Evaluation of ground conditions of residential developments by microtremor characteristics & surface-wave prospecting

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Abstract: The Japanese Government anticipates an occurrence of a Nankai earthquake in Shikoku Island in the near future. Takamatsu, the capital city of Kagawa Prefecture, has been seriously damaged by Nankai Earthquakes at intervals from 90 to 150 years. After the last Nankai earthquake the urban district has spread to hills and a number of residential developments have been constructed. Studies related to recent earthquakes have suggested that residential developments could be seriously damaged in the event of an earthquake. The seismic damage is closely related to the ground condition. It is therefore very important to clarify the ground conditions of residential developments when an earthquake-resistant design of a structure is considered.

The microtremor measurement is an effective method for conveniently and cheaply assessing the ground conditions. Horizontal and vertical spectrum (H/V spectrum) of the short cycle tremor is an effective property to analyse the ground motion characteristic and the evaluation of an earthquake's motion estimation. The authors also have applied surface-wave prospecting to estimate the S-wave velocity. This paper presents a cheap and conventional evaluation of the ground condition based upon the H/V spectrum and S-wave velocity.

Résumé: Le gouvernement japonais prévoit occurrence d'un tremblement de terre de Nankai en île de Shikoku dans un proche avenir. Takamatsu, la ville capitale de la préfecture de Kagawa, a été sérieux endommagé par Nankai Tremblements de terre à des intervalles de 90 à 150 ans. Après le dernier tremblement de terre de Nankai la zone urbaine s'est écartée aux collines et à un certain nombre de développements résidentiels ont été construits. Les tremblements de terre récents ont pour suggérer cela résidentiel des développements ont pu être sérieusement endommagés en cas d'un tremblement de terre. des dommages séismiques sont étroitement liés à la condition au sol. Il est donc très important pour clarifier les conditions au sol des développements résidentiels quand la conception de tremblement de terre-preuve d'une structure est considérée.

La mesure de microtremor est une efficace méthode pour commodément et à bon marché saisissant les conditions au sol. Horizontal et le spectre vertical (spectre de H/V) du tremblement court de cycle est un efficace propriété pour analyser le mouvement au sol caractéristique et l'évaluation de l' évaluation du mouvement du tremblement de terre. Les auteurs également se sont appliqués surface-ondulent la prospection pour estimer S-ondulent la vitesse. Cet article présente un bon marché et l'évaluation conventionnelle de la condition au sol sur le spectre de H/V et S-ondulent vitesse.

Keywords: earthquake, embankment, compaction, seismic risk

1. INTRODUCTION

In September 2001, the Japanese Government announced that the probability of the Nankai Earthquake occurrence is about 40% within 30 years in future. This probability of occurrence is very high, and it is considered that certainly a large earthquake will occur in the near future. If the Nankai earthquake will occur, it is anticipated that damage will be 2~3 times the damage of the 1995 Great Hanshin Earthquake. In Kagawa Prefecture where the authors live, preparation for the Nankai Earthquake and seismic risk of the area have been initiated and extensively planned.

In Kagawa Prefecture, the sufficient subsurface exploration is carried out before the construction of many residential land development projects, whereas it is almost not carried out after the construction. In the event of an earthquake, much damage will occur in valley filling embankments in hilly areas. The differential settlement or lateral displacement is mainly expected in the sloping part of embankment.

The authors have applied surface wave prospecting to various ground investigations in order to develop new techniques instead of cone penetrometer (Yamanaka et al 2004 & Saito, Yamanaka & Hasegawa 2005).

In this study, an area of residential developments that was prepared by cutting and filling of weathered granite is taken into consideration for the investigation. The ground condition is estimated by the analysis of microtremor characteristics of surface-wave prospecting of the ground by using an artificial seismic source. Similarly, the earthquake resistance of a residential development is also evaluated and the applications of microtremor characteristic and surface wave prospecting to the residential developments are also discussed.

2. SURVEY METHODS

2.1 Surface-wave survey using artificial seismic source

For analysis of S-wave velocity profile of the ground, PS logging using the borehole, etc. has been carried out. But in order to analysis two dimensions or three-dimensional profiles of the ground, this method is time consuming and costly. The surface wave exploration is a convenient method to obtain S-wave velocity distribution of the ground in about 20 m depth. This method measures and analyses the surface wave (Reyleigh Wave) that transmits near the ground surface (Hayashi, Suzuki & Saito, 2001).

Figure 1 shows the image of the surface wave prospecting. When a blow is struck at ground surface by hammers, the wave is generated. The wave propagates with respect to surface and subsurface condition. The wave, which propagates laterally along the surface is called the surface wave. In heterogeneous ground the surface wave (Rayleigh wave) velocity changes with the wavelength (frequency). In general, the elastic wave velocity increases with the depth, where longer wavelengths penetrate to a greater depth. Therefore, high frequency wave velocities tend to be slower and low frequency wave velocities tend to be faster. Using the difference between the propagation velocities by the wavelength (frequency), it is possible to obtain an S-wave (Secondary Wave) velocity profile of the heterogeneous ground by analyzing the reverse dispersion. The characteristics of the surface wave prospecting that was used in this study are as follows; 1) it is possible to easily obtain the S wave velocity of the ground, 2) it is possible to survey fast and cost effectively in a wide area, 3) it is simple to carry out the measurement and analysis.

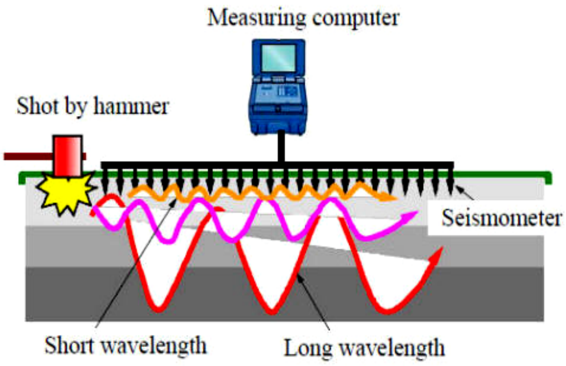

Figure 1. Image of the surface wave prospecting

Figure 2 shows the operational situation of the surface wave prospecting at the residential development. 24 velocity type seismographs of the 4.5Hz natural frequency are used as a geophone. Since it is measured on asphalt pavement a land streamer cable is used in the survey to efficiently carry out the installation, exchange and transfer of geophones. The receiving point and stroke point interval are made every 2m, and the stroke is carried out in the middle of each receiving point.

Figure 2. Operation of the surface wave prospecting

2.2 Microtremor measurement

Figure 3 shows operation situation of the microtremor measurement. The microtremor was measured using the portable speedometer. After the smoothly compacting ground surface of the measuring point by foot, the microtremor sensor is installed horizontally by checking the direction. Three directional components were measured simultaneously (two horizontal and the vertical) at each measuring point. The measurement is the velocity component, and it was measured at the 100Hz sampling frequency for 5-10 minutes per one measuring point.

Figure 3. Situation of the microtremor measurement

2.3 Topography and geology of the residential developments

Figure 4 shows the cross section of the residential development. The perimeter of residential development is in a low mountain region where ground undulations of 100m to 200m are observed. Main geology of the area is granite of Cretaceous period whereas rhyolite of the Tertiary period also occurs as in thin dykes, and talus deposits cover the bedrock. Therefore, the subsurface geology is composed of granite (basement rock), valley deposits and bank deposits with largest embankment thicknesses up to 25m.

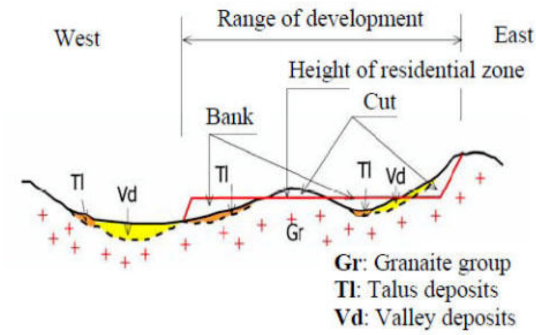

Figure 4. Section of the residential development

2.4 Plan of the residential developments

Figure 5 shows the plan of the residential development. Traverse lines (No.51, No.52 and Line A) of the surface wave exploration and measuring points (total of 30) of microtremor measurement are also added in Figure 5.

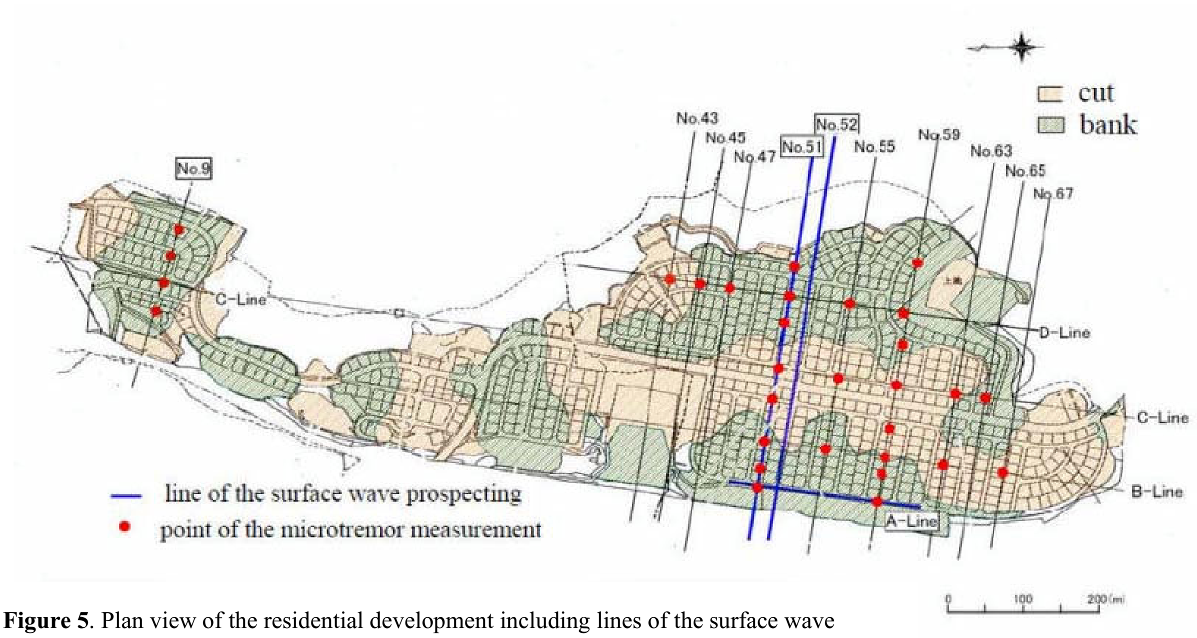

Figure 5. Plan view of the residential development including lines of the surface wave prospecting and points of the microtremor measurement

3. RESULTS AND DISCUSSIONS

3.1 surface wave prospecting

Figure 6 (a) and (b) show S-wave velocity distribution of each traverse line. In the surface at the starting and end points sides, S-wave velocity (Vs) = 200m/s or less, and the maximum thickness is about 2m. Layer of velocity Vs = 200m/s to 300m/s is thickly distributed in the middle level. The lower part exceeds Vs=1000m/s.

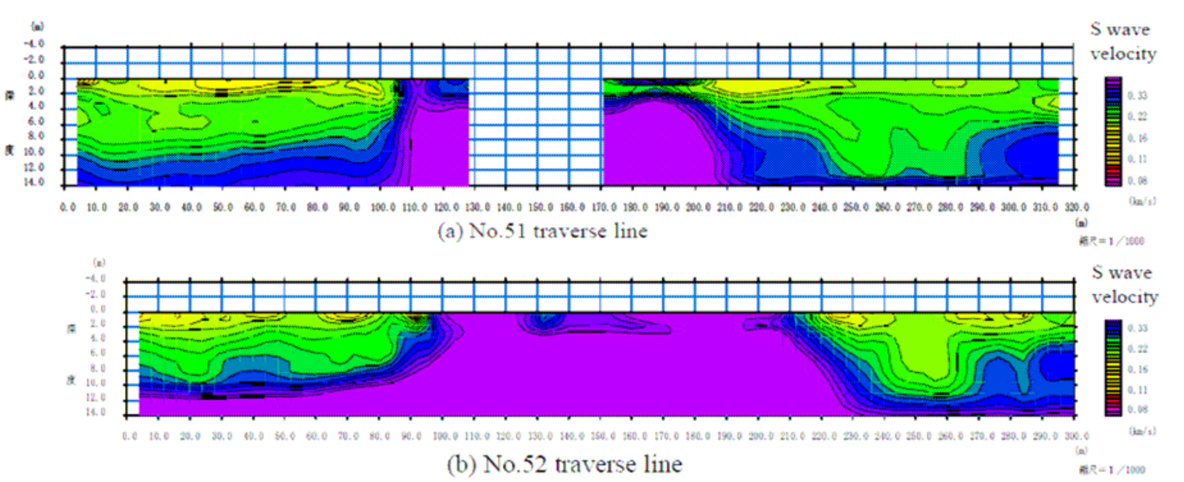

Figure 6. S-wave velocity distribution (each traverse line)

Figure 7 shows the cross section of the traverse line No.51. It is proves that the position of cutting surface of granite corresponds to the position on which velocity exceeded Vs=300m/s. Likewise, the most part of the bank deposit corresponds to Vs=200-300m/s S-wave velocity, and the shoulder of bank near the end point side and thick bank deposit show Vs=200m/s or less.

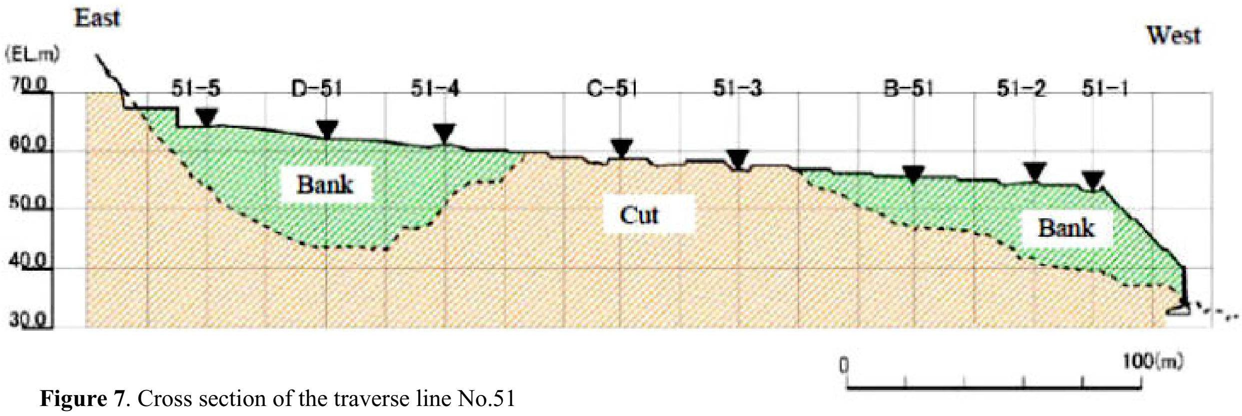

Figure 7. Cross section of the traverse line No.51

Figure 8 (a)-(c) show S-wave velocity distributions of the same depth in horizontal section. This analysis corresponds to the cutting surface of the central peak and the bank of both valley sides. It proves that the relationship between the range of velocity which exceeds Vs=300m/s and landform line before development is well corresponded. Similarly, it can be interpreted that the zone of high S-wave velocity increases with depth.

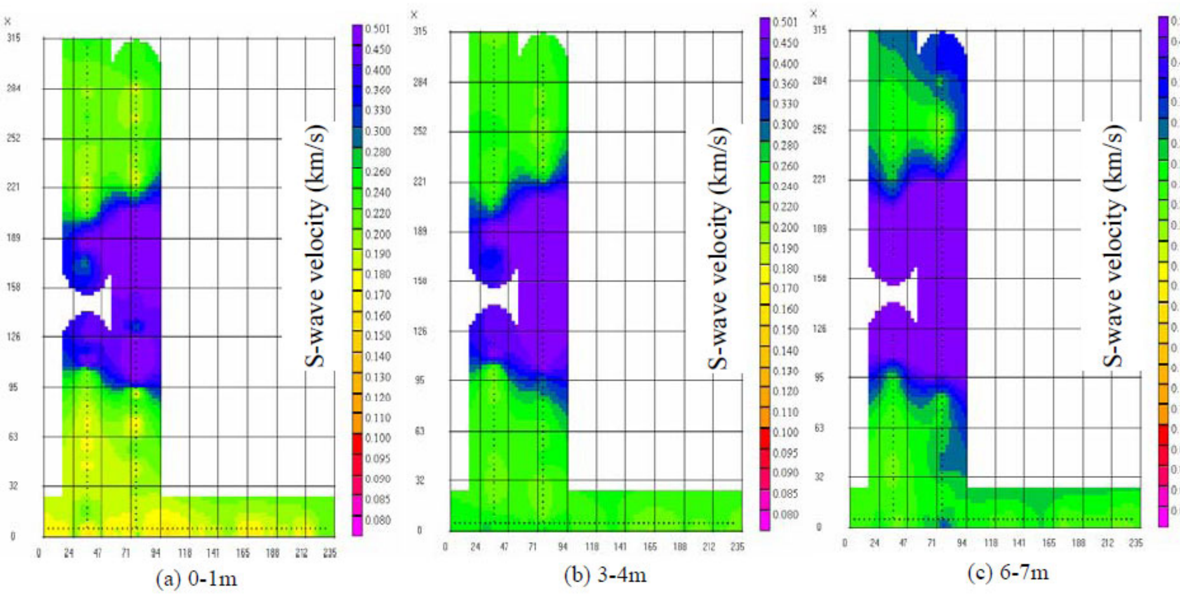

Figure 8. S-wave velocity distribution (the same depth horizontal section)

Table 1 shows the ground and geology corresponding to S-wave velocity, which was determined during the surface wave exploration. Though the bank deposit shows Vs=200m/s or less near-surface, most of the bank deposit has Vs=200-300m/s. The cutting zone has velocity over 300m/s, and it corresponded to the granite (basement rock).

Table 1. Result of the surface wave prospecting

S-wave velocity Vs (m/s)	Thickness of layer	Corresponding layer
-200	0-2m	Bank (near surface)
200-300	0-15m	Bank (middle)
300-	-	Rock (Cut)

3.2 Microtremor measurement

Figure 9(a) and (b) show examples of the H/V spectral ratio of the bank and cut part respectively. In the bank part, it is proven to have predominant period near the periods of 0.2~0.3 second (in Figure 9a.). In the cutting part the spectral shape is flat without observing the clear peak (in Figure 9b.). It became clear that the amplification factor of the cut part was smaller than the bank part.

Figure 10 shows the relationship between thickness of layer and predominant period. It shows that there is the positive correlation, although value is dispersed. According to the one-dimensional wave theory, it is known that 1/4 wavelength rule is followed on the proper period, when the ground is a monolayer. When this relation is established for the ground, the average S-wave velocity of the bank deposit is estimated as about 260m/s.

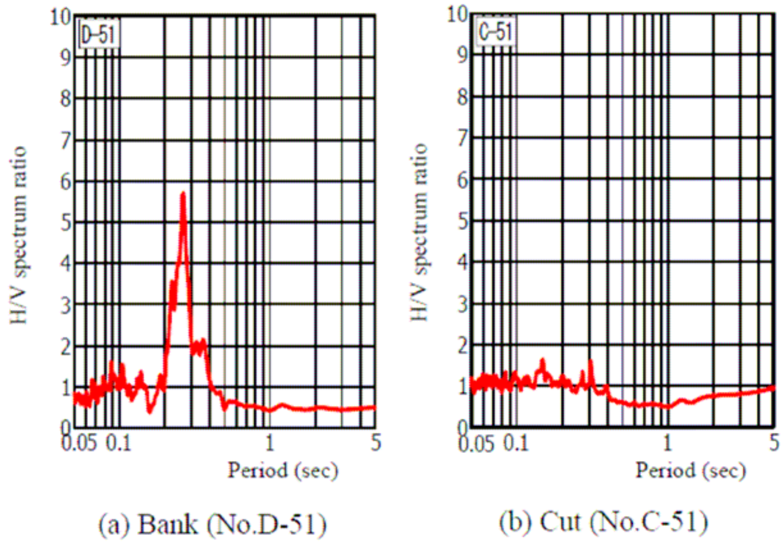

Figure 9. H/V spectrum ratio

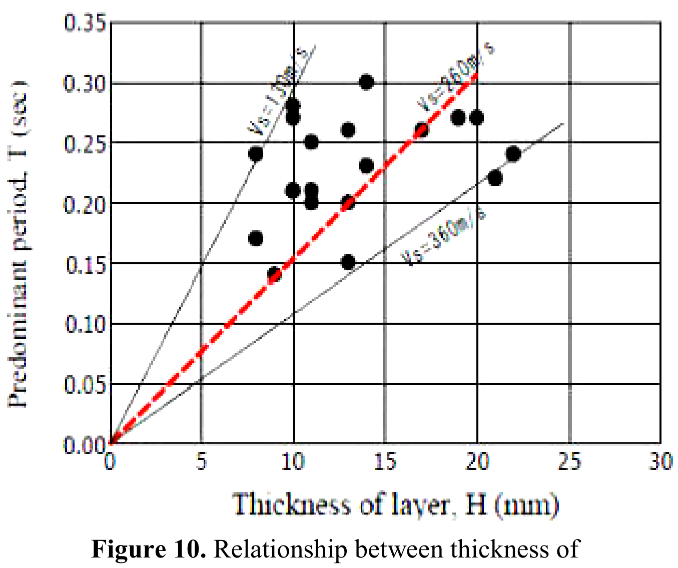

Figure 10. Relationship between thickness of layer and predominant period

The fill operations of the banks in the residential development area involved repeated laying of a thickness of 30cm of fill material followed by rolling compaction and compaction of 6 times by the 19 ton vibration roller. By filling in this manner it is considered that the strength of the bank deposit is equivalent to the embankment of the bullet train of Japan. Also, the measured value of the S-wave velocity of the fill material within the banks of around 260m/s is within expectation from previous experience.

4. CONCLUSIONS

From this study, following conclusions are made.

- As a result of S-wave velocity measurements in the residential development using the surface wave exploration, it was proven that the most part of bank part has S-wave velocity 200-300m/s, and that the surface layer is very thin and its S-wave velocity is 200m/s or less.
- The S-wave velocity distribution of the surface wave exploration and the geological cross section of the residential development area show a high degree of correlation.
- With the measurement by the microtremor, in the bank part, there is a clear peak of spectral ratio at a predominant period of 0.2-0.3 second. According to the one-dimensional wave theory, average S-wave velocity of the bank deposit is estimated at about 260m/s and it is equivalent to the result of the surface wave exploration.
- The S-wave velocity of the bank seems to be an almost appropriate value, because compaction is sufficient for the embankment using granite aggregate.

5. REFERENCES

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