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APPLICATION OF SURFACE-WAVE PROSPECTING IN ENGINEERING GEOPHYSICAL SURVEY

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***ABSTRACT*:** As far as geotechnical problem of Shikoku, Japan, there are many landslides caused by the fault and there are many artificial embankments in hilly area. The countermeasure to earthquake motion and the sustainability of river embankments on the assumption of the Nankai earthquake is important in Shikoku, and it is necessary to evaluate urgently the earthquake resistance of these embankments and fills. Thus the development of convenient, economical technology for the geotechnical survey is very essential. In this study, the two-dimensional evaluation of the ground earthquake resistance was performed by using the new surface-wave method along active fault and river embankment. It is understood that the surface-wave method along the active fault is not impressive because the fault plane was not clear and the interpretation was impossible. Likewise, the surface-wave method in the river embankment suggested that there is the possibility of deformation of embankment because of the insufficiently compacted materials and the undulation of embankment of the foundation.

KEYWORDS: geological survey, S-wave, earthquake disaster countermeasure

1. INTRODUCTION

In 2001, Japan Government announced that the probability of occurrence of the Nankai Earthquake is about 40% within 30 years. This probability of occurrence is very high, and it is considered that the large earthquake will certainly occur in the near future. When the Nankai Earthquake occurs, it is anticipated that the damage will be 2-3 times of the damage of the 1995 Hanshin Great Earthquake. In Kagawa Prefecture, the preparation to the Nankai Earthquake and the seismic risk of the area have been started to be discussed extensively.

In general, in order to estimate the seismic damage, it is necessary to understand return period of nearby active fault by means of detail investigation. Meantime the detail investigation on the earthquake resistance of infrastructure such as road and river embankment is also needed because the seismic damage is closely related to the ground condition.

The conventional boring method and the representative geotechnical survey technique give the only point ground information. But to understand the detail subsurface condition and to evaluate the earthquake resistance, it is necessary to obtain two or three-dimensional subsurface information.

Authors have carried out non-destruction survey for various soil strata by using the surface wave method (SAITO,et.al.,2005,2006). This paper describes the applicability in Shikoku by the new engineering survey method at the active fault and the river embankment of the surface wave prospecting using artificially generated seismic wave.

2. SURVEY METHOD

PS logging is carried out by using the borehole in order to obtain the S-wave velocity profile of the ground. However, this method takes long time and cost to analyse two dimensional or three-dimensional profiles of the ground. Instead of this method, the surface wave exploration is convenient to obtain S-wave velocity distribution of the ground up to the depth of 20 m. In this method, the surface wave (Reyleigh Wave) which transmits near the ground surface is employed (Hayashi,Suzuki & Saito, 2001).

Fig. 1 illustrates the surface wave prospecting method. In this method, wave is generated by hammering at the ground surface. The wave propagates with respect to surface and subsurface material condition. The wave which laterally propagates around the surface is called surface wave. The surface wave, which propagates in the heterogeneous ground along the surface, changes its propagation velocity. The propagation velocity generally depends on the wavelength (frequency).

In general, the elastic wave velocity increases with the depth and the wave which has long wave length penetrates more depth. Therefore, the wave velocity of the short wavelength (high frequency) becomes slow, and the wave velocity of the long wave length (low frequency) becomes fast. Using difference among propagation velocities with wavelength, it is possible to obtain S-wave (Secondary Wave) velocity profile of heterogeneous ground by analyzing reverse dispersion. The characteristics of the surface wave prospecting which was used in this study, are as follows; 1) it is possible to easily obtain S-wave velocity of the ground, 2) it is possible to survey quickly and economically in wide area, 3) it is easy to carry out the measurement and the analysis.

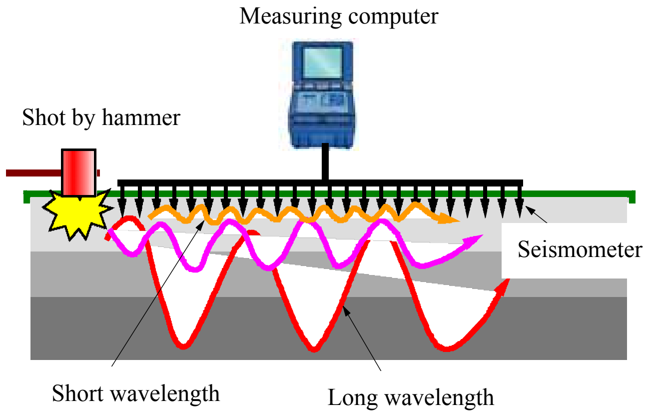

Fig. 1 Surface wave prospecting

3. APPLICATION TO ACTIVE FAULT

3.1 Outline of site and measurement method

Nagao Fault is located at the south of Takamatsu City, Kagawa Prefecture, and its length is about 20km in the direction of east-west. In order to estimate an earthquake risk for Nagao Fault, in 1996, Kagawa Prefectural office carried out trench survey and seismic reflection survey. Results of these investigations revealed that Nagao Fault is a reverse fault and it is a right-lateral fault with unit displacement of 1.5m to 2.0m.

Fig. 2 shows the location of investigation sites at Tanaka and Hikami-Miyashita (Miki Town). These sites are located at the southern edge of Sanuki Plain and center of Nagao Fault extended in the direction of east-west.

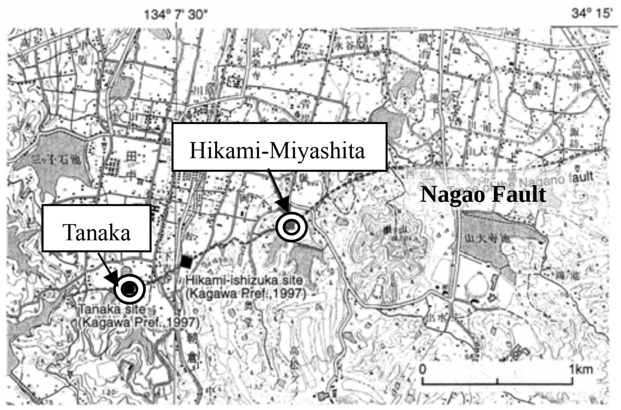

Fig. 2 Location of investigation site

Fig. 3 shows the operation of the surface wave prospecting at Tanaka along Nagao Fault. 24 velocity type seismographs of 4.5Hz natural frequency were used as geophone. This measurement was done on asphalt pavement. Thus for efficient installation, exchange and transfer of geophone, land streamer cable is used in survey. The receiving point and stroke point interval are made 1m, and the stroke is carried out in the middle of each receiving point.

Fig. 3 Operation of the surface wave prospecting at Tanaka site

3.2 Analysis of measurement result for active fault

3.2.1 Tanaka site

Tanaka site consists of the embankment, the terrace deposits (sandy silt, humus soil), and Mitoyo Formation of Tertiary Period from top to bottom. About 3.5 m differential height is observed at the base of terrace deposit. It is also observed that the fault surface inclines to south with 48°, and the fault is reverse fault having slope to south.

Fig. 4 shows the S-wave velocity contour by the surface wave prospecting at Tanaka. The conversion N-value obtained by the small dynamic cone penetrometer. It is clear that the low velocity range (V_s= 100-200m/s) is distributed up to 4m below the ground surface and the lower layers have S-wave contour with high value. The high-density zone (Vs=300m/s or more) is distributed in south part. This large bend zone of S-wave contour agrees with zone of actual active fault surface.

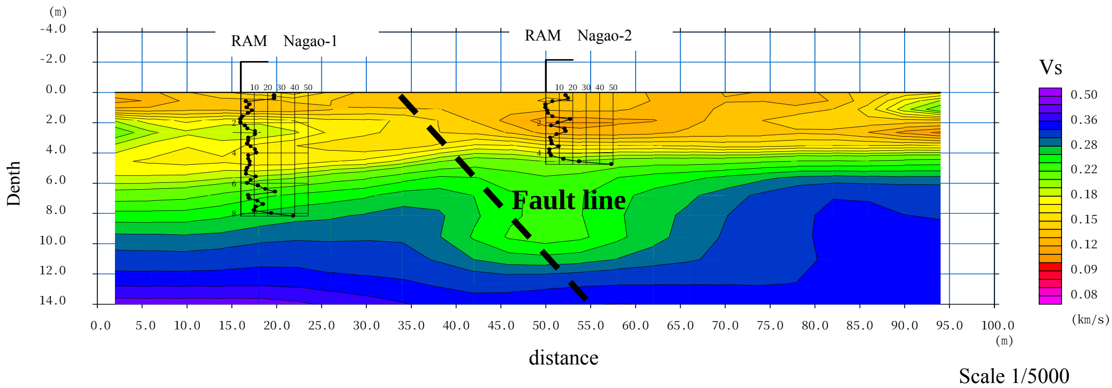

Fig. 4 S-wave velocity contour at Tanaka site

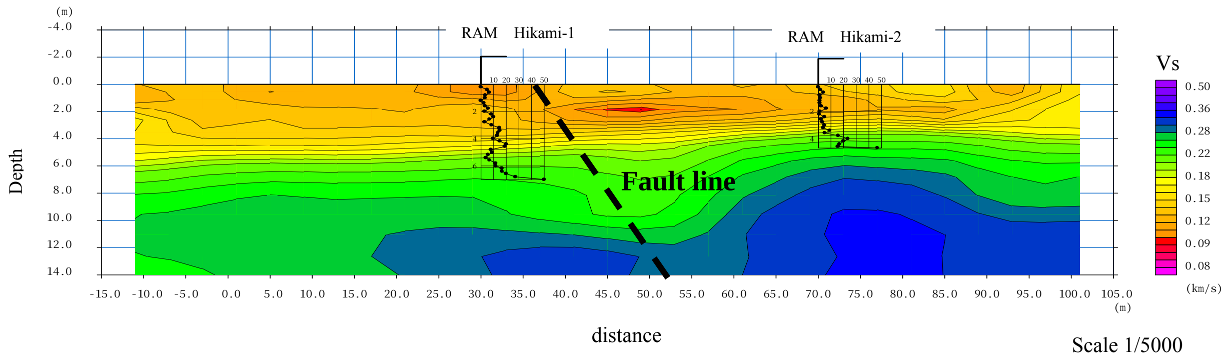

Fig.5 S-wave velocity contour at Hikami-Miyashita site

3.2.2 Hikami-Miyashita site

For the estimated geological section of Hikami-Miyashita site, about 1.5 m differential height was observed at the base of terrace deposit. It is also observed that the fault surface inclines to south with 65^o and the fault is reverse fault having slope to south.

Fig. 5 shows result of analysis at Hikami-Miyashita. S-wave velocity (Vs) is less than 200m/s at depth of 4-5 m from surface and this part is considered as the terrace deposits. The terrace deposit is different from the Mitoyo Formation and it consists of the altered granitic or serpentinite at lower part. Therefore the position where contour lines bend extensively is estimated as the active fault surface.

3.2.3 Relation between Vs and soil classification

Table 1 shows the relation between Vs and soil classification. The layer having value Vs=200m/s at surface corresponds to the embankment or the terrace deposits which has N-value 10 and the layer of over Vs=300m/s corresponds to the sand-gravel of Tertiary period which has N-value over 30.

Table 1 Relation between Vs and soil classification

S-wave velocity *Vs* (m/s)	N-value	Corresponding layer
～200	～10	Bank, Terrace
200～300	10～30	Silt，Sand
300～	30～	Sand-gravel

4. APPLICATION TO RIVER EMBANKMENT

4.1 Outline of site and measurement method

Fig.6 shows the location of surface wave prospecting on river embankment. The surface wave prospecting was carried out on the embankment at

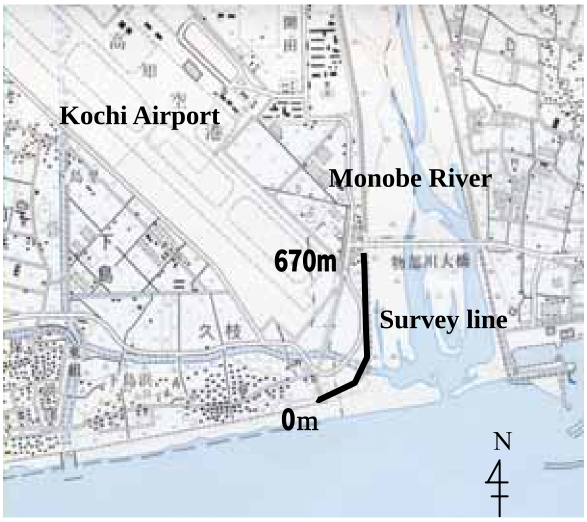

Fig.6 Location of survey(mouth of Monobe River)

the mouth of Monobe River in Nankoku City, Kochi Prefecture. The survey line is 670m long. And 24 velocity type seismographs of the 4.5Hz natural frequency were used as geophone. Since it is measured on asphalt pavement, the land streamer cable is used in the survey for convenience of handling. The distance of each receiving point were 2m, and the stroke was carried out in the middle of each receiving point.

4.2 Analysis or measurement result for river embankment

Fig. 7 illustrates the S-wave velocity contours. It also demonstrates N-value obtained by standard penetration test. It seems that the subsurface strata of the river embankment area of Nankoku City can be divided into two layers. The thickness of upper layer (embankment) is 5-10m and thickness decreases toward upper river. S-wave velocity (Vs) of the upper layer is 250-300m/s and rises a little at the part of sluice way. Likewise, Vs of the lower layer (gravel) is 300-400m/s.

Fig. 8 shows the relation between Vs and N-value. N-values in Fig.8 were obtained at the near boring hole and the present data were shown by the red point. This correlation agrees with the correlation by Imai et al (1982).

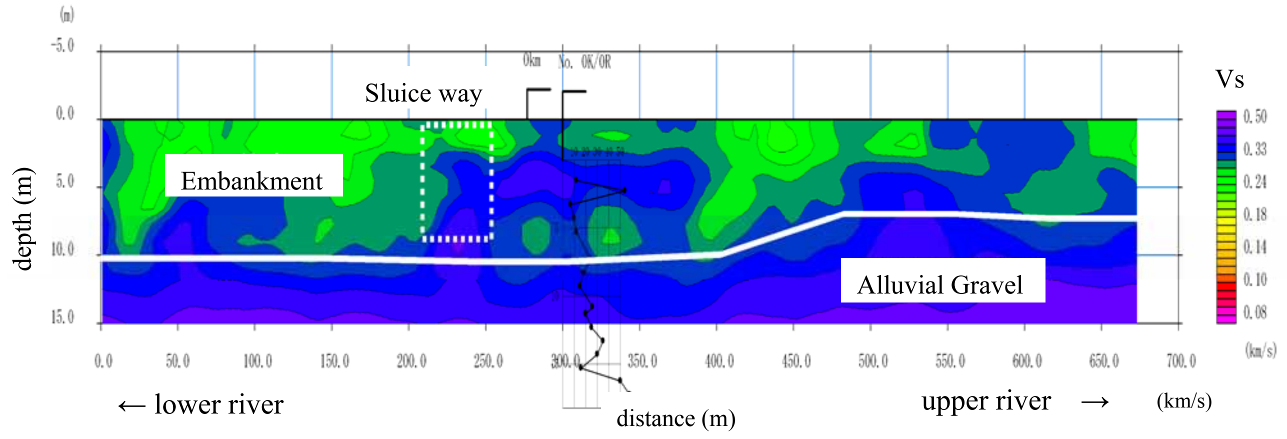

Fig. 7 S-wave velocity contour

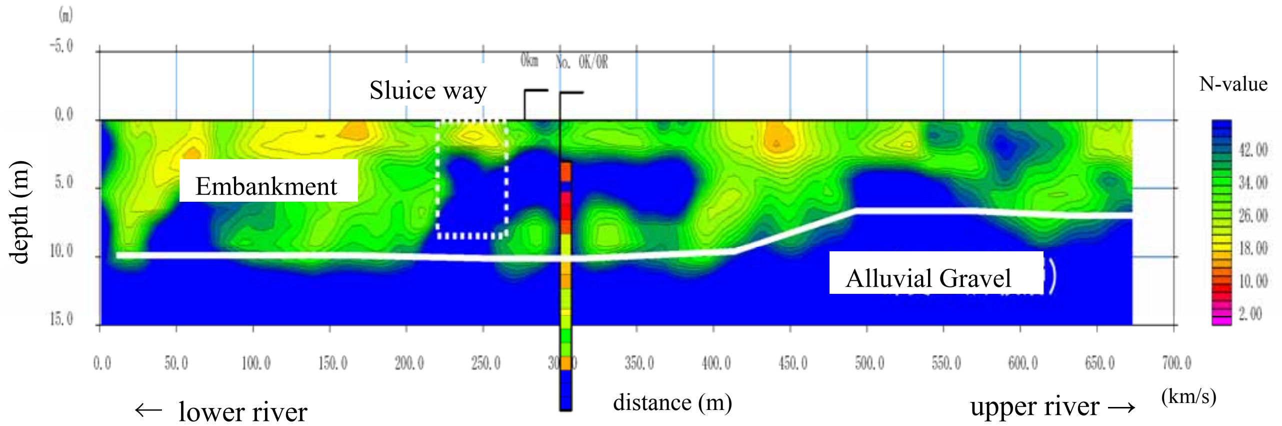

Fig. 9 Estimated N-value contour

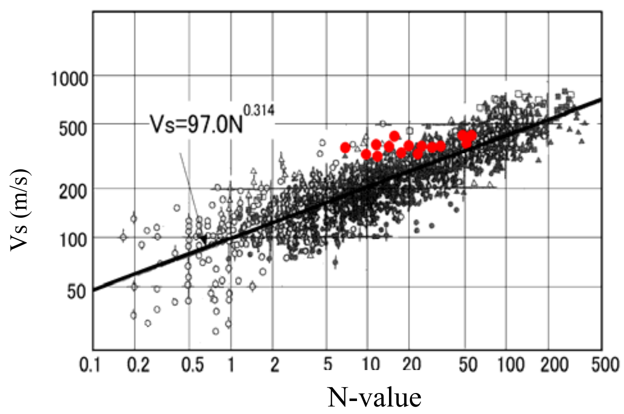

Fig. 8 Relation between N-value and Vs (Imai et al,1982)

Fig. 9 shows the estimated N-Value contour. N-value is calculated from Vs by using the equation in Fig. 8. It is found that N-value calculated from Vs is able to represent the ground strength (compacting degree).

Table 2 shows the Correlation between S-wave velocity and N-value at this site. it is also considered that there are some loose parts (N<10) at surface.

Table 2 Correlation between S-wave velocity and N-value at the river embankment

Layer	Vs (m/s)	Thickness (m)	Estimated N-value	Soil
Upper	250 - 300	5 - 10	15 - 30	Embankment
Lower	300 - 400	-	30 - 50	Gravel

And the basement of the river embankment has N-value more than 30 and its depth becomes shallow toward upper river.

5. CONCLUSION

Surface wave prospecting is a non–destructive seismic survey method, in which artificial seismic source is used and is found to be more useful in terrain like active fault and river embankment.

In active fault study, it is difficult to distinguish fault plane by surface wave prospecting but the method is very effective for identification of fault mobility. It is also felt that it is difficult to clarify the position of fault plane without information about the position of active fault.

During study of embankment, it is easy to obtain the correlation between S-wave velocity and N-value, and it helps to estimate depth of the basement of the embankment and loose materials.

In order to apply surface wave exploration method in disaster management and prevention system, it is necessary to storage many data and to improve the accuracy of analysis.

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