The 2007 Noto Peninsula, Japan Earthquake (M_w6.7): Damage to Wooden Structures

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Introduction

The 2007 Noto Peninsula earthquake (M_w 6.7, M_{jma} 6.9) produced strong shaking throughout central Japan with severe damage to over 600 buildings. The shallow event occurred close to the Japan Sea coast (37.22°N, 136.69°E, depth 11 km) on March 25, 2007 at 00:41:58 GMT. Analyses of seismic data showed that it was a thrust fault (striking northeast and dipping downward to the southeast) with dimensions of about 15 x 30 km² (Figure 1) (Aoi and Sekiguchi, 2007). There was no significant surface faulting from the earthquake but Global Positioning System (GPS) measurements showed surface displacements of 20 to 25 cm (Geographical Survey Institute, 2007). The recent seismicity of the Noto Peninsula region has been relatively low, and has included moderate events in 1933 (M_{jma} 6.0) and 1993 (M_{jma} 6.6). For the latest earthquake, there were significant strong ground motions throughout the Noto Peninsula (Figure 1), with maximum recorded ground velocities of 80 to 100 cm/sec. Although the region is a relatively sparsely populated area of Japan, there was considerable damage to wooden structures, which is the predominant type of construction. There were 630 totally and 13920 partially collapsed buildings, with concentrations of damage in Monzen and Anamizu, with lesser damage in downtown Wajima city (Cabinet Office, Government of Japan, 2007a). The cost of the total damage is estimated to be 65 billion yen (about $US 535 million) (Cabinet Office, Government of Japan, 2007b). Despite the large number of severely damaged houses, there was only 1 fatality (not related to a building collapse) and 336 injured persons.

As has been done for several recent earthquakes in Japan, detailed surveys of building damage were quickly carried out by several groups. This paper presents some statistical results of damage to wooden structures for the Noto Peninsula earthquake, which characterizes the fragility of this region of rural Japan to strong shaking. The damage statistics are somewhat different to the results for other earthquakes, and probably reflects the difference in regional construction practices.

Strong ground motions for the 2007 Noto Peninsula earthquake

The 2007 Noto Peninsula earthquake was recorded by many strong motion stations. Figure 1 shows the distribution of horizontal peak ground velocity, PGV (the larger amplitude of the two horizontal components). The PGV values exceeding 90 cm/s at Anamizu and Wajima are due to soft soil amplification.

The closest station to the fault plane at Monzen had severe shaking with a peak ground acceleration (PGA) of 1304 cm/s^2 (vector sum of three components) and a Japan Meteorological Agency (JMA) Seismic Intensity (I_{jma}) 6 upper (6.4). Since the waveforms at the JMA station in Monzen are not available, we estimated the peak ground velocity from the empirical relationship of ground motion (Fujimoto and Midorikawa, 2005):

$$I_{jma} = 1.291 + 1.017 \log_{10}(PGA*PGV) \pm 0.2 \tag{1}$$

From this relationship, the PGV at the station is estimated to be about 81 cm/s. Note that this function has a large variance, and this value could be an underestimate of the real PGV. Estimates from the attenuation relationship and observations of overturned tombstones give higher values.

Historical background in Monzen

Monzen is a small town on the west coast of the Noto peninsula, built around a historical Buddhist temple, Souji-ji. Due to its geolographical location, the town flourished as a trading port between northern and western Japan during the Edo era (17th to 19th century).

The typical houses in Monzen are constructed in a traditional style, consisting of column and beam structures with mud plaster walls (Figure 2). The roof is covered by Japanese tiles. Along with the long history of the town, most houses have an average age of 40~50 years, and some are more than 100 years old. People continually use these old buildings with occasional expansions and repairs. A special structural feature in this area is wooden boards nailed on the wall (Figure 2). The boards protect the mud plaster wall from the strong sea breeze, and improve the seismic performance of the houses.

Damage survey of wooden structures in Monzen

On April 6th and 7th, two weeks after the event, we carried out a damage survey for over 660 wooden structures in the severely damaged Hashiride and Touge districts in Monzen.

The damage survey included photos and damage classification for all wooden structures, as   could be recognized from outside inspection. The target structures were all kinds of wooden structures, including a houses, stores, and storage buildings. We classified buildings into three categories; no damage (Rank A), minor damage (Rank B), and severe damage (Rank C). Rank B is damage which does not affect the main structural members, but includes cracks in walls, crumbling of walls, and missing roof tiles. Rank C has damage to the structural components. For Rank C buildings   repair is difficult and the structure will likely be demolished. This category includes the following types of damage; a) visible tilts of the columns (Figure 3), b) total collapse of a story (Figure 4), and c) buildings which were already cleared at the time of the survey (Okada and Takai, 1999). The results of the damage survey are shown in Table 1.

In Hashiride, the damage ratio is almost same across the different locations, and the occurrence of Rank C damage is about 20~30% of all wooden structures (Figure 5(a)). Hashiride includes a business district in sections Hb and Hc, and many stores were severely damaged due to the large open spaces on the first floor. In Touge, the occurrence of Rank C damage is 10 to 52%, depending on the location. The hill side area (section Ta in Figure 5(b)) has less damage whereas the area close to a river has larger damage (section Tb in Figure 5(b)).

Typical damage we observed were cracks in the wall, exfoliation of the wall material, fallen roof tiles, shifting of roof tiles, and displacements of columns. We have also observed many instances of termite infestations and wood decay on the structural components, especially in houses with severe damage (Figure 6). These environmental degradations critically decreased the seismic performance of the wooden structures.

Comparison with damage for other earthquakes

Figure 7 shows the relationship between damage ratio of Rank C wooden structures and PGV for several recent earthquakes in Japan. PGV values are taken from the larger horizontal component of the strong motion record. Since the strong motion network at the time of the Kobe earthquake was not as dense as these days, PGV values were estimated from damage ratio functions of 1st or 2nd story buildings (Murao

and Yamazaki, 2000). The PGV values for the 2000 Western Tottori earthquake were estimated from overturned tombstones (Hayashi, 2004). And PGV values for the Mid-Niigata earthquake were computed from observed strong motion records.

The relationship for each earthquake follows the Gaussian cumulative function (Φ):

$$\text{Damage ratio} = \Phi((\ln \text{PGV} - \lambda)/\zeta) \qquad\qquad (2)$$

where λ and ζ are the mean and standard deviation, respectively. The parameters which best fit each dataset are; $(\lambda,\zeta)=(4.51, 0.41)$ for Kobe, $(5.57, 0.81)$ for Tottori, and $(5.62, 0.73)$ for Niigata (Murao and Yamazaki, 1999).

The damage ratio for the Kobe earthquake is more than twice that of the 2000 Western Tottori and 2004 Mid-Niigata earthquakes. Our value for the Noto Peninsula earthquake is intermediate between these extremes. One reason for the large differences is that the structure style is very different depending on the region. The Niigata, Tottori, and Noto areas have heavy snowfalls in winter, so the structural performance is higher than in the Kobe area. For example, the diameter of columns in the Tottori area is 10~20 % larger compared to houses in the Kobe area (Kitahara et al., 2002). The construction style of structures critically affects the seismic performance of wooden buildings. Another reason for the difference is the maintenance conditions. For the 1995 Kobe earthquake, older buildings had significantly more damage, whereas structural damage in Tottori did not depend on the building age (Hayashi, 2004). This is because the houses in Tottori are well maintained and there were fewer cases of termite infestations and wood decay (Hayashi, 2004).

In Figure 7, the PGV of the 2007 Noto Peninsula earthquake is obtained not from a strong motion record, but the empirical relationship in equation (1). The damage ratio is the percentage of Rank C damage in section Hb, where the JMA station is located (see Figure 5(a)). The damage ratio for the 2007 Noto Peninsula earthquake is higher than that of the 2000 Western Tottori and 2004 Mid-Niigata earthquakes, and lower than the 1995 Kobe earthquake.

Our data is not sufficient to provide a concrete conclusion, but one possible interpretation is that the damage ratio for wooden structure is lower than the 1995 Kobe earthquake because the wooden structures in Noto have relatively good seismic performance typical of buildings in these regions. The existence of the wooden board covers on the exterior walls is one example, which improves the strength of the structures. However, the higher damage compared to the 2000 West Tottori and 2004

Mid-Niigata earthquakes may be due to do poorer maintenance practices. More detailed analysis is needed to evaluate the strong motions in the near-source area and seismic performance of wooden structures of the Noto region.

Acknowledgements

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Table1: Number of the surveyed wooden structures.

	Hashiride district					Touge district			
	Ha	Hb	Hc	Hd	He	Ta	Tb	Tc	Td
Rank A	4	15	15	20	18	30	8	8	6
Rank B	35	62	74	14	27	59	21	35	24
Rank C	8	23	34	17	19	10	31	25	20
total	47	100	123	51	64	99	60	68	50

Figure 1: A contour map of PGV distribution from strong motion records. The numbers are added for PGV values greater than 50 cm/s. The fault geometry for the mainshock and aftershock distribution for the week after the mainshock (M_{jma}>2.0) is also shown.
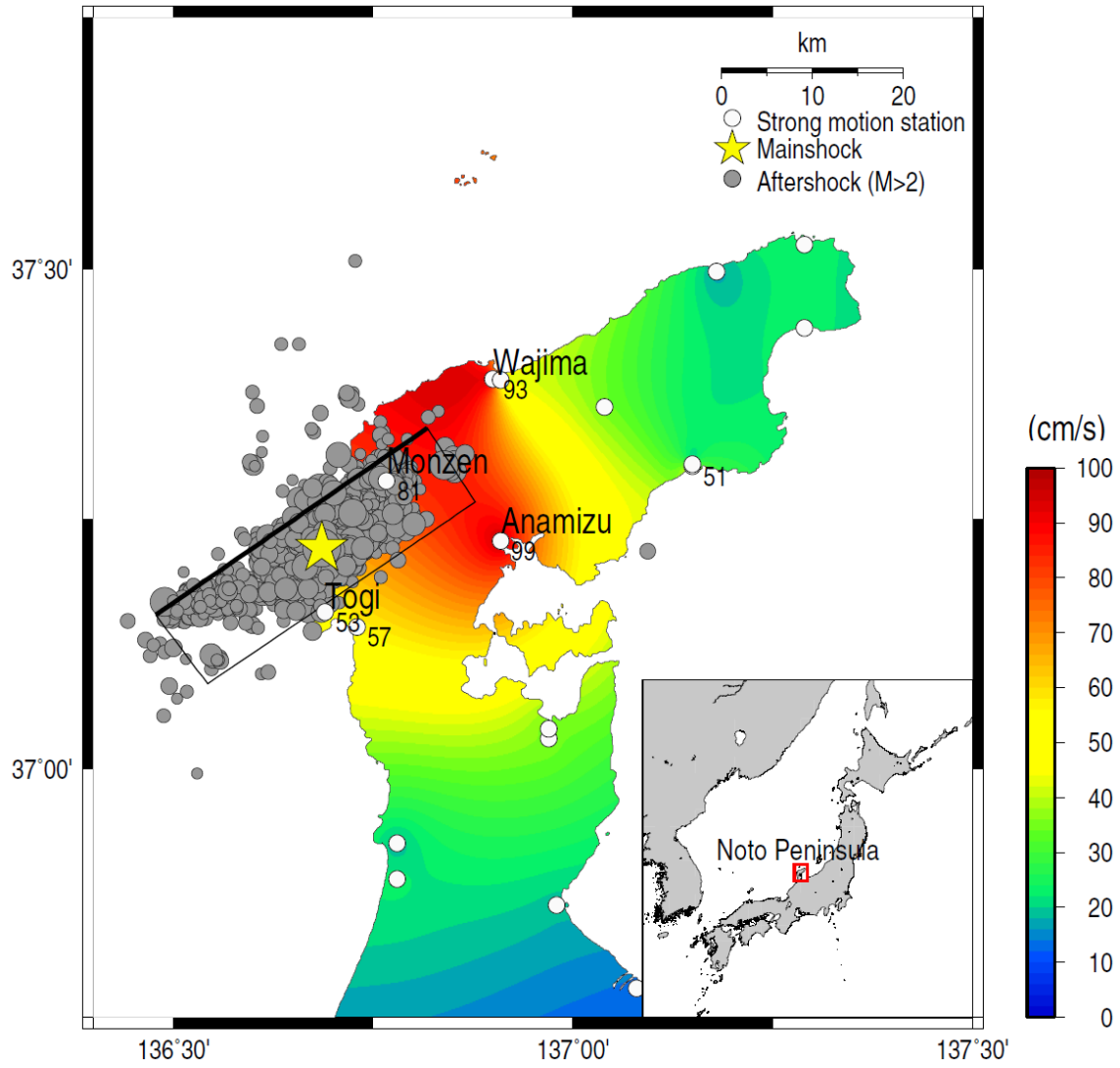
Figure 2: Typical wooden house in Noto. Houses are constructed in the traditional column and beam structure.

Figure 3: A house with severe damage on columns (Rank C). The columns are tilting forward more than 20 deg. and still standing.

Figure 4: A totally collapsed house (Rank C).

Figure 5: Areas of the damage survey (shaded areas) and the damage ratio of rank C wooden structures.
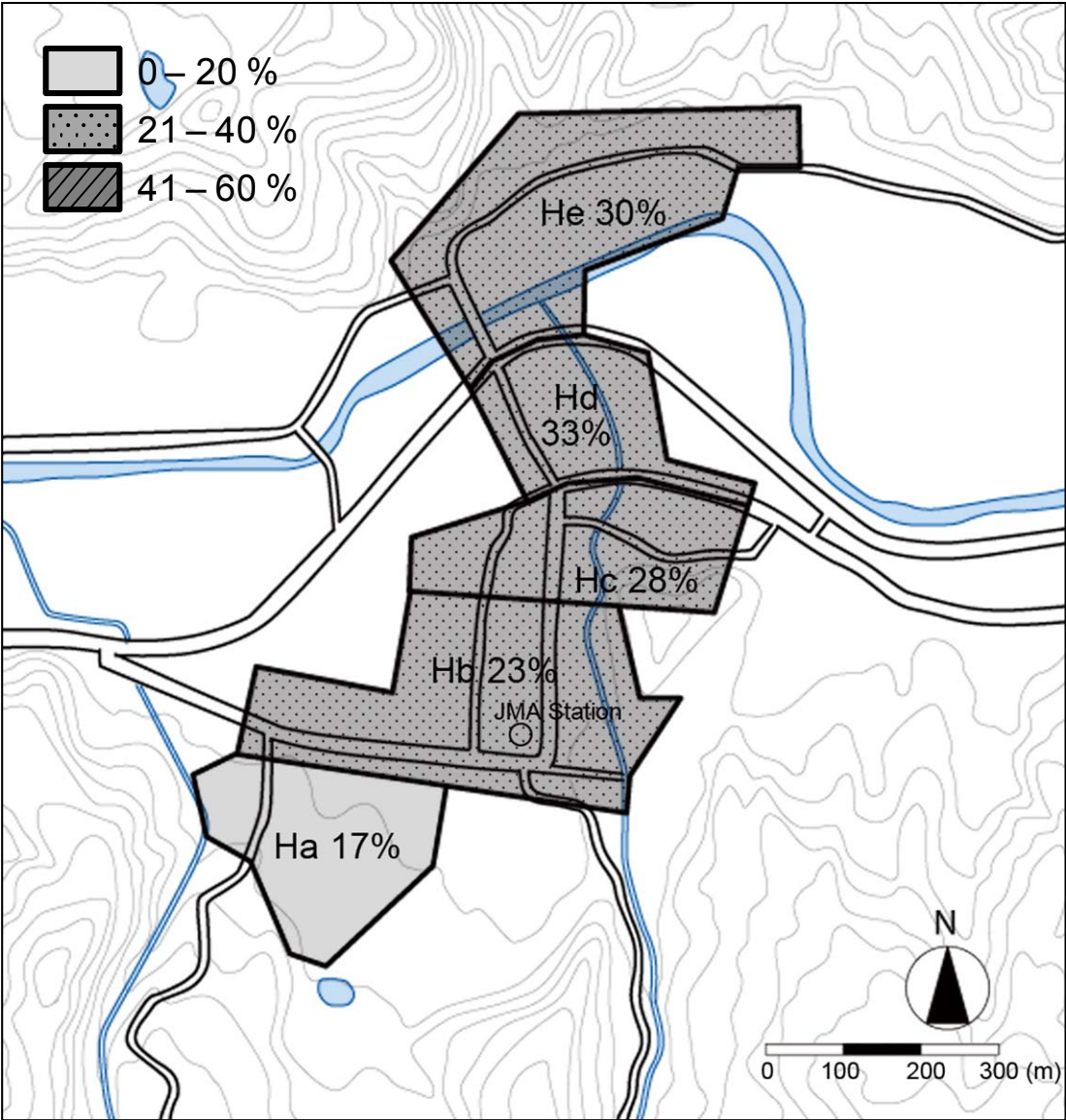
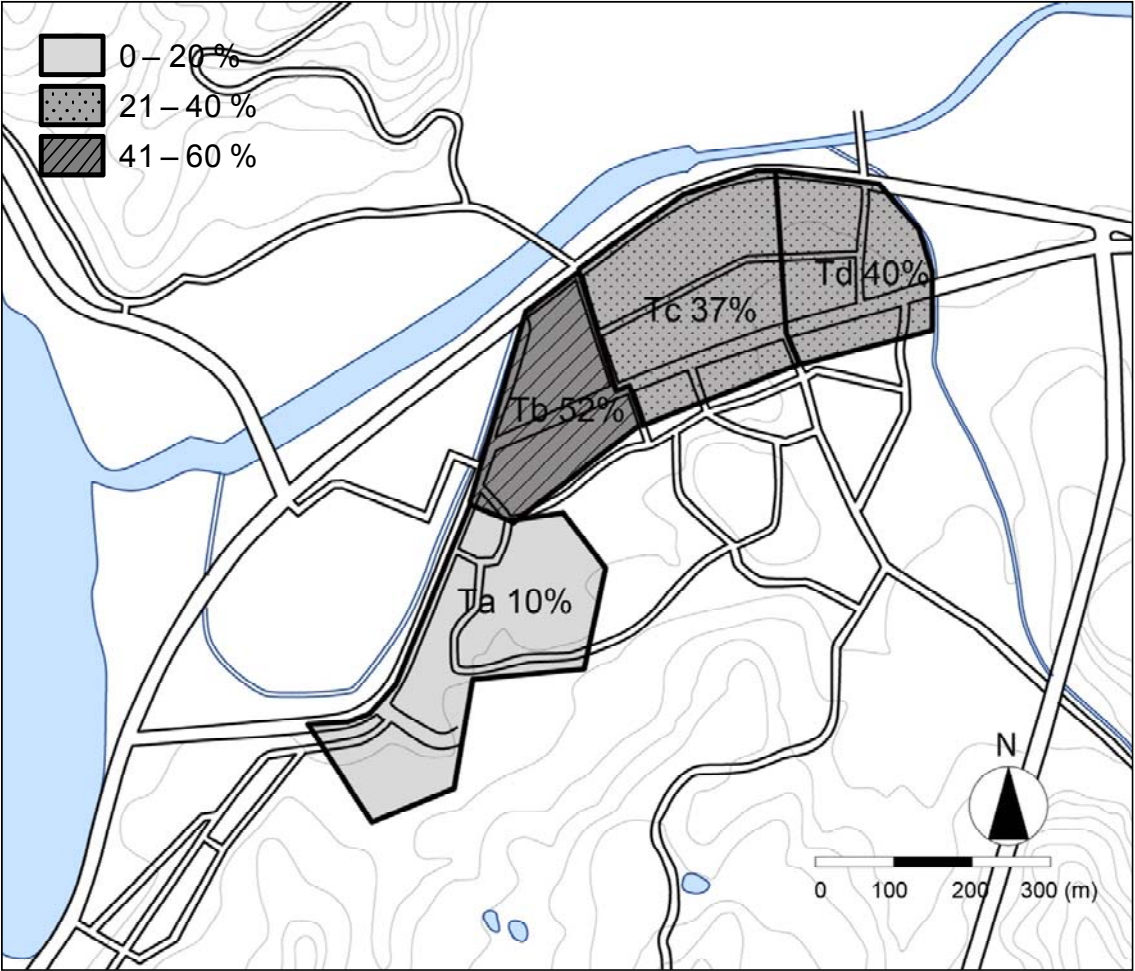(a) Hashiride district

Figure 5 (b) Touge district

Figure 6: Termite damage on columns.

Figure 7: Damage ratio of wooden houses for different earthquakes.