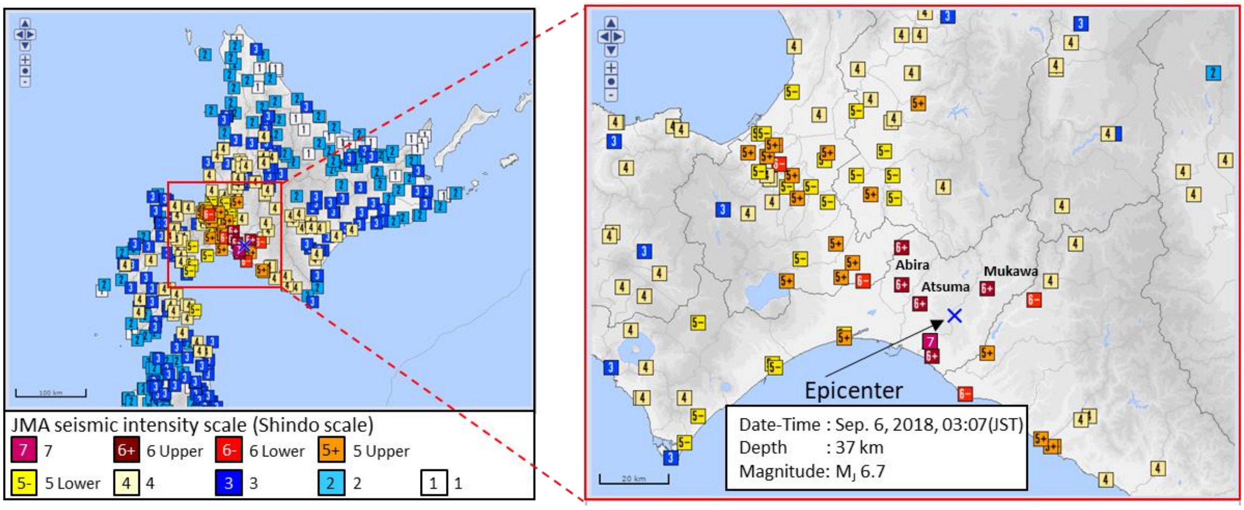


Fig. 1 – Map of JMA seismic intensity on the 2018 Hokkaido Eastern Iburi earthquake (Source: JMA)

We conducted a field survey in the affected area after the earthquake and found severely damaged buildings by various causes such as damaged by strong shaking in Abira Town and Mukawa Town where strong motion was observed, buildings crushed by large-scale landslides in Atsuma Town, and buildings damaged by liquefaction over a wide area in/around Sapporo City as shown in Fig. 2 (a), (b), and (c).

(a) Completely collapsed building by strong motion in Mukawa Town (b) Crushed building by landslides in Atsuma Town (c) Tilted building by liquefaction in Sapporo City

Fig. 2 – Characteristics of the building damage due to the 2018 Hokkaido Eastern Iburi earthquake

The distribution of seismic ground motion in the affected area was estimated by collecting a total of 629 (K-NET and KiK-net: 473; JMA: 156) strong motion records. Kriging interpolation was applied to these peak ground motion values considering the attenuation relationship from the causative fault plane and the soil amplification factor with nonlinearity, following the method adopted by QuiQuake [7]. Note that resultant PGVs of the two horizontal components were used in the calculation.

Figure 3 shows the estimated distribution of the peak ground velocity (PGV), which is the most commonly used index to estimate building damage, in 250-m grid for Abira Town. There are two observation stations of K-NET and one KiK-net in Abira Town. The estimated PGV distribution reproduces its value at the observation stations, and shows the distribution property corresponding to the degree of amplification and attenuation of PGV around the observation stations. As shown in Fig. 3, the range in which the PGV exceeds 100 cm/s is widely distributed from the northwest to the southeast in the central part of Abira Town.

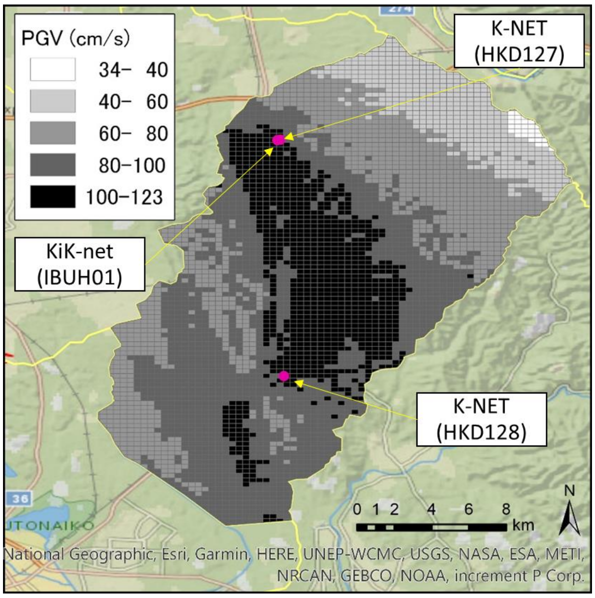


Fig. 3 – Estimated peak ground velocity (PGV) distribution in 250-m grid in Abira Town

3. Process of Building Damage Assessment by Abira Town Government

3.1 Flow of support for livelihood reconstruction of disaster victims

Figure 4 shows the flow of the support system of livelihood reconstruction for disaster victims in Japan. In order to provide various supports to disaster victims, it is necessary to determine who are affected to their properties and what kind of supports can be provided to them. When a building is damaged by a disaster in Japan, local governments carry out building damage assessment to issue disaster-victim certificates based on the damage level of each victim's housing. The assessment results are then compiled into a database, and disaster-victim certificates are issued to determine the owner (resident), time and location of the suffered property. After that, various kind of supports are provided using the victim master database, which enables to manage supports for each victim. Therefore, the building damage assessment is positioned as an important first step of the livelihood reconstruction for victims.

The methods of building damage assessment were varied among each local government at the time of the 1995 Kobe earthquake. Because of the unfairness in the assessment results, the affected area was confused by abundant requests for re-investigation. Learning from the lesson in the Kobe earthquake, the Cabinet Office of Japan published the guidelines showing a unified loss assessment method in 2001. The guidelines have been revised several times and the latest version was published in 2018 [8]. Following the guidelines, in the first stage assessment, the degree of damage to a house is investigated by visual inspection of the exterior. This result is shown to the residents and in case they do not accept it, in the second stage assessment, a detailed damage investigation including the inside of the building is conducted.

Following the unified assessment method, the building damage is classified into five classes as shown in Table 1. In the table, an approximate correspondence with visual inspection methods proposed by Grünthal ed. [9] and Okada and Takai [10] is also shown.

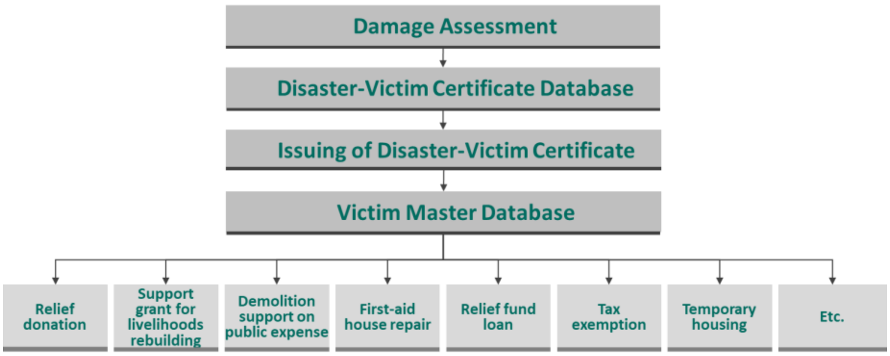


Fig. 4 – Flow of support activities for livelihood reconstruction of disaster victims

Table 1 – Earthquake loss evaluation classes of buildings by local governments in Japan and schematic images of other damage classification methods (Source: Yamazaki et al. [3])

Current Damage (Loss) Class	Former Damage (Loss) Class	Loss Ratio (r), Damage Index	EMS-98	Okada & Takai (2000)
Major	Major	$r \geq 60\%$	G4 G5	D4 D5
		$50\% \leq r < 60\%$	G3	D3
Moderate +	Moderate	$40\% \leq r < 50\%$		
Moderate –		$20\% \leq r < 40\%$	G2	D2
Minor	Minor	$0\% < r < 20\%$	G1	D1
No	No	$r = 0\%$	(G0)	D0

3.2 Building damage assessment using the comprehensive disaster victim support system

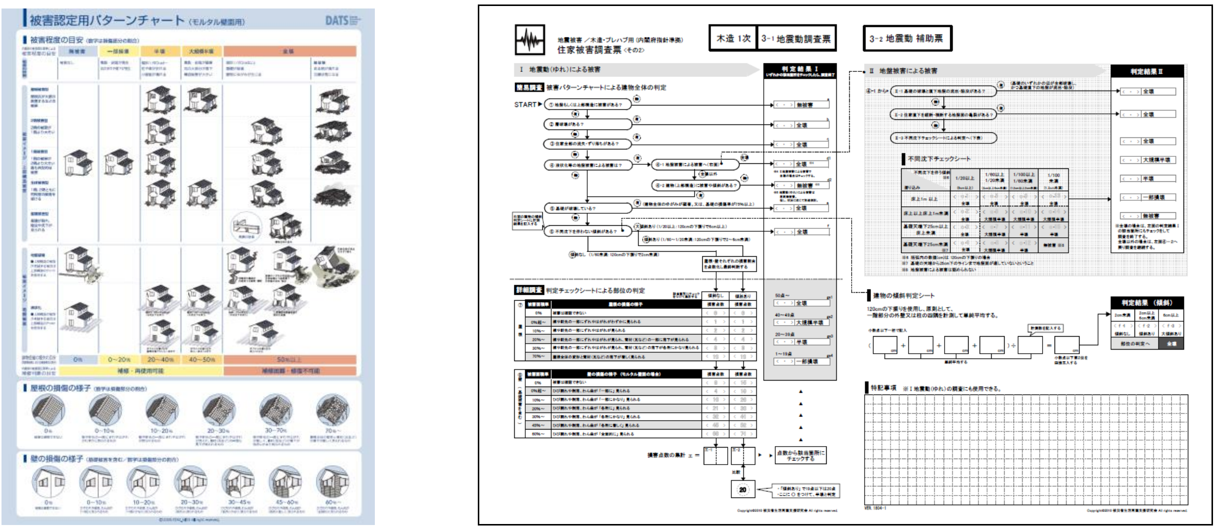
The comprehensive disaster victim support system was used in the building damage assessment in Abira Town after the 2018 Eastern Iburi earthquake. The system is composed of the following five subsystems in accordance with the above-mentioned flow of supports [11].

- Damage Assessment Training System (DATS), which enables to make everyone an “instant” damage assessment inspector.
- Data digitizing system to convert paper-based data to digital data using OCR scanner and QR code.
- Issuing system of disaster-victim certificates by linking three databases: the basic resident registration, the house ledger, and the damage assessment results, using each geolocation information.
- Disaster victim registration system to manage a support process centrally to speed up various procedures for supports and preventing support omissions.
- Management support system for operations relating livelihood reconstruction of disaster-victims undertaken by local governments

DATS was designed to bring a unified viewpoint among the investigators even if they do not have enough expertise in building structure by providing a standardized assessment workflow, which reflects the guideline by the Cabinet Office of Japan based on analysis of the damage assessment process following the 1995 Kobe earthquake, and an effective training procedure for disaster responders of local governments [12, 13, 14].

To evaluate the extent of building damage from outside quickly and objectively, DATS proposes to use damage pattern chart, which describes schematic illustrations of building damage patterns. The chart for superstructure damage caused by seismic motion were originally developed by Okada and Takai [10]. The chart was expanded by combing damage pattern due to land failure such as liquefaction proposed by Horie et al. [15]. These charts were derived from EMS-98 (the European Macroseismic Scale 1998) [9].

Figure 5 (a) and (b) show examples of assessment forms provided by DATS. The forms consist of three major parts to ensure that trained investigators can make the same judgments as those by specialists: the damage pattern chart provides visual illustrations by schematics of building damage patterns to help investigators to understand the assessment standard visually, a standardized assessment flow to unify the viewpoints of judgement, and a check sheet that describes the judgment criteria to keep the objectivity.



(a) Damage pattern chart for building damage assessment

(b) Assessment sheet for building damage assessment containing standardized assessment flow and check sheet

Fig. 5 –Examples of the forms for building damage assessment provided by DATS

3.3 Process of building damage assessment in Abira Town

In order to clarify the process of building damage assessment by Abira Town government, we conducted an interview survey on December 27, 2019 to the town officials who were engaged in management of building damage assessment.

The Abira Town started to make an assessment plan on September 11, 2018 and decided to use the comprehensive disaster victim support system after receiving advice from the members of Niigata Prefecture who joined to support the assessment operation based on the counter-part system by the Ministry of Internal Affairs and Communications. To make the assessment plan, the experts from universities that have developed the system worked with the town officials to collect and analyze damage information. As a result, since all the buildings in the town were considered to be damaged to some extent, the town government decided to investigate all the buildings of about 6,460 (about 2,940 residential and about 3,520 non-residential buildings).

The assessment was conducted by trained investigators based on the guideline of the Cabinet Office of Japan. The training was carried out not only on the first day but every day when new support members were dispatched. A total of 1,300 personnel were mobilized to conduct the assessment. About 90% of the investigators were support members from Hokkaido, Niigata and Iwate Prefectures and their municipalities. Figure 6(a) shows a scene of the lecture for the building damage assessment

The first stage assessment started on September 16, 2018 and the disaster-victim certificates were issued on September 30 using the system. The second stage assessment was conducted from October 1 to August 22, 2019. In addition to the paper-based assessment forms provided by DATS, the first stage assessment was conducted using a newly developed tablet application, which enable to record the location of buildings from GIS, the assessment results, and the photos of damaged parts. The recorded data were sent to a server in real time and used by assessment managers to ensure the quality of their assessment works and to track progress. Figure 6(b) shows a scene of investigation.

(a) Lecture for acquiring basic knowledge of damage assessment within a limited time effectively

(b) Exercise using assessment tools in the field

Fig. 6 – Scene of Training for building damage assessment using DATS in Abira Town

4. Analysis of Building Damage in Abira Town

A total of 7,011 damage certificates are issued using the comprehensive disaster victim support system. However, these data also include ones that are not suitable for analyzing building damage. We excluded the following data from the loss assessment: the cancelled records for issuance of disaster-victim certificates (385), those other than the final assessment (20), and duplicate certificates for one building (1,318). Regarding the multiple issuance, because a disaster-victim certificate is issued on a household basis rather than on a building basis, multiple households who live in the same building such as apartments received the same certificate. In the case of rented houses, since both the resident and the owner of the building received the same certificate, it was recorded in duplication. After the data cleansing, the remaining 5,287 certificates were used in the further analysis.

The building data are plotted on a layer of the estimated PGV distribution using GIS as shown in Fig. 7. It is confirmed that the major damaged buildings were distributed in the area where the seismic motion was relatively large.

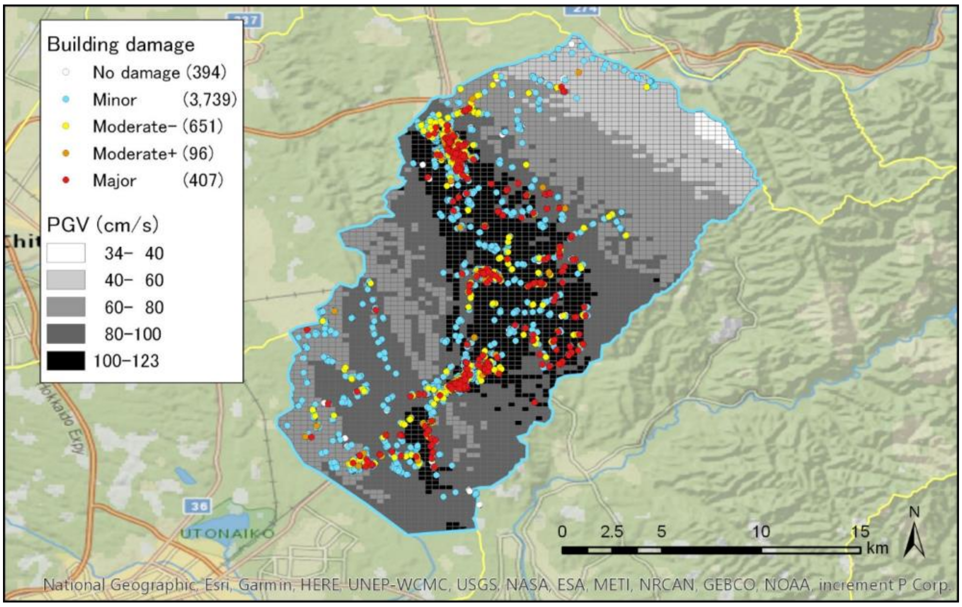


Fig. 7 – Building damage assessment using DATS in Abira Town

Table 2 shows the number of buildings in Abira Town with respect to the damage class, occupancy type, structural type and construction period. Looking at the structural type of residential buildings, "Wooden" accounts for 82.8%, "Reinforced Concrete (RC)" is about 1.1%, "Steel (S)" is 0.6%, "Light-gauge Steel (LS)" is 0.9%, "Prefabrication" is 1.0%, "Concrete Block (CB) is 3.9%, "Masonry" is 0.3%, and "Unknown" is 9.4%.

Figure 8 (a) shows the damage classification for the all buildings in Abira Town; 8% of them were major damaged and 22% were moderate- or more damaged. Figure 8 (b) shows the breakdown of damage by the occupancy type. A comparison of the major damage ratio shows that 3.7% of residential and 12.6% of non-residential buildings, indicating that the damage ratio of non-residential buildings was higher than that of residential ones.

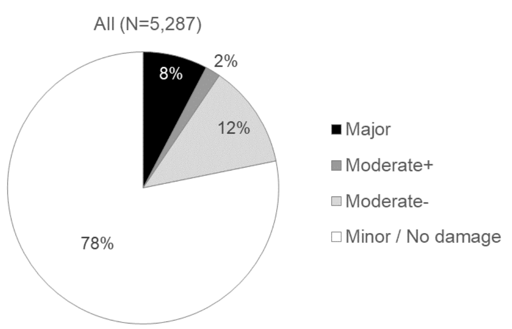
A detailed damage analysis was carried out for the residential buildings because various supports for rebuilding the livelihood of disaster victims are provided based on the damage level of their houses. Figure 9 shows the damage classification for the residential buildings with respect to the structural type. The ratio of major damage for each structural type is in the order of Masonry, CB, Wooden, and LS. There were no major damaged houses in the structural type of RC, S and Prefabrication.

Figure 10 shows the damage ratio of wooden houses in Abira Town with respect to the construction period and damage grade. The damage ratio tends to get smaller as the construction period becomes newer. The major damage ratio is greatly declined after 1982 as the effect of the revision of seismic provision. Note that the seismic provision for wooden buildings was further upgraded in 2000.

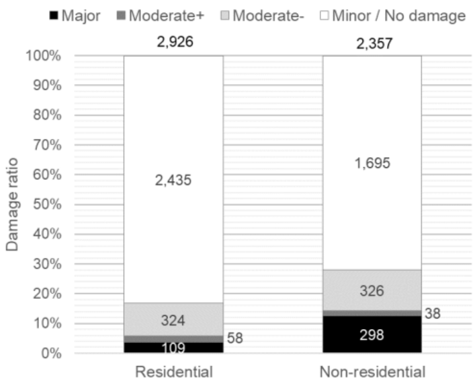
Figure 11 shows the relationship between the estimated PGV and the damage classification of wooden houses. It was found that the major damage ratio tends to increase as the seismic motion increases.

Table 2 – Number of buildings in Abira Town with respect to the damage class, occupancy type, structural type, and construction period.

Occupancy type	Structural type	Construction period	Major	Moderate+	Moderate-	Minor / No damage	Total
Residential	Wooden	-1951	5	1	7	13	26
		1952-61	7	3	12	36	58
		1962-71	26	15	53	116	210
		1972-81	34	28	130	460	652
		1982-90	10	4	32	328	374
		1991-2000	5	3	29	576	613
		2001-17	2	0	10	477	489
		Total	**89**	**54**	**273**	**2,006**	**2,422**
	RC	-1981	0	0	1	1	2
		1982-90	0	0	2	4	6
		1991-2000	0	0	0	19	19
		2001-17	0	0	1	4	5
		Total	**0**	**0**	**4**	**28**	**32**
	S	-1981	0	0	1	1	2
		1982-90	0	0	0	3	3
		1991-2000	0	0	0	3	3
		2001-17	0	0	0	8	8
		Total	**0**	**0**	**1**	**15**	**16**
	LS	-1981	1	0	0	1	2
		1982-90	0	0	0	3	3
		1991-2000	0	0	1	11	12
		2001-17	0	0	0	10	10
		Total	**1**	**0**	**1**	**25**	**27**
	Prefabrication	**Total**	**0**	**0**	**1**	**29**	**30**
	Wooden	Total	0	0	1	12	13
	RC	Total	0	0	0	1	1
	LS	Total	0	0	0	16	16
	CB	**Total**	**7**	**1**	**19**	**88**	**115**
	Masonry	**Total**	**4**	**0**	**0**	**4**	**8**
	Unknown	Total	8	3	25	240	276
	All	Total	109	58	324	2,435	2,926
Non-residential	All	Total	298	38	326	1,695	2,357
Unknown	All	Total	0	0	1	3	4
All	**All**	**Total**	**407**	**96**	**651**	**4,133**	**5,287**



(a) Damage classification



(b) Damage classification by occupancy type

Fig. 8 – Result of building damage assessment for the all buildings

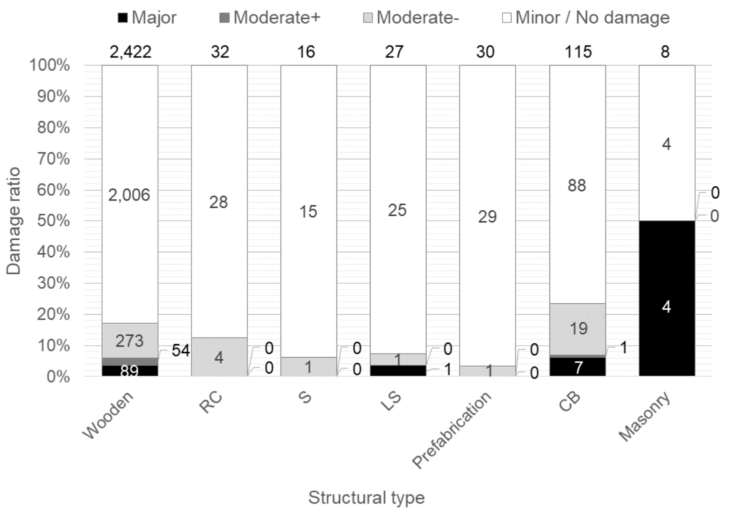


Fig. 9 – Damage classification for the residential buildings with respect to the structural type

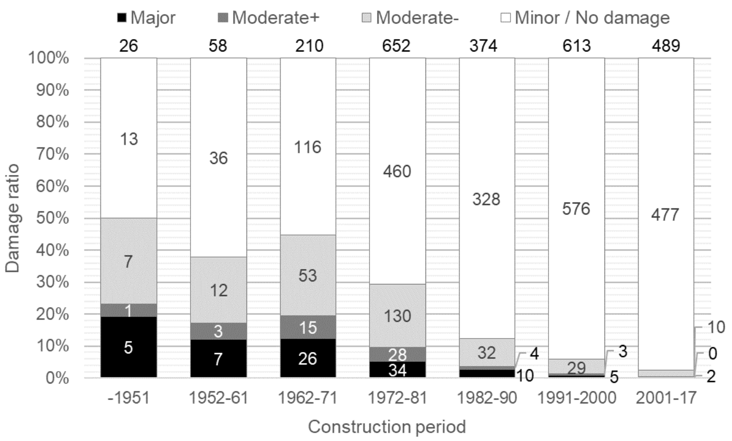


Fig. 10 – Damage classification for wooden houses with respect to the construction period

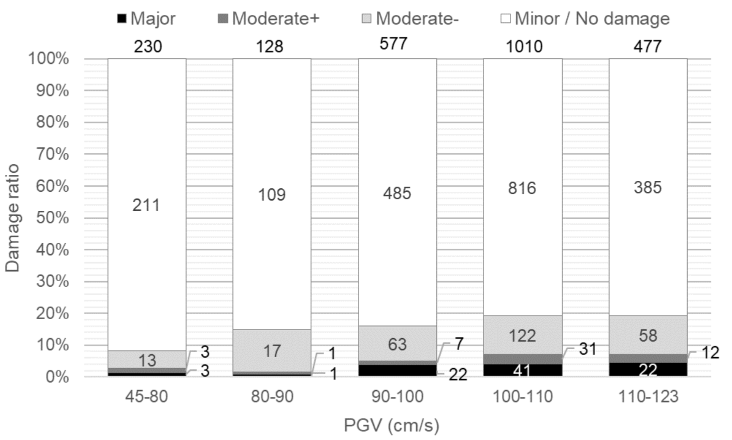


Fig. 11 – Relationship between the estimated PGV and damage class of wooden houses

In the damage category, "Major" representing a monetary loss over 50% is most important since the demolition of the building is a normal situation for this class. Figure 12 compares the ratio of major damage class for wooden buildings with respect to the construction period for Nada Ward in Kobe City [1] and

Nishinomitya City [16] due to the 1995 Kobe earthquake, Kashiwazaki City [17] due to the 2007 Niigata-Chuetsu-Oki earthquake, and the Mashiki Town [3] due to the 2016 Kumamoto earthquake, and Abira Town data in this study. For the same construction period, the major damage ratio of Abira Town is almost the same level as that of Kashiwazaki City and is much lower than those in Nada Ward, Nishinomiya City, and Mashiki Town.

The major damage ratio of Abira Town and Kashiwazaki City was much lower than the other three locations although the strong motion records are in the comparable level. One of reason is considered to explain this discrepancy. In the western Japan, like Kobe and Kumamoto, wooden houses are more vulnerable than those in the eastern (northern) Japan since typhoons are more frequent natural hazards than earthquakes, and thus heavy roofs were dominant for older wooden houses in the western Japan.

Based on the building damage data and estimated strong motion distribution due the 2018 Hokkaido Eastern Iburi earthquake, the present authors will try to develop new empirical fragility curves for Japanese buildings in the near future.

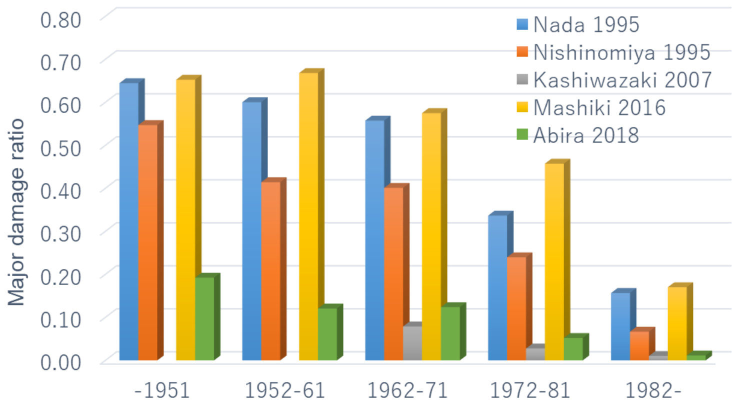


Fig. 12 – Compares the major damage ratio class for wooden buildings with respect to the construction period for five different datasets in Japan.

5. Conclusion

Building damage in Abira Town, Hokkaido, Japan, due to the 2018 Hokkaido Eastern Iburi earthquake was investigated based on the result of damage assessment by the local government. The structural material and construction period were seen to be significant factors to determine damage grades of buildings. The damage ratio of wooden houses gets smaller as the construction period becomes newer. Especially, it is clearly observed that the damage ratio was greatly reduced for newer wooden houses of the construction period after 1982, corresponding to the new seismic code in Japan. Although the major damage ratio of Abira Town is much lower comparing to those of the 1995 Kobe earthquake and the 2016 Kumamoto earthquake; it is almost the same level as that of the 2007 Niigata-Chuetsu-Oki earthquake. It is also revealed that the damage ratio of wooden houses tends to become higher as the PGV increases. The result of this study will be used in the development of fragility curves to assess building damage risk in Japan.

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