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Seismic site response of a large deep-seated landslide in Tokushima, Japan

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1. Introduction

In recent years, earthquakes have triggered numerous landslides, resulting in severe damage to local properties and great loss of lives directly. To mitigate this kind of geohazards, great efforts had been paid to the study on understanding the properties of coseismic landslides. By now, the amplification phenomenon which were considered as one of the most significant seismic site responses on the initiation of landslides had been analyzed by means of various methods, and these studies showed that the seismic responses can be affected by various factors (e.g. effects from topography, material and fracture) (e.g. Del Gaudio and Wasowski, 2011; Burjanek et al, 2012; Massa et al, 2014; Gisching et al, 2015). However our understanding on the seismic site response of deep-seated landslides where the geological and topographic conditions are more complicated is still limited. Particularly in Japan, there are many potential deep-seated landslides in the accretionary prism mountains that may be activated by the coming Nankai and/or Tonankai mega thrust earthquakes.

Therefore, seismic site responses of landslides with complicated geological and topographic background will be of great importance. In this study, we focused on understanding the features of amplification phenomenon and vibration behaviors of a large deep-seated landslide with sharp topography and multiple lithological stratums in Azue area, which was reactivated by the heavy rainfall in 2004 in Naka town, Tokushima prefecture (hereinafter called Azue landslide) by means of real time monitoring.

2. Method and result

Five seismometers with high sensitivity were installed on different locations of landslide area (Fig.1) for long-term strong motions monitoring. Meanwhile, dense ambient noise observations were also conducted on the landslide sub-blocks (Fig.1). For understanding the subsurface geological conditions of the landslide materials, some geophysical surveys (ERT and MASW) were performed on the landslide deposit area and sub-blocks, respectively (Fig.1).

Based on the numerous recordings, the spectral ratio method such as HVSR (Nakamura, 1989) and polarization analysis (Burjanek et al, 2012) were conducted to analyze the amplification and vibration features on landslide.

The HVSR curves embody the amplification phenomenon and the distribution of the HVSR curves on landslide sub-blocks from the ambient noise recordings indicate that some peaks at very low frequency bands of 0.2 to 0.5 Hz appear on some areas. In frequency bands ranging 1-10 Hz, the HVSR curves show that, with the increase of the distance, the peaks gradually appear, with the peak amplitude within 2-4. However, the HVSR peaks in high freqeuncy bands over 10 Hz cover the landslide sub-blocks widely with the peak amplitude within 5-6 (Fig.2).

In addition, the results of polarization analysis present that the vibrations of the block are mainly on the horizontal plane. In low frequency bands less than 1 Hz, vibration of the blocks indicate a systematic tendency along two directions on approximately N25° (±15°) and N150° (±10°), respectively. In the frequency bands of 1-10 Hz, predominant vibrations appear along N125° (±15°), except for some areas near the boundary of block. However in high frequency bands of 10-30 Hz, the vibration vary significantly from station to station without the systematic trend.

3. Discussion and conclusion

Through examining earthquake and ambient recordings from different locations of the landslide area, the different causes (material contrast and topography) on the localized amplifications of seismic motion for different areas were distinguished and summarized:

(1) Significant amplification resulting from topography occurs predominantly on the upper part of the landslide body. The specific directivities of these amplifications are approximately perpendicular to the direction of the local ridge axis. Amplifications on the landslide body resulting from material contrasts have their own directivities and these phenomena appear in both earthquake and ambient recordings.

(2) Amplification shows direction along the local slope aspect that relates to the superficial stratum, but is normal to the joint strikes of bedrock. Meanwhile, strong amplification could occur on landslide deposit areas due to the strong material contrasts, although the strong amplification does not possess pronounced directivities.

(3) For the relationship between the amplification and Polarization, it has been made clear that the vibration does not have pronounced directivity in weak amplification. However, strong vibration directivity appears when the amplification becomes stronger. In deep layer of the landslide body, the amplification direction and vibration direction are approximately consistent, while in shallow layers, these two directions are normally inconsistency.

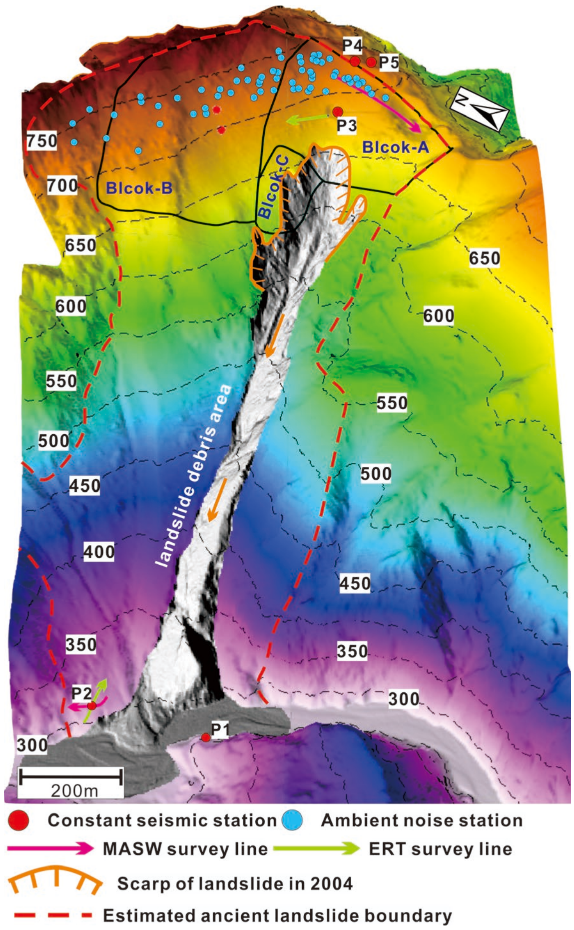

Fig.1 Azue deep-seated landslide and locations of monitoring system and the areas of geophysical surveys performed.

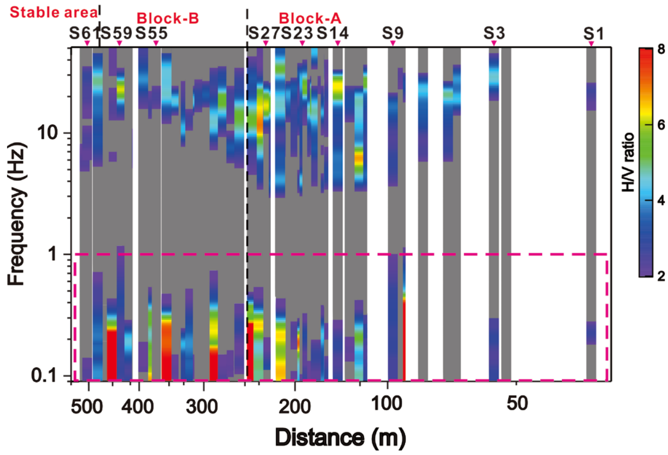

Fig.2. Distribution of the amplification on landslide blocks stacked all observation stations as a function of distance (x-axis), frequency (y-axis). The colour scale represents the amplitude of the H/V ratio. Vertical dash line presents the boundaries of the block-A, block-B and the stable area.