THE RELATIONSHIP BETWEEN FILL-DEPTHS BASED ON GIS ESTIMATION, EARTHQUAKE DAMAGE AND THE MICRO-TREMOR PROPERTY OF A DEVELOPED HILL RESIDENTIAL AREA

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ABSTRACT :

Following the 2001 Geiyo earthquake, which measured 6.7 on the Richter Scale, a lot of damage to the tiled roof of wooden houses occurred. This damage was more prevalent among houses in the fill part of the hillside, rather than the cut part. The developed area is classified as either a fill part, or cut part, based on GIS (Geographic information systems) technique. Based on the micro-tremor measurement of the ground, the ratio of the horizontal spectrum to the vertical spectrum, known as H/V, was investigated. The H/V ratio reaches a peak of approximately 2-4Hz in the fill part, but it has no predominant frequency on the cut part. It is probable that the damage done to houses with tiled roofs following the 2001 Geiyo earthquake is strongly affected to the H/V predominant frequencies found in the developed hill residential area.

KEYWORDS: Geographic Information Systems, fill, cut, micro-tremor measurement, predominant frequency, the 2001 Geiyo earthquake

1. INTRODUCTION

This study presents the relationship between fill-depths, earthquake damage and the micro-tremor property of a developed hill residential area. On March 24th, 2001, at 3:28 PM, the Geiyo Earthquake which measured Magnitude 6.7 on the Richter scale, 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 the 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 1,000 cm/s^2 or more, 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. However, the damage to the tile-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.

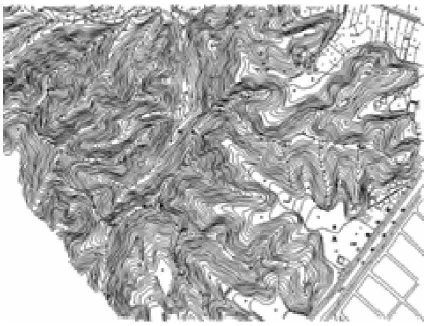
The developed area is classified as either a fill part, or cut part, based on GIS (Geographic information systems). Not only the zonation of the reclaimed fill area and the cut area but also each vertical soil thickness of fill and cut part were analyzed in detail by using the contour data extracted from the old topographical map before developing and the present map at the earthquake. The residential fill lands as topographical features to the earthquake hazards were revealed.

Furthermore, in order to investigate ground vibration property, a micro-tremor measurement technique was employed. A ratio of the horizontal spectrum to the vertical spectrum, known as H/V, reaches a peak of approximately 2-4 Hz in the fill part. However, it has no predominant frequency on the cut part. It is concluded that the damage done to houses with tile-roofs following the 2001 Geiyo Earthquake is strongly related to the predominant H/V frequencies and the fill depths found in the housing site.

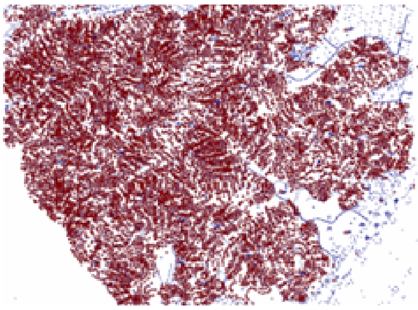
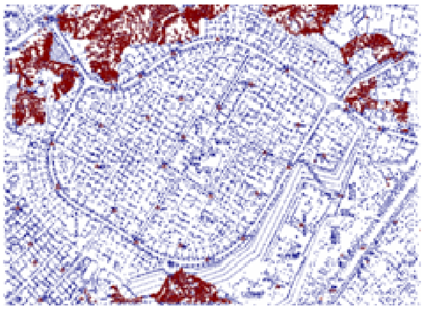
2. CLASSIFICATION OF CUT AND FILL GROUND USING GIS TECHNIQUE

2.1 Used city map information

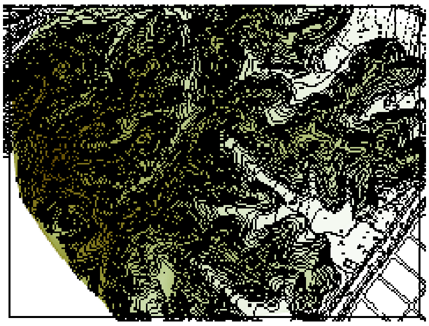
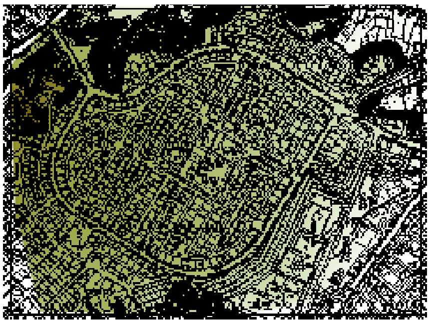
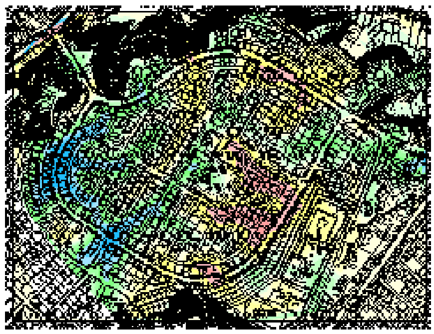
The developed land for housing is classified as either a fill part, or a cut part from a topographical map, based on GIS (Geographic information systems) technique. Not only the zonation of the reclaimed fill area and the cut area but also each altitude difference of fill and cut were analyzed in detail 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




(a) altitude values input in 1970 (e) altitude values input in 1998

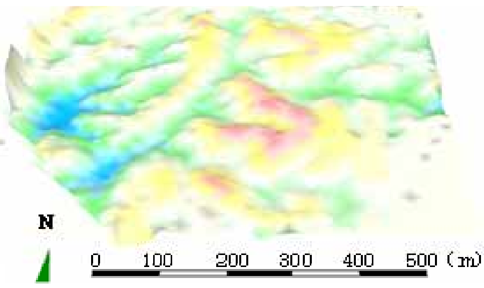



(b) extraction of contours 1970 (f) extraction of contours 1998

(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

Fig. 1 Making procedure to classify cut and fill ground

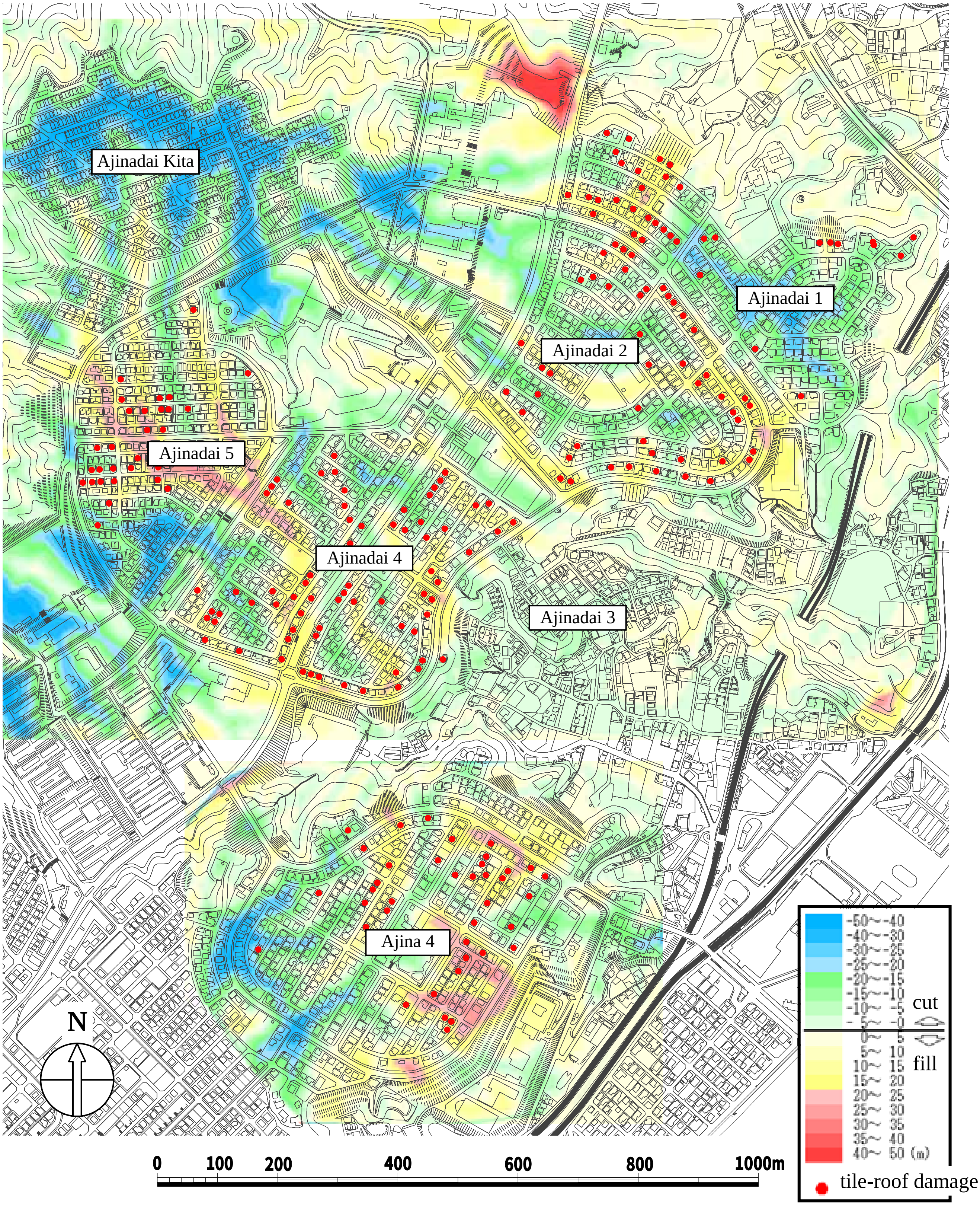


Fig. 2 Fill-depth and cut-height coloring based on GIS estimation and tiled roof damage of houses at developed hill residential area.

information of the altitude topography was taken from City planning maps in 1/2,500 scale with contour line at intervals of 2 meters. Two pieces of map in 1970 and three pieces in 1998 were presented from Hatsukaichi-city office.

2.2 Land classification procedure

Making procedure to classify cut and fill ground is shown in Fig. 1 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 file, which is the standard file format of the CAD. All the altitude values were inputted into each contour line data directly (Fig. 1(a), (e)). (2) For input of the altitude value, CAD software was used (AutoCAD2000LT; 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 6.0 was made to remove the data without altitude information (height 0) and only the altitude data was extracted (Fig. 1(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 were 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. 1(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. 1(d), (h), (j)). Fig. 2 shows 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.

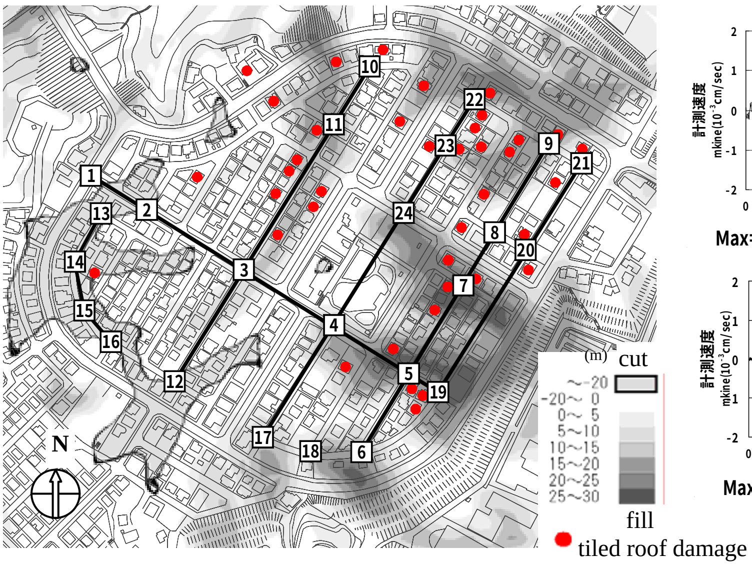


Fig. 3 Micro-tremor measurement point (Ajina, Hatsukaichi-city)

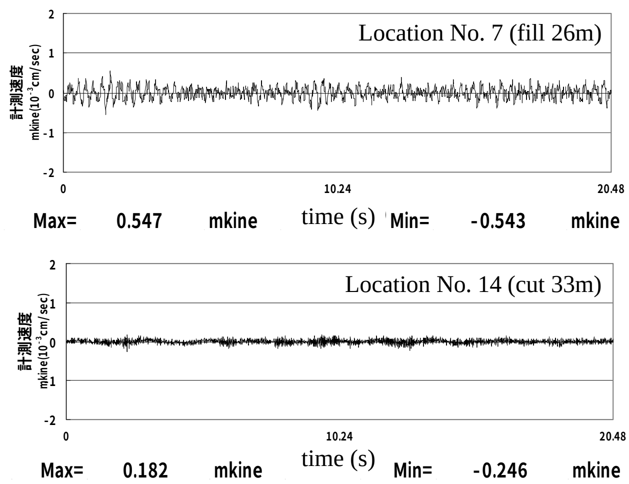


Fig. 4 Samples of velocity wave

3. MICRO-TREMOR CHARACTERISTIC OF IMPROVED HILL GROUND

3.1 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 earthquake 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. Figure 3 shows the micro-tremor measurement locations selected 24 points in Ajina area crossing the fill and cut ground. The measurement was executed at (a) 9 places on the cut ground, (b) 2 places on the ground near boundary area between the fill and the cut, and (c) 13 places 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; measurement 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, about 20 seconds (2,048 data) as shown in Fig. 4 were taken, 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.

3.2 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 shown in Fig. 5, corresponding to the type of the ground, respectively. In this figure, the power spectrum are displayed by the order of the ground depths (unit in meters) in turn from the left-top to the right-bottom. 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.

4. 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 Fig. 6. 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. 7. 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.

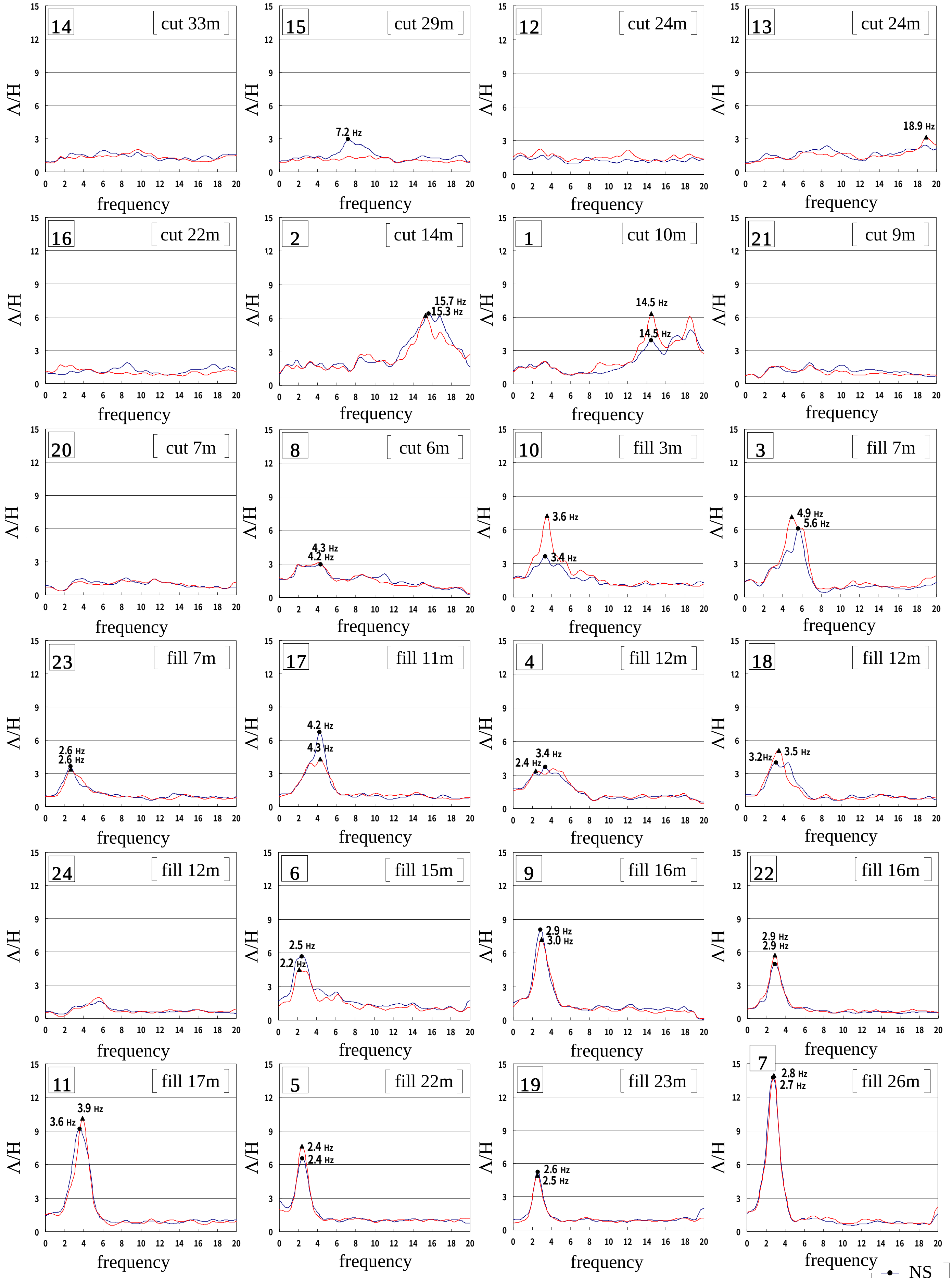


Fig. 5 H/V spectrum (displayed by the order of the ground depth)

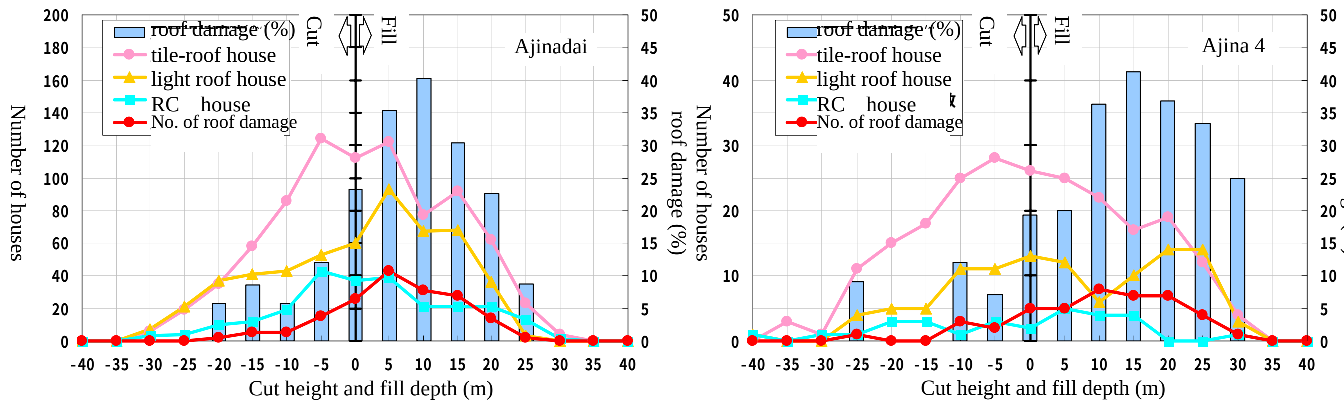


Fig. 6 Cut and fill soil thickness and the tiled roof damage ratio

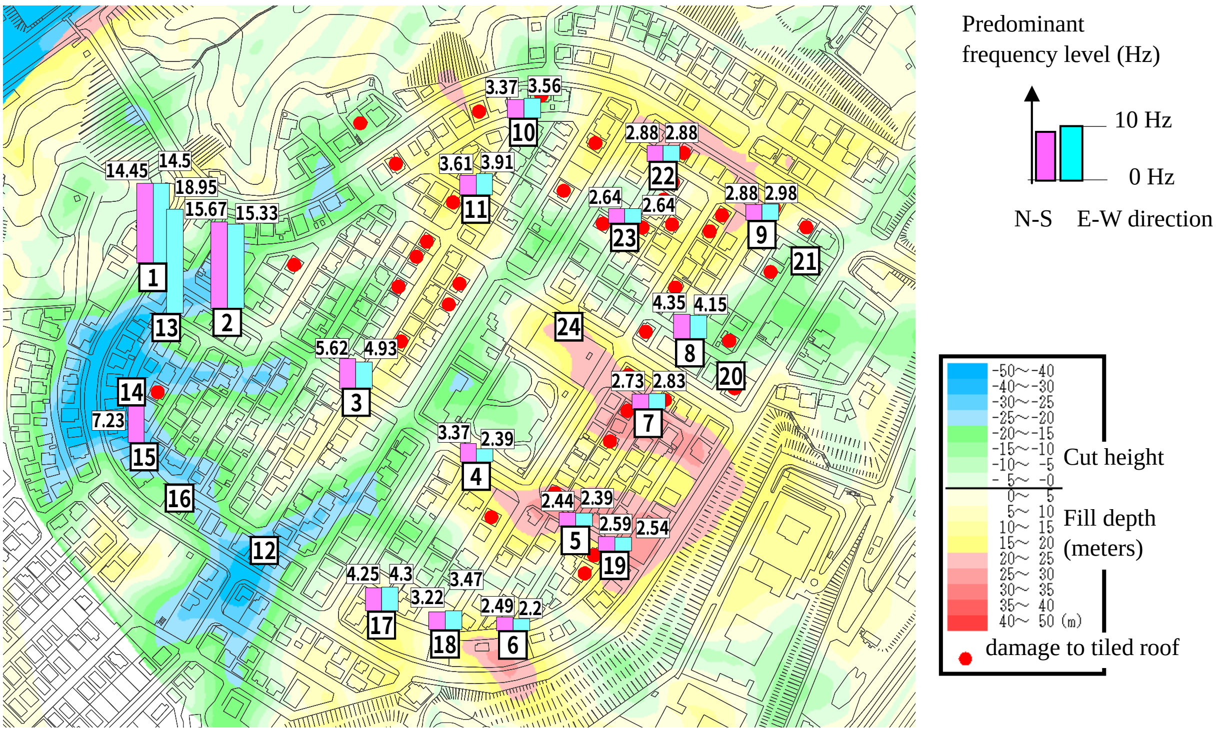


Fig. 7 The relationship between fill-depths based on GIS estimation, earthquake damage and predominant frequency of a developed hill residential area.

In the future, it is necessary to examine the relation to the damage and the vibration property of buildings for site predominant frequency. 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.

5. 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 were 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. GIS tools of TIN and grid generation technique also used 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 not 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; the lowest one is 2.2Hz. 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.

4) 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.

5) The tiled roof damage of the wooden houses appeared in the fill ground area by the Geiyo Earthquake, where predominant frequency is comparatively low and does not reach to 3Hz. On the other hand, the tiled roof damage does not appear in the cut area where the predominant frequency is relatively high as to exceed 10Hz. The altitude (vertical) drop of the cut and fill ground affects predominant frequency of the ground, and it is possible that the difference of vibration characteristics of the ground influenced to the tiled roof damage of the house.

ACKNOWLEDGEMENT

Residential map Zmap-TOWN II used here had the offer from Zenrin Co. Ltd. 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. I wish to express my gratitude in deep.

REFERENCES

Satoshi Iwai and Teruo Asano (2004) Wooden house damage on improved hills caused by the 2001 Geiyo earthquake, Japan and micro-tremor properties of the ground, 13th World Conference on Earthquake Engineering, August 1-6, Vancouver, BC, Canada

Architectural Institute of Japan: (2001) Reports on the damage investigation of the 2001 Geiyo earthquake, 249-384 (in Japanese).

Satoshi Iwai and Teruo Asano (2002) Damage of building structures caused by the 2001 Geiyo earthquake, Proc. of 39th Natural Disaster Science Symposium, 25-28 (in Japanese).

Satoshi Iwai, Hirotaka Matsumori, Kazushi Kandori, and Yasuhiro Ittanda (2003) Database on dynamic properties of wooden buildings and dynamic and static loading tests of wooden framed structures, Research Bulletin of the Hiroshima Institute of Technology, Vo. 37, 83-92 (in Japanese).