Displacement properties of a coastal landslide during a winter season

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Abstract

Weakly consolidated rocks are distributed widely in the area of eastern Hokkaido facing the Pacific Ocean. Therefore, the occurrence of coastal landslides has resulted in the recession of the shoreline. In this area, the soil layer is frozen due to the low temperature during the winter period, and the frozen soil may have some effects on landsliding. For this reason, coastal landslide displacement was monitored using a wire-type extensometer during the winter period. Although the cumulative landslide displacement of five months was as small as 8.6 mm, intermittent displacement was observed throughout the entire period. There was a close relationship between landslide displacement and tide level and/or sea waves. Heavy rain may have little effect on landslide displacement when topsoil is frozen.

Keywords: coastal landslide, frozen soil, sea wave, tide level

1. Introduction

Coastal landslides occur frequently due to seaside erosion along the coast of the Black Sea, the Caspian Sea, and even the Baltic Sea (Edil et al. 1983; Işik et al. 1988; Setayeshirad et al. 2013; Uścinowicz et al. 2014). In Japan, reductions in the amount of sediment carried from mountains to the sea by rivers have resulted in rapid recession of the shoreline. Although these depend on the geological and oceanographic conditions, slope failure, rock fall, and landslides occur in the coastal slope.

Weakly consolidated rocks, such as siltstone and argillaceous rock, are distributed widely in the area of eastern Hokkaido facing the Pacific Ocean (Yamagishi et al. 1994). Therefore, landslides often occur by coastal erosion, and this landsliding leads to yearly recession of the shoreline. In this area, the soil layer is frozen during winter due to the low temperatures and the frozen soil may have some effects on the displacement properties of landslides. For this reason, the displacement of a coastal landslide was monitored during the winter period.

Fig. 1 Location map of research site.

2. Overview of the research site and monitoring method

We selected a reactivated landslide located in the hillside along Akkeshi Bay, Hokkaido, as the research site (Fig. 1). The hillsides along Akkeshi Bay are a landslide-prone area (Fig. 2). Small to medium landslides occur every year, and large-scale landslides occur occasionally. The investigated landslide is a small reactivated landslide with a length of approximately 70 m and a width of approximately 15 to 20 m (Fig. 3). Its head scarp is located just below a small ridge of coastal hills, and its terminus is at the

Fig. 2 Ongoing landslides in hillsides of Akkeshi Bay.

Fig. 4 An installed wire-type extensometer.

Fig. 3 Research landslide as seen from the sea.

shoreline. Therefore, this landslide is subject to fluctuations of tide level and/or wave erosion.

The local geology consists of the Nemuro Group, composed of alternating Late Cretaceous sandstone, siltstone, and mudstone, and it has a homoclinal structure with a dip of approximately 20° south. Although the geological age is Cretaceous, the siltstone and mudstone are weakly consolidated and break down into sand-sized particles in a short amount of time. The annual average temperature in this region is 5.5 °C, and the daily mean temperature falls below 0 °C from December to March. However, the research site is located at the shoreline, so the lowest temperature is no lower than -15 °C, which is in contrast with inland areas of Hokkaido. The depth of snow during the coldest season is shallow because little solid precipitation falls during the winter period.

To observe the landslide displacement, we installed a wire-type extensometer with a resolution of 0.1 mm at the head scarp of the research site (Fig. 4). Landslide displacement was monitored every one hour from December 2013.

3. Results and discussion

Fig. 5 shows the landslide displacement of the four months from December 22, 2013, to April 28, 2014. Although the cumulative displacement of the landslide during the monitoring period was as small as 8.6 mm, intermittent landslide displacement was observed throughout the period. The maximum daily

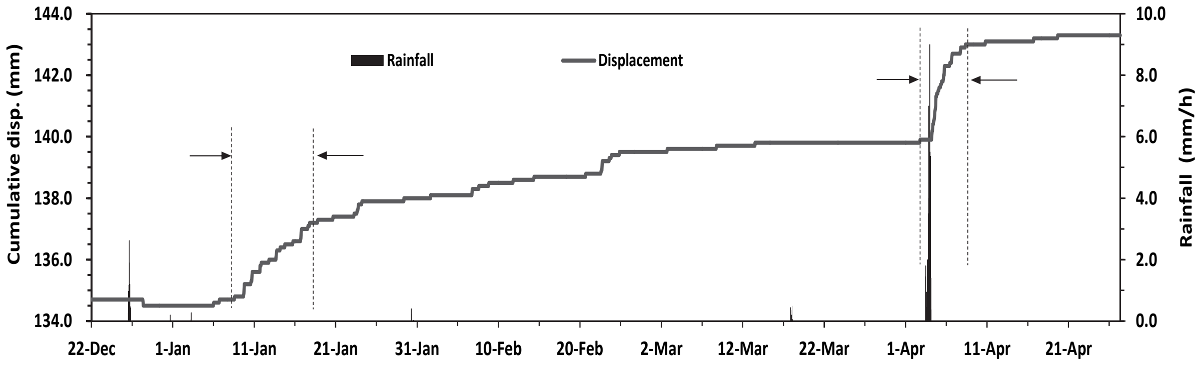

Fig. 5 Relationship between rainfall and cumulative displacement of landslide during the winter period.

displacement of 1.2 mm was observed on April 5, and small displacement was detected in even the coldest months of January and February.

Generally, precipitation in Eastern Hokkaido is small, and only a negligible amount of rain is observed in the coldest season. Thus, intermittent slight displacement may be due to oceanographic conditions. For this reason, we compared the tide data of Akkeshi fishing port with the observed landslide displacement and found a close relationship between the tide data and landslide displacement, as shown in Fig. 6. Therefore, there is a high possibility that the toe of the landslide was destabilized by an increase in pore-water pressure and/or wave erosion.

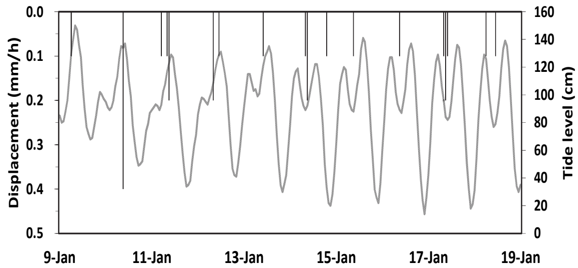

Fig. 6 Relationship between tide level and landslide displacement in the coldest season.

On the other hand, an atmospheric depression brought approximately 60 mm of rainfall with a maximum hourly rainfall of 9 mm on April 4. Landslide displacement was detected immediately after the end of the rainfall regime, and cumulative displacement of the three days following the event reached 2.3 mm. Fig. 7 shows the relationship between the rainfall and the cumulative displacement of the landslide.

When it rains, pore-water pressure increases because of rainwater infiltration into the slope. The increase in pore-water pressure causes a decrease in effective stress, resulting in landslides. Therefore, in this case, precipitation appears to have induced the landslide. However, the time lag between rainfall and landslide displacement tends to become shorter as the scale of the landslide scale becomes smaller. This landslide movement did not begin during the rain but instead began one hour after the rain. Because this research site is located in the zone of soil freezing and the topsoil was frozen to a depth of 40–80 cm for 4 to 6 months, there is a high possibility that rainwater infiltration was prevented by the frozen soil. Changes in the timing and thickness of snow cover can cause a dramatic reduction of frost depth and change in the soil water dynamics (Iwata et al. 2010). Therefore, climate change may have a significant impact on the landslide activities.

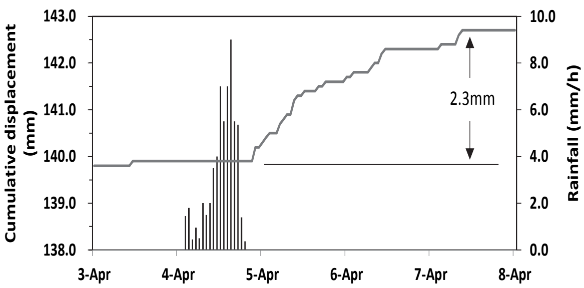

Fig. 7 Relationship between rainfall and cumulative displacement of the landslide.

The sea was rough during the approach and passing of the atmospheric depression after April 4 (Fig. 8). In addition to the tide level at Akkeshi fishing port, the average wave height, and the significant wave height, the highest wave height observed at Kushiro Port was also investigated. Fig. 9 shows that the landslide displacements occurred at times when high waves were generated.

Although detailed investigation is needed because Kushiro Port is about 40 km from Akkeshi fishing port, the effects of sea waves cannot be excluded. When landslide displacement is caused by waves, the total amount of displacement would increase unless the topsoil is frozen. In the future, we intend to add piezometers and soil temperature gauges to the present monitoring system to make a more detailed analysis.

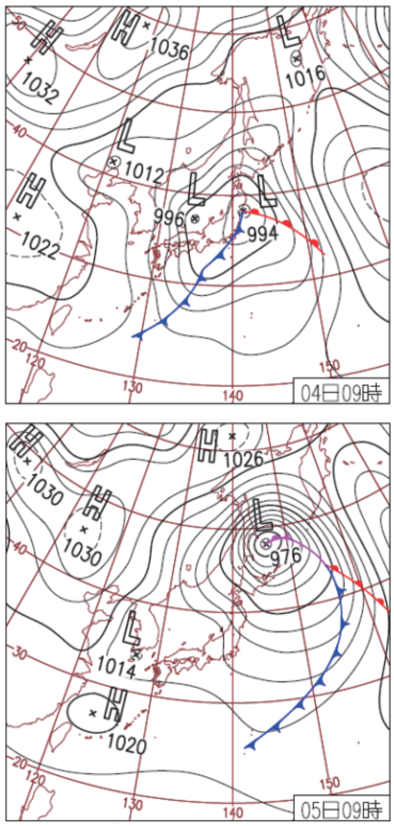

Fig. 8 Weather charts of April 4 and 5, 2014.
(http://www.jma.go.jp/jma/indexe.html)

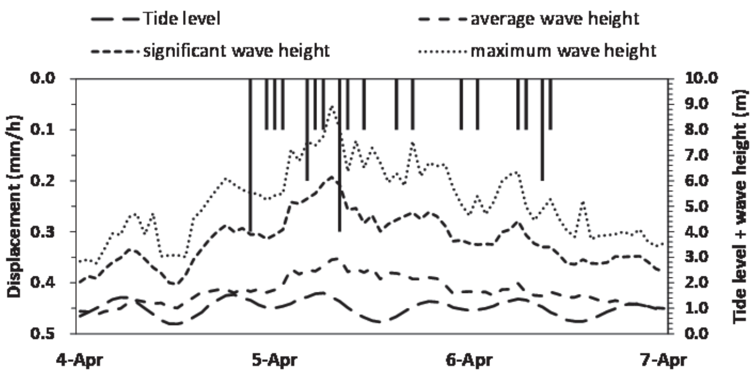

Fig. 9 Relationship between sea wave height and landslide displacement.

4. Conclusions

We monitored a coastal landslide during a winter season to clarify the relationships between landslide displacement and oceanographic conditions. Intermittent displacement was observed throughout the period, and there were close relationships between landslide displacement and tide level and/or sea waves. However, the physical mechanism and processes of landslide destabilization by these oceanographic conditions were not elucidated. On the other hand, heavy rains may have little effect on landslide displacement when the topsoil is frozen. It is necessary to advance further research of the effects of frozen soil on landslide stabilization or destabilization.

Acknowledgment

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