Seismic measurement in the mudstone landslide area

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Abstract

In the southeastern part of Hokkaido, Japan, landslides in sedimentary layers (especially mudstones, alternate layers of mud and sand in the Cretaceous and in the Tertiary) are often observed along the coastline. The surface layer is completely weathered due to cold temperature under which water in it exists as ice during winter. Ocean waves erode the bottom side of the shore in the situation where the landslide areas in this region are facing the Pacific. In these circumstances, the stability of the slopes along the coastline is decreasing. Owing to the tectonic setting that the Pacific Plate is subducting beneath the southeastern part of Hokkaido, large inter-plate and intra-slab earthquakes frequently occur. For example, ten earthquakes with magnitude larger than 7 are recorded there during recent ~20 years. Strong motion may be generated due to the non-linear behavior of the soft soils and the effect of the pore pressure in them, and in turn, unstable slope may slide or collapse due to the strong motion. It is important to grasp how the soils shake in response to the strong seismic motion. We installed a seismometer on the slope in the ~20 m distance from the coastline, in the landslide at Akkeshi, which is one of the coastal towns in the southeastern part of Hokkaido. The natural frequency of the seismometer is 2 Hz. The seismic signals are continuously recorded every 0.01 seconds with the resolution 24 bit. The observation started on Sep. 24, 2014, and continues until now. So far, M5 earthquakes which occurred in the southeastern part of Hokkaido were recorded. We will elucidate amplification mechanism and non-linear effect in the soil by analyzing obtained seismic waveforms.

Keywords: coastal landslide, earthquake, mudstone

1. Introduction

In recent days, global warming is causing various kinds of serious problems. Landslide accompanied with seashore erosion due to sea surface elevation is important especially for conservation of national land. In order to understand the process of the landslides, we have to grasp their characteristics depending on the causes such as rainfall, cut-off at the foot side, and earthquakes.

In the southeastern part of Hokkaido, Japan, landslides in sedimentary layers (especially mudstones, alternate layers of mud and sand in the Cretaceous and in the Tertiary) are often observed along the coastline (Yamaguchi et al., 1975). Since the water under the ground surface freeze due to a terrible coldness, the surface layer is completely weathered. Ocean waves erode the foot side of the shore because some of the landslide areas in this region are facing the Pacific. Resultantly, the slopes along the coastline are becoming unstable. With the tectonic setting that the Pacific Plate is subducting beneath the southeastern part of Hokkaido, huge inter-plate and intra-slab earthquakes frequently occur and have been actually occurred. For example, ten earthquakes with magnitude larger than 7 are recorded there during recent ~20 years. Therefore, it is a suitable place to understand the landslide mechanism depending on the various causes such as rainfall, sea shore erosion, and earthquake strong motions.

2. Observations

We selected a small scale (50 m length), coastal landslide at Akkeshi, which is one of the coastal towns in the southeastern part of Hokkaido, because it is easier to make a sensor network in order to grasp whole behavior of the landslide blocks. The location is shown in Figure 1. The Pacific Plate is subducting beneath the North American Plate there, generating M8 class inter-plate and intra plate earthquakes.

Photo 1 shows the satellite image of the landslide, while Photo 2 its view from the bottom side. The landslide block is facing the sea (Akkeshi Bay) so that the bottom side of the landslide is eroded by

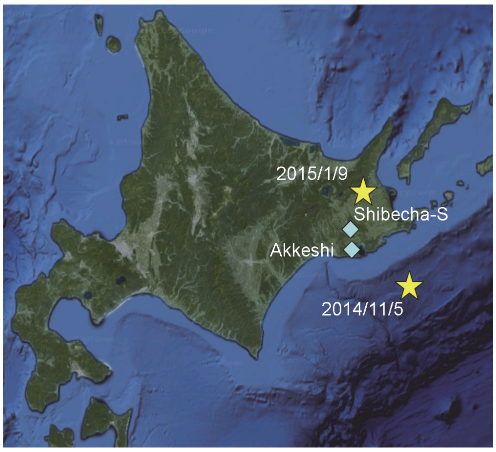

Figure 1: Map showing the location of Akkeshi, Shibecha-S (diamonds), and two epicenters (stars) analyzed in this study.

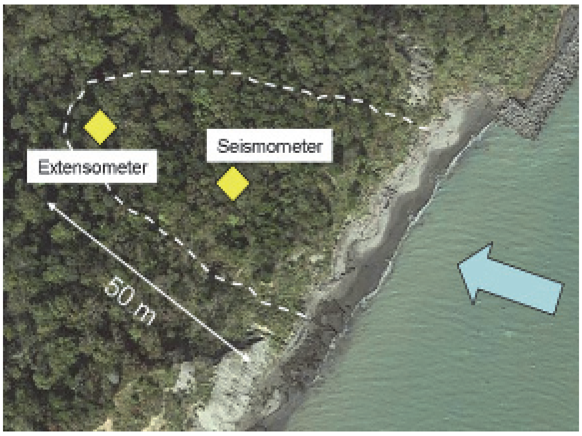

Photo 1: Aerial photo (from Google Map) of the landslide where we installed a seismometer. Yellow diamonds denote the locations where the instruments are settled. A dotted line and an arrow show the landslide blocks and the direction of the ocean waves, respectively.

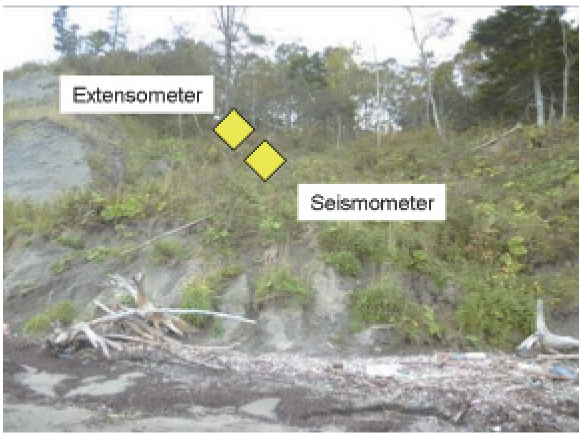

Photo 2: Landslide view from the bottom side. Yellow diamonds denote the locations where the instruments are settled.

ocean waves. The geology is completely weathered mudstone rich alternation with sandstone. The rocks near the ground surface are broken into almost soil properties due to the phenomena of freezing and thawing. Therefore, instability of the slope is brought to generate slope deformation as shown in Photo 3.

In this landslide, Matsuura et al. (2015) already installed an extensometer across the scarp to monitor the deformation of the slope. They also settled a potentiometer and a meteorological station in the landslide block. In this study, we installed a seismometer on the slope in the landslide block (~20 m distance from the coastline, denoted by yellow diamonds in Photos 1 and 2), to estimate the response of the slope to the seismic shaking. The natural frequency of the seismometer is 2 Hz. The seismic signals are continuously recorded every 0.01 seconds with the resolution 24 bit. The observation started on Sep. 24, 2014, and continues until now. Photo 4 shows the seismometers we settled in the landslide.

Photo 3: Slope deformation in the landslide where we settled a seismometer.

Photo 4: A seismometer which is settled on the slope.

3. Seismic waveforms due to a large earthquake

In Figure 2, we drew the seismograms for the M 4.6 event which occurred in the Pacific slab 89 km southeastward at depth of 48 km on Nov. 5, 2014. For comparison, the seismograms at Akkeshi station operated by Japan Meteorological Agency (JMA) and South-Shibecha (Shibecha-S) by National Research Institute for Earth Science and Disaster Prevention (NIED) are shown together. The seismometers are settled on the ground surface at Akkeshi (JMA) but buried on the bedrock at Shibecha-S.

In order to understand the frequency characteristics of the seismic waves, we visually picked direct S-times and calculated the spectrums for the waveforms from one second before to six second after the S-times. The results are displayed in the lower panel of Figure 2.

The peak ground velocity (PGV) at the landslide area reached 0.11 cm/s. This value is 4-5 times larger than that at Shibecha-S. It is suggested that the effect of amplification from the bedrock to the ground surface is large, even considering the difference in epicentral distance at landslide area and at Shibecha-S station.

On the other hand, PGV at landslide area was comparable to those at Akkeshi (JMA). However, the spectrums show that the frequency components were different. The seismic waveforms at landslide area contained more of high frequency (> 7 Hz) components.

4. Strong motion and landslide displacements

We show extensometer data from Sep. 24, 2014 to Feb. 7, 2015 in Figure 3 to compare with the strong motion which the landslide experiences. This landslide become active in the winter season (Matsuura et al., 2015), and had displacement of more than 8 mm from December, 2014 to January, 2015.

The landslide tended to move accompanied with rainfall, however, not with earthquake shaking. In fact, a M5.5 earthquake occurred on Jan. 9, 2015, with the epicentral distance about 100 km. The PGV at a landslide area exceeded at least 0.33 cm/s, but unfortunately, the waveform records were saturated due to high-gain recording. The day when this earthquake occurred is pointed by an arrow in Figure 3. No displacement was recorded accompanied with this earthquake. We interpreted that landslides are stable under the shaking as large as 0.33 cm/s and that much larger shaking would be necessary to make the soil plastic to cause landslide moving.

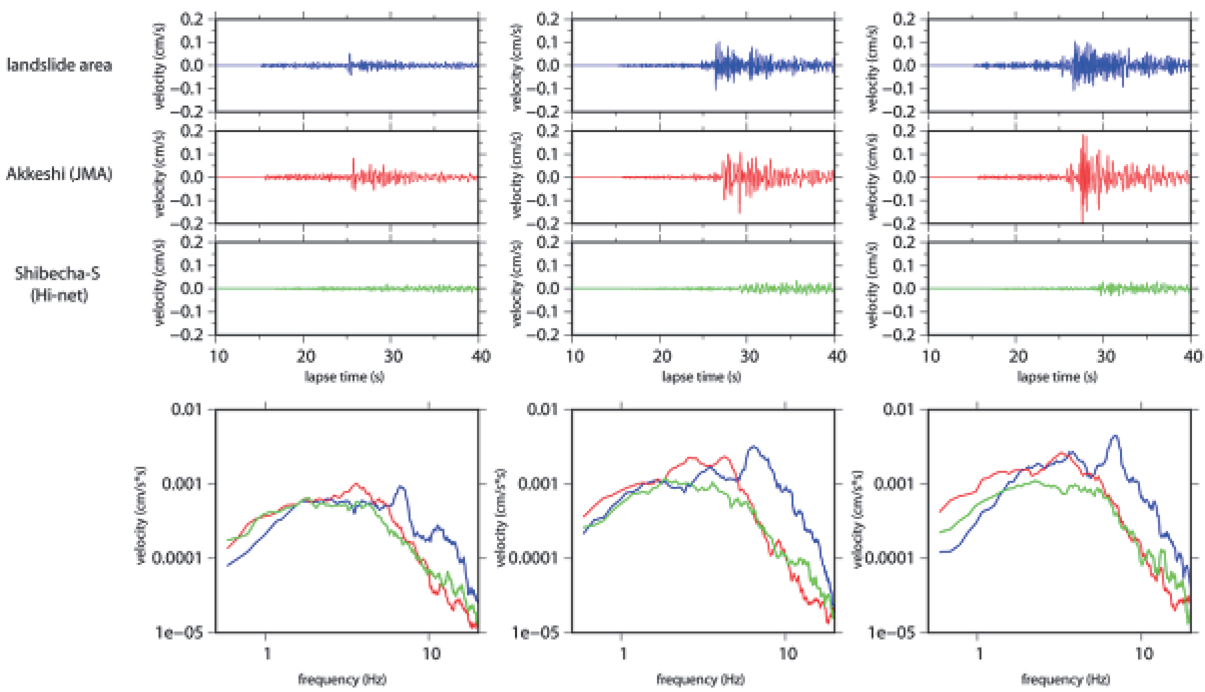

Figure 2: Seismic waveform data and spectrums for S-wave parts. The left, central, and right panels show the waveforms and spectrums for updown, north-south, and east-west components, respectively. The colors show the stations: blue (landslide area), red (Akkeshi, JMA), and green (Shibecha-S, NIED), respectively. The distances from the landslide to Akkeshi (JMA) and Shibecha-S were 3 km and 23 km, respectively.

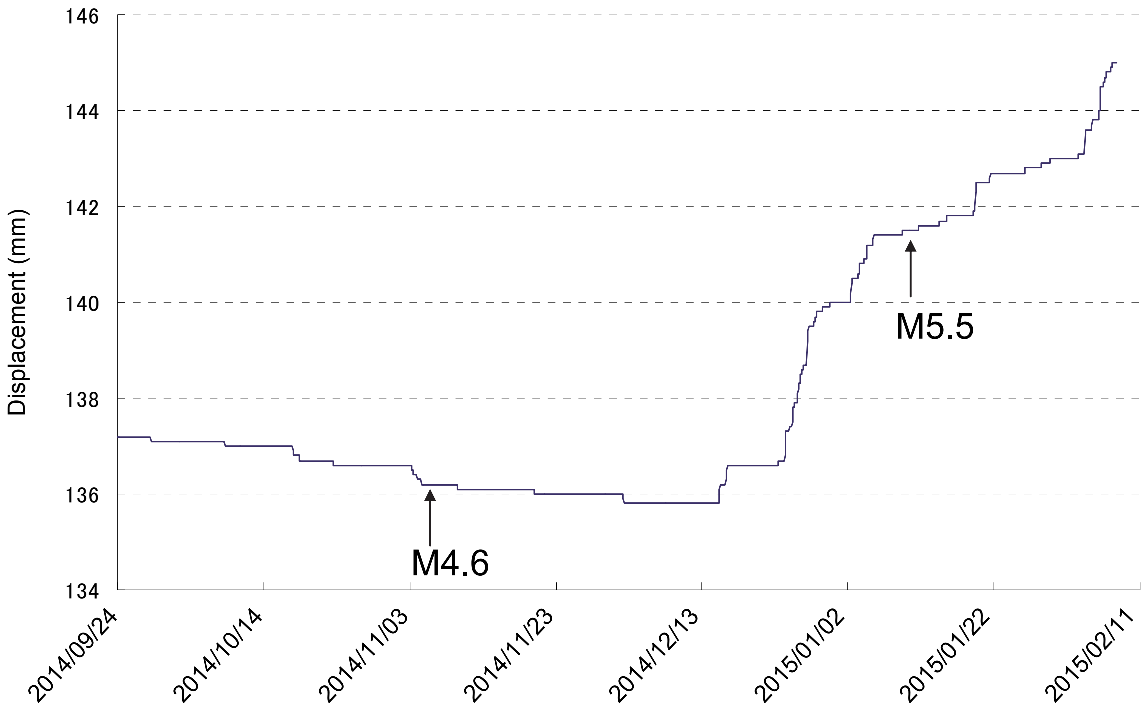

Figure 3: Extensometer data with large earthquakes (arrows).

5. Conclusions and future plans

We installed a seismometer in the coastal landslide area in the southeastern part of Hokkaido. One intra-slab event recorded by this seismograph was analyzed to understand the amplification effect. Comparison with the seismic waveform records at the permanent stations around revealed that there was 4-5 times amplification in PGV due to the existence of completely weathered mudstone, and that high frequency components were more largely amplified in the landslide area. So far, there was no landslide displacement in accompany with earthquake shaking, though the slope experienced the strong motion as large as at least 0.33 cm/s.

In the future, we should confirm that the amplification effect is the same or not for events with different back-azimuths. Moreover, we will measure a pore pressure in order to elucidate the ground water response to the seismic waves. Then, the answers to the following questions should be given. How do large seismic waves make the soil plastic and generate landslide displacement? How does the pore pressure respond at that time?

Acknowledgements

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