EFFECTS OF LOCAL SITE CONDITIONS ON BUILDING DAMAGE IN THE 2007 NOTO-HANTO EARTHQUAKE

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ABSTRACT :

The 2007 Noto-hanto earthquake of M_j=6.9 that occurred on March 25, 2007, caused extensive damaged to wooden houses in the affected area, with the most catastrophic damage in the Monzen-machi of Wajima city. The damage to wooden houses appears to concentrate along the foot of alluvial fans in the northern end of the district, suggesting the effects of local soil condition on the damage. In order to clarify the major cause of the damage, field investigations including boring, spectral analysis of surface waves methods were conducted in the district and two-dimensional shear wave velocity profiles were determined. It is shown that the thickness of soft alluvial deposit underlying the district varies from 7-25 m and increases toward the foot of alluvial fans and that the structural damage increases with increasing thickness of the soft alluvial deposit. Dynamic response analyses are conducted with the detected shear wave velocity profiles to estimate ground motions and structural response during the main shock. It is shown that the maximum response of wooden houses, i.e., damage level, in the area could mainly be controlled by strong ground motion with a period of about 1-2 s and that the ground motions in that period range were significantly amplified due to the nonlinear amplification of the thick soft layer underlying the district.

KEYWORDS: the 2007 Noto-hanto earthquake, building damage, microtremor measurements, natural site period, dynamic response analysis

1. INTRODUCTION

The 2007 Noto-hanto earthquake (M_j=6.9) that occurred on March 25, 2007, caused extensive damage to wooden buildings in the near-source region including Wajima city, Monzen-machi, and Anamizu city in Ishikawa Prefecture as shown in Figure 1. Damage to wooden houses in the Touge district of Monzen-machi developed in alluvial fans was especially catastrophic, with extent of damage generally increasing toward the foot of alluvial fans. This suggests the strong effects of local soil conditions on structural damage within the district. The objective of this paper is to summarize building damage of the district from an inventory survey as well as geological and geophysical conditions from the follow-up field investigations and to evaluate the effects of local site conditions on the damage to wooden houses, based on simplified response analyses of soil layer and building that are modeled from the field investigation.

2. DAMAGE TO WOODEN HOUSES IN TOUGE

2.1. Damage survey for wooden buildings in Touge district

The inventory survey was conducted on almost all buildings in the zone of the Touge district as shown in Figure 2. Various influential factors affecting the damage, including structural material and system, number of stories, and foundation of each building were examined as well as the level of its damage which is classified into six grades: D0-D1 (almost no damage), D2-D3 (slightly and moderately damaged), D4-D5 (heavily damaged and collapsed including demolition) according to the study by Okada and Takai (1999).

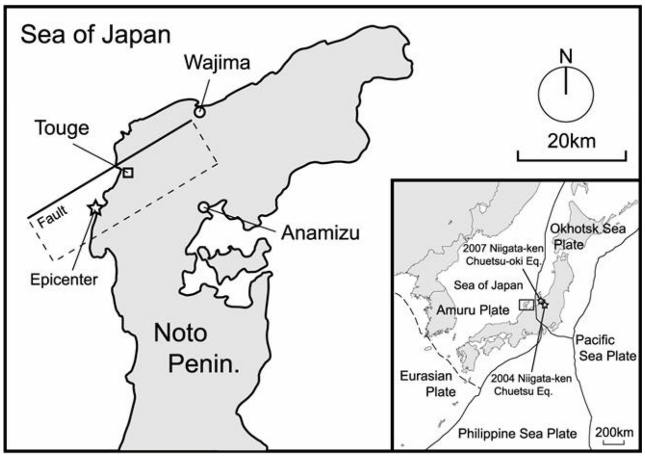


Figure 1. Map of the near-source region

Photo 1. Typical damage to wooden house

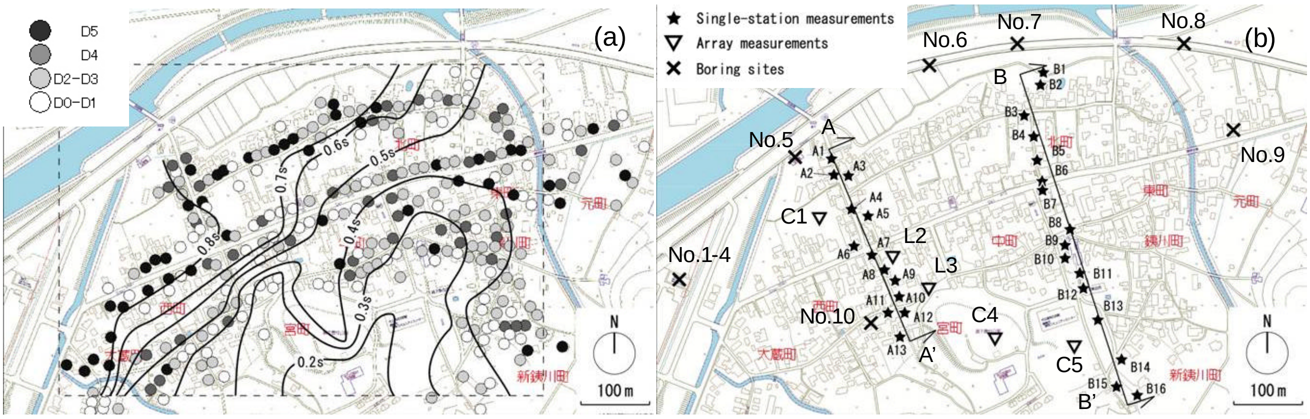


Figure 2. Maps showing (a) distribution of damage levels of wooden houses and contour lines of H/V peak period, (b) locations of single-station measurements, array measurements and boring sites

The number of buildings investigated was 353, and among them 291 buildings were traditional Japanese wooden houses with one- or two-story. A large number of damaged wooden houses sustained either partial or complete collapse typically of a soft first story (see Photo 1). Figure 2(a) shows the distribution of damage levels of wooden houses in the Touge district. The damage ratios falling in categories D0-D1, D2-D3, and D4-D5 are about 0.3, 0.4, and 0.3, respectively. The damaged houses appeared to increase toward the foot of alluvial fans and/or the river on the north of the district.

2.2. Relationship between H/V spectra and damage to wooden houses

To estimate local site effects on the building damage, microtremor measurements using a three-component sensor were performed at 87 sites as shown in Figure 2(a). Figure 3 shows horizontal-to-vertical (H/V) spectra of microtremors observed at 5 stations along A-A' line in Figure 2(b). The observed H/V spectra at stations A3, A5, and A6 on the north have prominent peaks, while those at station A9 and A13 on the south do not have any prominent peak. This suggests that the thickness of soft alluvial deposit could increase toward the north or the foot of alluvial fans.

The damage ratio of the nearest 10 houses at each station along Lines A-A' and B-B' (Figure 2(b)) is shown in Figure 4, together with the observation H/V spectra. The observed H/V peak periods are 0.5-0.8 s at stations A1-A6 and B1-B6 where almost one half of the buildings are classified into damage levels greater than D4; however, they are 0.2-0.5 s at stations A9-A13 and B11-B14 where only about 10 % of the buildings are in the same damage levels. The variation of H/V peak periods suggests that the soil profiles change drastically along the A-A' and B-B' lines, and, the damage ratio increases with increasing H/V peak period.

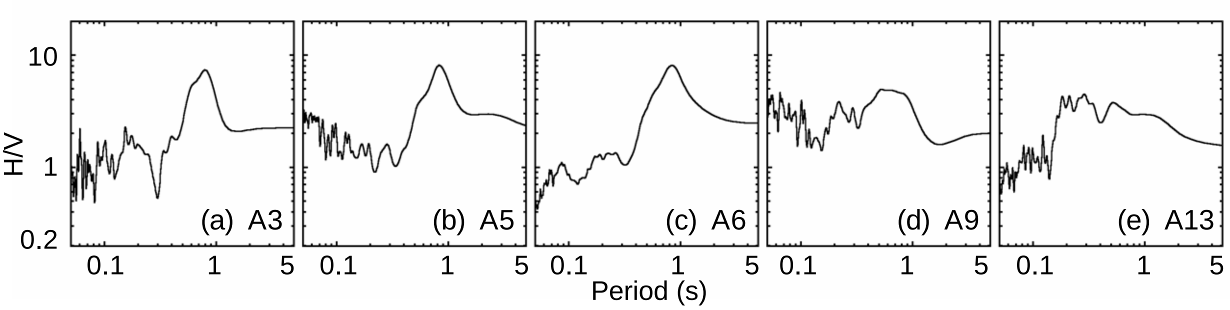


Figure 3. H/V spectra of microtremors observed at 5 stations along A-A' line

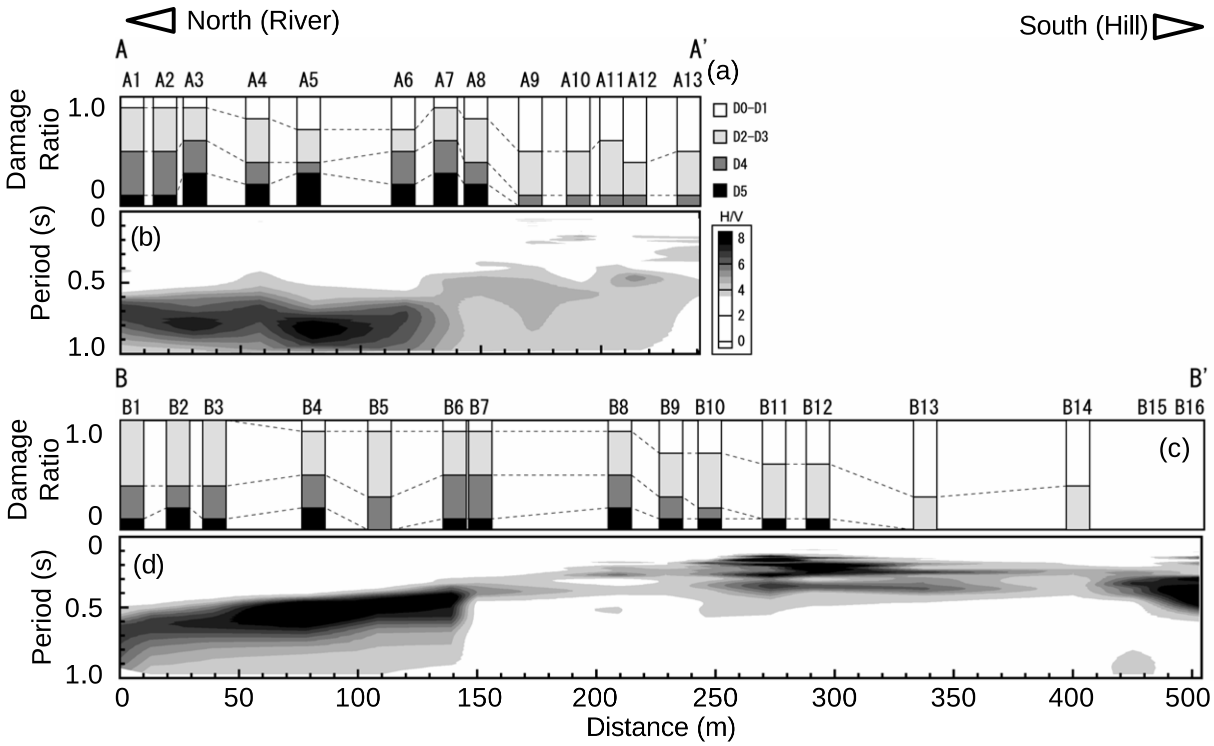


Figure 4. Variations of (a, c) the damage ratios and (b, d) H/V spectra, along A-A' line and B-B' line

To confirm the above results, contour lines of H/V peak period are shown in Figure 2(a), and the distributions of damage ratios between the two adjacent lines are plotted against the H/V peak period in Figure 5. Figure 2(a) confirms that the H/V peak period and the damage of wooden houses increases toward the foot of the alluvial fans and Figure 4 shows that the extensive damage classified into D4-D5 tends to increase with increasing H/V peak period. Especially, almost half of the buildings are classified into damage levels greater than D4 in the area with an H/V peak period greater than 0.6 s. The above findings indicate that the damage to wooden houses could be controlled by the local site effects.

3. SITE CONDITION

Figure 6 shows boring logs at 10 sites along the line shown in Figure 2(b). The boring logs shown in Figure 6 (a)-(d) obtained at the Monzen water quality control center on the west end of the district indicate that a sedimentary soft surface layer about 25 meters thick overlies a stiff gravelly rock layer. To estimate S-wave velocity (V_s) structure of the surface soil, microtremor measurements using array of sensors were performed at 5 stations that are shown in Figure 2 (b) with open triangles. The dispersion data resulting from the F-k spectrum analysis of the microtremor records (Capon, 1969; Tokimatsu, 1997) are shown in Figure 7 with open circles. Figure 8 shows the H/V spectra observed at or near the array center.

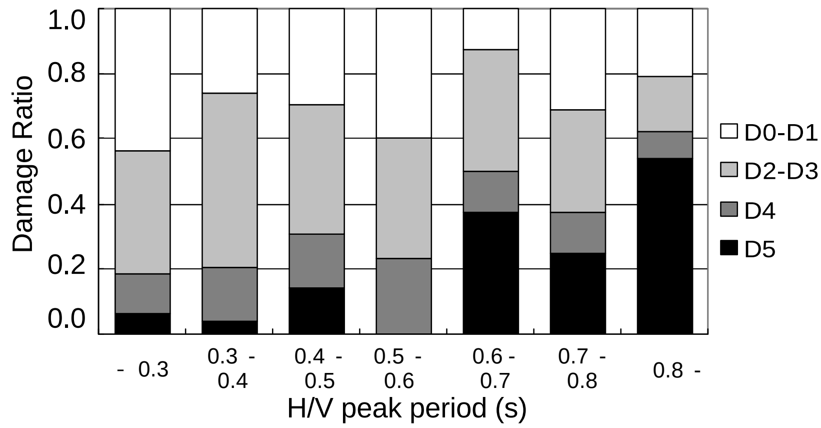


Figure 5. Distribution of damage ratios for wooden houses in each H/V peak period

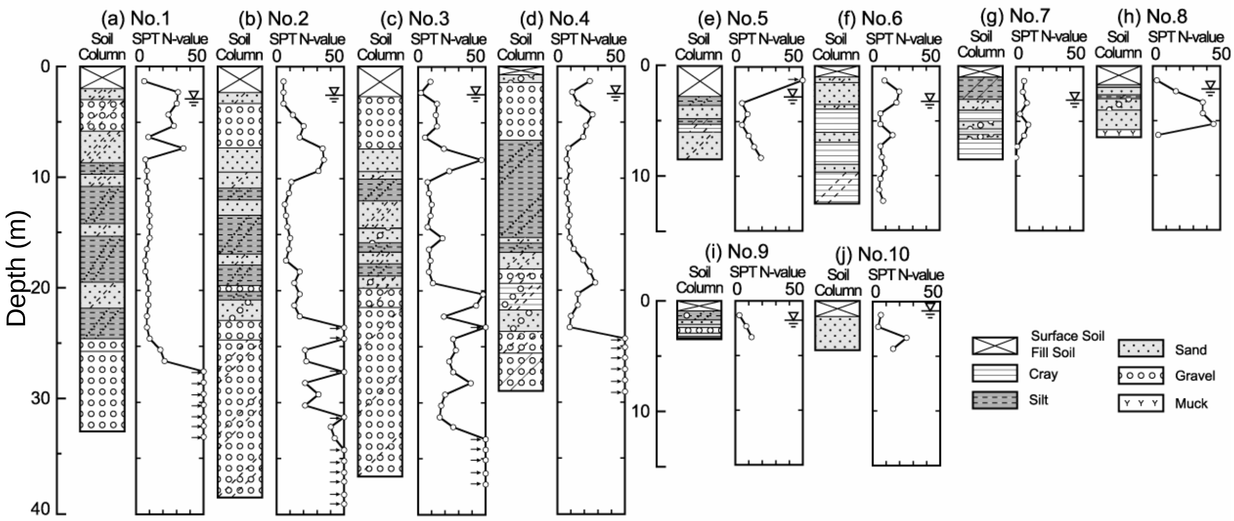


Figure 6. Boring logs

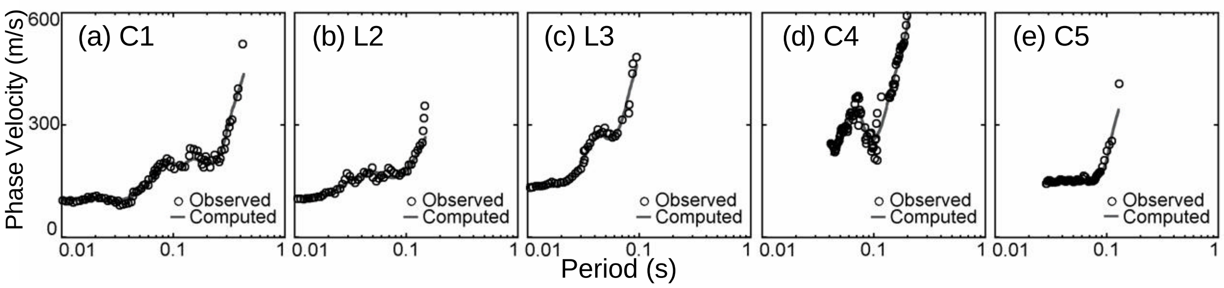


Figure 7. Observed and theoretical dispersion curves

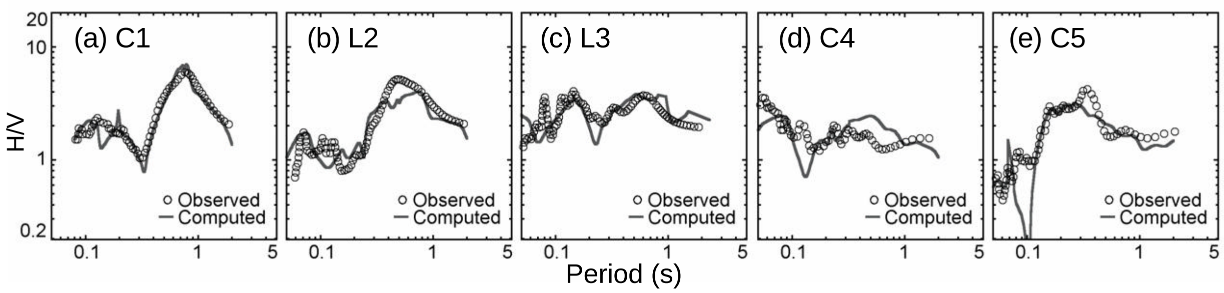


Figure 8. Observed and theoretical H/V spectra

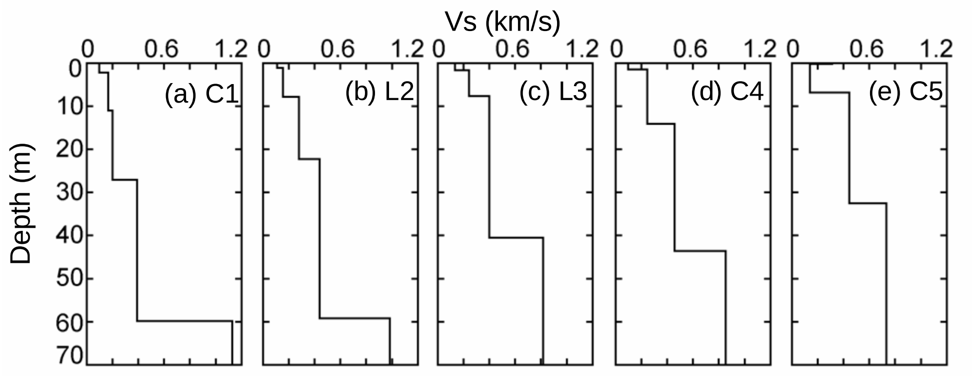


Figure 9. V_s profiles estimated from microtremors

The inverse analysis using both dispersion curve and H/V spectra (Arai and Tokimatsu, 2005) are performed to determine the V_s structure underneath each station. In the inversion, the V_s structure deeper than 60 meters is assumed from the study by Yamanaka et al. (2007). Figure 9 shows the Vs profiles estimated from the inversion. Solid line in Figure 7 and 8 are the theoretical dispersion curves and H/V spectra for the inverted V_s profiles. Good agreements between the observed and theoretical ones indicate that the inverted structures are reasonably reliable. It seems that the layer with V_s exceeding 400m/s that occurs at a depth of 20-30 m at stations C1 and L2 corresponds to the gravelly rock layer and that the thickness of the soft layer overlying the rock decreases from 25 m to less than 10 m toward the south of the district.

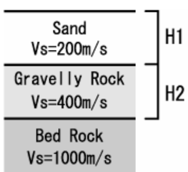
4. SIMULATION OF GROUND AND BUILDING RESPONSES

4.1. Outline of method and condition for simulation

To estimate local site conditions and their effects on damage to wooden houses during the main shock, simplified dynamic response analyses of ground and building were performed. The response analysis of the ground was conducted using a one-dimensional equivalent-linear response analysis of a deposit in which damping ratios are dependent on Fourier amplitude of shear strain in the frequency domain (e.g., Sugito et al., 1994). It is an extended version of SHAKE (Schnavel et al., 1972) to improve its deficit in over-damping in the short period range during strong shaking. The response analysis was performed with six three-layered soil models having natural site periods from 0.3-0.8 s. Table 1 summarizes the V_s values and the thicknesses of each model assumed the V_s profiles estimated from microtremor measurements (Figure 9). The nonlinear dynamic soil properties for sandy soil and gravel used in the analysis are based on the studies by Imazu and Fukutake (1986). The input bedrock motion for the analysis was artificially determined based on the target acceleration response spectrum with a damping ratio of 5%, characterized by predominant period, T_p, and maximum velocity, V_{max}, together with appropriate phase angles of the spectrum (Architectural Institute of Japan, 1997). In this study, T_p and V_{max} of the bed rock motion are assigned as 1 s and 0.8 m/s, respectively, based on the study by Arai (2008) and the phase angles of the bedrock motion were assumed to be those of the strong motion EW record during the main shock at K-NET Wajima station.

To estimate the maximum drift angle of wooden house, the equivalent-performance response spectrum of a SDOF building system (Hayashi, 2002) was used with a bi-linear model expressing the force-displacement relationship of the SDOF system. The equivalent height and ield drift angle of the SDOF system are

Table 1. Three-layered models of surface soils



T_g(s)	0.3	0.4	0.5	0.6	0.7	0.8
H1 (m)	0.0	8.7	17.0	22.9	28.4	33.5
H2 (m)	30.0	33.0	33.0	33.0	33.0	33.0

assumed to be 4.5 m and 1/100, respectively. The yield base shear coefficient of the system, C_y, is set as 0.2, 0.4, and 0.6.

4.2. Drift angle and damage ratio of wooden houses

Solid and broken lines in Figure 10 show the acceleration response spectra of the ground surface motions, S_{as}, and of the input bedrock motion, S_{aB} for the six model grounds. Also shown in the figure with symbolized thin lines are the equivalent-performance response spectra of wooden houses, S_{ae}, derived from the response analysis of building with different yield base shear coefficient C_y. The maximum drift angle, R_b, of wooden house for a given C_y can be determined from a crossing point between the response spectra S_{as} and S_{ae} (Hayashi, 2002).

Figure 10 confirms that the response spectra of the ground surface motions (S_{as}) at the sites with T_g greater than or equal to 0.6 s have large amplification in the period range between about 1-2 s, consistent probably due to non-linear amplification of surface soils. The above results and discussions are consonant with the variation of building damage shown in Figure 5.

Figure 11 summarizes the relation between the computed maximum drift angle, R_b, and natural site period, T_g, for wooden houses with different yield base shear coefficients, C_y. The figure shows that the maximum drift angles R_b of wooden houses increase not only with decreasing C_y but also with increasing natural site period T_g. The R_b becomes more than 1/10 when T_g becomes greater than 0.6 s. The effects of C_y on R_b are, however, significant only at T_g less than 0.5 s particularly when C_y is small, whereas they become independent of C_y when T_g becomes equal to or greater than 0.6 s. The trend is consistent with the field observation shown in Figure 5.

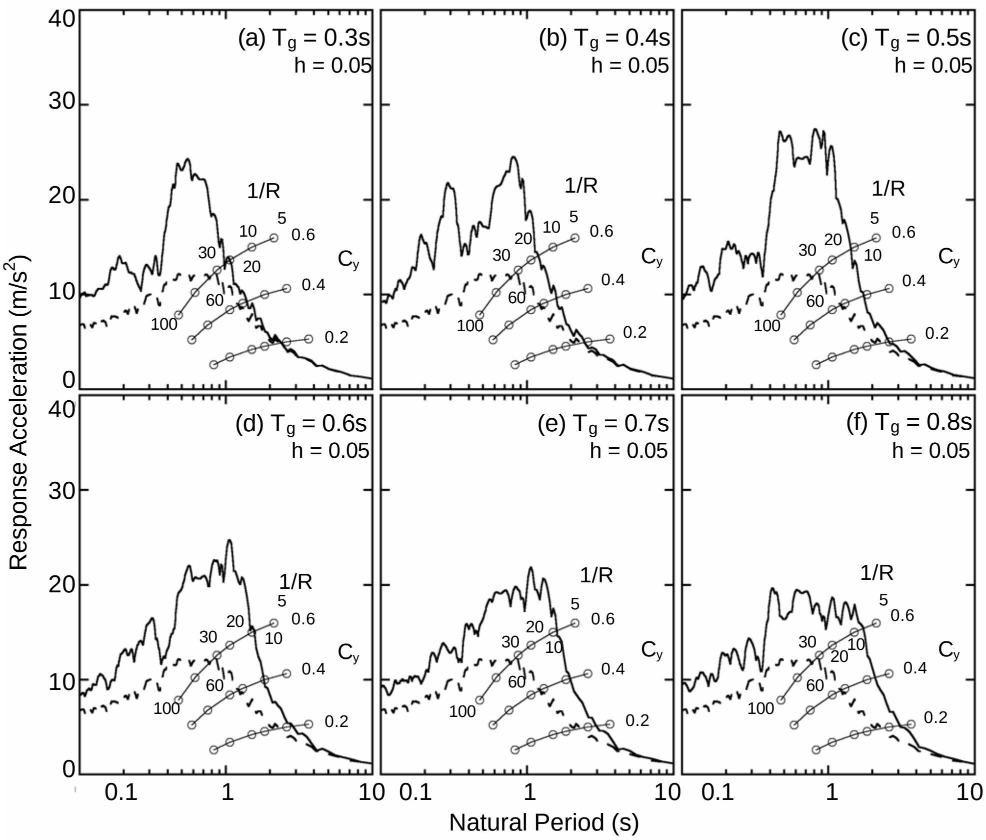


Figure 10. The acceleration response spectra of ground surface motion, S_{as} (solid lines) and input bedrock motion, S_{aB} (broken lines), and the equivalent-performance response spectra for wooden houses, S_{ae} (symbolized thin lines)

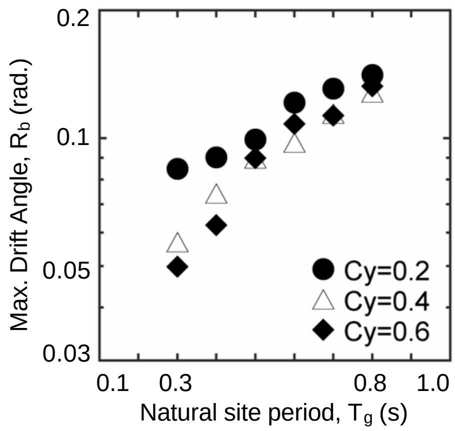


Figure 11. Relation between computed maximum drift angle, R_b, and natural site period, T_g, for wooden houses with different yield base shear coefficient, C_y

Detailed examination of Figure 10 suggests that the drift angle of the building increases with increasing response spectra of ground surface motions (S_{as}) in the period range between about 1-2 s and that the spectral amplitude in this range increases with increasing natural site period. In addition, the spectral peak at each site occurs at a period much greater than its natural site period estimated from microtremor measurements, suggesting that the elongation of site natural period could occur during the main shock due to nonlinear characteristic of soil during strong shaking.

5. CONCLUSIONS

Effects of local site amplification characteristics on strong motions and damage to wooden houses in the Touge district of Monzen-machi, Wajima city, Japan, during the 2007 Noto Hanto earthquake, have been examined based on inventory survey of buildings as well as microtremor measurements. Using dynamic response analyses of simplified models of both surface soils and wooden houses, ground motions and maximum drift angles of wooden houses within the district during the main shock were estimated. The following conclusions may be tentatively made:

1. The thickness of soft alluvial deposit underlying the district varies from 7-25 m, increasing toward the foot of alluvial fans, and the structural damage tends to be significant with increasing thickness of the soft alluvial deposit.

2. The computed drift angle of the building increases with increasing response spectra of ground surface motions (S_{as}) in the period range of about 1-2 s, suggesting that damage to wooden houses during the main shock was mainly controlled by strong ground motions in the period range of about 1-2 s.

3. The ground motions with a period range of about 1-2 s in the extensively damaged area were significantly amplified due to the non-linear amplification of the thick soft layer underneath.

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