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DAMAGE SURVEY OF THE WOODEN HOUSES DURING THE 1997 KAGOSHIMAKEN-HOKUSEIBU EARTHQUAKE

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SUMMARY

The 1997 Kagoshimaken-Hokuseibu Earthquake caused severe damage of wooden houses such as 70 major damage houses and 7328 slightly damage houses in Kagoshima prefecture in Japan. Analyses of wooden house damage in this earthquake is important to take lessons from an earthquake occurred in southern Kyushu for function and structure of urban safety system against earthquake disaster. I studied the cause of wooden house damage during the 1997 Kagoshimaken-Hokuseibu Earthquake based on the damage ratios of investigation sites and detailed survey of 15 major damaged houses in Miyanojo town and Turuda town in Kagoshima prefecture. Relationship between the damage ratios of wooden houses and distance from an estimated fault to investigation sites shows that the damage ratios are greater than or equal to 30 percent along the estimated fault, greater than 50 percent near the east side edge of the estimated fault and smaller than 20 percent in another area. In Yuda district, the damage ratios classified by geomorphic type are greater than 60 percent on *Shirasu*(volcanic sandy soil distributed extensively in southern Kyushu) plateau, from 30 percent to 55 percent on sandy and gravelly plateau and smaller than 10 percent on valley plain. These results have indicated that distance from sites to a fault and site amplification on *Shirasu* plateau must to be considered for earthquake disaster prevention in southern Kyushu.

INTRODUCTION

The 1995 Hyogoken-Nanbu Earthquake made the dead person who exceeded 6400 and more than two thirds of them were caused by pressure which was due to collapse of the wooden houses [1]. As wooden houses account for the great part of dwellings in Japan, it is important to make clear factors of earthquake damages of the wooden houses and to improve the seismic capacity of the wooden houses to decrease such an earthquake disaster.

It is necessary to collect and to analyze the strong earthquake motion records which were observed around damaged buildings, the data about the structure of the damaged buildings and the ground condition around them.

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Seismometers of JMA were being arranged in the whole country after the 1995 Hyogoken-Nanbu Earthquake, and the 1997 Kagoshimaken-Hokuseibu Earthquake is the first earthquake which caused severe damage of buildings after that. Though the valuable strong earthquake motion records are obtained near the epicenter, but the detailed investigation of damaged wooden houses and the analyses of damage factors which is enough to contribute to the earthquake disaster prevention are not done.
According to damage survey of recent major earthquake, it is well known that the damage of wooden houses is influenced by the structure of buildings, characteristic of topography [2] and the location of an earthquake fault [3]. However, the structure of wooden houses is influenced by regional construction method and characteristic of topography is seemed to vary from place to place. More research regarding relationship among them is required for earthquake disaster prevention.
This study is to investigate damaged wooden houses and to analyze the damage factors due to the 1997 Kagoshimaken-Hokuseibu Earthquake from the viewpoint of structure of wooden houses, topography and location of an earthquake fault.

OVERVIEW OF THE 1997 KAGOSHIMAKEN-HOKUSEIBU EARTHQUAKE AND SURVEY AREA

An earthquake of magnitude M=6.5(JMA scale) occurred on March 26, 1997 and an earthquake of magnitude M=6.3(JMA scale) on May 13, 1997 in northwest Kagoshima Prefecture in Japan. The seismic intensities of each town around focuses were upper 5 with Sendai, Akune and Miyanojo on March 26, and were lower 6 with Sendai, upper 5 with Miyanojo and lower 5 with Akune on May 13.
Though faults of these two earthquakes did not appear on the surface of ground, they are estimated that it would be the left strike-slip fault of WNW-ESE direction about 17 km long on March 26, and the left strike-slip fault of WNW-ESE direction about 10 km long and right strke-slip fault of NNE-SSW direction about 10 km long which are to be L character type on May 13th [4]. The distribution of aftershock of these earthquakes is shown by dashed lines in Figure 1. The faults are located in the neighborhood of the center in each aftershock distribution.
As the neighborhood of the epicenters was an upland and there are few houses, there were no damage of buildings around epicenters. The damage of buildings were severe in Izumi City, Akune City, Sendai City Togo town, Miyanojo town and Tsuruda town, and the most of damaged buildings were wooden houses.
As for wooden house damage, the number of total collapsed houses and partial collapsed houses were smaller than 1% of damaged wooden houses, and most of wooden house damage were slight damage of the roofs, walls finishing materials and so on.
The number of damaged wooden houses in Kagoshima Prefecture was 8 total collapse, 62 partial collapse and 7328 slight damage. On the other hand, the damage of reinforced concrete schoolhouses around Miyanojo town and Tsuruda town is 1 collapse, 3 severe damage and 6 moderate damage in the earthquake on March 26, and 3 collapse, 5 severe damage and 5 moderate damage in the earthquake on May 13. It was in Miyanojo town and Tsuruda town, where is located in the east side of the epicenter, that the damage of the wooden houses was especially severe. Therefore, in this research, it decides to investigate the damage of the wooden houses in Miyanojo town and Tsuruda town.
The number of wooden houses of both towns and the damaged wooden houses by the total of Kagoshima Prefecture agency are shown in Table 1.
The number of damaged houses of Tsuruda town was larger than that of Miyanojo town on March 26, and the the number of damaged houses of Miyanojo town was larger than that of Turuda town on May 13.
As for the earthquake ground motion on March 26, the maximum acceleration of 491(Gal) was recorded in the N-S direction and the maximum acceleration of 663(Gal) was recorded in the E-W direction to the seismometer of JMA, which is shown with the Seismograph A in Figure 1. On the other hand, as for the earthquake ground motion on May 13, the maximum acceleration of 902(Gal) was recorded in the N-S direction and the maximum acceleration of 901(Gal) was recorded in the E-W direction to the seismometer of K-net, which is shown with the Seismograph B in Figure 1.

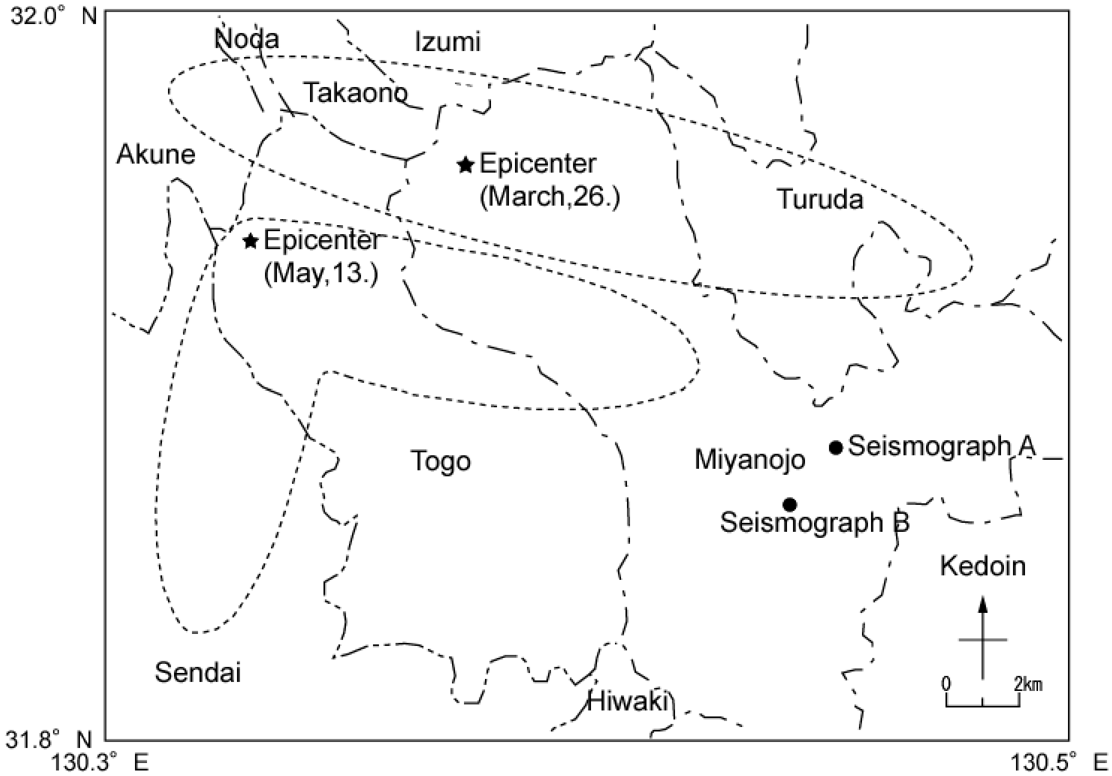

Fig. 1 Location of Epicenter and Distribution of Aftershocks

Table 1 Number of Damaged Houses

Town	Miyanojo		Turuda	
Date	March,26	May,13	March,26	May,13
Collapse	0	2	2	0
Partial Collapse	0	11	12	4
Slightly Damage	433	1389	1001	480

INVESTIGATION OF DAMAGED WOODEN HOUSES

The method of investigation of damaged wooden houses

Two types of house can be seen in Miyanojo town and Tsuruda town. One is a farmhouse with few bearing wall and boulder foundation by traditional construction method. The other is a exclusively residential dwelling with bearing walls and continuous footing by conventional construction method. The building construction of houses mainly depends on their construction year. The construction year of the farmhouse are older than that of the exclusively residential dwellings.

Though there were 14 total collapse and partial collapse houses in Miyanojo town and 17 total collapse and partial collapse houses in Tsuruda town, I investigated 6 houses in Miyanojo town and 9 houses in Tsuruda town which were obviously collapsed by the vibration of earthquake ground motion according to the method of seismic diagnosis of wooden house [5].

The investigation items are (1) extent of the damage, (2) kind of roof, (3) type of soil, (4) kind of footing, (5) construction year and degree of deterioration, (6) wall quantity and (7) modulus of eccentricity. The items from (1) to (5) are investigated by the hearing from the house owner and the checking external appearance of the house, and items (6) and (7) are evaluated by analyzing their plans. However, though

the earthquake resisting elements inside the walls could not be investigated, stiffness of a bearing wall is treated to be in proportion to its length.
The period of investigation was from September to November in 1999.

The seismic capacity of partial collapsed wooden houses

Eight of fifteen total collapse and partial collapse houses are old farmhouses. In this paper, these farmhouses are not excluded from the object of the analysis because it is difficult to evaluate their seismic capacity in the present situation where the seismic diagnosis for these old houses are not established.

As for the damage of seven exclusively residential dwellings, most of them had severe fall and slip of the tiles, cracks of paneling board on the interior walls and delaminations of finish on the external walls, and some had the pulling-out or the breakage of joints.

To estimate seismic capacity of damaged houses, their wall quantity and modulus of eccentricity were compared with those of 88 non-damaged or slightly damaged houses which had been constructed from 1994 to 1996 by conventional method of construction.

The distribution of wall quantity ratio is shown in Figure 2. Here the term 'wall quantity ratio' is used to show the ratio of wall quantity to necessary wall quantity under the Building Standard Law in Japan.

It is simply because earthquake resisting elements inside the wall such as brace were not evaluated about partial collapsed houses that the wall quantity ratio of partial collapsed houses seem to be rather small compared to non-damaged or slightly damaged houses. It seem to be quite all right to consider wall quantity ratio of partial collapsed houses is not smaller than those of non-damaged or slightly damaged houses.

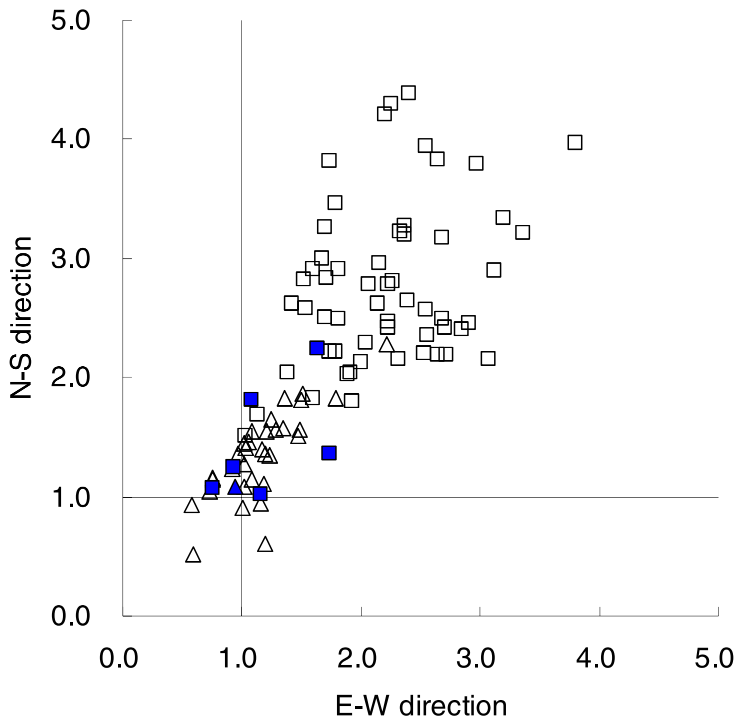

Fig. 2 Wall Quantity Ratio
closed triangle: two-storied house(partial), open triangle: two-storied house(non or slight)
closed square: one-storied house(partial), open square: one-storied house(non or slight)

The distribution of modulus of eccentricity is shown in Figure 3.
Though modulus of eccentricity of four of seven partial collapsed houses is greater than 0.15 which is the lower limit value to enforce buildings to increase their wall quantity prescribed by The Building Standard Law, that of some non-damaged or slightly damaged houses exceed 0.15.
These results suggest the lack of wall quantity and the exceeding of modulus of eccentricity are not main factor of partial collapse damage.

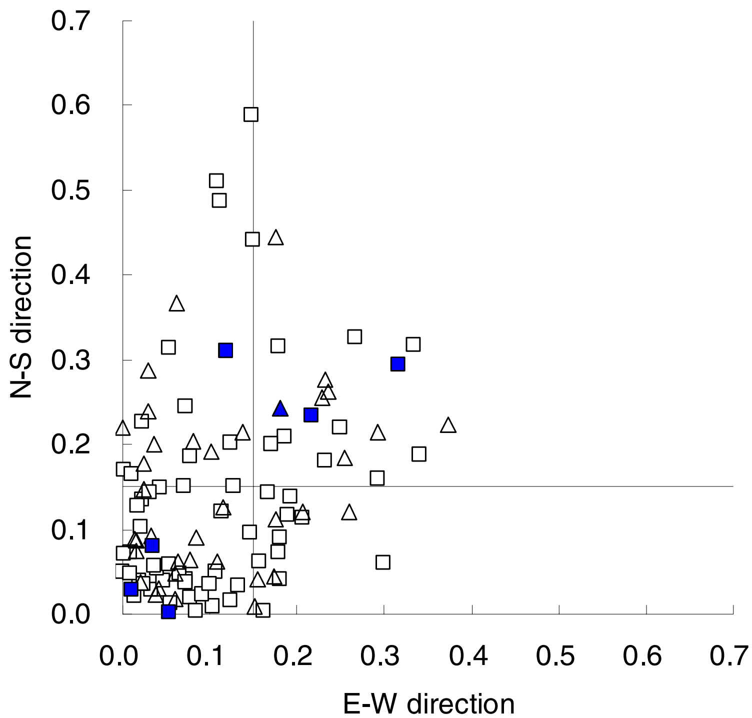

Fig. 3 Modulus of Eccentricity
closed triangle: two-storied house(partial), open triangle: two-storied house(non or slight)
closed square: one-storied house(partial), open square: one-storied house(non or slight)

DISTRIBUTION OF WOODEN HOUSE DAMAGE

Figure 4 and Figure 5 show the distribution of damage ratio of wooden houses by a subsection of a village. 99% of total number of damaged wooden houses were partial damage.
The damage ratio of wooden houses by a subsection of a village is defined as the number of damaged wooden houses divided by the number of houses in a subsection of a village. The number of damaged wooden houses is based on the earthquake damage data collected in each town.
Though the total number of damage houses in Turuda town is due to two earthquakes, most of them were caused by an earthquake on Mach 26(See Table 1). So the damage ratio of Turuda town on March 26 is excluded from the Figure 5.
Some areas where the damage ratios of wooden house are comparative high can be seen along the estimated faults, and the others where the damage ratios of wooden house are greater than or equal to 50% can be seen near the east side edge of estimated faults.
However, damage ratios of wooden houses are not similar everywhere in the areas. It indicates that the distribution and damage degree of wooden houses are concerned with the factors such as the relationship among the location of estimated fault, the location of a subsection of a village and the effect of topography on surface ground.

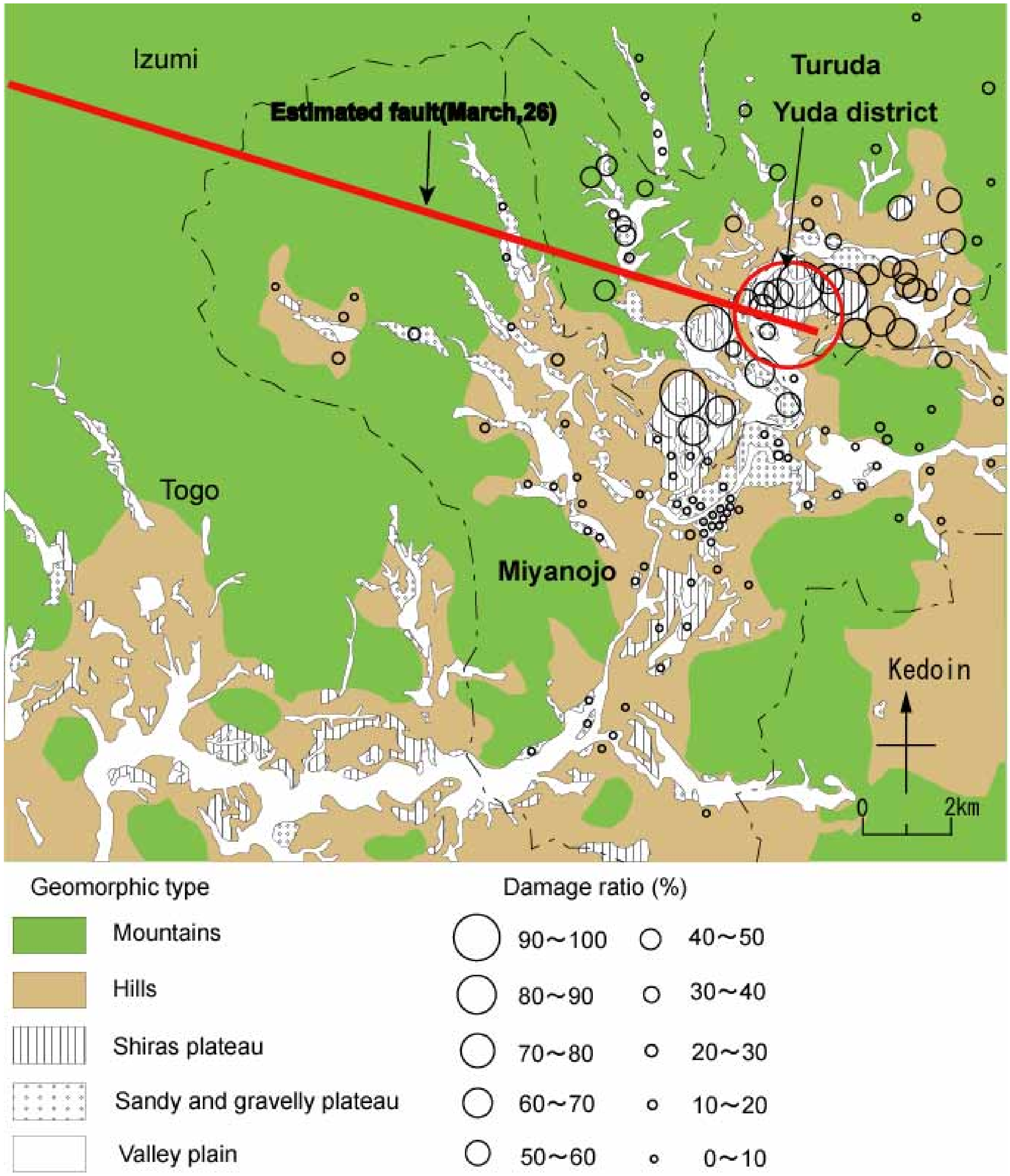

Fig. 4 Distribution of Wooden House Damage on March 26

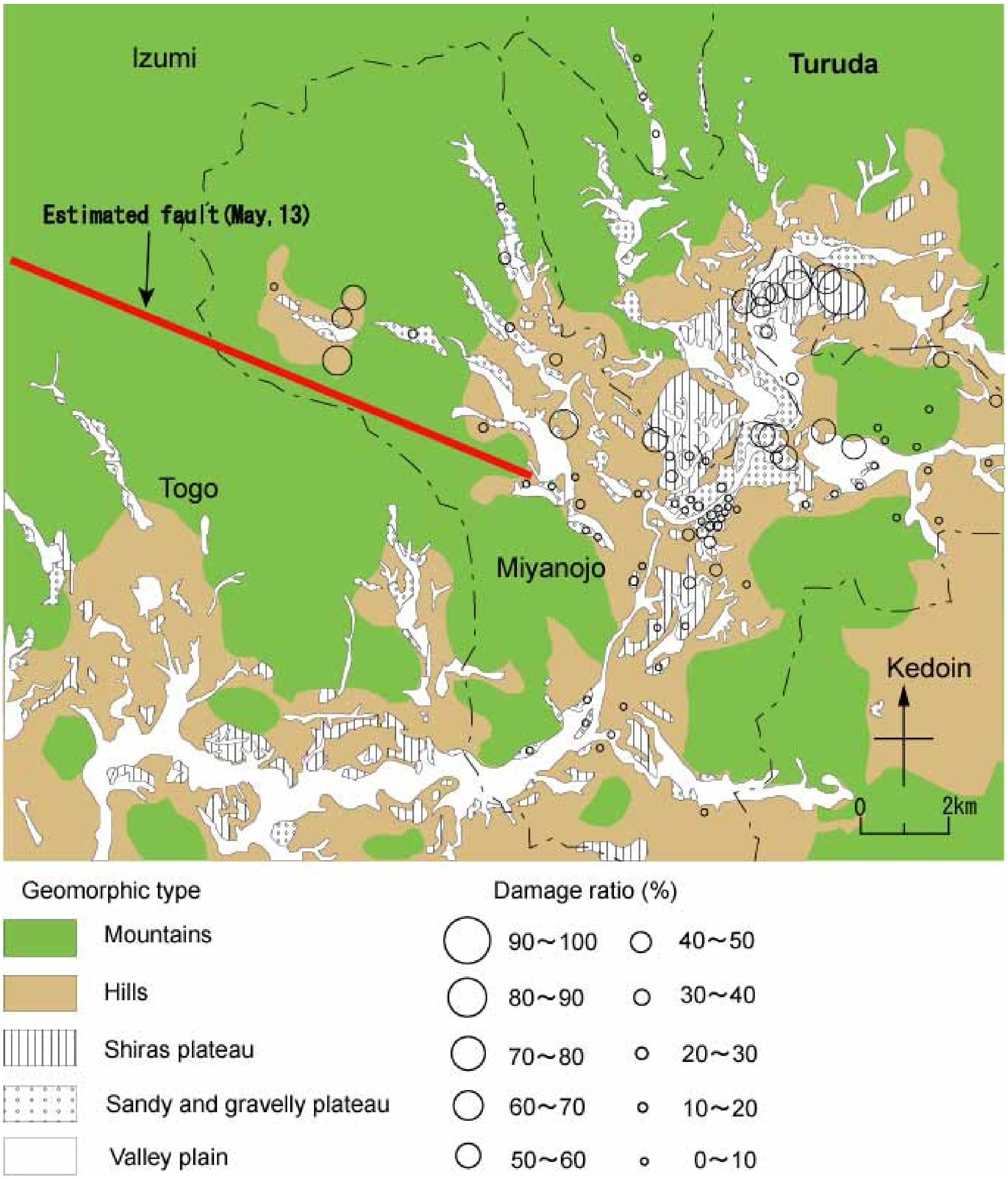

Fig. 5 Distribution of Wooden House Damage on May 13

RELATIONSHIP AMONG WOODEN HOUSE DAMAGE, LOCATION OF ESTIMATED FAULT AND GEOMORPHIC TYPE

The relationship between damage ratios classified by geomorphic type and distance from the estimated fault are shown in Figure 6 and Figure 7. Here, the distance from the estimated fault was depicted as a distance from an estimated fault to the center of a subsection of a village.
Subsections of a village on every geomorphic type where the damage ratio is greater than or equal to 30 % are located along Dx-axis on March 26 and are located within 6km from the estimated fault along Dx-axis on May 13. This indicates that the distribution of damaged wooden houses is influenced by the distance from an earthquake fault.

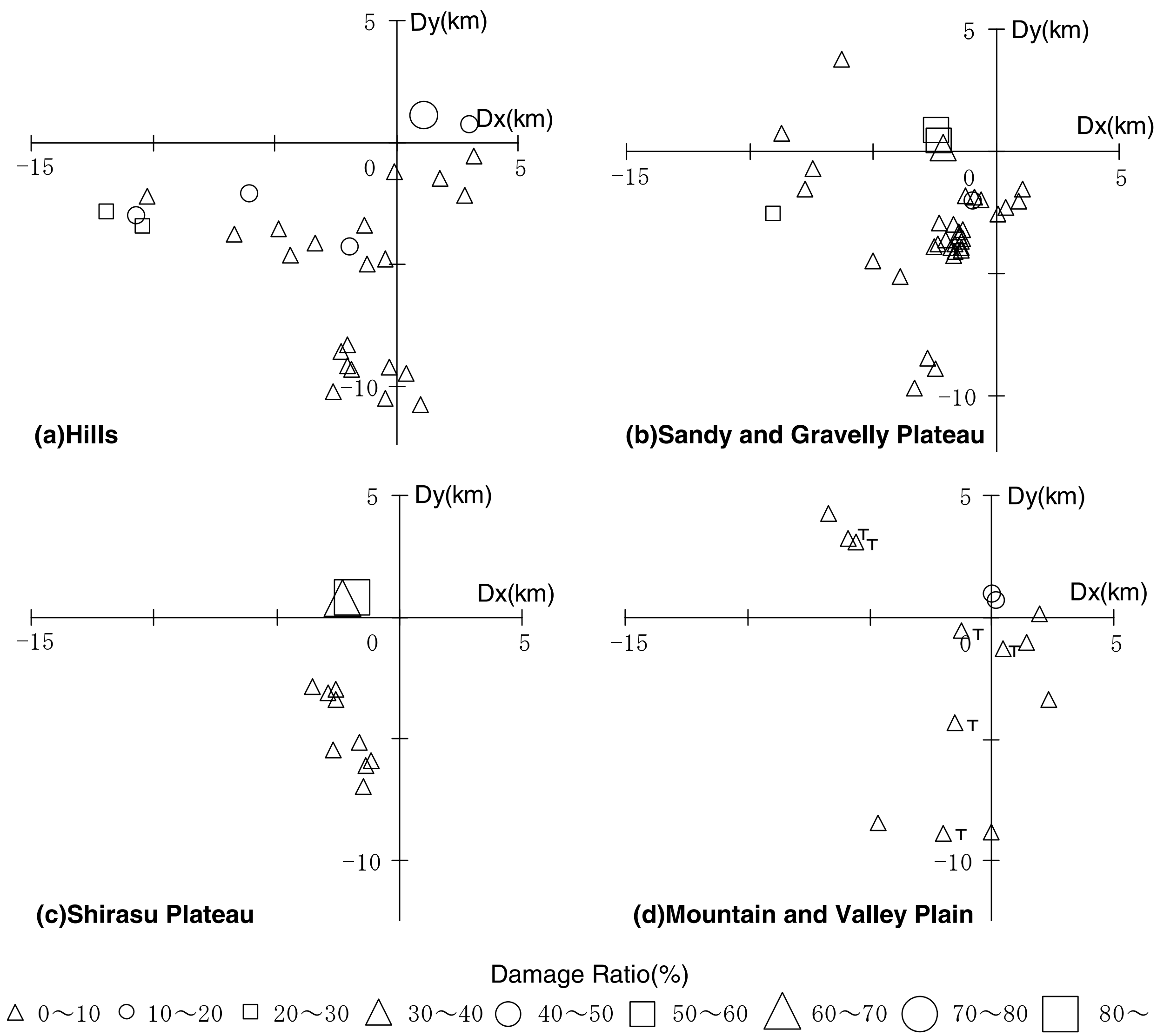

Fig. 6 Damaged Ratio Classified by Geomorphic Types on March 26
origin of coordinate: east side edge of estimated fault, Dx-axis: WNW-ESE direction, Dy-axis: NNE-SSW direction, open triangle with T: Mountain

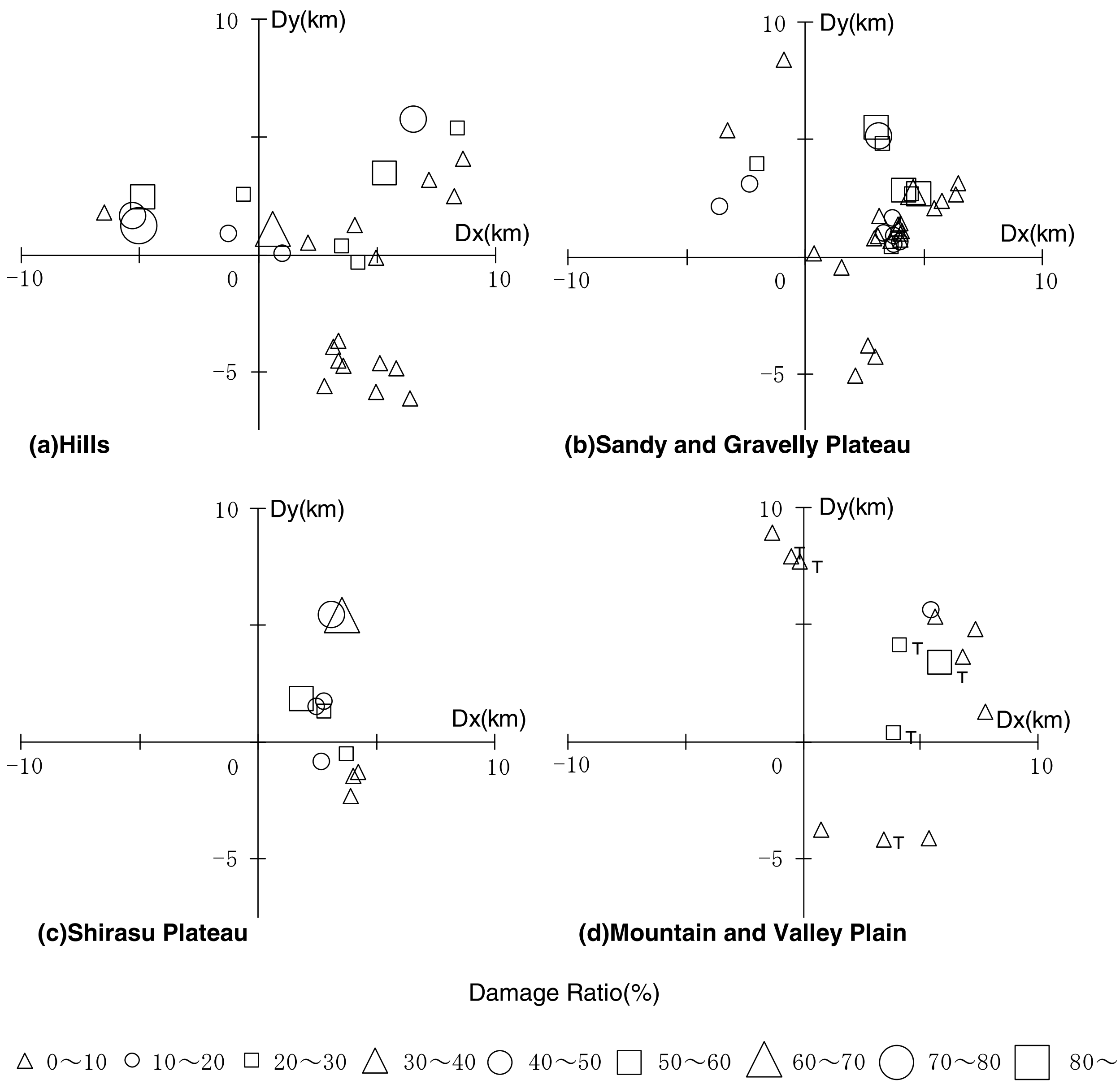

Fig. 7 Damaged Ratio Classified by Geomorphic Types on May 13
origin of coordinate: east side edge of estimated fault, Dx-axis: WNW-ESE direction, Dy-axis: NNE-SSW direction, open triangle with T: Mountain

Subsections of a village where the damage ratio is greater than or equal to 50 % are located parallel to Dx-axis or Dy-axis near the east side edge of estimated faults. Though this indicates existence of asperities in a shallow part of the east side edge of each fault, however, no existence of asperities are recognized in the result of source modeling of these two earthquakes using Emprical Green's function method [6].

In the case distances among subsections of a village exceeds about 1km, there are some cases where damage ratio become locally high or low on the same kinds of geomorphic type even if their distances from the estimated fault are similar. For example, in the area around the origin of coordinate on the hills and in the area where Dx and Dy satisfy 4<Dx<7 and 2<Dy<3 on the gravel plateau on May 26, some damage ratios became locally high or low. If the difference among seismic capacity of these damaged houses is regarded not to be a main factor of damage, these cases are believed to be due to site effects influenced by the geomorphic types, the scale of which is smaller than that of the geomorphic types in Figure 4 and Figure 5.

As for the damage ratio classified by geomorphic types, it is not clear whether the damage ratio of wooden houses has a connection with geomorphic type. Because there are insufficient areas which consist of some subsections on the different kinds of geomorphic type and where distances from the estimated fault to the subsections are similar.

However, in Yuda district(See Figure 4), where Dx and Dy satisfy $-3<Dx<-2$ and $0<Dy<1$ in Figure 6 and satisfy $3<Dx<4$ and $5<Dy<6$ in Figure 7, the difference among damage ratios classified by geomorphic type can be seen remarkably. The damage ratios are greater than or equal to 60% on *Shirasu* plateau, from 30 to 60 % on sandy and gravelly plateau and smaller than 10% on valley plain.

CONCLUSION

The objective of the study was to investigate the damaged houses and to analyze the damage factor from the viewpoint of relationship among structure of damaged wooden houses, geomorphic type and location of estimated fault. In conclusion, the following four points are obtained. 1) There were no remarkable difference of wall quantity ratio and modulus of eccentricity between partial collapsed houses and non-damaged or slightly damaged houses. The lack of wall quantity and the exceeding of modulus of eccentricity do not seem to be main factor of the partial collapse damage. 2) Comparative high damage ratio could be seen along the estimated faults and near the east side edge of them on every geomorphic type. The extent of damage ratio of wooden houses is influenced by the distance from the fault to the site. 3) Since the sample was very small, a conclusion about the relationship between the damage ratio of wooden houses and geomorphic type could not be drawn. However, the damage ratio of wooden houses were higher on *Shirasu* plateau than on sandy and gravelly plateau and on valley plain in Yuda district. It is necessary to consider site amplification on *Shirasu* plateau for earthquake disaster prevention in southern Kyushu. 4) There were some case where damage ratio of subsection became high or low in locally in a area on the same geomorphic type even if distances from the estimated fault was similar. It is believed to be due to site effects influenced by smaller geomorphic types.

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