13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 575

WOODEN HOUSE DAMAGE ON IMPROVED HILLS CAUSED BY THE 2001 GEIYO EARTHQUAKE, JAPAN AND MICRO-TREMOR PROPERTIES OF THE GROUND

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SUMMARY

This paper presents relation between wooden house damage and ground shaking intensity by the 2001 Geiyo earthquake, Magnitude 6.7, Japan. Tile-roof damage of wooden houses caused by the earthquake was surveyed at residential districts in and near the western part of Hiroshima City. A questionnaire investigation for housing damage and ground shaking intensity was also developed. Furthermore, a micro-tremor observation was employed to investigate ground vibration property. The results are as follows: (1) Extensive damage of roof-tiles occurred on fill ground than cut ground. (2) The questionnaire seismic intensity is high on alluvium ground near hills and on ridges, and on fill ground on improved hills. The threshold intensity above which the roof-tile damage starts to appear can be between 5.5 and 6.0. (3) A ratio of horizontal spectrum to vertical one based on the micro-tremor measurement is found to have clearly different characteristics between fill and cut ground. This ground vibration property corresponds to larger roof-tile damage of wooden houses in fill ground on improved hills.

INTRODUCTION

On March 24th, 2001, at 3:28 PM, the Geiyo Earthquake, Magnitude 6.7, shook the Seto Inland Sea (Seto-naikai) area expanding from Chugoku and Shikoku in western Japan. The quake caused moderate damage to the region in and around western Hiroshima prefecture. The JMA (Japan Meteorological Agency) intensity scale showed V-strong to VI-weak (very strong; equivalent to 8 or 9 on the Modified Mercalli scale). The maximum acceleration was recorded 1000 cm/s^2 or more, but building and other urban facility damages were not so severe, because focal depth was relatively deep as about 50 kilometers, and the period of earthquake vibration was short. However, damages of roof-tile of conventional Japanese-style wooden houses occurred much in fill on improved hills.

This study presents relation between wooden house damage and ground shaking intensity by the 2001 Geiyo earthquake, Magnitude 6.7, Japan. Roof-tile damage of wooden houses caused by the earthquake was surveyed at residential districts in and near the western part of Hiroshima City and Hatsukaichi City. Also questionnaire investigation for housing damage and ground shaking intensity was developed in some

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areas of Kure City and Hatsukaichi City. Furthermore, a micro-tremor observation was employed to investigate ground vibration property.

OUTLINE OF EARTUQUAKE DAMAGE

Due to the Geiyo earthquake in 2001, one person was killed in Kure City, Hiroshima Pref. and one person in the Hojo City, Ehime Pref., respectively, and the total of 288 people were injured in Chugoku and Shikoku districts. The number of building damage in Hiroshima prefecture had the complete damage of 60 houses, the half damage of 497 houses, and the partial damage of 34,735 houses (as of May 31, 2001). Many of private house buildings, which were completely and/or half destroyed, stood on the steep slope land around the downtown of Kure City, accompanied by a lot of sudden falls of stone retaining walls (Photo 1). A partially damaged building contains often falls of roof-tiles and mortar walls. A number of damaged buildings is based on the report of the city, so more damage have existed actually.

Photo 1 Damaged house stood on the steep slope land (Kure City)

Photo 2 Tile-roof damage of wooden houses on improved hills (Hiroshima City)

There was no complete damage to wooden houses in Hiroshima City. Totally 108 half damage of buildings and 6,478 partial damage occurred in the entire Hiroshima City (as of June 25, 2001 by Hiroshima City Fire Department). The building damage concentrates at western part of Hiroshima City, and developed especially on the hill ground, as shown in Photo 2. After the 1995 Kobe earthquake, a large-scale earthquake damage estimation was put out in many big cities in Japan, and on April in 1997, in Hiroshima City. At that time, the magnitude level of the Geiyo earthquake is assumed to be 7.25, and building damage due to the earthquake distributed much in the delta soft subsoil zone of the central Hiroshima City than on the surrounding hill ground of the city. However, the actual housing damage in Hiroshima City differs from the estimation. A lot of tile-roof damage of wooden houses was also concentrated at the newly developed town on the hill ground in Ajina and Ajinadai of Hatsukaichi City, as the same as in Hiroshima City.

RELATION BETWEEN WOODEN HOUSE DAMAGE AND IMPROVED LAND ON HILL GROUND

Koi-ue district in Hiroshima City

The damage of the wooden house tile-roof was surveyed in 3 chome and 5 chome areas on Koi-ue district in Hiroshima City, on April 4 of about ten days after the earthquake occurrence. Figure 1 shows the housing damage state. The red round mark shows the house with damage, whose roof is covered by a blue waterproof seat. The houses were made on the hill ground, and passes about 30 years. As for tile-roof damages, there is considerably a lot of damages in the Koi-ue district compared with damages in the delta soft-subsoil region in the center of Hiroshima City, where the house damages were hardly seen. The house site is piled up with the having retaining wall, and damage is caused by the crack and the collapse of the retaining wall.

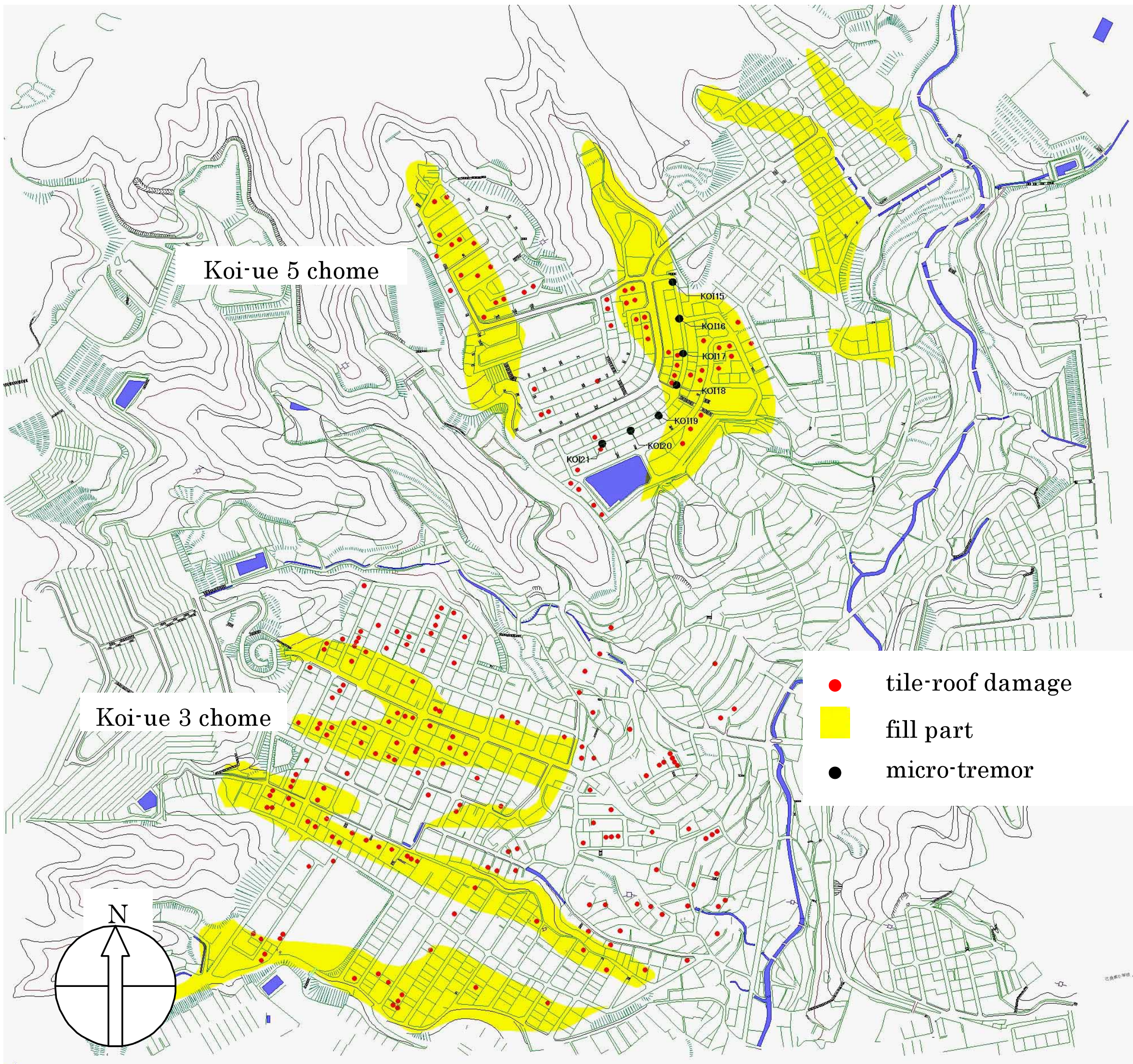


Figure 1 Housing damage state (Koi-ue, Nishi Ward, Hiroshima City)

The classification of the cut and the fill ground in the Koi-ue district[4)] was shown in Figure 1. A lot of tile-roof was damaged in the fill part than in the cut part.

Ajinadai district in Hatsukaichi City

The roof damage states of the residential quarter in Ajina and Ajinadai, Hatsukaichi City, were investigated on the 28th April and 8th of May, on which one month passed from the earthquake occurrence. Figure 2 shows the tile-roof damage states. A red round point indicates a house observed roof damage, a brown round point a house with roof damage reported due to a questionnaire survey described later, and a blue round point liquefaction, respectively.

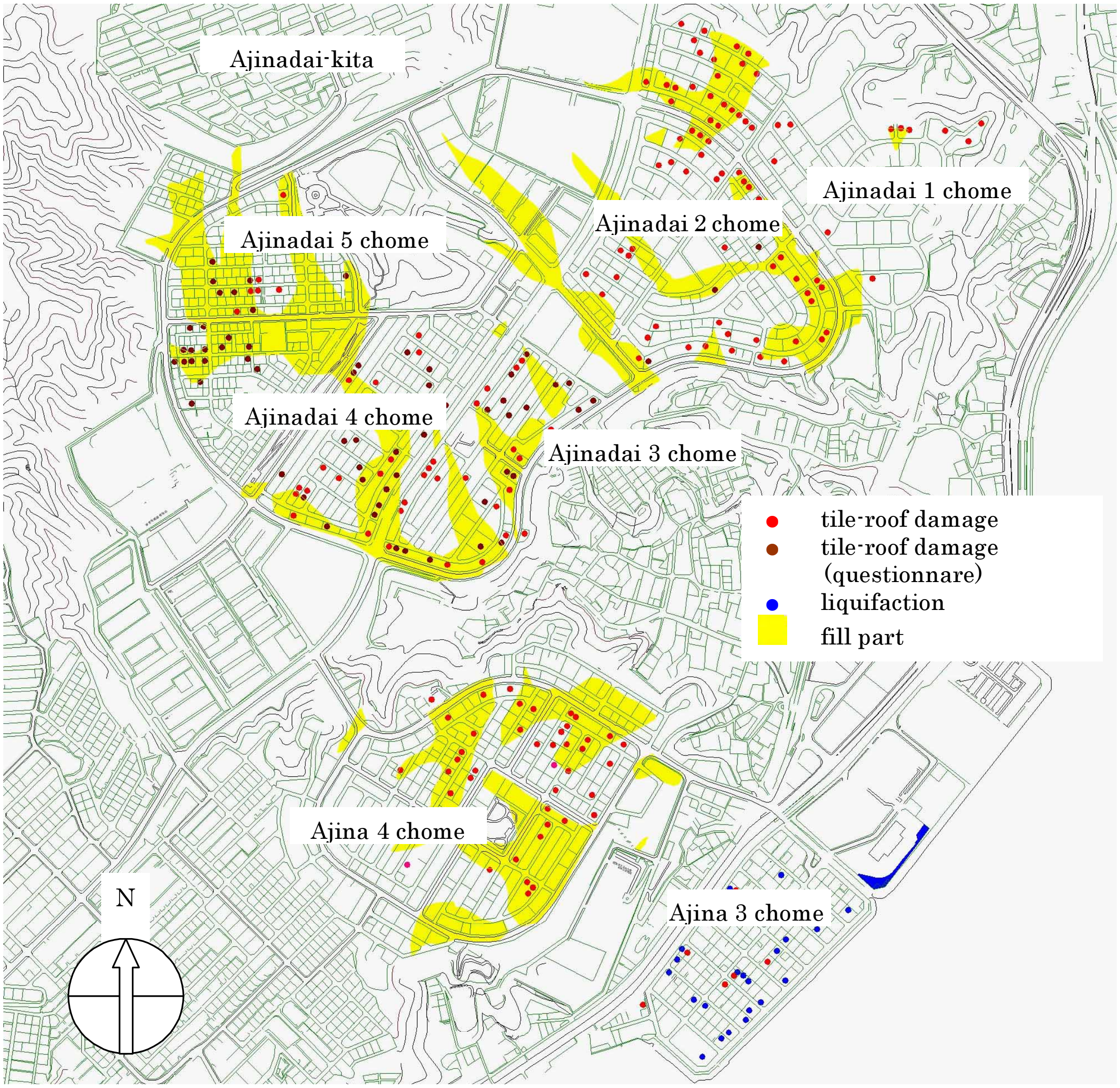


Figure 2 Housing damage state (Ajina and Ajinadai, Hatsukaichi City)

The fill of yellow area in Fig. 2 shows the results that the author distinguished the cut and fill according to difference of the altitude data of each 10m of the geographical features before and after improvement. The fill thickness is thought to be about 5-10m in average. The maximum thickness of the fill shows 20m under some circumstances. The tile-roof damage by a questionnaire and a site investigation confirmed the considerable correspondence. A lot of tile-roof damage on the fill land is obviously recognized.

HOUSE DAMAGE BY AERIAL PHOTOGRAPH AND SEISMIC INTENSITY DUE TO QUESTIONNAIRE SURVEY

Investigation method

The roof damage was examined based on the Aerial photograph taken immediately after the Geiyo earthquake (about 1/2,500 scale taken in March, 2001). Houses which had been covered with a blue waterproof seat were specified from the Aerial photograph. The questionnaire survey was executed in the region where a lot of those damage existed, and the relation between the wooden house damage and the seismic intensity was examined. The question item extracted referring to Ohta's methods [5), 6)], and the added items were included in survey sheets which related to the tile-roof damage such as the roof forms and the tile-roof damage locations. The collection ratio is 48% in 260 collections for 542 distributions in Kure City. The ratio in Ajinadai was 56% in 239 collections for 400 distributions, and in Miyauchi was 47% in 93 collections for 200 distributions.

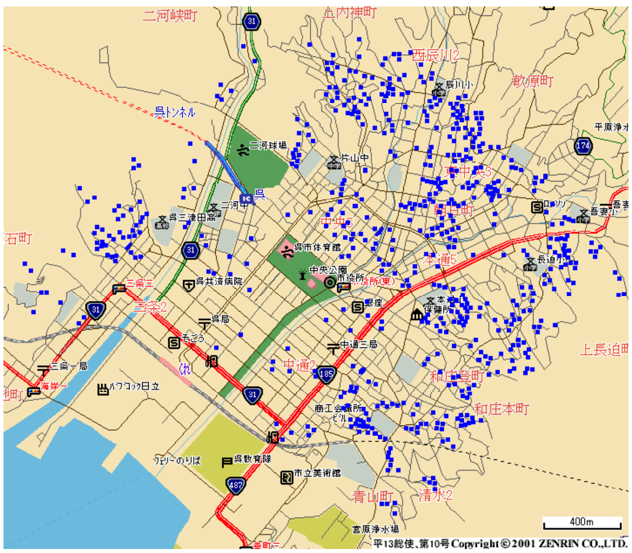


Fig. 3 Distribution of blue waterproof seat in Kure City

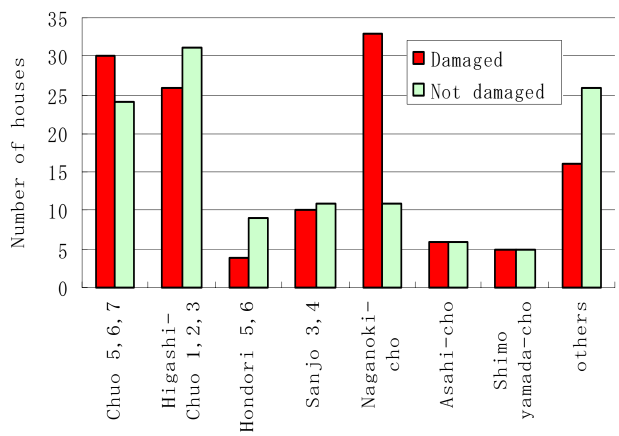


Fig. 4 Tile-roof damage of each town by the questionnaire

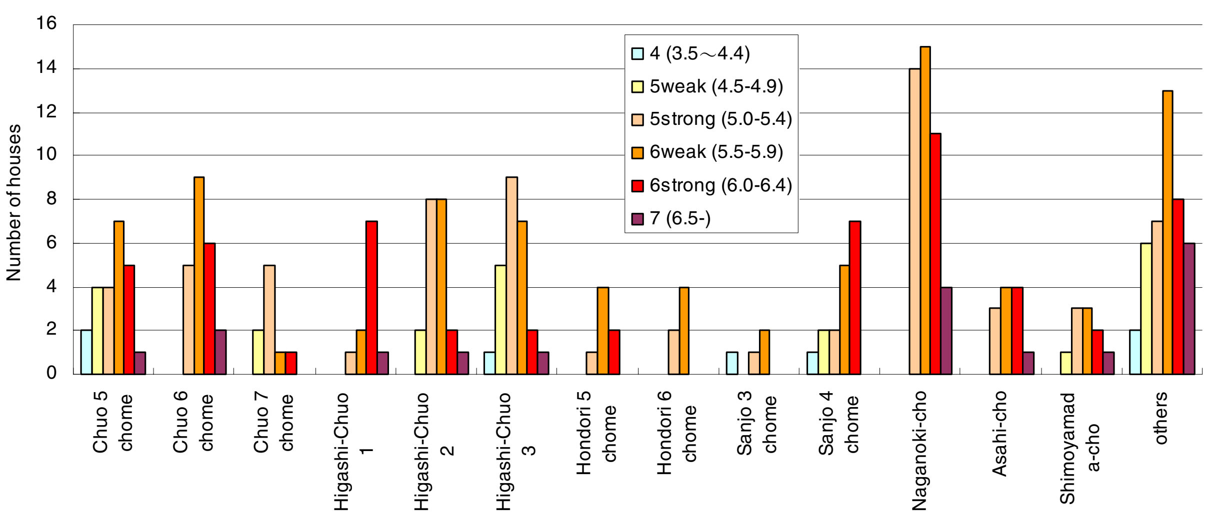


Fig. 5 Questionnaire seismic intensity in Kure City

Kure City

Figure 3 shows the distribution of the waterproof seat on damaged roof in Kure City. It is understood that there was a lot of tile-roof damage on the hill ground around the town compared with the city center. In Fig. 4, the presence of the tile-roof damage of each town by the questionnaire is summarized. From total of questionnaire seismic intensity of Fig. 5, it is understood that the seismic intensity was 5.5-6.5 and relatively high in the steep slope land which is adjacent to ridge convex. On the other hand, seismic intensity was 5.0-6.0 in seismic intensity at the city central on flat ground in which tile-roof damage does not exist. Relation of the average value of the questionnaire seismic intensity to the presence of the tile-roof damage is shown in Fig. 6. A structural condition of an individual building and a ground condition that the building is located are included in the questionnaire seismic intensity. The questionnaire seismic intensity in the house with the tile-roof damage appears is seen roughly from 5.5 to 6.0.

Ajinadai district in Hatsukaichi City

The presence of tile-roof damage of each town of Ajinadai, Hatsukaichi City is shown in Fig. 7. The questionnaire seismic intensity is shown in Fig. 8, and the relation to the average value of the questionnaire seismic intensity and the presence of the tile-roof damage is shown in Fig. 9, respectively.

The threshold intensity above which the roof-tile damage starts to appear can be between 5.5 and 6.0, which is similar to VI or less JMA seismic intensity scale. It is shown that the level by the questionnaire seismic intensity is a little increase at the place where the tile-roof damage occurs.

MICRO-TREMOR CHARACTERISTIC OF IMPROVED HILL LAND

Investigation method

From the wooden house damage states due to the 2001 Geiyo earthquake, a lot of tile-roof damage appears more in the fill part than the cut part of the improved hill. As for the feature of the damage, the 2001 Geiyo earthquake motion is predominant in the short period component and the earthquake power has not so severe. Knowing the vibration characteristic of the ground and the relation to damage is very important for the wooden damage reduction in the future. Then, the micro-tremor measurement of the ground was executed. Asada [7)] used such a technique in which the house damage risk was estimated from the micro-tremor characteristic research in the 1978 off-Miyagi Pref. earthquake.

The equipment used to the micro-tremor measurement is small size velocity meters of electromagnetic moving coil type [made by Tokyo Sokushin SM-121 (horizontal motion), and SM-122 (vertical motion); natural period for 2.0 seconds; measurement frequency 0.5Hz-50Hz]. Two kinds of micro-tremor measurement records (velocity and displacement) were selected and recorded. After recording the calibration voltage for 10-15 seconds at beginning of the measurement, the data were collected continuously for about five minutes at 0.01 seconds sampling interval. In the data analysis, about 20 seconds (2048 data) were selected, in which the shape of waves was steady and stationary, when there was no big noise in the record among five minutes. The power spectrum was analyzed, and in addition, a spectrum ratio of a horizontal element to the vertical element of the micro-tremor (hereafter, it is presented as an “H/V spectrum”) was calculated about each record of the velocity and displacement.

Damage in Ajinadai and relation to ground micro-tremor characteristic

Figure 10(a)- (c) shows the micro-tremor measurement locations selected 28 points as shown in Ajinadai crossing the fill and cut ground. The measurement points were (a) 7 places in the cut ground, (b) 2 places in the cut ground near boundary between the fill and the cut, (c) 9 places in the fill ground near boundary between the fill and the cut, and (d) 11 places in the fill ground. The micro-tremor measurement was executed at nighttime when an external noise was few. The power spectrum of the velocity record of these horizontal east-to-west component was shown in Figure 11 divided into four

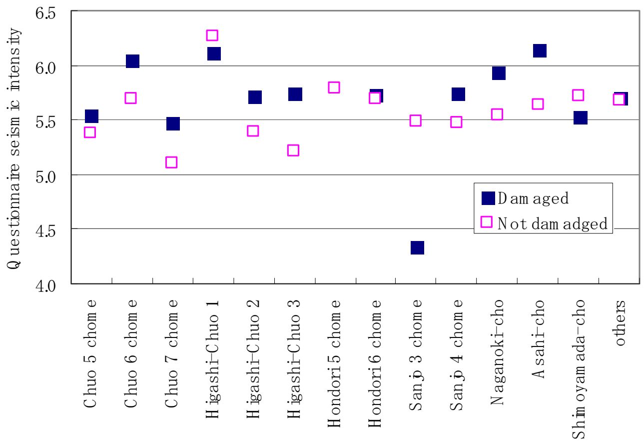


Fig. 6 Questionnaire intensity to the tile-roof damage

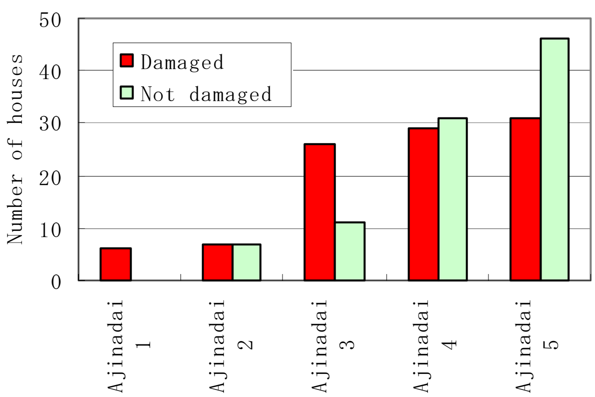


Fig. 7 Tile-roof damage of each town of Ajinadai

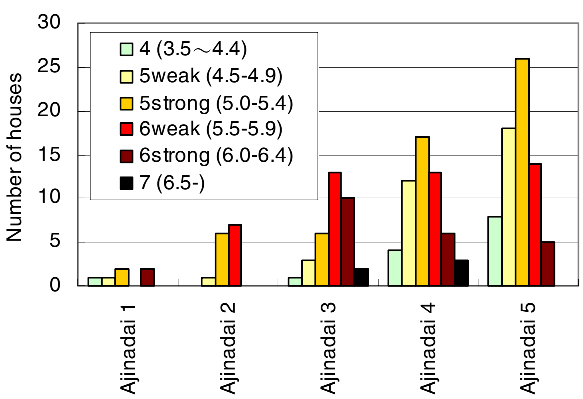


Fig. 8 Questionnaire seismic intensity

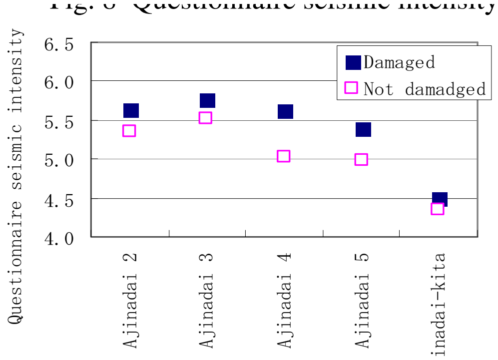
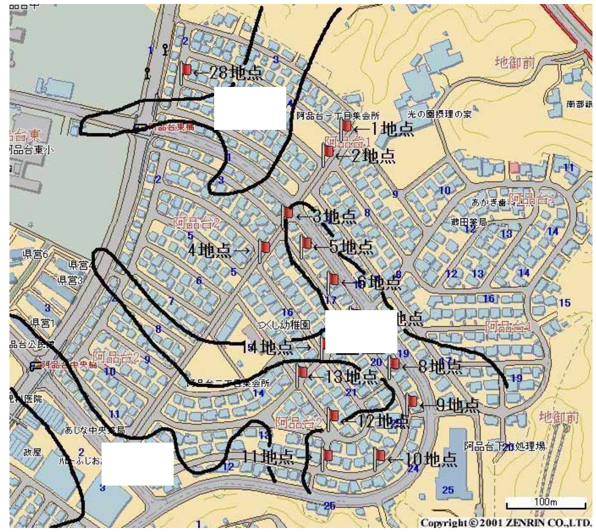
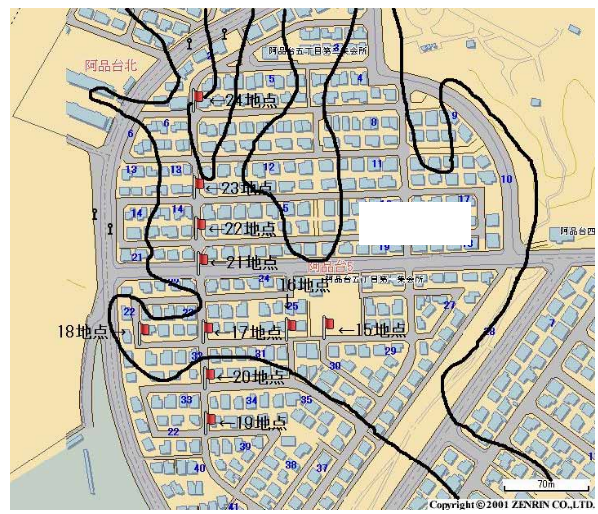


Fig. 9 Questionnaire intensity to the tile roof damage



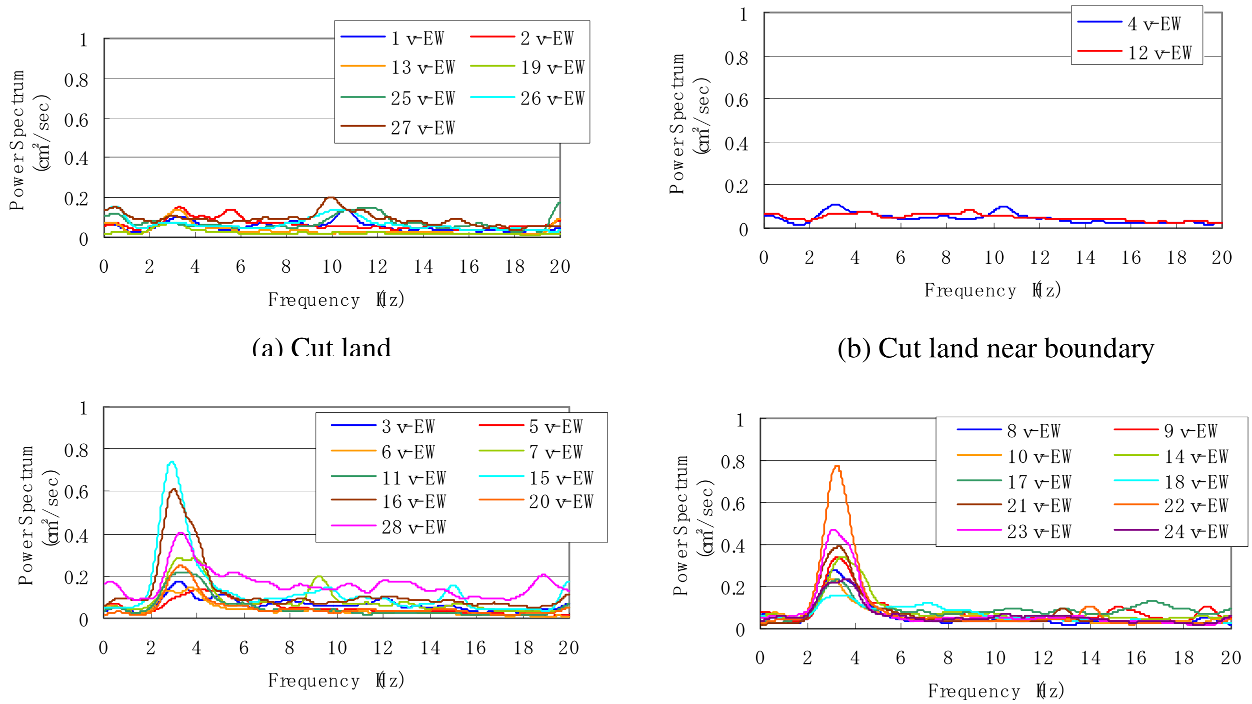
(a)



(b)

(c)

Fig. 10 Measurement locations in Ajinadai categories, correspond to the type of the ground, respectively. The first figure such as "1v-EW" shows the micro-tremor measurement point number in Figure 10, and "v" means a velocity record, and "EW" is an east-to-west component (Hereafter, Figures 12 and 13 are also similar).



(a) Cut land

(b) Cut land near boundary

(c) Fill land near boundary

(d) Fill land

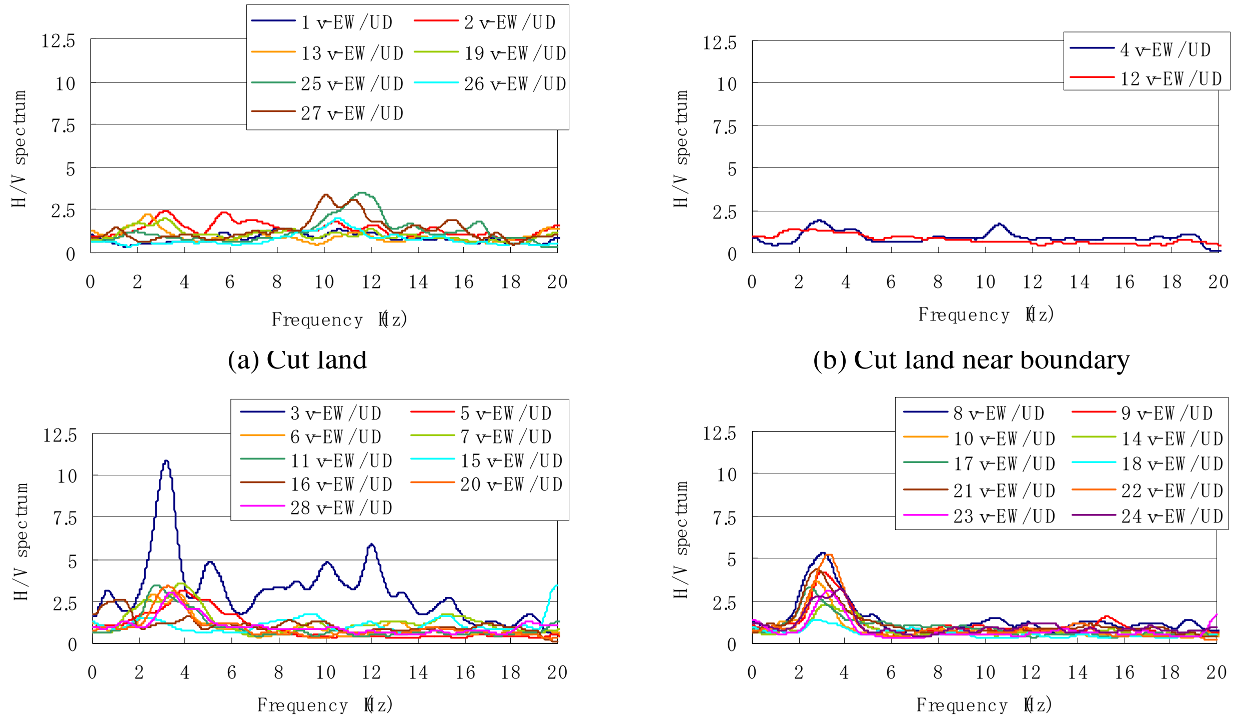
Fig. 11 Power spectrum of the velocity record of these horizontal east-to-west component

An H/V spectrum (a ratio of horizontal spectrum to vertical one) based on the micro-tremor measurement is found to have clearly different characteristics between the fill part and the cut part in the improved hill ground, as shown in Fig. 12. Moreover, about 3Hz in frequencies of the fill ground was predominant, and it is so considerably near the natural vibration of wooden houses that it be possible to relate with the amplification of vibration by the resonance. This ground vibration property corresponds to larger roof-tile damage of wooden houses in fill ground on improved hills.

As mentioned above, it has been understood that a spectrum and spectrum ratio characteristics have the pattern by which each feature correspond to four categories dividing by cut and the fill. Moreover, a south-to-north component showed the tendency which roughly looked like the east-to-west component. However, those features may relate old geographical features before improvement of housing lot.

Damage in Koi-ue and relation to ground micro-tremor characteristic

The micro-tremor measurement was executed at seven points, shown in Fig. 1, at the daytime on Koi-ue 5 chome district, Hiroshima City. An H/V spectrum is shown in Fig. 13. The a, b, and c in explanatory notes show the results of several measurements at the same point, thus they designate the difference of the spectrum. Although Koi-ue district has a little complicated geographical features between cut and fill, micro-tremor characteristic has the harmonized result with Ajinadai. The predominant frequency of H/V spectrum of the velocity record of the micro-tremor is 3-4Hz in a fill part of the ground where comparatively a lot of tile-roof damage is observed. On the other hand, the vibration characteristic at the site in cut ground is almost flat in frequency range about from 0.5Hz to 20Hz.



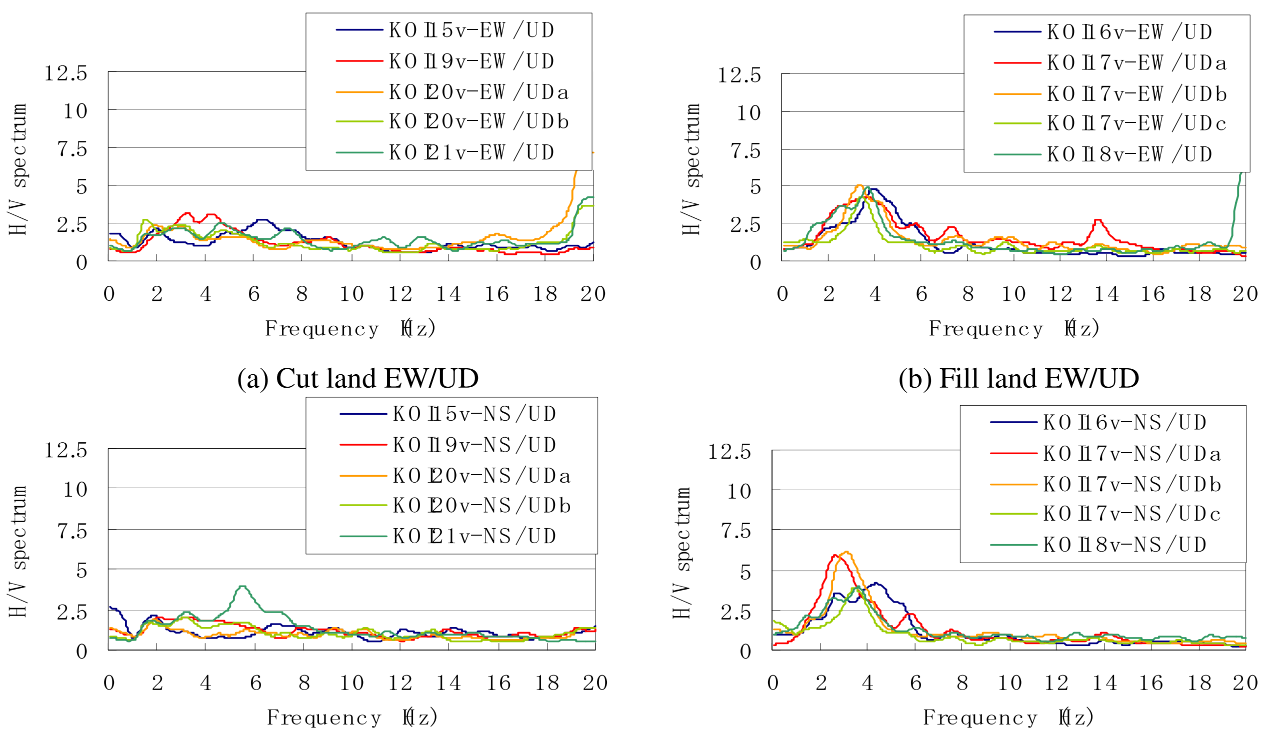
(a) Cut land

(b) Cut land near boundary

(c) Fill land near boundary

(d) Fill land

Fig. 12 H/V spectrum based on the micro-tremor measurement in Ajinadai district



(a) Cut land EW/UD

(b) Fill land EW/UD

(c) Cut land NS/UD

(d) Fill land NS/UD

Fig. 13 H/V spectrum based on the micro-tremor measurement in Koi-ue district

Even in the H/V spectrum also measured by the displacement record, almost the same tendency as the velocity record was obtained. The reliability of data is confirmed by which the influence of the presence of the noise between the velocity and displacement records. A clear difference of the characteristics by the observation in both the south-to-north and east-to-west direction was not seen. As mentioned above, the H/V spectrum tends to be almost flat at sites in the cut ground, except a little predominant frequency in about from 10Hz to 12Hz range. On the other hand, the H/V spectrum has a clear peak in about 3Hz in the fill ground, and it is understood to have combined vibration characteristics of both ground in the vicinity of boundary between the cut and fill. Thus, the difference between the cut and fill appears to the characteristic of the H/V spectrum.

Based on survey of the data base on a wooden building[8)], the average value of natural periods was between 0.3-0.4 seconds through many two-story wooden houses in conventional frame method in many cases. The standard deviation through conventional frame houses is as considerably large as 0.2 seconds. The predominant frequency in the fill is near the natural frequency of a wooden house, and it is possible that the vibration amplification by the resonance caused the tile-roof damage of a wooden house. In the future, it is necessary to examine the relation to the damage and the vibration property of buildings for site predominant frequency. Although the judgment of the cut and fill has done from the comparison of the topographical maps before and after the improvement in this time, the detailed judgment of the cut and fill has more difficult especially on a terrace type in the improved land because it is not smooth. There must be a useful tool for the damage measures of houses on the improved hill, if the correspondence of the micro-tremor characteristics to the earthquake damage will make clear.

CONCLUSIONS

This paper presents the relation between roof-tile damage of wooden houses and ground shaking intensity by the 2001 Geiyo earthquake, Japan. The roof-tile damage of wooden houses caused by the Geiyo earthquake was surveyed at residential districts in and near the western part of Hiroshima City, Koi-ue, Nishi-Ward, and Ajinadai, Hatsukaichi City. Also questionnaire investigation for housing damage and ground shaking intensity was developed in Kure City and Ajinadai. Furthermore, a micro-tremor measurement technique was employed to investigate ground vibration property. The results are as follows:

1) From the wooden house damage states due to the 2001 Geiyo earthquake, a lot of tile-roof damage appears more in the fill part than the cut part of the improved hill.

2) The region where a lot of tile-roof damage existed was extracted from the Aerial photograph, and the questionnaire sheet by the Ohta's method was distributed to wooden house residents in Kure City and Ajinadai, Hatsukaichi City. From the investigation results, the larger questionnaire seismic intensity appears in the fill land on the improved hill and in the vicinity of the boundary between the hill and the alluvial soil ground. The tile-roof damage has revealed in those areas. Moreover, the seismic intensity was large from the foot to the ridge on the hill ground in Kure City, and a lot of damage also appeared. The threshold intensity above which the roof-tile damage starts to appear can be between 5.5 and 6.0, which is similar to VI or less JMA seismic intensity scale. The level by the questionnaire seismic intensity is a little increase at the place where the tile-roof damage occurs.

3) An H/V spectrum (a ratio of horizontal spectrum to vertical one) based on the micro-tremor measurement is found to have clearly different characteristics between the fill part and the cut part in the improved hill ground. Moreover, about 3Hz in frequencies of the fill ground was predominant, and it is so considerably near the natural vibration of wooden houses that it possibly relates with the amplification

of vibration by the resonance. This ground vibration property corresponds to larger roof-tile damage of wooden houses in fill ground on improved hills.

ACKNOWLEDGEMENT

This research was supported in part by the Grant-in-Aid for Scientific Research (Special research promotion expense (1)) "An integrated research on the urban earthquake disaster due to the Geiyo earthquake in 2001" (the research number: 13800001 and the research representative; Takahiro Nakayama, Dr. of Engineering, Professor of Hiroshima Institute of Technology). Residential map Zmap-TOWN II used here had the offer from (Inc.) Zenrin. Moreover, the investigation, the measurement, and the analysis of this research are due to many students of Hiroshima Institute of Technology, Department of Civil and Architectural Engineering; Hidekazu Ozaki, Koji Ishida, Shin-ichi Ohmori, Yosuke Kaihara, Masashi Shintani, Mitsutaka Abe, Tetsuo Miyabe, Naohisa Hiraishi, Noriko Yamashiro, Toyomitsu Harada, Shuta Yagi and Kazuyuki Okamoto. We wish to express our gratitude of deep.

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