Fill-Depths Estimation of Developed Hill Area Using GIS and the Predominant Frequency of the Ground Caused Housing Damage

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SUMMARY:
This study presents the relationship among fill-depths of a developed residential hill area, earthquake housing damage and the micro-tremor property of the site. Using GIS (Geographic Information Systems), the improved hill ground is classified into three parts, those are fill, cut and boundary area between the cut and fill. Vertical soil thickness of fill or cut part was analyzed by using the contour information extracted from the old topographical map before developing and the present residential area-map at the earthquake. GIS tools of TIN and GRID generation technique are effective to obtain the altitude drop before and after the land development. Moreover, an H/V spectrum, as a ratio of Horizontal spectrum to Vertical one, is compared, based on the micro-tremor measurement. The damage to wooden houses due to the earthquake is strongly related to the predominant frequency of the developed hosing site.

Keywords: fill, wooden house damage, GIS, micro-tremor measurement, the 2001 Geiyo Earthquake

1. INTRODUCTION

On March 11th, 2011, in Japan, in coastal areas the damage caused by a huge tsunami was very serious by the East Japan great earthquake disaster. In inland areas, landslide failures also occurred extensively on the residential ground developed for housing in the Tohoku district and the Kanto district, where the JMA (Japan Meteorological Agency) seismic intensity showed V or more (very strong; equivalent to 8 or 9 on the Modified Mercalli scale).

In west Japan, an outbreak of Magnitude 8- or over-class earthquake along the Nankai trough is concerned in the near future, and the inland active fault earthquake, whose outbreak probability is low, but it brings serious damage when it occurs. In the Chugoku district of west Japan, there exists much land developed for housing, filled valleys or former river channels. Furthermore, the weathered granite is distributed over the inland widely, and a lot of hazardous areas caused by a heavy rain and an earthquake exist. Therefore it is necessary to raise disaster prevention or mitigation consciousness for the damage in the land developed for housing.

On March, 2001, the Geiyo Earthquake which measured Magnitude 6.7 on the Richter scale shook the Seto Inland Sea area expanding from Chugoku and Shikoku in west Japan. The maximum acceleration was recorded over 1,000 cm/s^2, but damages to building and other urban facility were not so severe, because the focal depth was deep as about 50 kilometers, and the predominant period of earthquake vibration was relatively short [Architectural Institute of Japan (2001)]. However, the damage to the tile-roofs of Japanese conventional-style wooden houses occurred more widespread among wooden houses on the fill part of improved hills rather than the cut part. 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 districts of Hatsukaichi City, as the same as Koi-ue district in Hiroshima City.

2. RELATION BETWEEN WOODEN HOUSE DAMAGE AND IMPROVED LAND ON HILL GROUND

2.1 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 1 shows the tile-roof damage states [Iwai, S. and Asano, T. (2002, 2004)]. A red small round point indicates a house observed roof damage, a brown round point a house with roof damage reported due to a questionnaire survey, and a blue round point liquefaction occurrence, respectively.

The fill part of yellow area in Fig. 1 shows the results that Asano, T. (2002) 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.

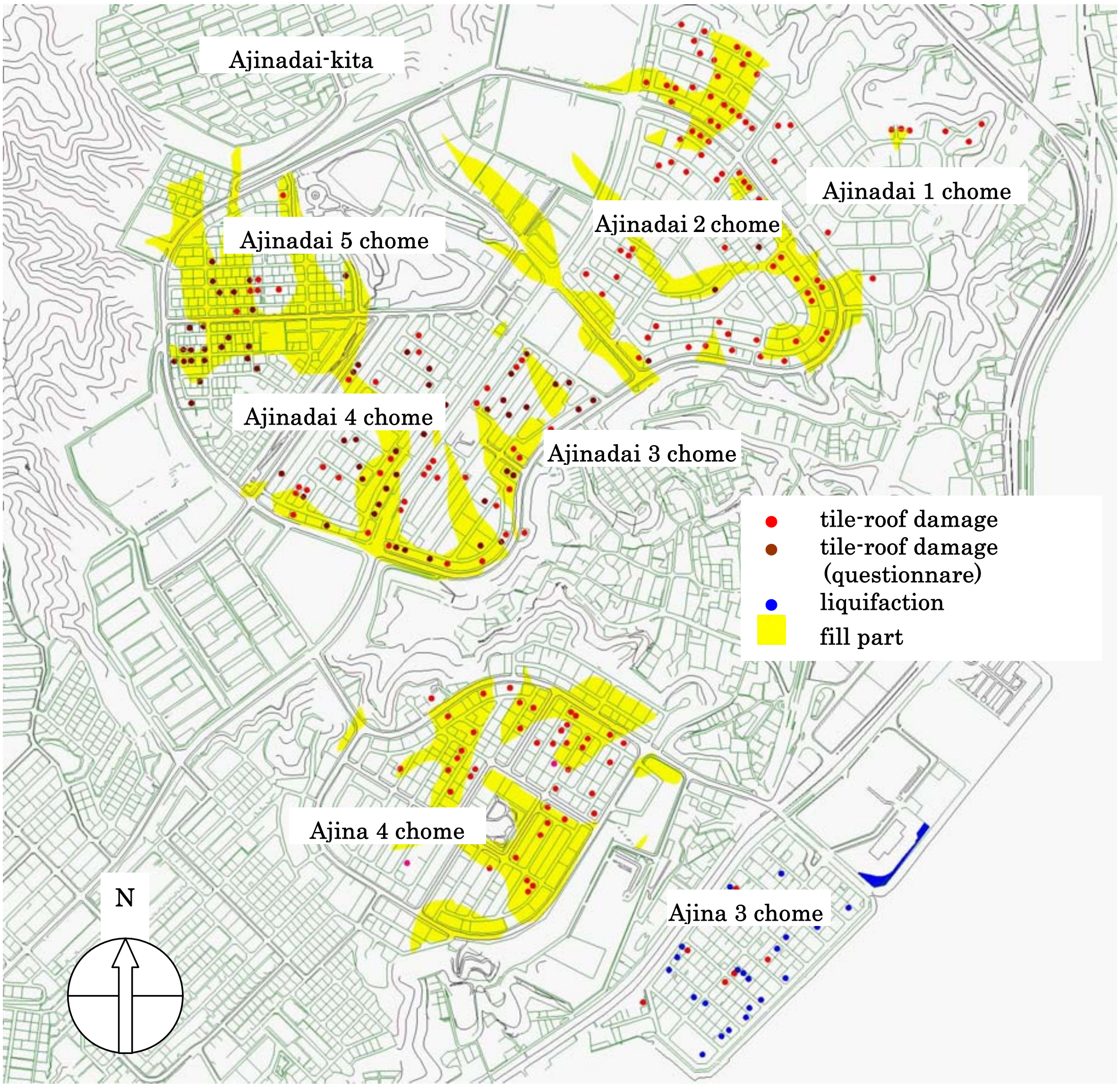


Figure 1 Housing damage state (Ajina and Ajinadai, Hatsukaichi City)

2.2 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 4th of about ten days after the earthquake occurrence. Figure 2 shows the housing damage state [Iwai, S. and Asano, T. (2002, 2004)]. The red small 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 at the earthquake. 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 retaining wall, and damage is caused by the crack and the collapse of the retaining wall. The classification of the cut and the fill ground in the Koi-ue district was shown in Figure 2. A lot of tile-roof was damaged also in the fill part than in the cut part.

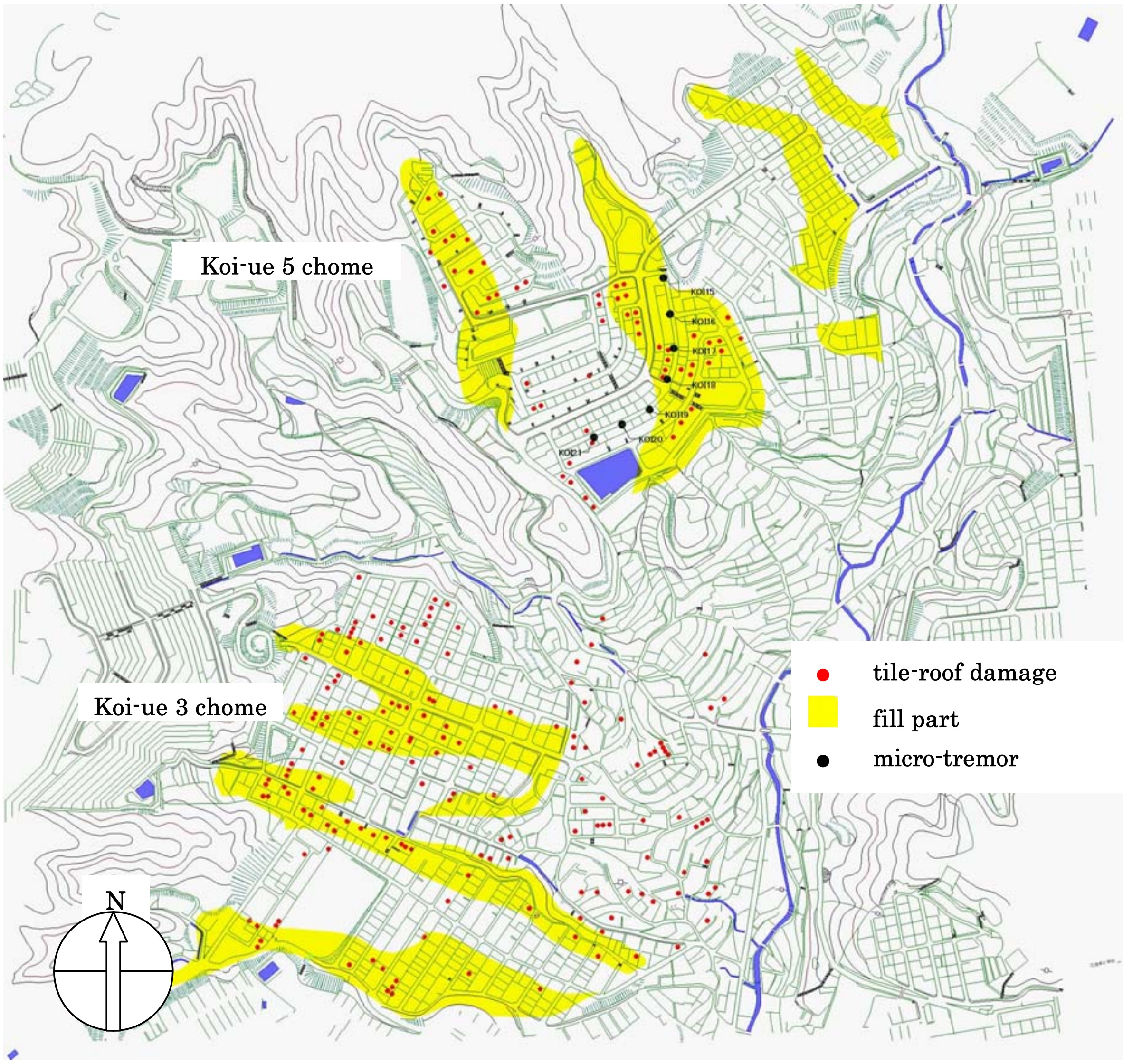
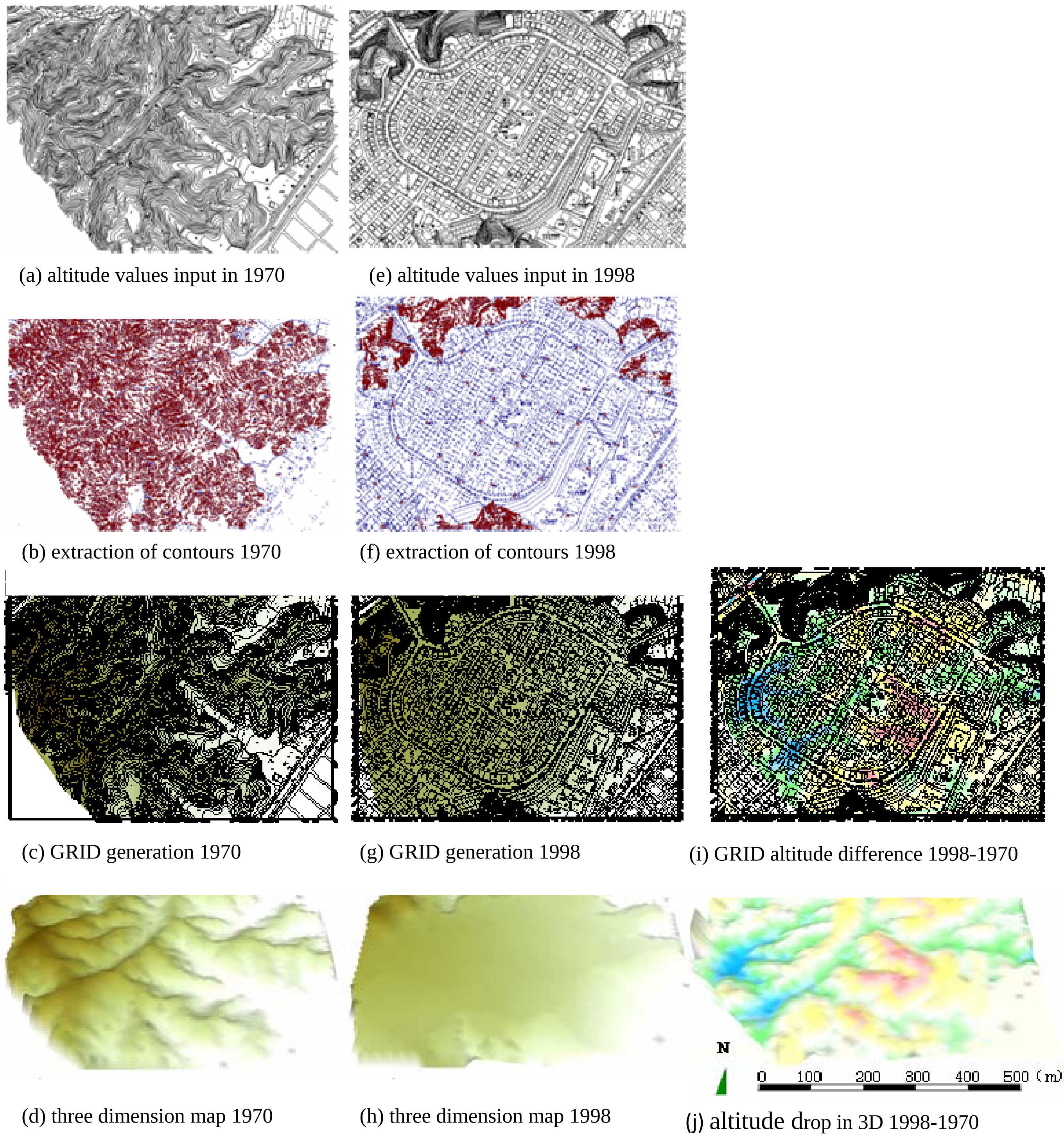


Figure 2 Housing damage state (Koi-ue, Nishi Ward, Hiroshima City)

3. CLASSIFICATION OF CUT AND FILL GROUND USING GIS TECHNIQUE

3.1 Used City Map Information

The developed land for housing is classified as either a fill part, or a cut part from a topographical map, based on GIS (Geographic information systems) technique. Not only the zonation of the reclaimed fill area and the cut area but also each altitude difference of fill and cut were analyzed in detail by using the contour data extracted from the old topographical map before developing and the present (new) map after developing at the earthquake. It became possible to evaluate quantitatively the cause of the earthquake disaster in the residential fill lands by preparing the classified data of the fill and cut area with new and old elevation value in every each land developed for housing area. Accuracy of the altitude drop depends on a figure of topography map. The information of the altitude topography was taken from City planning maps in 1/2,500 scale with contour lines at intervals of 2 meters and the



(a) altitude values input in 1970
(e) altitude values input in 1998
(b) extraction of contours 1970
(f) extraction of contours 1998
(c) GRID generation 1970
(g) GRID generation 1998
(i) GRID altitude difference 1998-1970
(d) three dimension map 1970
(h) three dimension map 1998
(j) altitude drop in 3D 1998-1970

Figure 3 Making procedure to classify cut and fill ground (in case of Ajina, Hatsukaichi City) [Iwai, S. and Kandori, K. (2006)]

topography in 1/25,000 scale with contour lines at 10 meters. Two pieces of map in 1970 and three pieces in 1998 were presented from Hatsukaichi-city office. In case of Koi-ue, Hiroshima-city, maps in 1962 and 2003 (DM; Digital Maps) were used.

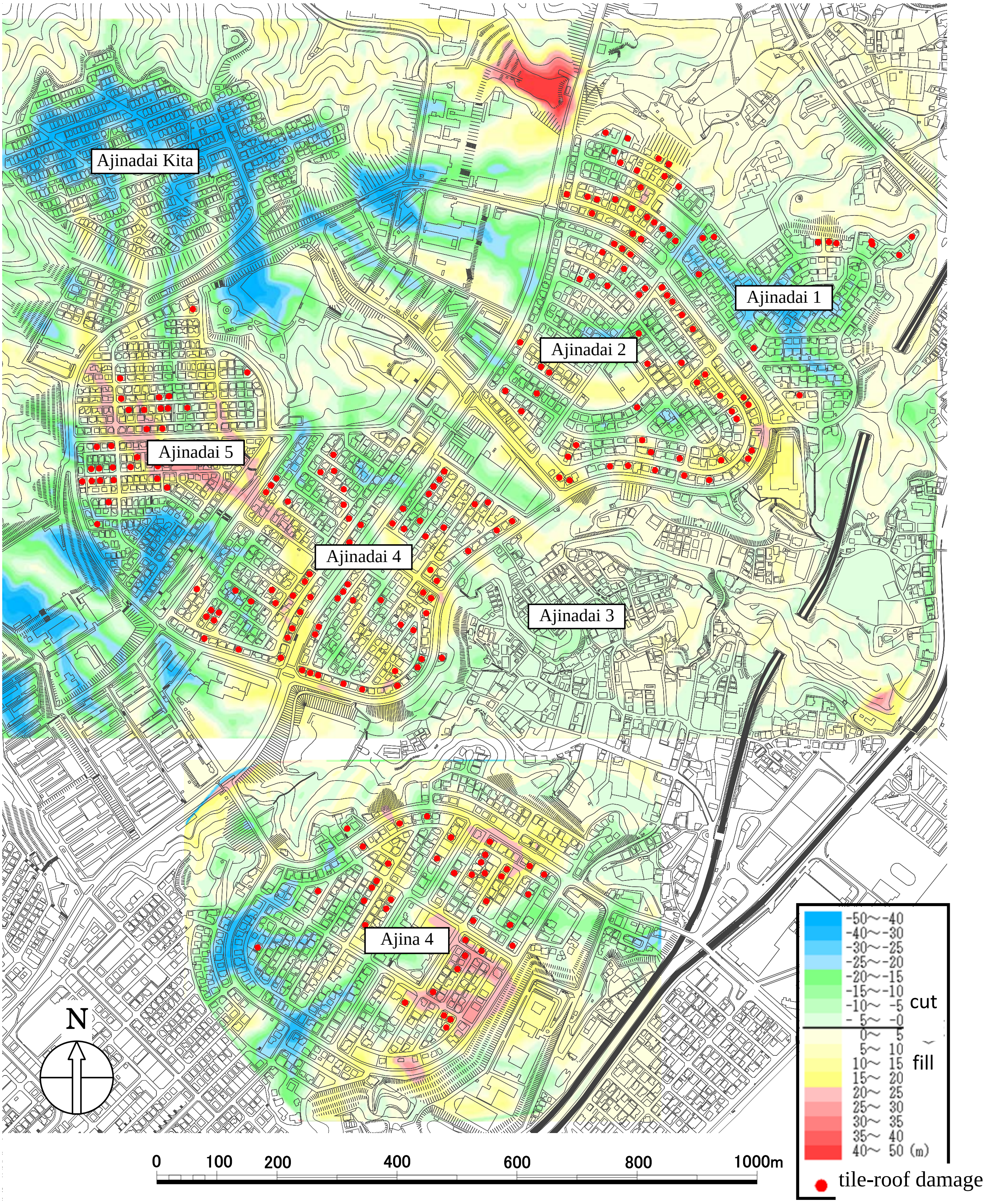


Figure 4 Fill-depth and cut-height coloring based on GIS estimation and tiled roof damage of houses at developed hill residential area (Ajina and Ajinadai, Hatsukaichi City)

3.2 Land Classification Procedure

Making procedure to classify cut and fill ground is shown in Fig. 3 [Iwai, S. and Kandori, K. (2006)] from the top to the bottom. (1) Scanner-reading data of topographical (analog) maps before and after the housing development were converted into vector data for the DWG (**d**ra**w**in**g**) file, which is the standard file format of the CAD. All the altitude values were inputted into each contour line data directly (Fig. 3(a), (e)). (2) For input of the altitude value, CAD software was used (AutoCAD; Autodesk Inc.). A lot of things such as a house or a road irrelevant to altitude are included as line data in the map, so it is necessary to remove them to analyze the topography. Therefore a processing program with Microsoft Visual Basic was made to remove the data without altitude information (height 0) and only the altitude data was extracted (Fig. 3(b), (f)). (3) The extracted data has a text format data of X- and Y-coordinate of the map position from the plane right-angled coordinate systems, and the Z-coordinate of the altitude inputted. The DWG file which finished coordinate input (X, Y and Z) by the CAD was converted into DXF (Drawing Interchange File) which is a text format. The DXF can be analyzed as a readable text by another program. (4) Using the Windows version GIS (SIS; Spatial Information System, Informatix), these data are divided into a GRID (lattice) data of every coordinates at an equal interval with altitude about an arbitrary area before and after the land development. The GRID is made by interpolation method as the function of the GIS (Fig. 3(c), (g)). A GIS tool-TIN (the network domain of the Triangulated Irregular Network) Interpolation method is employed. TIN generates GRID altitude from a point as an unknown value at a triangular internal point in the lattice generation from neighborhood points. (5) The difference of the altitude before and after the land development from the GRID data was used to distinguish cut or fill ground (Fig. 3(d), (h), (j)). Figs. 4 and 5 show fill-depth and cut-height coloring, based on GIS estimation, and tiled roof damage of houses at developed hill residential area. The damage to the tiled roofs of conventional Japanese-style wooden houses was more prevalent among wooden houses on the fill part of improved hills rather than the cut part, as shown in Figs. 6 and 7.

Figure 5 Fill-depth and cut-height coloring based on GIS estimation and tiled roof damage of houses at developed hill residential area (Koi-ue, Nishi Ward, Hiroshima City)

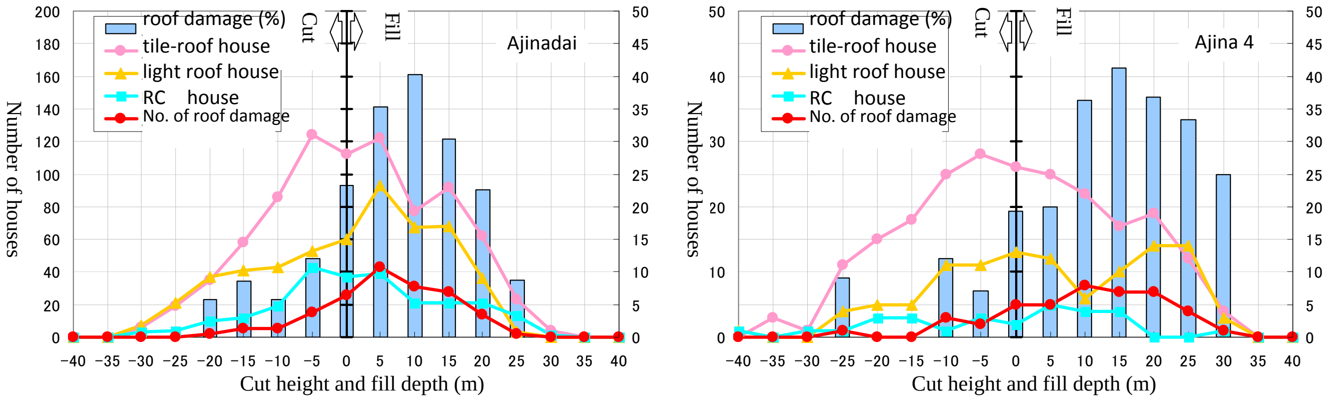


Figure 6 Cut and fill soil thickness and the tiled roof damage ratio
(Ajina and Ajinadai, Hatsukaichi City)

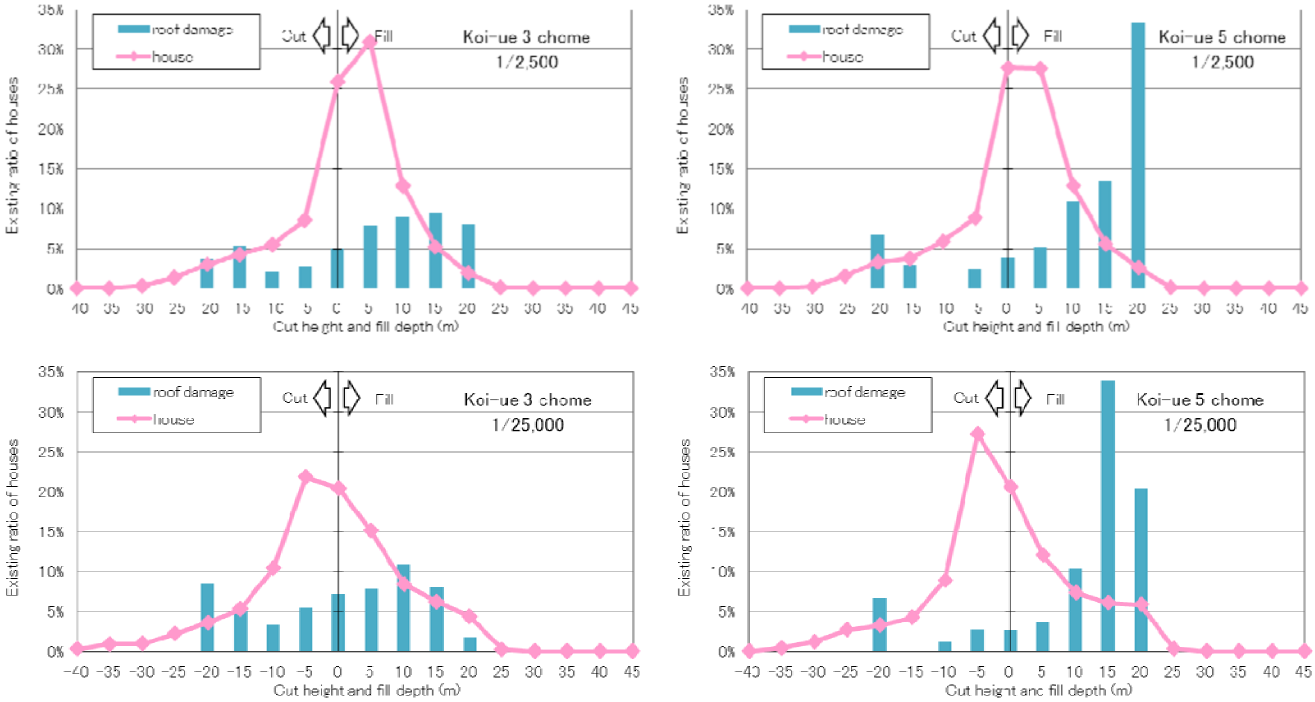


Figure 7 Cut and fill soil thickness and the tiled roof damage ratio
(Koi-ue, Nishi Ward, Hiroshima City)

4. MICRO-TREMOR CHARACTERISTIC OF IMPROVED HILL GROUND

4.1 Micro-Tremor Measurement 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 ground motion is predominant in the short period component and the shaking power has not so severe. Knowing the vibration characteristic of the ground and the relation to wooden house damage is very important for the damage reduction in urban area for the future. Then, the micro-tremor measurement of the ground was executed. The 24 micro-tremor measurement spots were selected in Ajina area crossing the fill and cut ground. The measurement was executed at (a) 9 spots on the cut ground, (b) 2 spots on the ground near boundary area between the fill and the cut, and (c) 13 spots on the fill.

The equipment used to the micro-tremor measurement is small size velocity meters of electromagnetic moving coil type [made by Tokyo Sokushin Co., Ltd SM-121 (horizontal motion), and SM-122 (vertical motion); natural period for 2.0 seconds; measurable frequency 0.5Hz-50Hz]. Two kinds of micro-tremor measurement records (velocity and displacement) can be selected and recorded. After recording the calibration voltage for 10-15 seconds at beginning of the measurement, the data were collected continuously during about five minutes at 0.01 seconds sampling interval. In the data analysis, five sets of about 20 seconds data (2,048 data) were taken, in which the shape of waves was steady and stationary, when there was no big noise in the record. 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.

4.2 Ground Micro-Tremor Characteristic of Improved Hill and Relation to Housing Damage

The power spectrum of the velocity record of these horizontal east-to-west (EW) component and north-to-south (NS) component were analyzed shown in Fig. 8, corresponding to the type of the ground, respectively [Iwai, S. (2008)]. The power spectrum is displayed by the order of the ground depths (unit in meters) in turn from the left to the right. 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. The vibration characteristic at the site on cut ground is almost flat in frequency range about from 0.5Hz to 20Hz, except a little predominant frequency from 14Hz to 18Hz range. On the other hand, the H/V spectrum has a clear peak in about 3Hz on the fill ground. It is understood to have combined vibration characteristics of both ground in the boundary area between the cut and fill. Thus, the difference between the cut and fill appears to reveal the characteristic of the H/V spectrum. As mentioned above, it has been understood that a spectrum and spectrum ratio characteristics have the pattern by which each feature correspond to three categories dividing by (1) the cut, (2) the fill and (3) their border area. Moreover, a south-to-north component showed the tendency that roughly looked like the east-to-west component. Those features may relate old geographical features before improvement of housing lot. Predominant frequency of surface soil known as "1/4 wave length" law tends to correspond with this result.

5. THE RELATIONSHIP BETWEEN FILL-DEPTHS AND EARTHQUAKE DAMAGE OF HOUSING IN A DEVELOPED HILL RESIDENTIAL AREA

The altitude (vertical) drop of the cut or fill ground affects the tiled roof damage of houses, as shown in Figs. 4 and 5. Many tiled roof damage of wooden houses by the 2001 Geiyo Earthquake appeared in the fill ground area, where the predominant frequency shows low and does not reach to 3Hz, as shown in Fig. 9. On the other hand, the tiled roof damage was not seen in the cut area where high predominant frequency is obtained as to exceed 10Hz. The vertical drop of the cut and fill ground affects predominant frequency of the ground, and it is possible that the difference of the predominant frequency of the ground influenced the tiled roof damage of the house. Moreover, about 2-4Hz 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. Based on survey of the data base on a wooden building, the average value of natural periods was between 0.3-0.4 seconds through many two-story wooden houses of conventional Japanese-style frame construction 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 tiled roof damage of a wooden house.

The damage of the wooden houses appears in the fill soil area by the earthquake, where predominant frequency is comparatively low and it does not reach to 3Hz. On the other hand, the house damage does not appear in the cut soil area where the predominant frequency is relatively high as to exceed 10Hz. The altitude drop of the cut and fill affects predominant frequency of the ground, and it is possible to estimate the damage of the house influenced to the ground vibration characteristics.

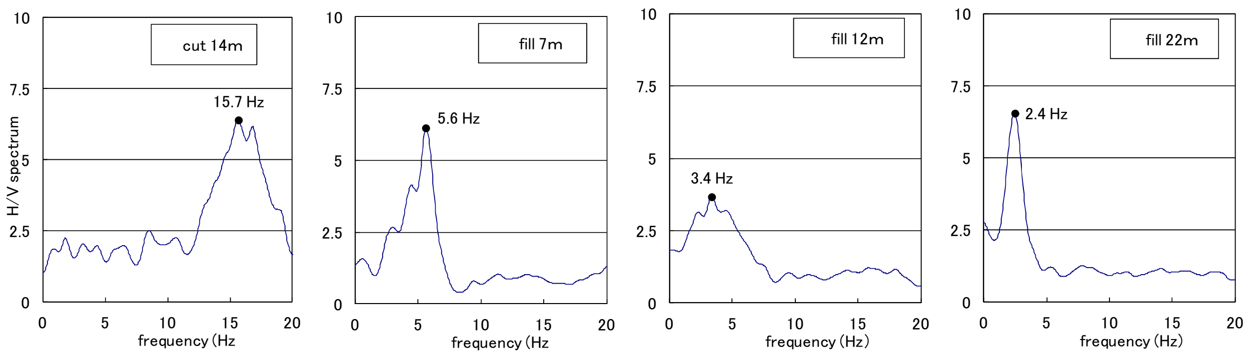


Figure 8 H/V spectrum of velocity record of horizontal to vertical component against fill or cut soil thickness and the predominant frequency [Iwai, S. (2008)].

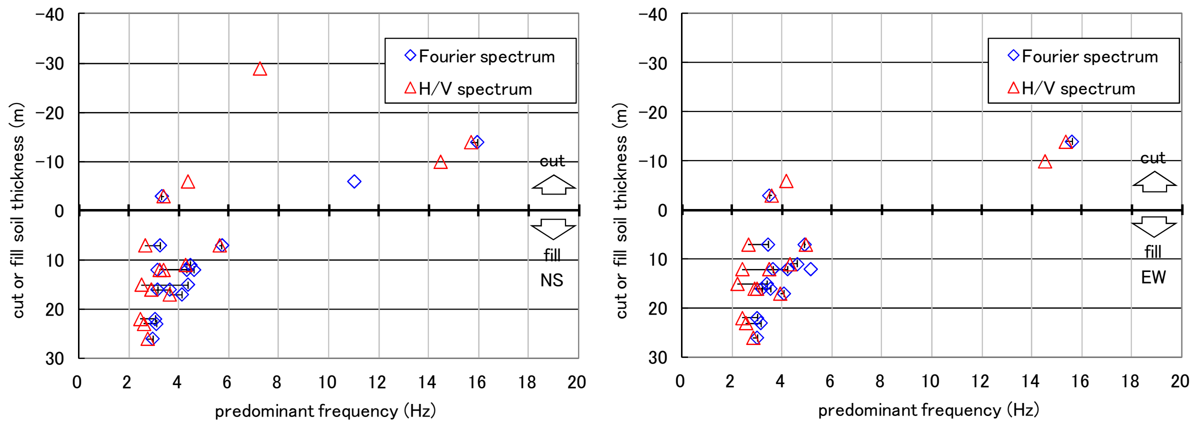


Figure 9 The relationship between fill or cut soil thickness based on GIS estimation, and predominant frequency of the ground in a developed hill residential area.

6. CONCLUSIONS

1) The developed area is classified as either a fill part or a cut part, based on GIS. Not only the zone classification of the reclaimed fill area and the cut area but also each vertical soil thickness of fill and cut part can be analyzed in detail by using the contour data extracted from the old topographical map before developing and the present map at the earthquake. The altitude information is used effectively to extract contour lines from irrelevant data to altitude in detail with 1/2,500 scale maps, or roughly with 1/25,000 scale maps. GIS tools of TIN and GRID generation technique are effective to obtain the altitude drop before and after the land development.

2) The tiled roof damage of wooden houses by the Geiyo Earthquake in 2001 occurred largely in fill ground part or the border ground area from vertical drop +5m to -5m, and on the other hand, the outbreak of the tiled roof damage tended hardly to be seen in the cut part of the ground.

3) In the fill ground and the border area between the cut and fill ground, remarkable predominant frequency is obtained from H/V spectrum based on the micro-tremor measurement. The predominant

frequency shows about 2-4Hz at a fill ground depth of 0-20m, and it shows low not to reach over 3Hz in the area with more than 20m depth of the fill ground. It is recognized that predominant frequency tends to be low as the vertical drop (thickness) of the fill ground increases. The border area between the cut and fill with a vertical drop of ±5m has about 4Hz in frequency range. The predominant frequency is slightly high compared with the one of the fill ground. The predominant frequency does not have clear peak in H/V spectrum on the cut ground area with a vertical drop more than 20m. In some cases, the predominant frequency is very high to exceed 14Hz at a vertical drop of 5-20m in the cut area.

4) The damage of the wooden houses appears in the fill soil area by the earthquake, where predominant frequency is comparatively low and it does not reach to 3Hz. On the other hand, the house damage does not appear in the cut soil area where the predominant frequency is relatively high as to exceed 10Hz. The altitude drop of the cut and fill affects predominant frequency of the ground, and it is possible to estimate the house damage influenced to the ground vibration characteristics.

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