

ANALYSIS OF BUILDING DAMAGE IN MASHIKI TOWN DUE THE 2016 KUMAMOTO, JAPAN, EARTHQUAKE

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ABSTRACT

This study investigates the building damage in Mashiki Town, Kumamoto Prefecture, Japan, due to the 16 April 2016 Kumamoto earthquake. The result of damage investigation by the local government is analyzed from the view points of structural material and construction period. As a result, the damage ratio of wooden buildings was much higher than that of steel, light-gauge steel, and RC buildings. The damage ratio of wooden buildings gets higher as the construction period becomes older. Within the construction period of 1982-2016 that corresponds to the new seismic code in Japan the damage ratio becomes smaller for newer wooden buildings. The spatial distribution of damaged buildings is further investigated with their location information on GIS. Compared with an estimated PGV distribution, the result of this study will be used for the development of vulnerability functions of Japanese buildings.

Keywords: The 2016 Kumamoto earthquake; Wooden house; Damage ratio; Construction period; Seismic code

1. INTRODUCTION

Building damage due to strong shaking is one of the most significant effects of earthquakes, especially for inland (crustal) earthquakes. Even in the last few decades, a large number of buildings were collapsed or severely damaged in the world, such as in the 1994 Northridge (California, USA) earthquake, the 1995 Kobe (Japan) earthquake, the 1999 Kocaeli (Turkey) earthquake, the 2003 Boumerdes (Algeria) earthquake, the 2009 L'Aquila (Italy) earthquake, the 2010 Haiti earthquake, the 2011 Christchurch (New Zealand) earthquake, the 2015 Gorkha (Nepal) earthquake etc. Since the collapse of buildings is the major cause of human casualties and shares a large portion of economic losses, the increase of seismic capacity of buildings has been the most prioritized issue in earthquake engineering and disaster risk reduction.

The damage patterns and damage levels of buildings are highly dependent on the structural materials, building laws and regulations, and local construction practice, and hence the investigation on actual earthquake damage situations is quite important and is useful to develop vulnerability functions of buildings. In this regard, the definition of damage levels and the classification of building types are crucial issues. The damage status of buildings can be judged by visual inspection in the field (Grünthal ed. 1998; Building Research Institute 1996; Okada & Takai 2000) or from aerial (Hasegawa et al. 2000) or satellite imagery (Yamazaki et al. 2005; Brunner et al. 2010) and Lidar data (Moya et al. 2018), but

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the damage investigation including the internal damage situation is necessary to assess monetary losses of and is often conducted by local governments in Japan for the purpose of property-tax exemption and financial support (Yamazaki & Mura0 2000; Yamaguchi & Yamazaki 2000).

A series of earthquakes hit Kumamoto Prefecture in Kyushu Island, Japan, on April 14 and 16, 2016. A large number of buildings, mostly wooden houses, were damaged and some of them were totally collapsed. A number of engineers and researchers for various organizations conducted damage investigation of buildings in Mashiki Town, where the building damage was most severe in the earthquake. Among them, the local governments in Kumamoto Prefecture carried out field investigation in order to issue disaster-victim certificates (Urakawa et al. 2010; Tanaka & Shigekawa 2014; Mashiki Town 2017). The people who have had their houses damaged by a natural disaster require this certificate to be eligible to receive various aids.

In this paper, the result of damage assessment provided by the Mashiki Town government is used to analyze the characteristics of building damage due to the Kumamoto earthquake. The result of the analysis is compared with those by other damaging earthquakes in Japan.

2. APRIL 2016 KUMAMOTO EARTHQUAKE

A Mw6.2 earthquake hit Kumamoto Prefecture on April 14, 2016 at 21:26 (JST). A considerable amount of structural damages and human casualties had been reported due to this event, including 9 deaths (Cabinet Office of Japan 2016). The epicenter was located in the Hinagu fault with a shallow depth. On April 16, 2016 at 01:25 (JST), about 28 hours after the first event, another earthquake of Mw7.0 occurred in the Futagawa fault, closely located with the Hinagu fault. Thus, the first event was called as the "foreshock" and the second one as the "main-shock". The focal planes of the both events were located close to the center of Mashiki Town (about 33-thousand population), which is to the east of Kumamoto City (about 735-thousand population). A total of fifty (50) direct-cause deaths were accounted by the earthquake sequence, mostly due to the collapse of wooden houses in Mashiki Town and landslides in Minami-Aso Village (Cabinet Office of Japan 2016; Yamazaki & Liu 2016). The total number of aftershocks (larger than magnitude 3.5) reached 340 times as of April 30, 2017, one year after the first event. This number is the largest among recent inland earthquakes in Japan (Japan Meteorological Agency 2017).

Figure 1 shows the location of these causative faults and Japanese national GNSS Earth Observation Network System (GEONET) stations in the source area (Geospatial Information Authority of Japan (GSI) 2016). Note that the GEONET system has about 1,300 stations covering Japan's territory

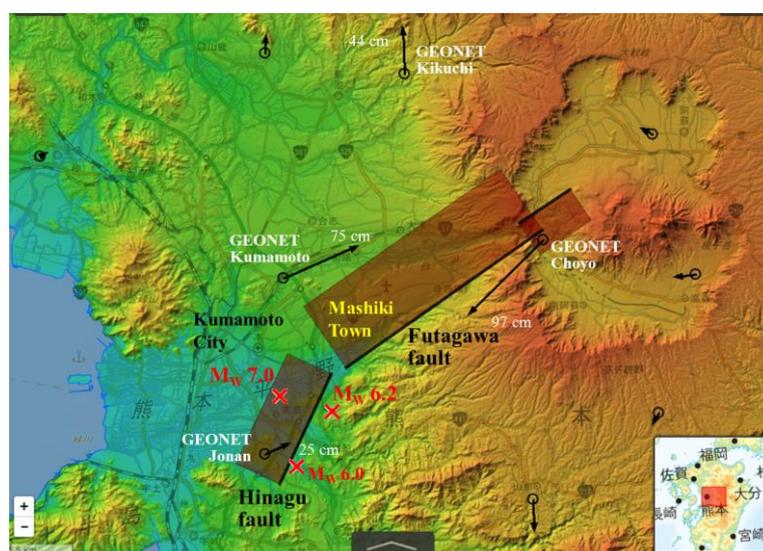


Figure 1. Location of causative faults and GNSS stations in the 2016 Kumamoto earthquake

uniformly. The displacement of 75 cm to the east-northeast (ENE) was observed at the Kumamoto station while that of 97 cm to the southwest (SE) was recorded at the Choyo station during the main-shock. These observations validated the right-lateral strike-slip mechanism of the Futagawa fault. A detailed distribution of coseismic displacements in Mashiki Town was estimated by the present authors (Moya et al. 2017) using the Lidar data acquired before and after the April 16 main-shock (Asia Air Survey 2016).

The peak ground acceleration (PGA) and the peak ground velocity (PGV) recorded at the KiK-net Mashiki station (KMMH16) were 925 cm/s^2 and 92 cm/s in the foreshock while those were $1,313 \text{ cm/s}^2$ and 132 cm/s in the main-shock (Suzuki et al. 2016). These values are quite large in the recent earthquake records Japan. Even a larger PGV value, 183 cm/s , was recorded on the ground floor of Mashiki Town office building in the main-shock with $\text{PGA} = 897 \text{ cm/s}^2$. The location of these two seismic stations are plotted in Figure 2 on a mosaiced orthorectified aerial image acquired by GSI (2016) on April 29, 2016. In general, building damage was most severe in the south of the town-office building while damage situation was much smaller around the KiK-net station (Yamada et al. 2017).



Figure 2. Mosaiced orthorectified aerial image by GSI and location of seismic stations in Mashiki Town

3. BUILDING DAMAGE ASSESSMENT IN MASHIKI TOWN

Since the building damage in the Kumamoto earthquake sequence was most severe in Mashiki Town, a number of research groups conducted field investigations (NILIM 2016; Sugino et al. 2016; Yamada et al. 2017) and the results were used to explain the heavy damage situation of buildings, compared with the recorded seismic motions. But these damage surveys were mostly visual inspection from the road side or some used aerial photographs, they are applicable only to significant damage levels, such as “total collapse” or “partial collapse”. Another drawback of these kinds of voluntary investigations is the difficulty to obtain detailed building information, such as the structural-material and construction-year. In this regard, only the damage investigation by local governments can link the damage classification result with the detailed building information.

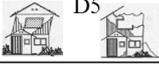
Several vulnerability functions (fragility curves) for Japanese buildings had been developed (Yamaguchi & Yamazaki 2000; Yamazaki & Murao 2000; Midorikawa et al. 2011) and actually used in damage assessments for scenario future earthquakes, but that the damage (loss) evaluation methods were different depending on local governments at the time of the 1995 Kobe earthquake (Murao & Yamazaki 1999). After the Kobe event, the central government issued the unified loss evaluation method (Cabinet Office of Japan 2013) and the workflow and training procedure were proposed (Urakawa et al. 2010;

Tanaka & Shigekawa 2014). The affected local jurisdictions in Kumamoto Prefecture followed this method and hence the results of these loss evaluations for buildings can be considered as the data of the same category.

Moshiki Town (2017) recently issued the summary report on the response/recovery activities for the Kumamoto earthquake. In the report, a total of 10,742 buildings are classified in to five classes by their damage (or monetary loss) classes, shown in Table 1. Note that this classification was carried out following the unified loss evaluation method (Cabinet Office of Japan 2013). In the table, an approximate correspondence with visual inspection methods (Grünthal ed. 1998; Okada & Takai 2000) is also shown. Note that the result of loss assessment by local government is important for affected people to receive financial support and property tax reduction. In Mashiki Town, the first stage assessment, viewing from outside, was conducted for all the buildings. This result was shown to the residents and in case, they did not accept it, the second stage assessment, viewing the damage status of inside a building, was carried out.

The final result of the property loss evaluation is shown in Figure 3 (Mashiki Town 2017). It is observed from the figure that the major damage buildings are distributed widely, especially along the Futagawa fault line. The overall damage grade gets smaller in the northern and eastern areas. In the central part of Mashiki Town, major damaged buildings exist more around the Town office building than around the KiK-net station, which is consistent with field observations.

Table 1. Earthquake loss evaluation class of buildings in Japan and schematic images of other damage classification methods

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	$40\% \leq r < 50\%$	G2 	D2 
Moderate -		$20\% \leq r < 40\%$	G1 	D1 
Minor	Minor	$0\% < r < 20\%$	(G0) 	D0 
No	No	$r = 0\%$	(G0)	D0

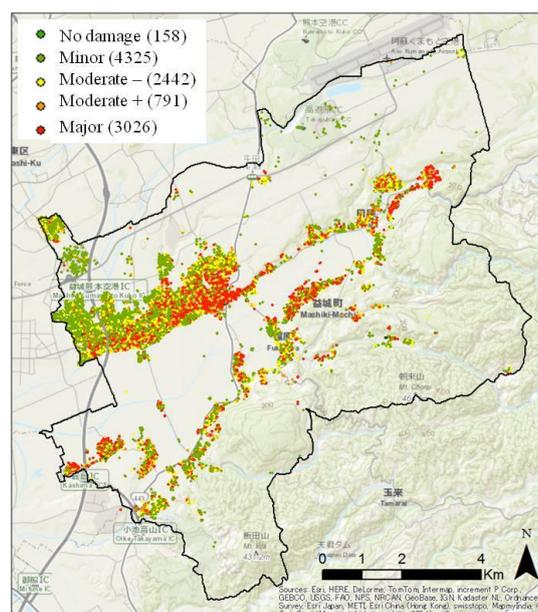


Figure 3. Result of damage (loss) assessment by Mashiki Town government (2017)

Figure 4 compares the acceleration response spectra (the resultant of the two horizontal component, 5% damping ratio) for the recorded motions at the two seismic stations for the foreshock (April 14) and the main-shock (April 16). In the figure, the result for the connected time histories (April 14 and April 16 in 5-s interval) is also plotted. It is seen for the KiK-net station that in a short period range less than 0.7 s (0.8 s for the Town office station), the April-14 event exhibits higher response values than those of the April 16 event. But in the longer period range, the April 16 event shows higher response values. It is also noticeable, especially for the April 16 event, that the Mashiki town office record shows much higher values than those of the KiK-net stations in the period longer than 0.7 s, which corresponds to the structural damage of wooden buildings in Japan.

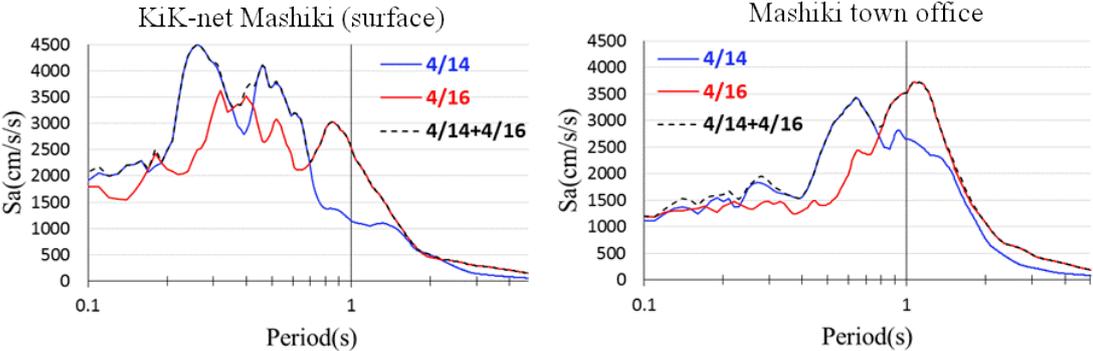
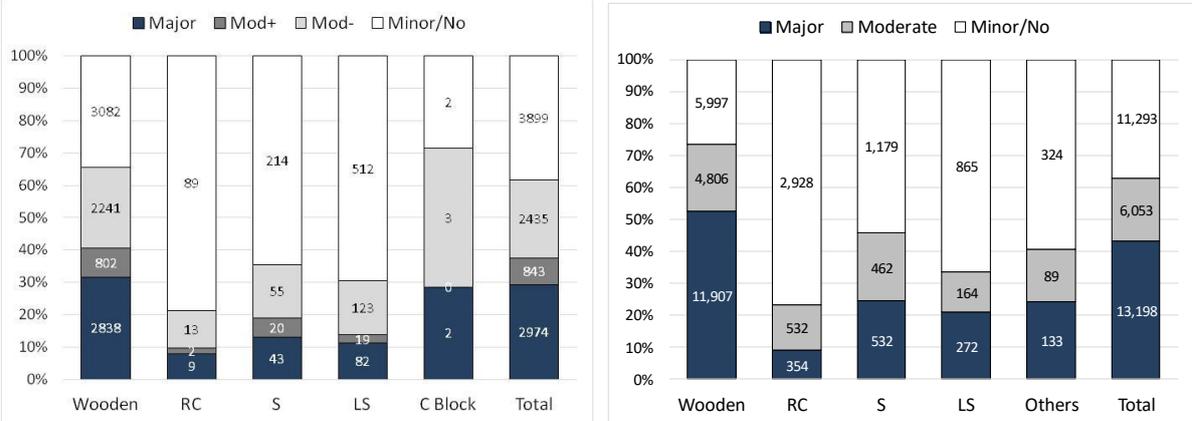


Figure 4. Acceleration response spectra (the resultant of the two horizontal component, 5% damping ratio) for the records at KiK-net Mashiki station and Mashiki Town office.

4. ANALYSIS OF BUILDING DAMAGE IN MASHIKI TOWN

The building damage data shown in Figure 3 were analyzed based on the structural material and construction period. From all the loss assessment data, non-residential or non office-use buildings, such as a storage barn, were excluded. Figure 5 shows the damage classifications for a total of 10,151 buildings in Mashiki Town due the 2016 Kumamoto earthquake and that for 30,544 buildings in Nada Ward due the 1995 Kobe earthquake (Yamazaki & Murao 2000). The ratio of major damage for each structural type (material) is in the order of "wooden", "Steel (S)", "Light Gauge Steel (LS)", and "Reinforced Concrete (RC)" buildings for the both datasets. Although there is a 21-years time difference, the vulnerability of buildings with respect to the structural type is quite similar. Note that at the time of the Kobe earthquake, the damage class "Moderate" corresponded to the monetary loss ratio $20\% \leq r < 50\%$, which is the summation of "Moderate+" and "Moderate-" in the Mashiki data.



(a) Mashiki Town in 2016 Kumamoto EQ (b) Nada Ward in 1995 Kobe EQ

Figure 5. Damage classification of buildings by local governments with respect to the structural type.

The effect of construction period, which corresponds to the change of seismic code in Japan, was then investigated only for wooden buildings since the number of buildings for other structural types is not large enough. Figure 6 shows the damage ratio of wooden buildings in Mashiki Town with respect to the construction period and damage (loss) category. It is clearly observed that within the construction period of 1982-2016 that corresponds to the new seismic code in Japan the damage ratio becomes smaller for newer wooden buildings. Note that the seismic provision for wooden buildings was upgraded in 2000.

In the damage category, "Major", which represents the monetary loss over 50%, is most important since the demolition of the building is a normal situation for this class. Figure 7 compares the ratio of major damage class for wooden buildings with respect to the construction period for Nada Ward in Kobe City (Yamazaki & Muraio 2000) and Nishinomiya City (Yamazuchi & Yamazaki 2000) due to the 1995 Kobe earthquake, and Kashiwazaki City (Nagao et al. 2011) due to the 2007 Niigata-Chuetsu-Oki earthquake, and the Mashiki Town data in this study. For the same construction period, the major damage ratio of the Mashiki Town is almost the same level as that of Nada Ward. The damage ratio of Nishinomiya City is slightly small than that of Nada Ward since the city includes the area of lower seismic motion in the northern part.

The major damage ratio of Kashiwazaki City was much lower than the other three locations although the strong motion records are in the comparable level. Similarly, the major damage ratios for recent earthquakes in Japan were much smaller than that in the Kobe earthquake for the same ground motion level. A few reasons are considered to explain this discrepancy. First, the damage assessment method was not unified and the local governments issued higher damage grades following citizens' requests. The regional difference in construction practice for wooden buildings may be the second reason. In the

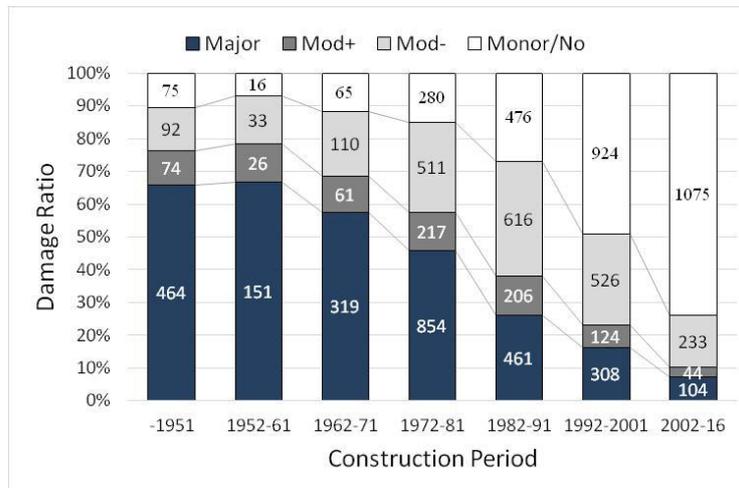


Figure 6. Damage classification of wooden buildings in Mashiki Town with respect to construction period.

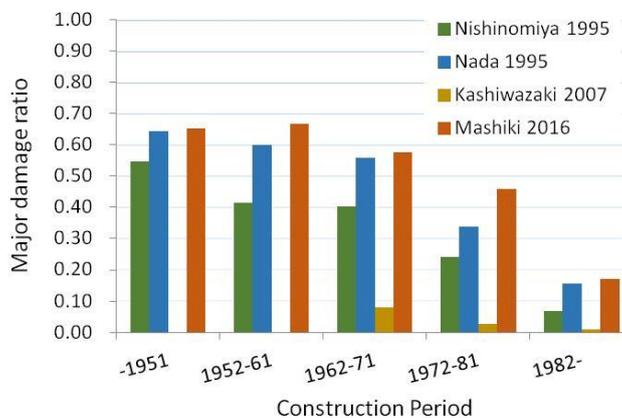


Figure 7. Compares the major damage ratio class for wooden buildings with respect to the construction period for four different datasets in Japan.

western Japan, like Kobe and Kumamoto, wooden houses are more vulnerable than those in the eastern (northern) Japan since typhoons are a more frequent natural hazard than earthquakes, and thus heavy roofs were dominant for older wooden houses in the western Japan. The lack of seismometers at the time of the Kobe earthquake gave uncertainty in estimating strong motion distribution.

Based on the building damage data and estimated strong motion distribution due the 2016 Kumamoto earthquake, the present authors will try to develop new empirical vulnerability functions for Japanese buildings in the near future. To do this task, the damage assessment data and inventory data of buildings in Kumamoto City should be included because the city has a much larger number of buildings and has the areas of small to large shaking levels.

5. CONCLUSIONS

Building damage in Mashiki Town, Kumamoto Prefecture, Japan, due to the 2016 Kumamoto earthquake was investigated based on the result of damage investigation by the local government. The structural material was seen to be the primary factor to determine damage grades of buildings as well as the strong motion intensity. The major damage ratio of wooden buildings gets higher as the construction period becomes older. It is clearly observed that within the construction period of 1982-2016 that corresponds to the new seismic code in Japan the damage ratio becomes smaller for newer wooden buildings. A similar trend of damage was also observed for other structural materials, RC and steel, but the ratios are much smaller than those for wooden houses. A preliminary study on the spatial distribution of damaged buildings was also conducted on a GIS.

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7. REFERENCES

- Asia Air Survey Co., Ltd. (2016). The 2016 Kumamoto Earthquake. An approach of crustal deformation analysis based on comparison of two periods of Lidar measurement. <http://www.ajiko.co.jp/article/detail/ID5725UVGCD/> (Accessed on 1 Dec. 2017).
- Brunner D, Lemoine G, Bruzzone L (2010) Earthquake damage assessment of buildings using VHR optical and SAR imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 48(5), 2403-2420.
- Building Research Institute (1996). Final report of damage survey of the 1995 Hyogoken-Nanbu earthquake, 1996 (in Japanese). <http://www.kenken.go.jp/japanese/research/iisee/list/topics/hyogo/pdf/h7-hyogo-jp-all.pdf>, (Accessed on 1 Dec. 2017).
- Cabinet Office of Japan (2013). Operational guideline for damage assessment of residential buildings in disasters, (in Japanese), <http://www.bousai.go.jp/taisaku/pdf/shishinall.pdf>, (Accessed on 1 Dec. 2017).
- Cabinet Office of Japan (2016). Summary of damage situation in the Kumamoto earthquake sequence (in Japanese), <http://www.bousai.go.jp/updates/h280414jishin/index.html>, (Accessed on 1 Dec. 2017).
- Geospatial Information Authority of Japan (GSI) (2016). The 2016 Kumamoto Earthquake (in Japanese), <http://www.gsi.go.jp/BOUSAI/H27-kumamoto-earthquake-index.html> (Accessed on 1 Dec. 2017).
- Grünthal G. ed. (1998). European Macroseismic Scale 1998 (EMS-98), European Seismological Commission, sub commission on Engineering Seismology, Working Group Macroseismic Scales. Vol. 15, Luxembourg.
- Hasegawa H, Yamazaki F, Matsuoka M, Sekimoto I (2000). Determination of building damage due to earthquakes using aerial television images, *12th World Conference on Earthquake Engineering*, paper 1722, Auckland, New Zealand.

- Japan Meteorological Agency (2017). The number of aftershocks of recent inland earthquakes in Japan. http://www.data.jma.go.jp/svd/eqev/data/2016_04_14_kumamoto/kaidan.pdf (Accessed on 1 Dec. 2017).
- Mashiki Town (2017). Review report on the response to the 2016 Kumamoto earthquake (in Japanese), http://www.town.mashiki.lg.jp/common/UploadFileDsp.aspx?c_id=76&id=1217&sub_id=1&flid=4657 (Accessed on 3 Dec. 2017)
- Midorikawa S, Ito Yuki, Miura H (2011). Vulnerability functions of buildings based on damage survey data of earthquakes after the 1995 Kobe Earthquake, *Journal of Japan Association for Earthquake Engineering*, 11(4), 34-47 (in Japanese).
- Moya L, Yamazaki F, Liu W, Chiba T (2017). Calculation of coseismic displacement from lidar data in the 2016 Kumamoto, Japan, earthquake, *Natural Hazards and Earth System Sciences*, 17, 143-156.
- Moya L, Yamazaki F, Liu W, Yamada M (2018). Detection of collapsed buildings due to the 2016 Kumamoto, Japan, earthquake from LiDAR data, *Natural Hazards and Earth System Sciences*, 17, 65-78.
- Murao O, Yamazaki F (1999). Comparison of building damage evaluation by local governments after the 1995 Hyogoken-Nanbu Earthquake, *Journal of Architecture, Planning and Environmental Engineering*, 515, 187-194 (in Japanese).
- Nagao T, Yamazaki F, Inoguchi M (2011). Analysis of building damage in Kashiwazaki city due to the 2007 Niigata-ken Chuetsu-oki earthquake, *Proc. 32nd Asian Conference on Remote Sensing*, Taipei, Paper No. 228.
- National Institute for Land and Infrastructure Management (NILIM) (2016). Quick report of the field survey on the building damage by the 2016 Kumamoto earthquake, Technical Note No. 929 (in Japanese), <http://www.nilim.go.jp/lab/bcg/siryounn/tnn0929.htm> (Accessed on 3 Dec. 2017)
- Okada S, Takai N (2000). Classifications of structural types and damage patterns of buildings for earthquake field investigation, *Proceedings of the 12th World Conference on Earthquake Engineering*, paper 0705, Auckland, New Zealand.
- Sugino M, Yamamuro R, Kobayashi S, Murase S, Ohmura S, Hayashi Y (2016). Analyses of building damages in Mashiki Town in the 2016 Kumamoto Earthquake, *Journal of Japan Association for Earthquake Engineering*, 16(10), 69-85 (in Japanese).
- Suzuki W, Aoi S, Kunugi T, Kubo H, Morikawa N, Nakamura N, Kimura T, Fujiwara H (2016). Strong motions observed by K-NET and KiK-net during the 2016 Kumamoto earthquake sequence, *Earth, Planets and Space*, 69(19), DOI 10.1186/s40623-017-0604-8.
- Tanaka S, Shigekawa K (2014). Development of training system for building damage assessment using actual buildings, *Journal of Disaster Research*, 9(2), 188-197.
- Urakawa G, Hayashi H, Tamura T, Inoguchi M, Horie K, Higashida M, Hamamoto R (2010). Building comprehensive disaster victim support system, *Journal of Disaster Research*, 5(6), 687-696.
- Yamada M, Ohmura J, Goto H (2017). Wooden building damage analysis in Mashiki town for the 2016 Kumamoto earthquakes on April 14 and 16, *Earthquake Spectra* (accepted for publication).
- Yamaguchi N, Yamazaki F (2000). Fragility curves for buildings in Japan based on damage surveys after the 1995 Kobe earthquake, *Proceedings of the 12th World Conference on Earthquake Engineering*, paper 2451, Auckland, New Zealand.
- Yamaguchi N, Yamazaki F (2001). Estimation of strong motion distribution in the 1995 Kobe earthquake based on building damage data, *Earthquake Engineering and Structural Dynamics*, 30(6), 787-801.
- Yamazaki F, Murao O (2000). Vulnerability functions for Japanese buildings based on damage data due to the 1995 Kobe earthquake, In: *Implications of Recent Earthquakes on Seismic Risk, Series of Innovation in Structures and Construction*, Imperial College Press, 2, 91-102.
- Yamazaki F, Yano Y, Matsuoka M (2005). Visual damage interpretation of buildings in Bam city using QuickBird images following the 2003 Bam, Iran earthquake, *Earthquake Spectra*, 21, S329-S336.
- Yamazaki F, Liu W (2016). Remote sensing technologies for post-earthquake damage assessment: A case study on the 2016 Kumamoto earthquake, Keynote Lecture, *6th Asia Conference on Earthquake Engineering*, Cebu City, Philippines.