ANALYSYS OF BUILDING DAMAGE IN KASHIWAZAKI CITY DUE TO THE 2007 NIIGATA-KEN CHUETU-OKI EARTHQUAKE

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ABSTRACT: This study investigates the building damage in Kashiwazaki city due to the 2007 Niigata-Ken Chuetsu-Oki, Japan earthquake. Most building fragility functions, used for damage estimation in scenario earthquakes in Japan, were developed based on the actual damage data from the 1995 Hyogoken-Nanbu (Kobe) earthquake. However, already sixteen years have passed after this event, and hence it is better to employ recent earthquake data. In this study, the damage ratios of buildings are investigated from the view points of structural material and the construction period. As a result, for wooden houses, the damage ratio gets higher as the construction period becomes older. It is clearly observed that within the construction period 1982-2007, the damage ratio becomes smaller for newer wooden houses. The reduction of damage ratio with construction period is also observed for other structural materials (RC and steel), but the ratios are much smaller than those for wooden houses. The spatial distribution of damaged buildings is further investigated with their position information on a geographic information system (GIS). The results are compared with the distribution of recorded peak ground velocity (PGV) values and the damage ratio is plotted comparing with the empirical fragility function from the Kobe earthquake. It is observed that the building damage ratios in the 2007 Niigata-Ken Chuetsu-Oki earthquake are lower than those from the Kobe earthquake.

1. INTRODUCTION

Lots of building damages were observed in recent earthquakes in Japan due to seismic shaking, such as the 1995 Hyogoken-Nanbu (Kobe), the 2004 Niigata-Ken Chuetsu, the 2005 Fukuoka-Ken Seiho-Oki, and the 2007 Niigata-Ken Chuetsu-Oki earthquakes. Based on these experiences, Central Disaster Prevention Council and local governments in Japan have estimated the building damages against scenario earthquakes to develop the earthquake disaster mitigation strategy.

Building damages were mainly estimated based on the damage observations in the 1995 Kobe earthquake. For example, the building fragility functions, used in the earthquake damage estimation in Yamanashi prefecture and the regional risk assessment in Tokyo (NLIRO, 2006), were developed based on the actual damage data in Nada Word of Kobe city from this earthquake (Murao and Yamazaki, 1999). Similarly, the wooden building fragility functions (Central Disaster Prevention Council, 2003) used for damage estimations by Iwate and Nara prefectures have been developed based on the actual damage data in Nishinomiya city from the Kobe earthquake, in Tottori city from the 2000 Tottoriken-Seibu earthquake, in Kure city from the 2001 Geiyo earthquake. However, it is questionable whether we can use still these empirical fragility functions mainly developed from the experiences from the Kobe earthquake since sixteen years have passed after the event. For example, it is known that more than 60% of buildings have been constructed after the development of the new seismic design code in 1980s, and the seismic resistance of wooden houses is greatly influenced by the construction period. Therefore, the conditions might be different for recent wooden houses from those at the 1995 Kobe earthquake. However, due to the lack of detailed building damage data, the empirical formulas from the Kobe earthquake have been used. From this background, this study tries to revise the fragility function based on building damage data in Kashiwazaki city due to the 2007 Niigata-Ken Chuetsu-Oki earthquake, obtained by extensive and detailed studies after the earthquake.

This study provides the spatial distribution of building damage ratio using a geographic information system (GIS), and compares those with observed seismic recordings in the city.

2. THE NIIGATA-KEN CHUETSU-OKI EARTHQUAKE AND BUILDING DAMAGE DATA

The central part of Niigata prefecture, Japan was hit by a strong M_{JMA} 6.8 earthquake on July 16, 2007. Fifteen people were killed and 1,319 houses were collapsed in Niigata prefecture. Kashiwazaki city was most severely affected in the prefecture with 14 people killed and 1,109 houses collapsed.

Building damage data are provided by "Digital Data Utilization Council of the Niigata-Ken Chuetsu-Oki Earthquake" established within the taxation department of Kashiwazaki city. These data were created based on the building damage survey by the city, and the data include building attributes and damage classification. Therefore the data is quite useful for updating the building fragility functions.

Table-1 Contents of building damage data

Name	Survey data	Afflicted data	Taxation roll data
The number of data	86,157	34,712	13,288
Survey number	○	○	○
Building number	○	-	○
Damage score	-	○	○
Damage classification	-	○	○
Building location	○	○	○
Building type	○	○	○
Building status	○	-	○
Structural material	○	-	○
Construction period	○	-	○
Roof material	○	-	○
Floor space	○	-	○
The number of floors	○	-	○

Table 1 shows the structure of the building data for this study. The "survey data" in Table 1 was created before conducting a damage survey for the whole area of Kashiwazaki city, consisting of about 86,000 buildings. The "afflicted data" is the building damage data for which afflicted proof was issued, consisting of about 34,000 buildings. The "taxation roll data" is linked with house taxation roll as a part of the afflicted data and consists of 13,000 items, mainly related to the damaged buildings more than moderate damage. The survey data include details of buildings, such as the building location (city block), building type and status, structural material, construction period, roof material, floor space, the number of floors. The afflicted data include the building location, type and damage classification, in which the damage level is categorized as "severe damage", "significant damage and "moderate damage" based on the damage score calculation following the manual by the Central Disaster Prevention Council. The taxation data include damage classification in addition to the contents of survey data. In this study, the afflicted proof is considered to be the evidence of building damage, by which the buildings belong to the afflicted data and taxation roll data are only considered to be the damaged buildings in the analysis. The afflicted data is available in the shape file format for GIS while the taxation roll data is available only in Excel format. Thus these data were integrated based on the survey number, using a table combination function in GIS.

3. BUILDING DAMAGE ANALYSYS

As the preparation for the analysis, all the records in the survey data were converted from the property level to the building level based on building number. Through this step, the number of buildings in the dataset became 62,043 while that of property is 86,157. In this study, a damage analysis is performed for the building level.

3.1 Categories of Damaged Building and Investigation of Damage Ratio

First, all the damaged buildings were categorized by their use and building type. The number of damaged residential buildings (houses) is 22,714, and that is about 70% of all the residential buildings in the city. The number of damaged non-residential buildings is 11,998, and that is about 40% of all. In the damaged residential buildings, the number of apartment buildings is considered to be only few or none. About 70% of damaged non residence is categorized as an annex building, such as warehouse, storage room, etc. The reason why the ratio of these annex buildings is high is concluded that these buildings only meet the standard as a "simple" building.

To assess the building damage, the detailed information of buildings, such as structural material and construction period, is very important. As mentioned above, the details of damaged buildings are mainly available for

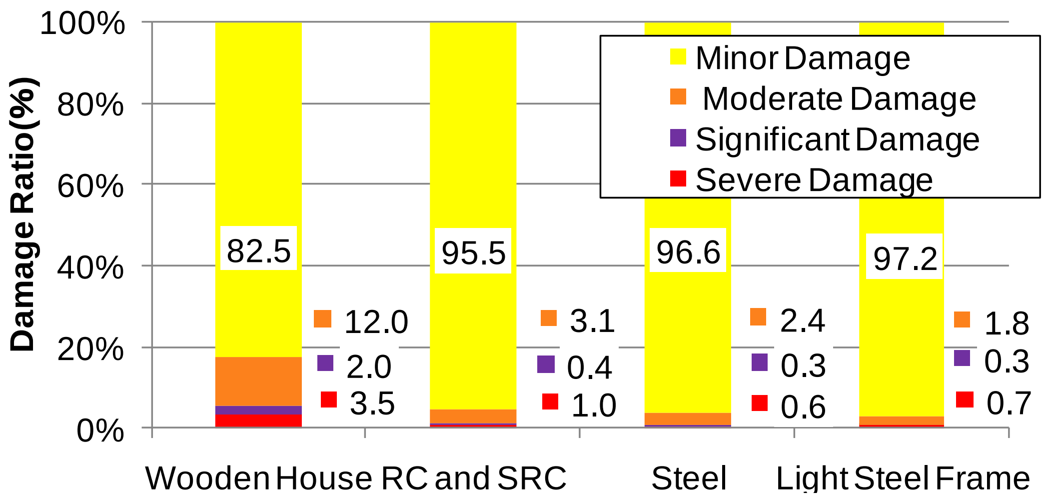
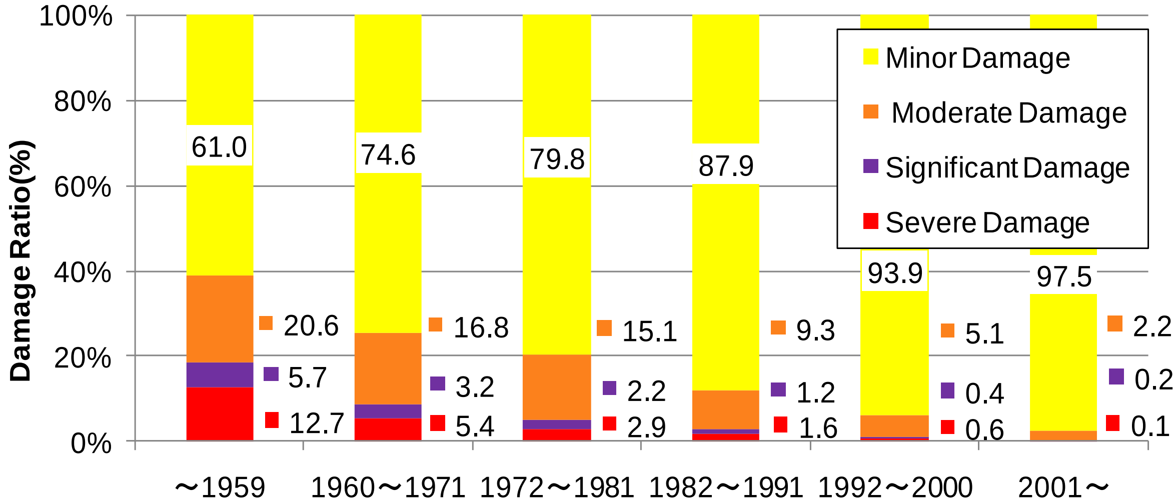
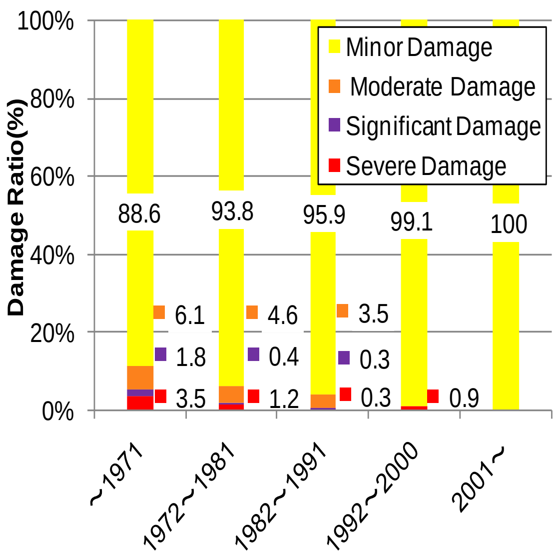


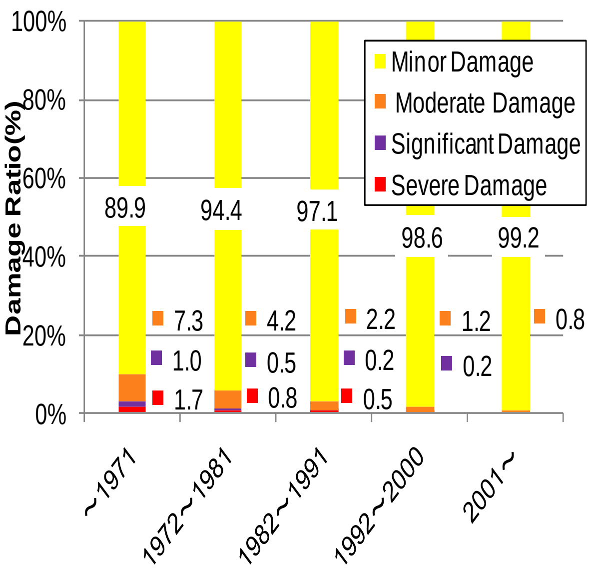
Figure-1 Damage ratio from structural materials



(a)



(b)



(c)

Figure-2 Damage ratio due to construction period (a) wooden house (b) RC and SRC (c) steel moderate damage to severe damage buildings. Therefore the buildings without any damage and with less than moderate damage are integrated into one classification as “minor or no damage”.

Figure 1 shows the variation of damage ratios of buildings depending on structural materials such as wooden, reinforced concrete (RC) and steel framed reinforced concrete (SRC), steel, and light steel frame structure. In this study, the wooden buildings are dealt with only houses (residential purpose). The other materials are dealt with all buildings' use, to ensure the parameters of these materials. It is observed that wooden houses showed higher damage ratios than any other structural materials throughout all the damage classifications except minor damage. For example, it is about 18% of wooden houses for damages classifications more than moderate damage, but it becomes less than 5% for other materials. This trend is similar to that in the cities of Kobe and Nisinomiya after the Kobe earthquake (Murao and Yamazaki, 1999; Yamaguchi and Yamazaki, 2000).

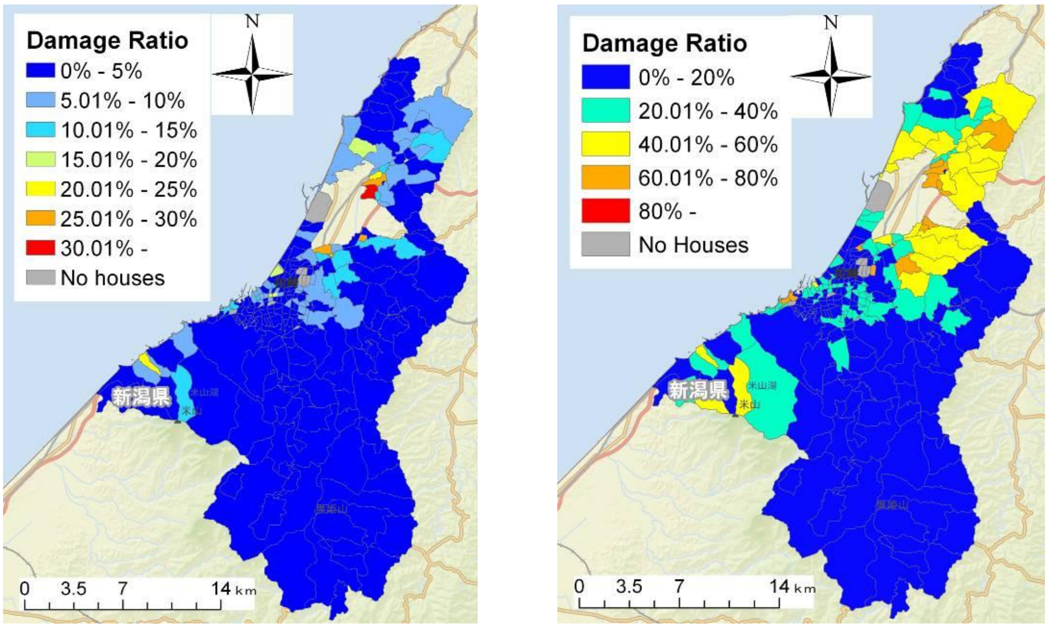
The damage ratios of buildings were further investigated in terms of construction period, in addition to structural materials. Variation of damage ratios with construction period were calculated about the building damaged more than moderate damage. In this study, construction period is divided into seven groups such as “-1959”, “1960-1971”, “1972-1981”, “1982-1991”, “1992-2000”, and “2001-” according to the revised years of the building seismic code in Japan. For RC and SRC, steel structures, damage data before 1971 were integrated into one group as "-1971" since those numbers were limited. No clear data for construction period were divided into the other period groups based on the data proportion of each construction period. Figure-2(a) shows variations of damage ratios depending on the construction periods for wooden houses. It is noted that the damage ratio becomes higher as the construction period becomes older for all damage classes (except minor or no damage). Figure-2(b) and (c) show variation of damage ratios against construction period for RC and SRC, and steel structures, respectively. These figures show the similar trends observed for wooden houses, which is consistent to the damage observations in the Kobe earthquake.

It is generally integrated into one period group after 1982, when the latest seismic standard was issued, for the damage estimation against scenario earthquakes. However, as shown in Figure-2(a), there is a significant difference in the damage ratio especially of wooden houses after 1982, which indicates the importance of aging effect that is not considered in the current damage estimation. Of course, it should be kept in mind that the reasons of these differences in damage ratio are not only aging, but also the minor changes of the seismic standard. At any rate, the division of construction period is needed to reconsider.

3.2 Building Damage Distribution

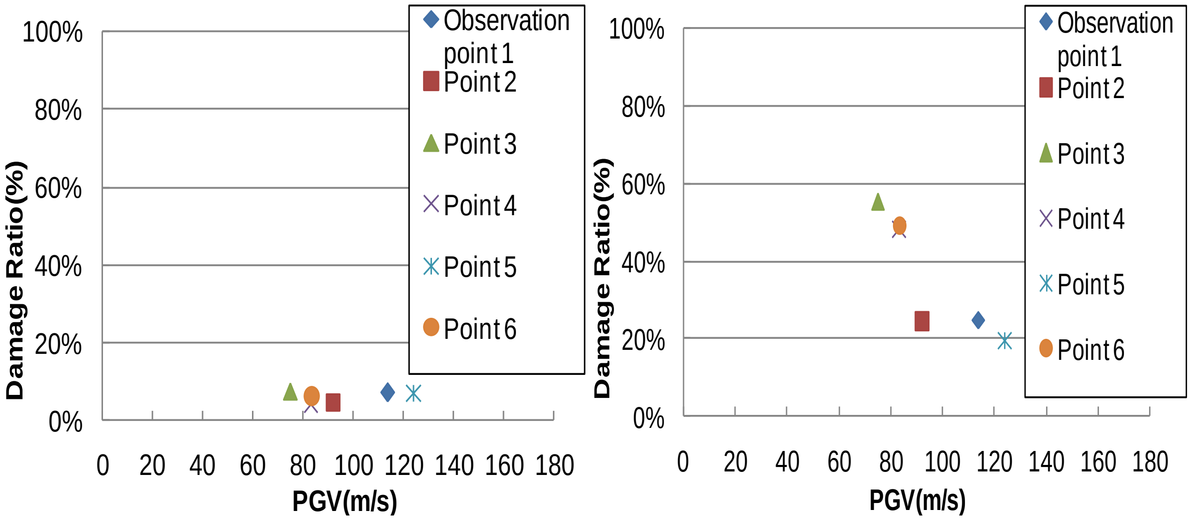
To understand the spatial distribution of damaged buildings, a further study was performed using GIS. The geographical feature of Kashiwazaki city is surrounded by hills on three sides, and looks out on the Sea of Japan to northwest. Urban areas are located in the middle of the city, and there are very few houses in a south piedmont area. The locations of damaged buildings belong to the afflicted data and the taxation roll data were obtained on the digital map from the Statistics Bureau of Japan, and distributed over 264 city blocks in Kashiwazaki city. Therefore, the damage ratio was calculated for each city block. It is noted that the afflicted data and taxation roll data only documented the building damages greater than moderate damage class. In this analysis, the wooden houses were mainly investigated, because the other materials were shortage of their parameters. Figure-3(a) shows the distribution of the severe damage ratio for wooden houses. A blank area in the north is Kariwa village, where nuclear power plant exists and is independent from Kashiwazaki city. There are some blocks showing high damage ratios in the north and west areas of the city. Most of the blocks in the south area showed the damage ratio less than 5%. Figure-3(b) shows that of equal to or more than moderate damage, and this distribution is almost same as the study by Furuya et al. (2008). Similar as the severe damage ratio, most of the blocks in north and west sides show high damage ratios.

These results were compared with observed seismic records in the city to understand the relationship between the damage ratio and seismic intensity. A total of 11 seismometers existed in the city at the time of the earthquake and 6 of them were selected to use in this study. 5 seismometers were difficult to correlate with the damage ratios since no many houses existed around them, or one sensor is too near from the others. The damage ratios of city blocks smaller than 350 ha and within 300 m or 500 m from the seismometers, were calculated. However if a selected city block is much larger than the circle, the farthest one is omitted and recalculated. The damage ratio calculated by the above method is compared with the recorded peak ground velocities (PGV). Figure-4(a) and (b) show the relationships between the wooden-house damage ratio of city blocks within the radius of 300 m and PGV for severe damage and equal to or more than moderate damage, respectively. In Figure-4(a), the damage ratio is almost constant for the PGV range 70 - 130 m/s. In Figure-4(b), the damage ratio becomes lower as PGV becomes higher, which is opposite to the general trend. These trends are also found in the result for city blocks within 500 m radius from a seismometer. To explain the trend in Figure-4(b), the proportion of construction period was calculated



(a) severe damage (b) equal to or more than moderate damage

Figure-3 Distribution of damage ratio of wooden houses



(a) severe damage (b) equal to or more than moderate damage

Figure-4 Relationship between the damage ratio and seismic records

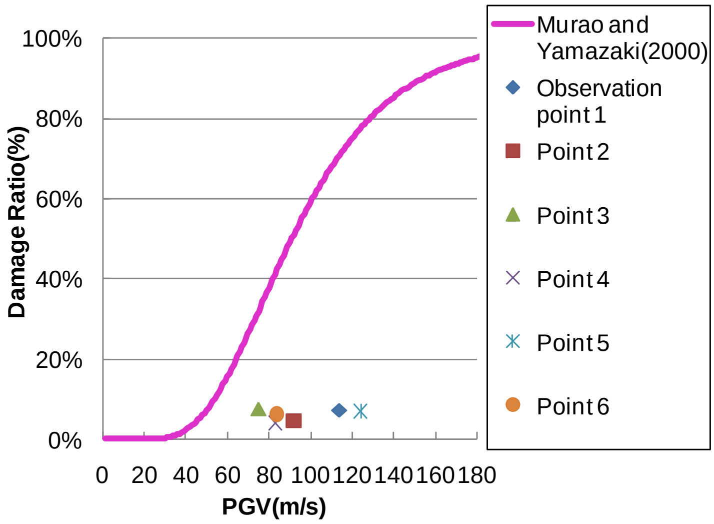


Figure-5 Comparison between the fragility function from the 1995 Kobe earthquake and the results of this study in city blocks around these seismometers. However, no notable facts were not found, the results for each observation point were similar. A further investigation for the difference of wooden houses might be necessary.

Finally the relationship between the severe damage ratio of wooden houses and PGV were compared with thr empirical fragility function from the Kobe earthquake. Figure-5 compares the relationship by Murao and Yamazaki (1999) and the result of this study. It is found that the severe damage ratios in this study are much lower than the empirical fragility from the Kobe earthquake. The difference in the damage classification method and its levels, "significant damage" exists in the damage class in the Niigata-Ken Chuetsu-Oki earthquake but does not in the Kobe earthquake data, may explain the difference to some extent. The difference in wooden structure construction between in Kobe and Kashiwazaki may be another possible reason, the structural frame and foundation were stronger in Kashiwazaki to withstand heavy snow loads of the area. A further research is necessary, however, to obtain a solid conclusion to this matter.

4. CONCLUSIONS

This paper analyzed building damages in Kashiwazaki city due to the 2007 Niigata-ken Chuetu-Oki earthquake. Firstly, the damage ratios of buildings were investigated in terms of structural materials and the construction periods, which showed the similar trends observed in the 1995 Kobe earthquake. Damage ratios of wooden houses showed significant differences depending on the construction periods, even after the latest seismic code has been issued. Therefore it is necessary to reconsider the current damage estimation models, which assume the same fragility function after the last update of the seismic code in 1981. Secondly, the distribution of the building damage ratio was studied for each city block in Kashiwasaki city, and the damage ratios near seismic stations was compared with the recorded PGV values. However, no good trend was obtained from this comparison. A further study is required to reflect the difference of construction periods which shows the significant contribution to the variation of damage ratios. Finally, the severe damage ratio for wooden houses and PGV relationship obtained here was compared with the empirical fragility curve from the Kobe earthquake, which shows the lower damage ratios in the 2007 Niigata-ken Chuetu-Oki earthquake than in the Kobe earthquake. Factors not considered in this study, e.g. regional difference of wooden house construction, must be introduced to explain this difference.

ACKNOWLEDGEMENT

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