Debris Scattering Assessment

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Summary

In this paper two things are done. (1) Statistical data concerning debris scattering of collapsed buildings caused by earthquakes is presented. (2) An investigations of the factors influencing the extent of the debris is performed. Debris scattering caused by earthquakes is one of the main factors for blocking of streets, particularly in dense urban areas. Therefore it is crucial for evacuation issues. The authors of this paper believes this information is valuable to study the vulnerability of the evacuation routes. Furthermore, it can be used to perform simulations evacuation during an earthquake where the blockage of streets are considered.

1. Introduction

This paper should be considered as a direct continuation of preceding ones in which the permanent ground deformation (Moya et al., 2017a) and an automatic procedure to extract collapsed buildings (Moya et al., 2017b), produced during the 2016 Mw 7.0 Kumamoto earthquake, was performed using a pair of Lidar data. Here the same database is used to grasp some insights regarding the extent of the debris scatter produced by the collapsed buildings.

On April 14, 2016, an Mw 6.5 earthquake ocurred in Kumamoto prefecture, Japan. The epicenter was located at the end of the Hinagu fault. About 28 hours later (April 16, 2016), another earthquake of Mw 7.0 ocurred in the Futugawa fault. Hereafter, the first and second event will be designated as foreshock and mainshock, respectively. Both events, were located in the suburban area of Kumamoto city. Therefore, extensive damage ocurred (Liu and Yamazaki, 2017). After the foreshock and before the mainshock, a high-density Lidar data were acquired over the

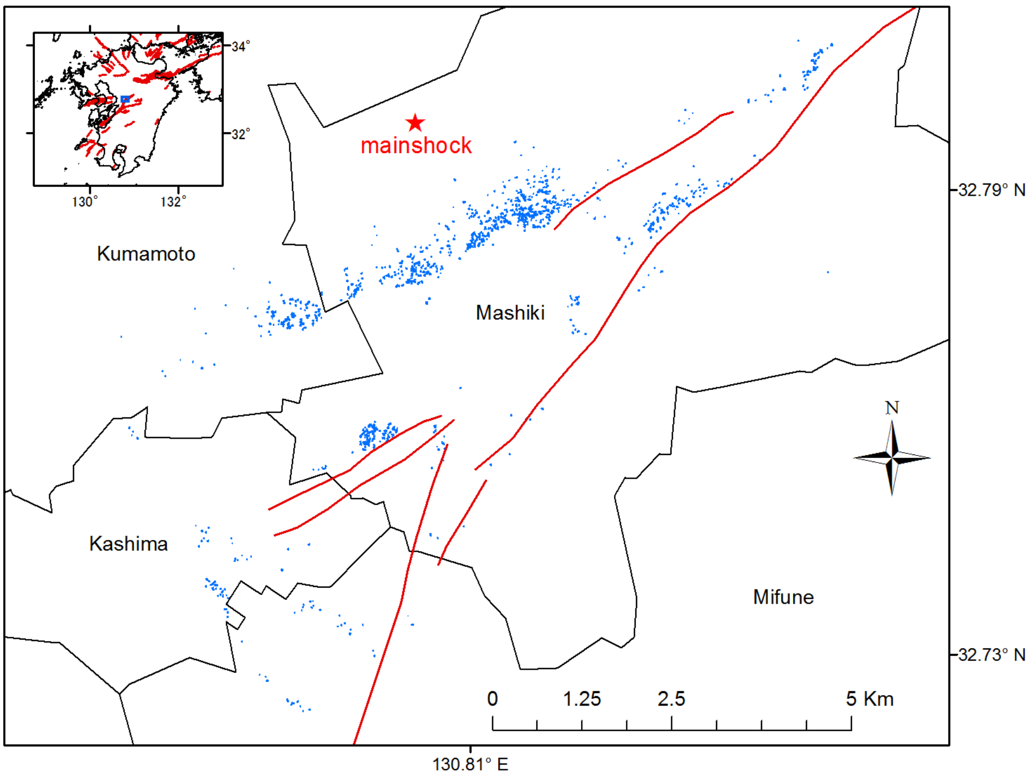


Figure 1: Location of the selected buildings (blue polygons) in the study area. The red lines depict the location of the active faults and the inset shows the location of the study area in the Kyushu Island, Japan.

affected area. The raw Lidar data had an average point-density of 1.5-2 points m^{-2}. Later, after the mainshock, a second mission was send to acquire Lidar data. This second dataset had an average point-density of 3-4 points m^{-2}. Both Lidar dataset were used to generate a pair of digital surface model (DSM): before (BDSM) and after (ADSM) the mainshock. The spatial resolution of the DSMs is 50 cm.

In this paper we will explore the potential use of Lidar to quantify the debris scattering. In this paper, by *debris scattering* we refer to the maximum distance that the main part of the debris has moved horizontally. The debris scattering is a critical issue in the transportation network. A clean transportation network is important for an efficient evacuation of the population and for the transportation of the resources. Relief sources, food, medicine, and shelter are such examples.

2. Debris scattering inspection

The dataset inventory used in this study were selected from the collapsed buildings extracted automatically from the pair of DSMs (Moya et al., 2017b). A closer look by visual inspection of the DSMs and aerial photos taken before and after the mainshock was perform for each collapsed building in order to filter the following buildings: (1) non-collapsed buildings classified as collapsed by the automatic procedure, (2) collapsed buildings with its four sides constrained by close structures that could disturb the natural pattern of the debris expansion, such as neighbour buildings, and (3) collapsed buildings that was difficult to quantify the debris scattering. Therefore, a total of 1099 buildings were selected for the quantification of the debris scattering. Figure 1 shows the spatial distribution of the selected buildings.

In order to perform a systematic quantification, a profile of images were created for each building, such as the one shown in Figure 2. From a comparison between BDSM (Figure 2a) and ADSM (Figure 2b), it is evident the presence of lateral displacement of the buildings, which is now considered as debris. Here the objective is to quantify the extent of that debris. Figure 2c shows the difference of elevations between ADSM and BDSM. The positive values depicts the location of debris, which are shown mostly as red pixels. Here, we focus on debris that could represent a risk during a disaster situation; thus, a very thin layer of debris does not represent a problem. Therefore, an image thresholding technique was applied to Figure 2c with a threshold value of 50 cm. That is, if the difference of elevation was greater than or equal to 50 cm, it is assigned one value (white pixel), else it is

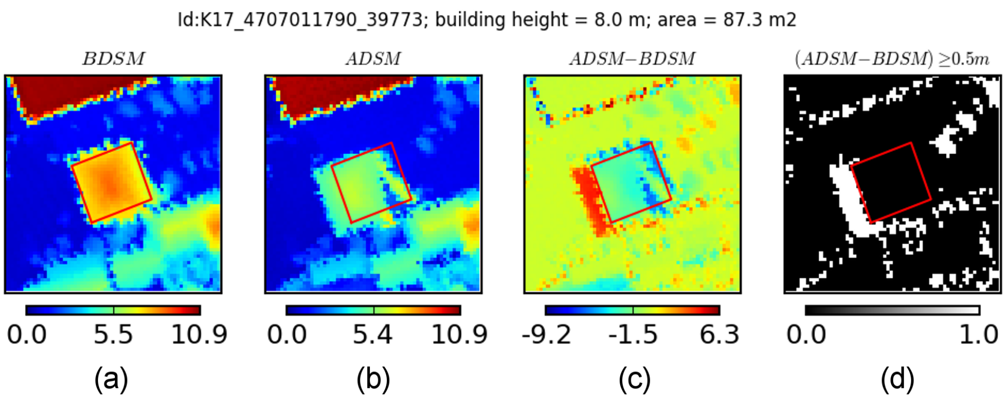


Figure 2: Lidar data of a collapsed building. (a) BDSM; (b) ADSM; (c) ADSM - BDSM; (d) Binary image where white pixels show difference of elevation between the DSMs greater than or equal to 50 cm.

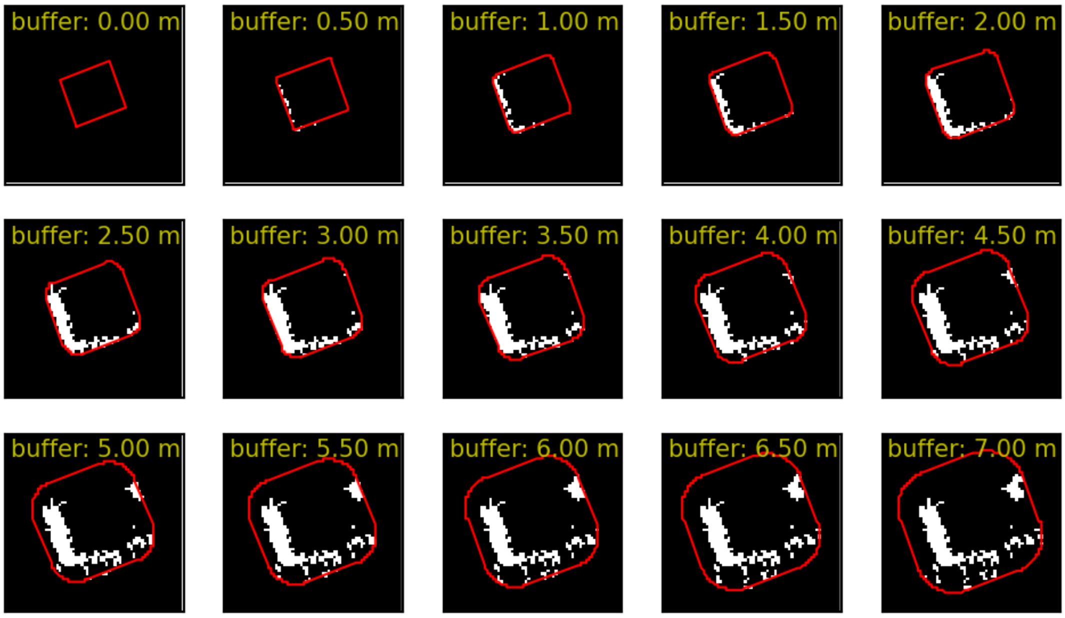


Figure 3: Polygons parallel to the building footprint. White pixels outside the polygons were filtered.

assigned zero value (black pixel). The resulting binary image is shown in Figure 2d.

In order to quantify the debris scattering, polygons parallel to the footprint with distances multiples of 50 cm were prepared. Figure 3 show 15 polygons with distances to the building footprint ranging from 0 m to 7 m. Besides, all the debris located outside of the polygons were filtered. It can be observed clearly that the main part of the debris has expanded a distance of 3.5 m. The multiples of 50 cm used was selected based on the resolution of the DSMs.

The same procedure was performed to each collapsed building. Figure 4 shows the histogram of the estimated debris scattering. Two main groups are observed: buildings with no debris expansion and buildings with debris scattering which are mainly concentrated at 3 m.

3. Influence of the height on the debris scattering

In this section, the relation of the debris scattering and the building hight is studied. It is expected that the higher the building, the larger the debris scattering. Figure 5 illustrates a scatter plot between the debris scattering

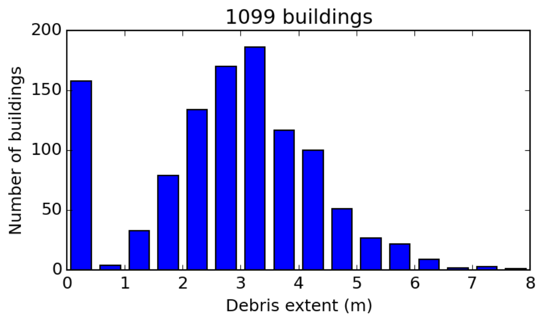


Figure 4: Histogram of debris scattering of collapsed buildings during the 2016 Kumamoto earthquake

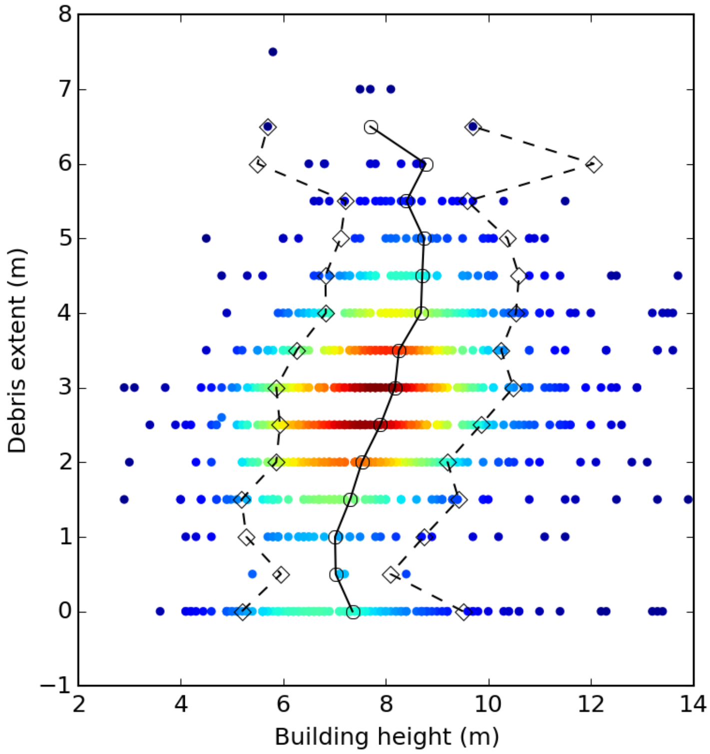


Figure 5: Scatter plot between the debris scattering and the building height.

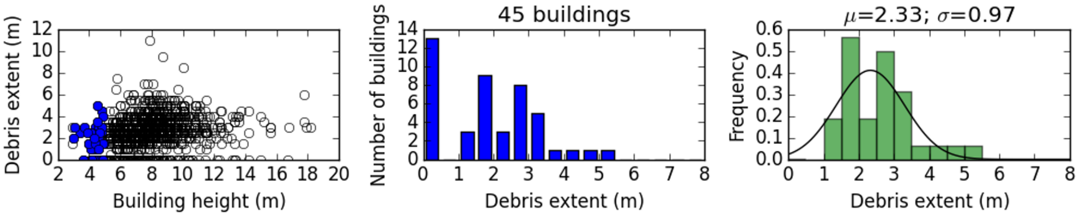
and the building height. The color depicts the density points, where the red color represent the largest density. On the vertical axis, it is observed that the points are clustered in multiples of 50 cm. The solid line shows the location of the average of the points clustered at multiples of 50 cm and the dashed line shows the average plus/minus the standar deviation. It is observed a linear correlation for debris scattering within the range 1m-5m.

Therefore, the building height is influencing the frequency distribution (Figure 4) of the debris scattering. Figure 6 shows the histogram of the estimated expanded debris once again; but separated in groups by ranges of 2 m. In the left column the buildings used are shown as blue dots. Thus, Figure 6a shows the buildings with height ranging [3 m, 5 m), Figure 6b for heights ranging [4 m, 6 m), etc. The Figures at the center shows the histogram of the debris extent for each group. Again, it is observed a significant amount of buildings that did not experienced debris scattering. However, it is observed that the amount decreases when the bulding height increases. Furthermore, the buildings that experienced debris scatter are normally (Gaussian) distributed. The Figures at the right shows the Gaussian function fitted to the collapsed buildings that experienced debris scattering. It is recognized that the average (μ) of the fitted curve increases while the building height increases as well.

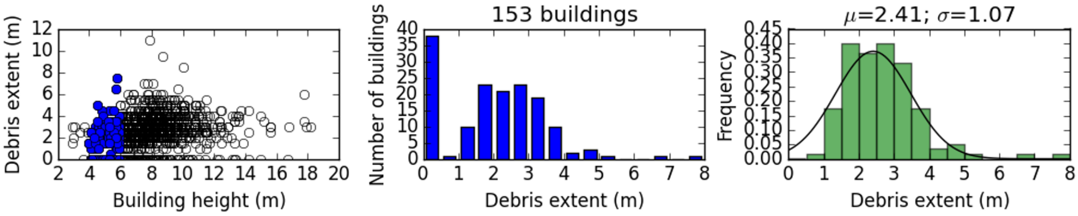
4. Conclusions

A significant amount of collapsed buildings (1099) were inspected and its debris scattering was quantified. A pair of Lidar dataset and aerial images were employed for this purposed. The distribution of the debris extent was presented and its correlation to the building height has been proved.

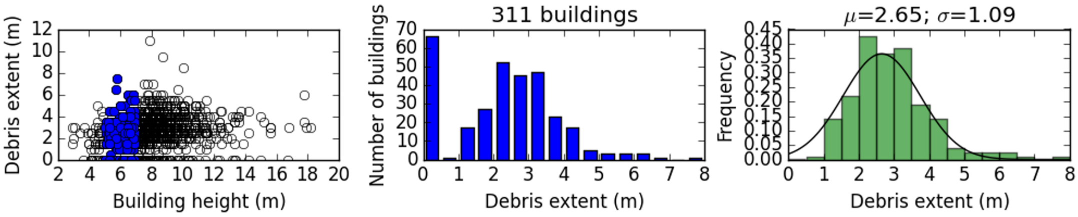
These results represent a preliminar report. It is necessary the evaluation of other factor that might influence the distribution of the debris extent, such as the PGA and the aspect ratio of the building (longitude/width).



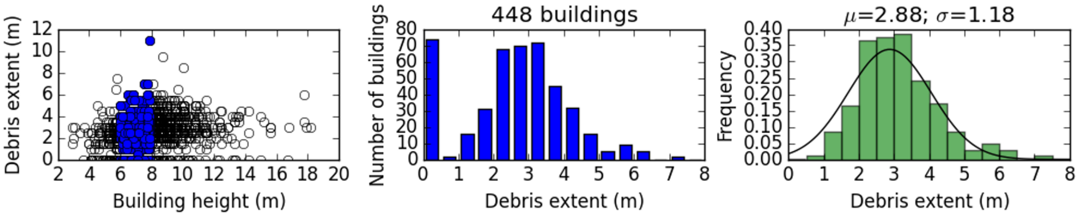
(a) 3 m ≤ building height < 5 m



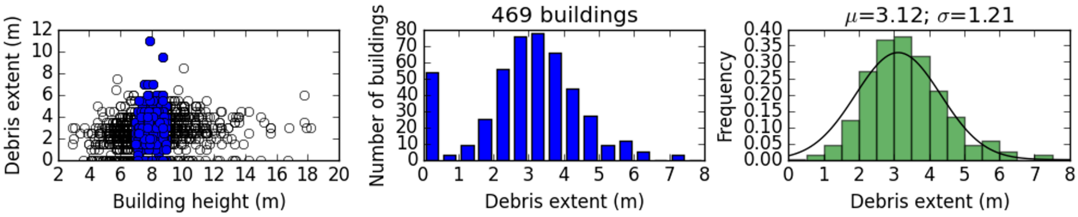
(b) 4 m ≤ building height < 6 m



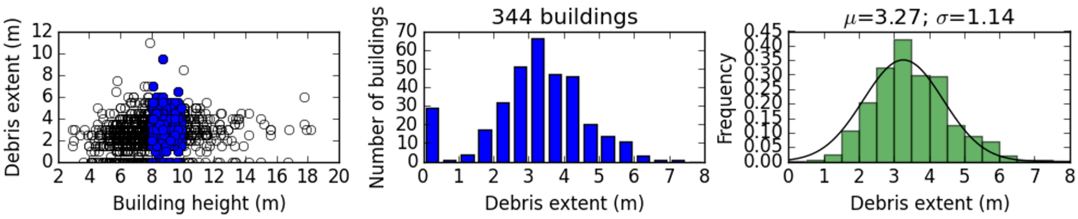
(c) 5 m ≤ building height < 7 m



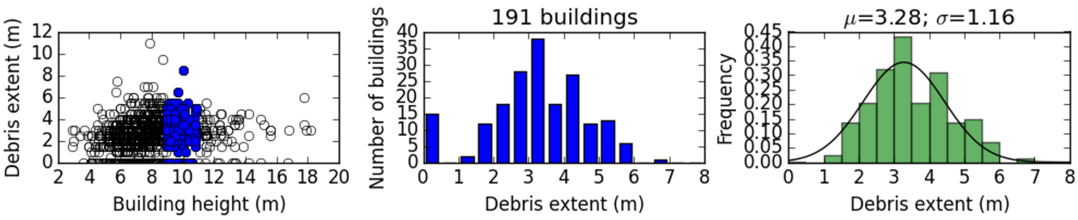
(d) 6 m ≤ building height < 8 m



(e) 7 m ≤ building height < 9 m



(f) 8 m ≤ building height < 10 m



(g) 9 m ≤ building height < 11 m

Figure 6: Histogram of debris extent of buildings filtered by building height

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