

Application of Active and Passive Surface Wave Methods to Landslide Areas

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Abstract: We applied the surface wave methods to many landslide areas to evaluate the applicability of the methods to the mountainous region. We usually carry out MASW, MAM and single station three-component (3C) microtremor measurements. Five to ten single (vertical) component and one 3C velocity sensors were deployed with 2 to 10 m spacing intervals. We usually use a 10 kg sledge hammer for MASW and recorded about 30 minutes of ambient noise for MAM processing and horizontal-to-vertical spectral ratio. A joint inversion estimated 1D Vs profiles to generally 30 m deep at each site. The results from various investigation sites confirmed that the active and passive surface wave methods provided reliable dispersion curves and successfully estimated Vs profiles to several tens of meters deep in the landslide areas.

Keywords: *Landslide, Surface wave method, S-wave velocity, Horizontal-to-vertical spectral ratio.*

Introduction

A seismic refraction method was often used to delineate 2D or 3D structure of landslides. The method generally requires explosive sources and it is difficult to carry out the method nearby residential area. The method cannot provide Vs that was essential to estimate external force associated with ground motion from natural earthquakes. Active and passive surface wave methods, such as MASW (Park et al., 1999) and MAM (Hayashi et al., 2022), have been getting popular to estimate Vs structures in flat plains with unconsolidated sediments. The methods were, however, rarely applied to mountainous area since the theory of the methods was based on 1D layered medium. We applied the surface wave methods to the gravitational slope deformation to evaluate the applicability of the methods to the mountainous region.

Data acquisition and processing

We carried out MASW, MAM and single station three-component (3C) microtremor measurements at three sites, A (on slope in the deformation

area), B (on slope outside of the deformation area) and C (at base of the deformation) as shown in Figure 1. Four single (vertical) component and one 3C velocity sensors (geophone) were deployed with 5 m spacing intervals. We used a 10 kg sledge hammer for MASW and recorded 30 minutes of ambient noise (microtremors) for MAM processing and horizontal to vertical spectral ratio (H/V or HVSR). A joint inversion estimated 1D Vs profiles to 30 m deep at each site. Initial model for the inversion used a community velocity model (CAO, Japanese Government, 2017) in greater depth.

Investigation example

The investigation site is the gravitational slope deformation in Nagano prefecture, Japan. Geology of the site is chert, mudstone and sandstone in Middle to Late Jurassic accretionary complex. The deformation area is approximately 250 m length, 150 m width, and 150 m height (Figure 1). Average slope angle is 30 degrees. We installed several inclinometers in the deformation area and they detected continuous slight creeping with infrequent large momentary movement.

Figure 2 compares dispersion curves, H/V spectra, and estimated Vs profiles at each site. There was clear difference among the dispersion curves on sliding body (No.1, No.2, and No.3) and those outside sliding body (No.4 and No.5) and base (No.6). There was no clear peak in the H/V spectrum at the site No.6 and it implied

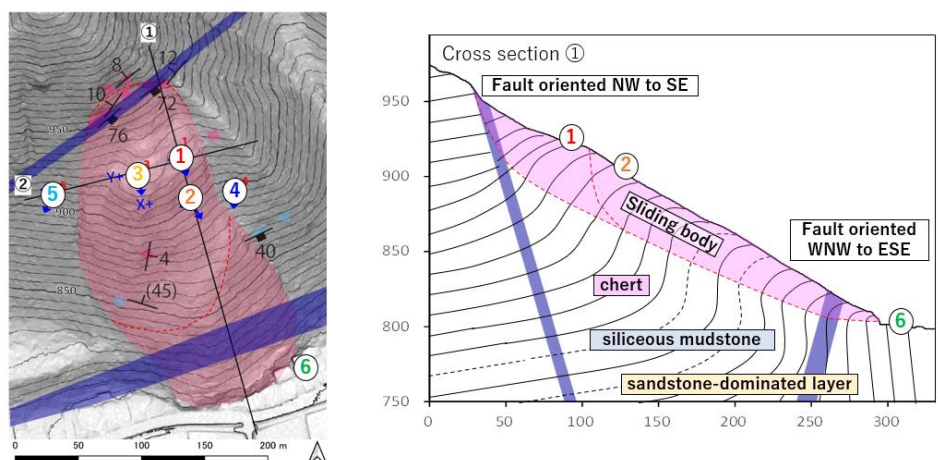


Figure 1, A plan view (left) and a cross section (right) in the investigation area. Surface wave methods were carried out at No. 1 to No. 6.

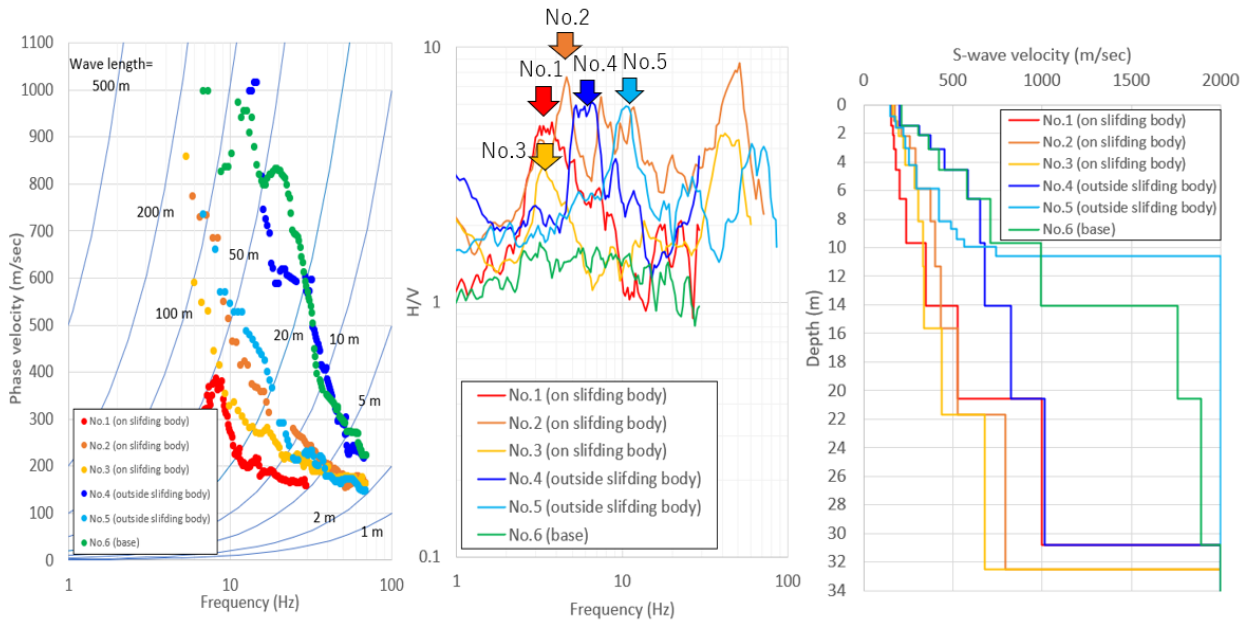


Figure 2, Comparison of dispersion curves, H/V spectra and estimated Vs profiles at each site.

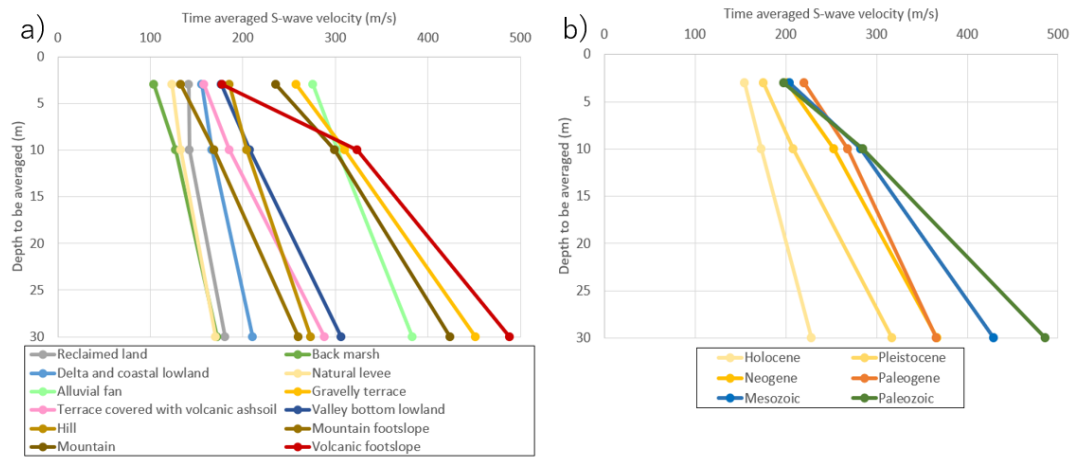


Figure 3, Time-averaged Vs for three depths by geomorphologies (a) and geological ages (b).

that a high velocity layer was very shallow at the base. The resultant Vs profiles show that depth to a low Vs layer with Vs lower than 500 m/sec were about 14 to 22 m deep at the site No.1, No.2 and No.3, and about 4 to 9 m at the sites No.4, No.5 and No.6. Depth to a high velocity layer with Vs higher than 1500 m/sec was about 30 m as the sites No.1 to No.6, and 10 m to 14 m at the site No.5 and No.6.

Vs by geomorphology and geology

We registered all observed data (dispersion curves, H/V spectra, etc.) and processing results (Vs profiles, etc.), in a relational database together with other site information, such as coordinate, elevation, topographic relief, slope angle, geomorphology, and geology etc. to a database. Total number of Vs profiles in the database is more than 4000 throughout Japan. Figure 3 compares the time-averaged Vs for three depths (3 m, 10 m, and 30 m) by geomorphologies (a) and geological ages (b). The time-averaged Vs varies depending on both geomorphology and geology. It is interesting that the time-averaged Vs increases rapidly with depth as geological age gets older.

Conclusions

The results from various investigation sites confirmed that the active and passive surface wave methods provided reliable dispersion curves and successfully estimated Vs profiles to several tens of meters deep in the landslide areas.

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