SEISMIC PERFORMANCE OF WOODEN HOUSES DAMAGED IN THE 2007 NOTO HANTO EARTHQUAKE AND EVALUATION OF STRUCTURAL REGIONALITY

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ABSTRACT:

This study performed a damage survey and seismic performance evaluation in the Kuroshima District, which was subjected to strong shaking during the 2007 Noto Hanto Earthquake. We selected eight typical houses and four typical mud-walled storehouses without serious damage in the region. From the results, the base shear coefficient for wooden structures in the Kuroshima District is relatively high; 0.51 for wooden houses and 0.78 for mud-walled storehouses, at the deformation angle of 1/30 rad.

Finally, in order to clarify the impact of the structural regionality of the wooden houses on the maximum deformation angle during the strong shaking, seismic evaluation was carried out based on the equivalent performance response spectrum method. The damaged houses in Kuroshima were compared to damaged houses in the 2000 Western Tottori Earthquake, and in the Northern Miyagi Earthquake of July 26, 2003. Structural regionality of the wooden houses is found in equivalent height, peculiar mode, and base shear coefficient, all of which have an impact on the maximum deformation angle.

KEYWORDS: The 2007 Noto Hanto earthquake, Wooden house, Traditional structure, Mud plaster wall, Seismic performance, Structural regionality

1. Introduction

The 2007 Noto Hanto Earthquake (M_J 6.9) 1) which struck on March 25, 2007, registered an upper 6 on the Japanese intensity scale in Ishikawa Prefecture. Damage investigation immediately after the earthquake reported that this earthquake mostly damaged wooden houses, collapsing many traditional timber-framed houses with mud walls2). As to the input ground motion to buildings, the peak ground velocity was estimated to be over 100 cm/s in the basin based on building damage investigation, microtremor measurement, and a survey of overturned tombstones carried out in the Hashiride District in the Monzen area, Wajima City3). In order to mitigate future earthquake damage to wooden houses, it is important to properly assess the seismic performance of wooden houses that sustained little damage despite the possibly high input ground motion and examine the reasons why they survived the strong shaking. Based on this background, this paper reports on the seismic performance assessment of houses with traditional timber framing in the Kuroshima District.

2. Structural characteristics of damaged wooden houses in Kuroshima District

2.1 Outline of wooden houses

Kuroshima Town is a district with many residential houses along the narrow north-south coast of the Noto Peninsula on the outer sea side (Fig. 1). Wooden houses in this district are characterized by exterior wall finishing with narrow wood siding referred to as clapboards and the use of black roof tiles. These features, which are frequently found on mud-walled storehouses, are specifications best suited to the weather conditions in the Hokuriku Region. Clapboards are intended to protect mud walls from the strong wind, whereas roof tiles are excellent against strong wind and resistant to the cold. Measures against strong wind are also found between a mud-walled storehouse and residence, with a corridor connecting these houses in many cases. The distance between a storehouse and residence therefore tends to be short.

2.2 Inventory survey of wooden houses

An inventory survey of damaged wooden houses was conducted in the Kuroshima District for five days in April 2007. The survey covered 8 wooden houses and 4 mud-walled storehouses having relatively small damage. Among these houses, Photos 1 and 2 show a typical residence (OU House) and mud-walled storehouse (OUD Storehouse), respectively, with clapboards and tiles frequently seen in the Kuroshima District.

Table 1 gives the outline of houses under survey, which are 30 to more than 100 years old. The foundations are mostly concrete, and the walls are mud walls excepting the KA house. All of the 12 houses are roofed with tiles without using clay. Many of the exterior walls are finished with clapboards, which are placed horizontally with their edges overlapping one another.

The damage levels of these houses were judged in consideration of interior damage observed in the inventory survey to investigate the relationship between the damage level and seismic performance (Section 3.2). Damage was classified into 5 levels based on the visual criteria proposed in Reference 4): severe, moderate, slight, marginal, and no damage. Table 1 gives the judged damage levels where damage was recognized. Note that no termite infestation was observed in any of the investigated houses.

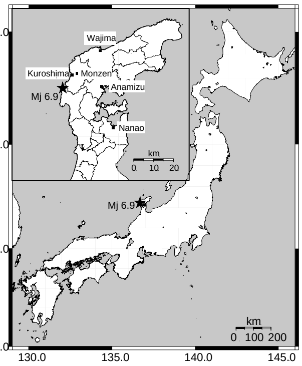


Fig. 1 Locations of 2007 Noto Hanto Earthquake epicenter, Kuroshima district, and houses

Photo 1 OU House in Kuroshima (viewed from the mountain side)

Photo2 OUD Storehouse in Kuroshima (viewed from the sea side)

Table 1 Outline of buildings under inventory survey and damage level

Bldg.		Age (Year)	Height[*1](m)		Base shear coef.[*4]		Natural freq.(Hz)		Weight(kN)		Damage level
			1st Story[*2]	2nd Story[*3]	Ridge	Beam	Ridge	Beam	1st layer	2nd layer	Judgment
Residence	MO	60	2.8	2.0	0.50	0.77	3.1	4.3	213.7	106.8	Moderate
	MS	Over 100	2.8	1.9	0.68	0.65	3.7	4.5	250.8	153.7	Marginal
	MZ	59	3.5	2.8	0.48	0.34	5.3	4.8	200.1	116.9	Marginal
	KA	30	3.3	2.9	0.47	0.38	4.1	5.0	144.8	96.4	No
	KG	60-70	2.8	-	0.53	0.68	3.9	5.3	274.7	-	Slight
	KB	36	3.1	2.7	0.70	0.47	4.1	3.3	342.2	136.4	Marginal
	KM	46	3.4	2.6	0.35	0.32	3.2	2.5	313.5	130.2	Marginal
	OU	45	3.2	2.7	0.47	0.37	4.0	3.0	305.4	159.6	Slight
Storehouse	OID	Over 100	2.5	1.3	0.87	0.81	4.3	4.9	58.1	55.8	Moderate
	KBD	40	2.8	2.5	0.69	0.66	3.8	4.0	108.1	92.5	No
	KMD	Over 100	2.7	1.3	0.89	0.58	6.5	N. A.	89.9	96.5	Slight
	OUD	80	2.5	1.4	0.97	0.75	5.4	5.3	69.9	67.5	No

*1: Only the KG House is one-storied. The others are two-storied.
*2: Length from foundations to girder on the first floor.
*3: Length from floor to girder on the second floor.
*4: At a building deformation angle of 1/30 rad.

2.3 Earthquake damage of wooden houses

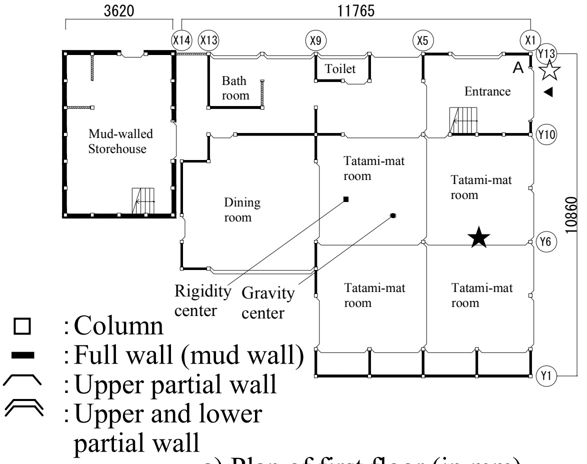
Figure 2 shows the plans of the OU House and OUD Storehouse as representative cases of wooden houses among those investigated in the Kuroshima District. The cross-sectional size of the columns of the house and storehouse are 115 by 115 mm and 125 by 125 mm, respectively, both being spaced with 905 mm spans. The walls of the OU House are mud walls 65 mm in thickness. There are many full walls upstairs but fewer downstairs. In some cases, there are no full walls or columns downstairs directly beneath the full walls upstairs.

As for the OUD Storehouse, all of the peripheral columns are through pillars, with the thickness of walls between them being 140 mm. Most storehouses examined are full two-storied houses with a rectangular plan longer in the ridge direction. The OUD Storehouse appears to be a part of the OU House from outside, as its entrance can only be reached through a corridor in the OU House.

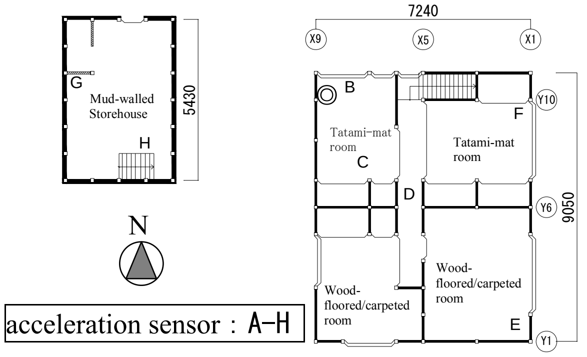
Both floors of the OU House were damaged. On the first floor, a stud in the center of the upper partial wall on structural plane Y6 between X1 and X5 slipped slightly as indicated by the *black star* in Fig. 2. Part of the tiling of room below the lean-to roof dropped at the point indicated by the *white star* in the figure. On the second floor, cracking occurred on the surface of a full wall as indicated by the *double circle* in the figure.

2.4 Vibration properties of wooden houses by microtremor measurement

The microtremor of the houses under inventory survey was measured in order to grasp the basic vibration properties of houses in the Kurhoshima District. Eight acceleration sensors were placed at points A to H in the OU House and OUD Storehouse as shown in Fig. 2, for instance, to conduct simultaneous measurement for 5 min. The transfer functions and relative acceleration spectra at points B to H on the second floors with respect to point A on the ground surface were calculated from the measured microtremor data. The natural frequencies of the houses were read from the peak frequencies of the determined transfer functions. Also, the planar vibration modes of the houses were determined from the phases of transfer functions and the values of relative acceleration spectra at their natural frequencies.

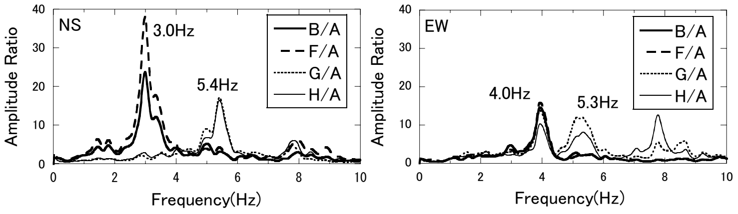


a) Plan of first floor (in mm)



b) Plan of second floor (in mm)

Fig. 2 OU House and OUD Storehouse



a) NS direction
(beam dir. of OU House,
ridge dir. of OUD Storehouse)

b) EW direction
(ridge dir. of OU House,
beam dir. of OUD Storehouse)

Fig. 3 Transfer functions of second floors of OU House and OUD Storehouse with respect to ground surface (absolute value)

a) OU in the ridge dir.

b) OU in the beam dir.

c) OUD in the ridge dir

d) OUD in the beam dir.

Fig. 4 Planar vibration modes of OU House and OUD Storehouse

Figures 3 and 4 show the transfer functions (absolute values) and planar vibration modes, respectively, of the OU House and OUD Storehouse obtained from the microtremor measurement. Figure 3 reveals that the natural frequencies of the OU House are 4.0 and 3.0 Hz in the ridge and beam directions, respectively, whereas those of the OUD Storehouse are 5.4 and 5.3 Hz in the ridge and beam directions, respectively. Figure 4a shows that the OUD Storehouse tends to vibrate at the natural frequency of the OU House in the ridge direction (4.0 Hz). However, it scarcely vibrates at the natural frequency of the OU House in the beam direction, and the OU House scarcely vibrates at the natural frequencies of the OUD Storehouse in both directions, suggesting little effects of the adjacent houses. Most other closely built houses in the Kuroshima District that look as if they are integrated have their own vibration properties independent of the adjacent houses, suggesting little coupled effect.

3. Relationship between seismic performance and earthquake damage of wooden houses

3.1 Method of assessing seismic performance

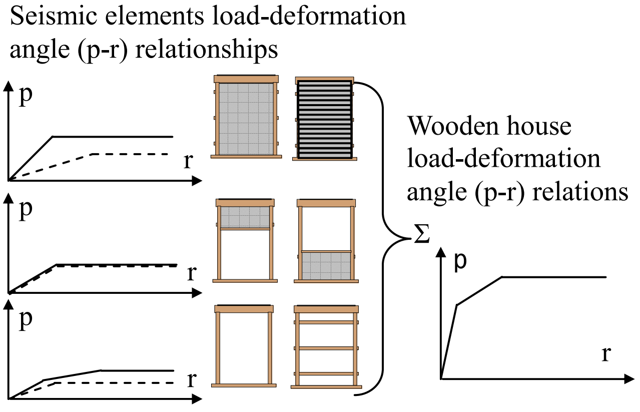


Fig. 5 Outline of the technique for calculating the bearing capacity of each floor used for the limit bearing capacity calculation of wooden houses

The seismic performance of houses under study was assessed by a bearing capacity calculation method used for the calculation of the limit bearing capacity of wooden houses$^{5)}$. In this assessment, the bearing capacity of each structural plane was calculated by summing the load-deformation angle relationships in the ridge and beam directions on the assumption of a rigid floor as shown in Fig. 5. The addition followed the rule predetermined for each seismic resisting element similarly to Reference 4). The base shear coefficient was calculated by dividing the bearing capacity of one floor at a specified drift angle by the sum of the weight of the mass system for each floor.

The rules of addition are explained as follows: The bearing capacity of full walls, such as mud walls, is calculated by dividing the column span by the reference column span (1,820 mm) and multiplying the quotient by the reference bearing capacity. The bearing capacities of clapboard, gypsum board, and structural plywood are assumed to be the same regardless of the fastener type and spacing. The bearing capacities of upper and lower partial walls are calculated by multiplying the number of column spans independently of the wall material. The bearing capacities of penetrating tie beams and tenon joints in the timber framing are corrected by dividing the reference height (2,730 mm) by the column length on each floor. As to the bearing capacity of penetrating tie beams, only horizontal ones are taken into account.

The weight of the mass system for each floor used for calculating the bearing capacity is determined as the sum of the fixed and movable loads. The fixed load is calculated from the value per unit area stipulated in Article 84 of the enforcement ordinance of the Building Standards Law. The weight of the mud walls of the storehouses is differentiated from that of residences to express the large difference between their thicknesses. As the wall thickness of the residences is of a standard size ranging from 53 to 88 mm, the value for “lathed walls of traditional wooden houses,” 830 N/m^2, is therefore applied to the walls of the residences regardless of the thickness. On the other hand, the unit weight of the mud walls of the storehouses is assumed to be 0.01 N/cm^3, as their thickness ranged from 130 to 190 mm$^{6)}$. The weight of mud firewalls under the roof tiles of the storehouses is also calculated by assuming their thickness to be the same as the other walls. A value of 600 N/m^2 specified in Article 85 of the ordinance for calculating the seismic force is adopted as the movable load.

3.2 Base shear coefficient

The base shear coefficients (C_B) are determined by dividing the bearing capacity at a drift angle of 1/30 rad by the building weight (weight for calculating seismic force) to grasp the seismic performance of the houses under study. Figure 6 shows the C_B of each house and contribution of each seismic resisting element. The graphs are arranged so that the northernmost house is placed on the left end, shifting southward to the right, as Reference 3) revealed that the damage ratio in the Kuroshima District tended to be higher in its northern part. In the figure, major seismic resisting elements are divided into 3 groups: full walls, upper/lower partial walls, and timber framing.

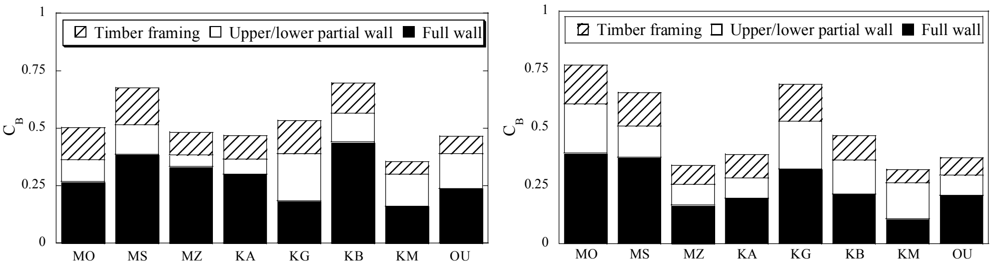
Figure 6 reveals that the C_B of the residences are 0.35 to 0.70 (0.52 on average) and 0.32 to 0.77 (0.50 on average) in the ridge and beam directions, respectively, whereas those of the storehouses are 0.69 to 0.97 (0.85 on average) and 0.58 to 0.81 (0.70 on average) in the ridge and beam directions, respectively. By averaging both directions, the C_B of the residences and storehouses are 0.51 and 0.78, respectively. The contributions of full walls to the C_B are approximately 30 to 70% and 70 to 90% in the residences and storehouses, respectively. However in some cases, the upper and lower partial walls of residences also serve as important load bearing elements along with full walls, as their contributions to the C_B of residences range as high as from approximately 10 to 50%.

4. Relationship between structural regionality of damaged wooden houses and building responses

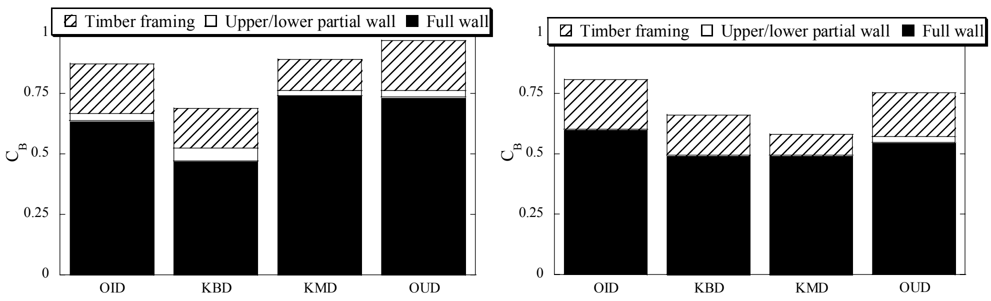
4.1 Comparison of bearing capacities (C_B)

In order to grasp the structural regionality of the wooden houses in the Kuroshima District, the C_B of houses under inventory survey determined in Section 3 above is compared with those of two-storied wooden houses damaged during the 2000 Western Tottori Earthquake and 2003 Northern Miyagi Earthquake[4), 7)] (hereafter referred to as residences in Tottori and Miyagi, respectively). The numbers of residences examined in Tottori and Miyagi are 10 and 7, respectively. In the comparison, mud walls are treated as full walls, and other walls are treated as upper/lower partial walls. The bearing capacity values of timber framing are used as they are. The KG House, which is the only one-storied house in the houses under study in the Kuroshima District, is excluded from the comparison to deal with only two-storied residences and storehouses (hereafter referred to as residences in Kuroshima and storehouses in Kuroshima, respectively).

Figure 7 shows the averages and standard deviations of the C_B in the ridge and beam directions of two-storied houses in different regions. The contribution of each load bearing element is also shown in the graphs. This figure reveals no marked difference in the proportions of load bearing elements contributing to the C_B between regions. When comparing the C_B of different regions in the smaller of the two directions, that of residences in Kuroshima in the beam direction (0.47) is approximately 20% greater than residences in Miyagi in the ridge direction (0.41) and approximately 40% greater than residences in Tottori in the ridge direction (0.34), with the difference being 0.13 at the most.

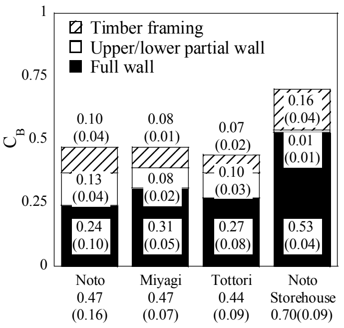


a) In the ridge direction of residences b) In the beam direction of residences

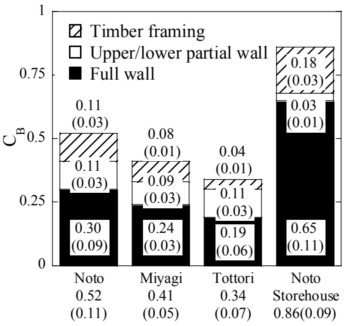


c) In the ridge direction of Storehouses d) In the beam direction of Storehouses

Fig. 6 Base shear coefficient of wooden houses and contribution of each seismic resisting element



a) Ridge direction



b) Beam direction

Fig. 7 Averages of base shear coefficients of 2-storied wooden houses (standard deviations)

4.2 Comparison of equivalent heights and peculiar modes (balance between the bearing capacities of upper and lower floors)

This section discusses the structural regionality in terms of factors other than C_B among the seismic performances of two-storied wooden houses in different regions. The houses are replaced with mechanical models of equivalent SDOF systems for simplicity. Specifically, each house under study is replaced with an equivalent SDOF system by assuming its C_B at a drift angle of 1/30 rad on the first floor to be the yield shear coefficient, Cy (hereafter Cy = C_B), in Reference 8) to determine the equivalent height, H_{et}, the ratio of equivalent mass to mass, $M_e/M = \mu$, and peculiar mode, u_2/u_1, which is the balance between the bearing capacities of upper and lower floors. The differences among house types and regions are investigated in regard to these values. Table 2 gives the average C_B, H_{et}, μ, u_2/u_1 determined in the ridge and beam directions for residences in Kuroshima, Miyagi, and Tottori, as well as storehouses in Kuroshima. According to Table 2, no appreciable difference is observed among the values of μ for houses and storehouses in all regions, ranging from 0.9 to 1.0, but the values of H_{et} and u_2/u_1 vary widely between the house types and among regions. It is therefore found that not only C_B but also H_{et} and u_2/u_1 show the structural regionality of two-storied wooden houses.

Table 2 Two-storied wooden houses in different regions (number of houses surveyed)

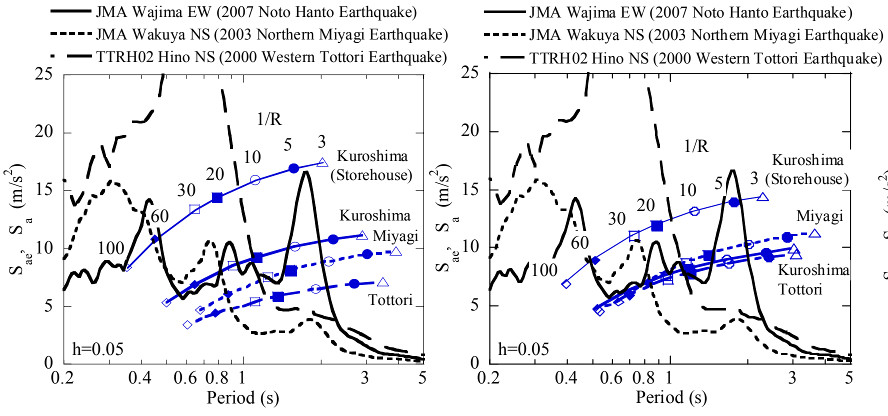
	C_B		H_{et} (m)		u_2/u_1		μ	
	Ridge	Beam	Ridge	Beam	Ridge	Beam	Ridge	Beam
Residences in Kuroshima (7)	0.52	0.47	4.2	4.2	1.5	1.4	1.0	1.0
Residences in Miyagi (7)	0.41	0.47	5.0	5.0	2.2	2.2	0.9	0.9
Residences in Tottori (10)	0.34	0.44	4.0	4.0	1.5	1.5	1.0	1.0
Storehouses in Kurhoshima (4)	0.86	0.70	3.4	3.4	1.3	1.4	1.0	1.0

4.3 Effects of structural regionality on building response

Based on the results of investigation described in Sections 4.1 and 4.2, the effects of the structural regionality of wooden houses on their maximum response deformation angle (R) are examined using the performance equivalent acceleration response spectra[8)]. The performance equivalent acceleration response spectrum of a building, S_{ae}, is the critical performance (critical bearing capacity and critical deformation) of a building converted to an equivalent acceleration response spectrum so as to be directly comparable with the seismic load for design and the acceleration response spectra, S_a, (damping factor: 5%). In other words, the value of R for a building to an arbitrary input ground motion can be estimated from the intersection of the S_a of the earthquake motion and the S_{ae} of the building.

The performance equivalent acceleration response spectra, S_{ae}, in the ridge and beam directions of residences and storehouses in Kuroshima, Miyagi, and Tottori are determined using SDOF system models used in Section 4.2. The input earthquake motions are the records of the 2007 Noto Hanto Earthquake, Northern Miyagi Earthquake on July 26, 2003, and 2000 Western Tottori Earthquake captured by the strong motion observation networks of the JMA and the National Research Institute for Earth Science and Disaster Prevention. Specifically, these are horizontal motion records (one of the two orthogonal components with a greater maximum velocity) of these earthquakes obtained at stations near the area where the authors conducted the inventory survey (JMA Wajima, JMA Wakuya, and TTRH02 Hino)[9), 10)]. Figure 8 shows the obtained S_{ae} of the wooden houses in the ridge and beam directions and S_a of the input ground motions. In addition, Fig. 9 shows the S_{ae} in the direction with the smaller C_B from each region and the S_a of the strong motion records of the 1995 Hyogo-ken Nambu Earthquake, 2004 Niigata-ken Chuetsu Earthquake, and 2007 Niigata-ken Chuetsu Oki Earthquake (one of the two horizontal components with the greater maximum velocity) at JMA Kobe, JMA Kawaguchi, and NIG018 Kashiwazaki[9), 10)] for reference. Figure 8 reveals differences in the seismic performance of wooden houses due to structural regionality. Also, Figs. 8 and 9 reveal that the factor determining the value of R of wooden houses is in many cases the spectrum shape of S_a in the constant velocity zone.

Figure 10 shows the R of houses in each region in response to the 6 input ground motions determined from Figs. 8 and 9 to investigate the effects of the differences in H_{et} and C_B on R. Figure 10a reveals that the value of R for houses in Miyagi (in the ridge direction) with a high H_{et} is smaller than that of residences in Kuroshima (in the beam direction) with a relatively low H_{et} under all strong motion records used. In consideration of the fact that u_2/u_1 is used for calculating H_{et}, it is inferred that the R value of a house can be kept low when its H_{et} is high and u_2/u_1 is good (close to 2 with good balance between the bearing capacities of the upper and lower floors). On the other hand, Fig. 10b reveals that the R values of residences in Kuroshima (in the beam direction) with a relatively large



a) Ridge direction b) Beam direction

Fig. 8 Acceleration response spectra of strong motion records and performance equivalent acceleration response spectra of wooden houses

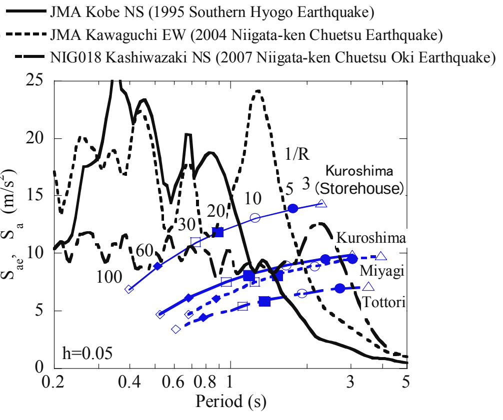
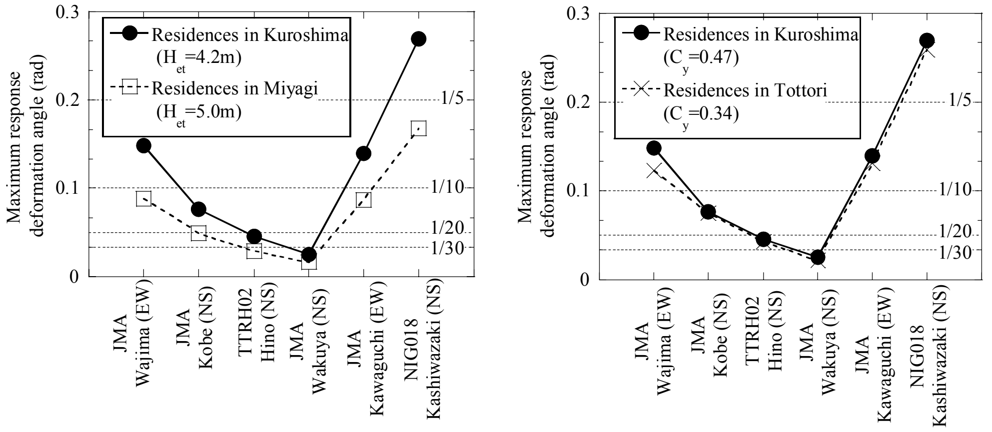


Fig. 9 Acceleration response spectra of strong motion records and performance equivalent acceleration spectra of wooden houses



a) Effect of equivalent height (residences in Kuroshima and Miyagi) b) Effect of yield shear coefficient (residences in Kurhoshima and Tottori)

Fig. 10 Maximum response deformation angle of wooden residences under strong motions recorded in Japan in recent years

C_B and residences in Tottori (in the ridge direction) with a relatively small C_B are similar under all input ground motions. This suggests that, as described in Reference 12), increasing the bearing capacity of wooden houses does not necessarily curb the maximum response during an earthquake. However, Fig. 9 suggests that the R value of a house with a high C_B such as storehouses in Kuroshima may be kept low under a ground motion with S_a having relatively low peaks on the short period side of the constant velocity zone such as NIG018 Kashiwazaki, as S_{ae} exceeds S_a in such a case.

5. Conclusions

A field survey was conducted on wooden houses damaged during the 2007 Noto Hanto Earthquake to assess their seismic performance and structural regionality. The seismic performance of these houses was also compared with those of wooden houses damaged during the 2000 Western Tottori Earthquake and 2003 Northern Miyagi Earthquake using performance equivalent acceleration response spectra. The conclusions in this study are as follows:

1) Storehouses are built so close to wooden houses in the Kuroshima District that they appear to be a part of the houses. However, each building has its own vibration properties with no significant coupled effect. Also, microtremor measurement detected little torsional vibration.

2) The average base shear coefficients of wooden residences and storehouses in the Kuroshima District under study at a drift angle of 1/30 rad are 0.51 and 0.78, respectively. The proportions of contribution of full walls (mud walls, etc.) in residences and storehouses are approximately 30 to 70% and 70 to 90%, respectively, proving full walls to be a major load-bearing element. It is also found that the contribution of upper/lower partial walls ranged from 10 to 50% in residences, and some of them are serveed as an important load bearing element along with full walls.
3) The structural regeonalities of wooden houses in Kuroshima, Miyagi, and Tottori are found in their base shear coefficient at 1/30 rad, equivalent height, and balance between the bearing capacities of upper and lower floors (peculiar mode). A large equivalent height and good balance between the bearing capacities of upper and lower floors of a house lead to a low maximum response deformation angle. A high base shear coefficient at 1/30 rad of a wooden house does not reduce the maximum response deformation angle in many cases under the strong motions in recent earthquakes.

This paper points out that increasing the bearing capacity alone is not sufficient for reducing the maximum response deformation angle of wooden houses, although it depneds on the spectrum properties of the ground motion.

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REFERENCES

1) USGS (2007). Magnitude 6.7 - NEAR THE WEST COAST OF HONSHU, JAPAN. (On-line). <http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/us2007aiae.php>.
2) JSCE (2007). Report on the damage investigation of the 2007 Noto Hanto Earthquake, pp.290-301. (in Japanese).
3) Hiroshi Arai, Takeshi Morii, Masumi Yamada, Hidemaru Shimizu, and Yasuhiro Hayashi (2008). Peak ground velocity and cause of damage to wooden houses estimated in near-source area during The 2007 Noto Hanto Earthquake. *Journal of structural and construction engineering (Transaction of AIJ).* No.624, pp.227-234. (in Japanese).
4) Hidemaru Shimizu, Yasuhiro Hayashi, Yoshiyuki Suzuki, Yukio Saito and Masami Goto (2005). Evaluation of structural characteristics and seismic performance of damaged wooden houses by The Northern Miyagi earthquakes of July 26, 2003. *Journal of structural and construction engineering (Transaction of AIJ).* No.598, pp.43-49. (in Japanese).
5) Yoshiyuki Suzuki, Yukio Saito, Kenichi Katagihara, Kohju Ikago and Senri Nojima (2002). Method of evaluating seismic performance of wooden frames –Limit bearing capacity analysis in a wide range of deformation. *The 11th Japan earthquake engineering symposium,* pp.1523-1528. (in Japanese).
6) Hiroyuki Nakaji, Yoshiyuki Suzuki, Masami Goto, Izumi Iwamoto and Kouji Yamada(2007). Static cyclic loading test for evaluation of seismic capacity of traditional houses in Higashi Mikawa. *Journal of structural and construction engineering (Transaction of AIJ).* No.612, pp.133-140. (in Japanese).
7) Tatsuru Suda, Yasuhiro Hayashi and Takeshi Morii (2003). Study on Damage of Wooden Houses at Hino Town in The 2000 Western Tottori Prefecture Earthquake. Part 2: Study on Seismic Performance of Wooden Houses. *Summaries of technical papers of annual meeting AIJ.* B-2, pp.69-70. (in Japanese).
8) Yasuhiro Hayashi (2002). Evaluation of seismic design load based on equivalent-performance response spectra. *The 11th Japan earthquake engineering symposium,* pp.651-656. (in Japanese).
9) JMA (2007). Japan Meteorological Agency | Earthquake Information. (On-line). <http://www.jma.go.jp/en/quake/>.
10) NIED (2007). Kiban-Kyoshin Network. (On-line). < http://www.kik.bosai.go.jp/kik/index_en.shtml >.
11) NIED (2007). Kyoshin Network K-NET. (On-line). < http://www.k-net.bosai.go.jp/ >.
12) Takeshi Morii, Yasuhiro Hayashi and Akiko Saratani (2005). Semiempirical method for predicting seismic damage of wooden houses based on seismic performance. *Journal of Institute of Social Safety Science.* No.7, pp.281-289. (in Japanese).