Effects of Snow Load on Water Infiltration in the Ground Surface Layer of a Landslide

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Abstract

We observed the pore-water pressure and infiltration capacities in a re-activated landslide with a shallow sliding surface in Japan. Observations on the response of pore-water pressure to meltwater and/or rainfall (hereinafter referred to as "MR"), show different characteristics for periods with and without snowfall. In particular, during a period of melting snow, MR infiltrates the ground by ~20 to 100 mm/day for over a month. We determine patterns in infiltration capacities based on observations that gradually increased from the maximum water equivalent of snow to the height of summer, followed by a slow reduction from summer to early winter. It can be said that one of the reasons for infiltration capacity changes, was the compression and expansion by the snow load of the underground shallow parts composed by overconsolidated clay. The oxidation layer occurs at $K_{sat}=1\times10^{-5}$ m/s from the ground level (G.L.) to G.L. −0.8 m, and the reduction layer is $K_{sat}=5\times10^{-7}$ m/s from G.L. −0.8 m to G.L. −2 m. In the event of huge amounts of MR in the ground, the water vertically infiltrates the oxidization and reduction layers. It then constitutes a throughflow from a boundary layer when the reduction layer is saturated. It can be said hydraulic characteristics of geology prescribe an upper limit of the pore-water pressure.

Keywords: heavy snow districts, field observations, pore-water pressure, infiltration capacity, compression, expansion

1. Introduction

Landslides in regions subject to snows frequently occur owing to an increase in pore-water pressure caused by melting snows. However, Matsuura (2000) reported that pore-water pressure fluctuations during seasons with and without snowfall were totally different, with landslides having a gentle slope angle and shallow sliding surface. Okamoto et al. (2008) studied by the safety factor increasing by snow load, which was increased the effective stress of landslide mass with shallow sliding surface and a gentle slope angle. Okamoto et al. (2015) reported field observations of a vertical displacement gauge on shallow ground, reflect compression and expansion in association with snow loading and unloading. This suggested occurrence of a clayey soil in an overconsolidated state. We suggest that snow load affects the process of infiltration of meltwater into the ground, and influences the fluctuation of pore-water pressure characteristics. We describe hydrological and soil mechanical characteristics of the surface layer in a re-activated moving landslide body in a heavy snow district.

2. Overview of the study site

The Busuno landslide site, Niigata Prefecture, Japan, is situated in the mountainous area facing the Sea of Japan, where it is underlain by Neogene sedimentary rocks (Fig.1). This region is affected by heavy snowfall with a maximum snow depth of over 5 m. The study site comprised a landslide area of 300 m long and 50-70 m wide, at an elevation of 550-650 m, with a mean inclination of 10˚-15˚. This site is a typical example of a re-activated landslide and the sliding surface depth was 3-6 m. The surrounding forest cover ratio was 7%, comprising *Cryptomeria Japonica* and broadleaf trees. The density of vegetation cover is almost 100% in summer, but is absent in winter, the region being snowbound. The dominant vegetation species are *Miscanthus sacchariflorus* and *Phragmites australis.*

3. Test and Observation method

3.1 In-situ infiltration test

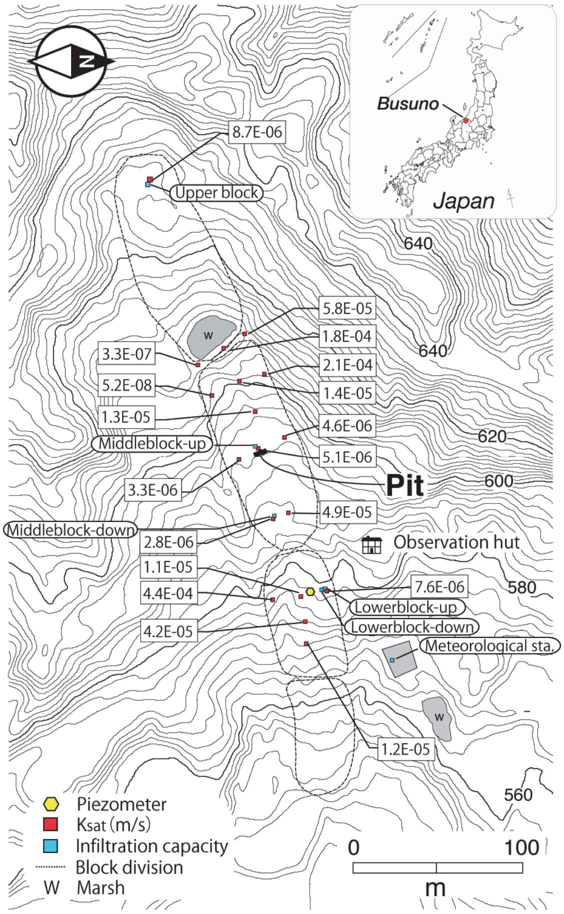

Fig.1 Locations of installed sensors and horizontal distribution of hydraulic conductivities of top soil in the Busuno landslide

Infiltration capacities were measured by a portable single ring infiltrometer that consumed a small amount of water (4.5 l). We measured 6 points (1. Upper block, 2. Middle block-up, 3. Middle block-down, 4. Lower block-up, 5. Lower block-down, 6. Meteorological station), across the landslide in order to investigate patterns of spatial distribution. Cylindrical pipes were placed in the soil and were then studied. Water temperature for tests was adjusted to approximately 0˚C to unify viscosity.

3.2 Saturated permeability test

We carried out constant head and falling head permeability tests on 3 samples collected from one spot. We dug a pit to G.L.−2 m for sampling soil in the middle block that revealed a vertical profile of permeability. The vertical section was divided into 2 layers comprising oxidization and reduction zones. Soil specimens in the oxidization layer of organic clayey soil from the ground level to −0.8 m, were sampled vertically to assess vertical infiltration. Soil specimens in the reduction layer of tuffaceous clayey soil, were sampled parallel to the slope, to assess lateral flow.

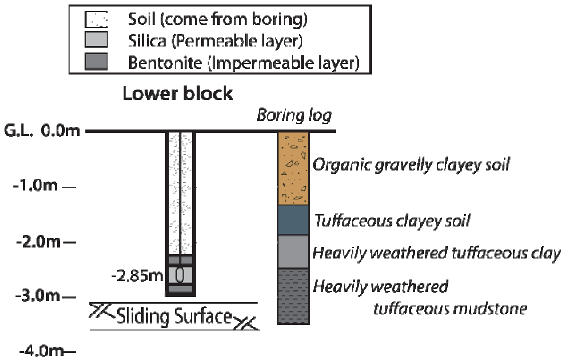

Fig.2 Depth of sliding surface and piezometers and boring log

3.3 Pore-water pressure

Pore-water pressure was observed using a diaphragm-type piezometer of a full scale of 50 kPa, which was installed in the clayey soil in the middle block at G.L. −2.85 m. The surrounding space in the silica sand, and the top and bottom were plugged with Bentonite (Fig.2).

3.4 Meteorological observation

The snow depth was observed using a laser-type snow depth gauge at a meteorological station. The water equivalent of snow was observed using a metal wafer type sensor. The water that reaches the ground (hereinafter referred to as MR) was observed using lysimeters with a tipping-bucket discharge gauge.

4. Results and discussion

4.1 Observation of the pore-water pressure

Figure 4 shows the fluctuation of pore-water pressure, snow depth, snow load and MR. The pore-water pressure fluctuation during times with and without snowfall displayed totally different characteristics. The pore-water pressure reacts sharply on MR in seasons lacking snowfall. However, pore-water pressure reacts little in the season of snowfall, especially during the snowmelt period. The snowmelt period was usually marked by infiltration on the ground surface by melting-water of 20-100 mm/day for over a month. Figure 4 shows that the upper limit of the pore-water pressure fluctuation was approximately 16 kPa (=164 cmH_2O) over the whole period. We took the piezometer depth at G.L. −2.85 m into consideration with the water table approximately at G.L. −1.2 m. Figure 2 shows the piezometer depth and boring log. A slightly brown oxidized color zone, termed the oxidization layer, occurred from ground surface to G.L. −80 cm. A blue-gray reduction color zone, was termed the reduction zone, from G.L. −80 cm. Figure 3 shows the vertical profile of hydraulic conductivities and a stratigraphic profile. The hydraulic conductivity of

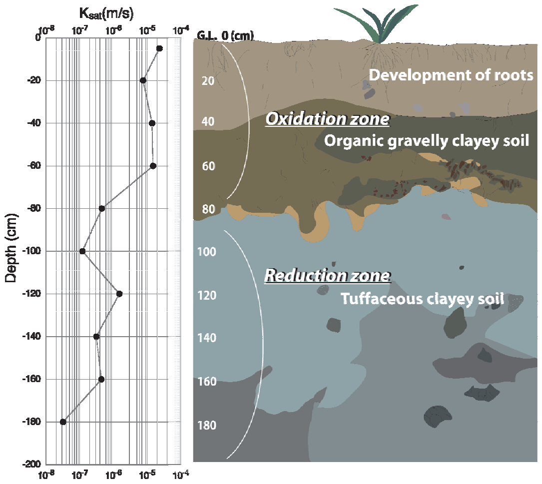

Fig.3 Vertical profiles of the hydraulic conductivity

the oxidization layer is of the order of 10^{-5} m/s. Further, the mean hydraulic conductivity of the reduction layer is of the order of $5*10^{-7}$ m/s. This result suggests that there is a difference of 500 times between the former and the latter, which is the boundary of permeability. The water table corresponded to the boundary between the oxidization and reduction layers. Water infiltrates vertically into the oxidization layer, and then forms a throughflow from under the boundary layer, in the case of a saturated reduction layer.

4.2 Seasonal changes of infiltration capacity

Figure 1 shows the horizontal distribution of saturated hydraulic conductivities that were partial at specific points; the mean value is $5*10^{-5}$ m/s, the maximum value is $1*10^{-4}$ m/s, and the minimum value is $1*10^{-8}$ m/s. Consequently, we infer that a saturation overland flow does not occur even after heavy rains (>180 mm/h).

Infiltration capacities were tested twelve times in the field, and the results suggest seasonal variation of the infiltration capacity. Figure 5 shows changes in infiltration capacities, MR, snow depths, and air temperatures. We conducted infiltration tests at lower block-up and down on March 5, 2013. Results of a field snow survey at the maximum water equivalent of the snowfall period, show a snow depth of 470 cm, mean density of snow being 0.44 g/cm^3, and a snow load of 19.4 kN/m^2 acting on the earth's surface. Results showed that infiltration capacities gradually increased from the maximum water equivalent of the snow season to the height of summer, and slowly reduced from summer to early winter.

4.2.1 Upper block(×), Middle block-down(△)

The infiltration capacity of the upper block and middle block-down were increased by over 3 times from each initial observation on May 12th and 25th and July 5th. At these points, the inclination angles were 3°, these being water catchment topographies. The ground surface was in a saturated state, like a marsh, after the snowmelt period, as noted in field investigations. Moreover, the hydraulic conductivity at the spot of Middle block-up and infiltration capacity were closed result on May 12. Following this, the water table gradually lowered with increased permeability.

4.2.2 Lower block up • down (○•■)

Infiltration capacities of the lower block-up • down were at 1.3, 1.9 times with each other from March 5 to the period following snowmelt. Moreover, these were at over 2 times with each other from after snowmelt to summer. Okamoto et al. (2015) report soil expansion by decrease in the snow load from mid-April to the beginning of May, during the snowmelt period. The ground surface was compressed by a snow load reaching 20 kN/m^2, which with a decreased void ratio. According to the study by Tavenas et al. (1983), the void ratio of clays is positively correlated with its permeability. It is possible that the pore-water pressure response was

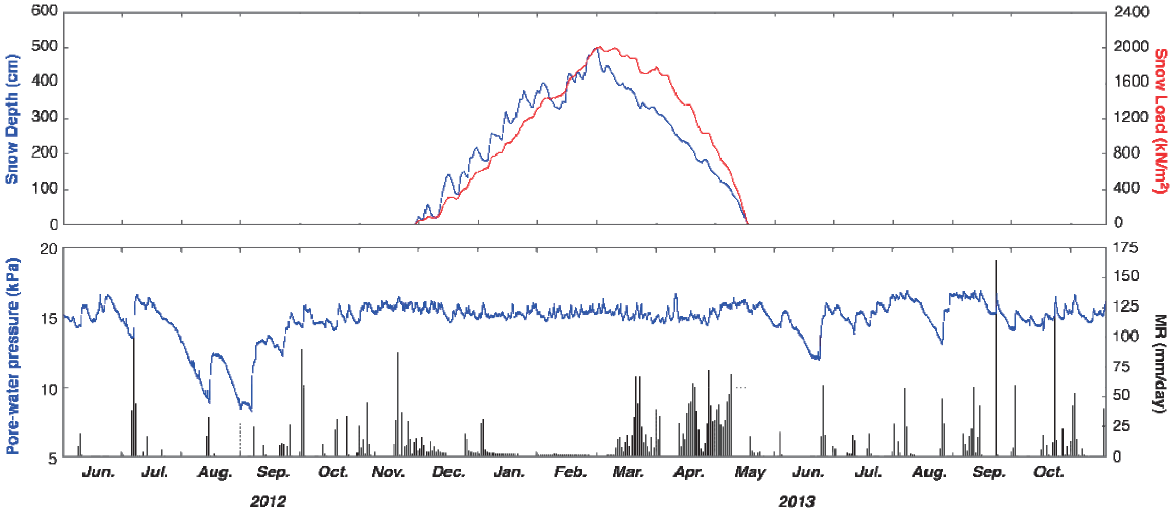

Fig.4 Fluctuation of the pore-water pressure and its related factors

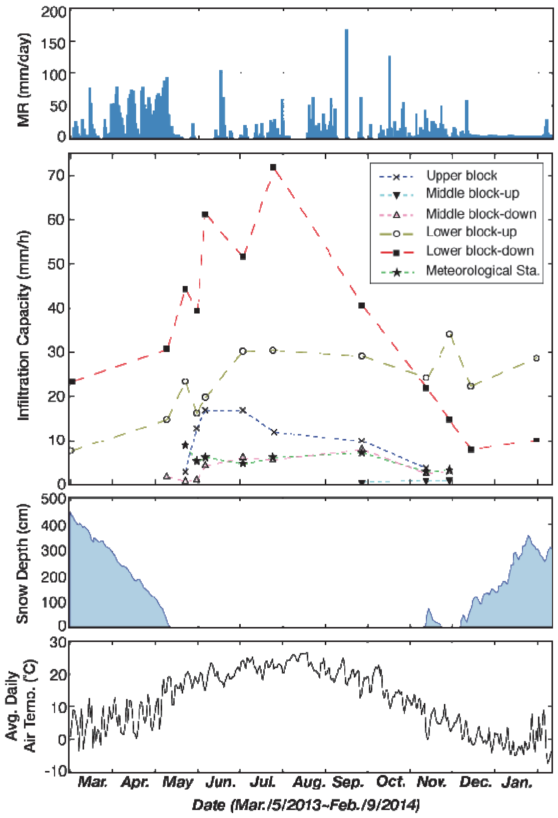

Fig.5 Changes of Infiltration capacities and its related factors

delayed by lowering the infiltration capacity. It seems reasonable to assume that the earth's surface gradually expanded by unloading of snow, thereby increasing the void ratio and permeability. Some authors suggest that the control of seasonal changes in infiltration capacities is due to plant growth and animal activities within the soil (e.g., Gifford, 1972; Cerda, 1996; Bormann and Klaassen, 2008). Roots of reed grass and Amur silver-grass in all the surrounding top soils in the landslide area were active during seasons with a high temperature. This suggests the influence of pipes and macropores on water infiltration.

4.2.3 Meteorological station (★)

A meteorological station was established, and it consists of an artificial ground of sand. We conducted tests with the assumption of it remaining unchanged the void ratio over a whole year. Results indicate that the first observation value was high, that explained problems of cylindrical pipe driving. There were few changes in infiltration capacities.

5. Summary

We observed infiltration capacities and pore-water pressure of a landslide with a shallow sliding surface in a heavy snowfall district of Japan.

Infiltration capacities changed with seasons. It is possible that infiltration capacities were affected by snow loads on the ground surface. Result from these tests indicates that permeability changes by changing void ratios in soils, which is a result of compression and expansion of the underground shallow parts composed of overconsolidated clay by the snow load.

According to the vertical profile of hydraulic conductivity, the oxidation layer existed from $K_{sat}=1\times10^{-5}$ m/s from ground surface to G.L. −0.8 m, the reduction layer from $K_{sat}=5\times10^{-7}$ m/s from G.L. −0.8 m to G.L. −2 m. As a result of the pore-water pressure observations and the vertical profile of hydraulic conductivity, the boundary between the hydraulic characteristics of the geology prescribed saturated and un-saturated states. In addition, the boundary regulates the upper limit of the pore-water pressure fluctuation.

Response characteristics of the pore-water pressure have been sparsely investigated. We plan to conduct further observations and to run numerical simulations.

Acknowledgements

The present study was funded by a Grant-in-Aid for Challenging Exploratory Research, Disaster Prevention Research Institute, Kyoto University (No. H26-02).

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