Comparison of a snowpack on a slope and flat land by focusing on the effect of water infiltration

Shinji Ikeda[1*], Takafumi Katsushima[2], Yasuhiko Ito[1], Hiroki Matsushita[3], Yukari Takeuchi[4], Kazuya Akiyama[1]

[1]Snow Avalanche and Landslide Research Center, Public Works Research Institute, Myoko, JAPAN

[2]Toyama National College of Technology, Imizu, Japan

[3]Civil Engineering Research Institute for Cold Region, Public Works Research Institute, Sapporo, JAPAN

[4]Tohkamachi Experimental Station, Forestry and Forest Products Research Institute, Tohkamachi, Japan

ABSTRACT: Water infiltration of snowpack plays an important role in wet avalanche formation. Several studies have examined water infiltration of snowpacks on flat land. However, because the infiltration process includes uniform flow as well as preferential flow (e.g., vertical flow through a water channel), the effect of water infiltration into snowpack may differ between flat land and slopes, where avalanches may occur. We simultaneously observed snow pits on flat land and on a slope (40° incline, northeast aspect). The observations, conducted from January to April 2012, showed that the Melt Form (MF) ratio (the ratio of the total thickness of the layers comprising the MF to the thickness of all the layers of the snowpack) was on average 26% higher for the snowpack on the slope than for the snowpack on flat land. The largest difference between the MF ratios of the slope and flat land was observed in early March, when the MF ratio was 99% for the slope and 54% for the flat land. We analyzed these observations using a multi-layer snowpack model proposed by Katsushima et al. (2009). The model included parameterization of the vertical water channel process in a snowpack. Of the total amount of infiltrated water, the amount infiltrating through vertical water channels was 14% for the slope and 47% for the flat land. Our results suggest that the notable difference in the MF ratios was attributable to the differences in the water infiltration process between the sites.

KEYWORDS: Water infiltration of snowpack; Wet snow; Snow stratigraphy; Snowpack model

1 INTRODUCTION

In regions such as the Hokuriku distinct of Japan where heavy snow can persist during warm air temperatures, liquid water is supplied to snowpacks by snow melt and rainfall even in mid-winter. Under these circumstances, the risk of wet snow avalanches exists throughout the winter period.

Liquid water infiltration of snowpack plays an important role in wet avalanche formation through the creation and alteration of snow layer structures and snow grain type, density, water content, and strength. Infiltration can include uniform flow as well as preferential flow (e.g., vertical water channel flow), and infiltration processes may differ between flat lands and slopes where where avalanches can occur. However, most observations of water infiltration of snowpack have been conducted on flat land (Wakahama, 1963; Colbeck, 1979; Jordan, 1983; Waldner et al., 2004). Thus, we conducted snow pit observations simultaneously at a flat site and on a slope and compared the results, focusing on the snow layer structure and snow grain type.

Corresponding author address: Shinji Ikeda, Snow Avalanche and Landslide Research Center, Public Works Research Institute, 2-6-8 Nishiki-cho, Myoko, Niigata, 944-0051, Japan; tel: +81 255 72 4131; fax: +81 255 72 9629; email: s-ikeda55@pwri.go.jp

2 STUDY SITE AND METHODS

2.1 STUDY SITE

The study was conducted at the Tohkamachi Experimental Station of the Forestry and Forest Products Research Institute in Niigata, Japan (37° 08′ N, 138° 46′ E, 200 m a.s.l.). The average maximum annual snow depth at the site was 2 m, and the average temperature was almost 0°C even during January and February (Yamanoi et al., 2000). Snowmelt and rainfall often occur even in mid-winter, and typically create moist or wet snowpacks throughout the winter. The study sites established on flat land (FLT) and on a slope (SLP) were selected to avoid the typical wind loading and wind erosion. The slope angle of SLP was 40°, and a NE slope aspect was selected to avoid large differences in snow melting caused by solar radiation.

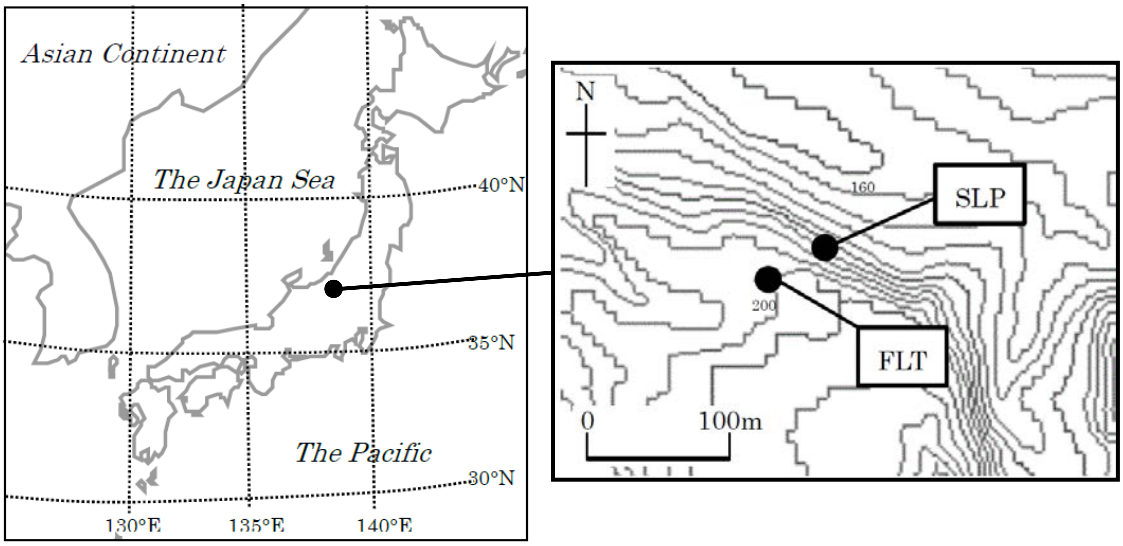

Figure 1. Study site

2.2 OBSERVATION METHODS

For each snowpack, a snow pit was dug down to ground level from the snow surface. Observations of the pit wall were made following the international classification for seasonal snow on the ground (Fierz et al., 2009). Observations were conducted every 20 days. The observed items and methods used are as follows.

Snowpack layer structure: the position and thickness of the layers were determined by visual means and by touch using hands or fingers.

Snow-grain type and diameter: determined by using a snow crystal screen, which had three grids of 1, 2, and 3 mm, with a hand loupe (10×).

Hardness: measured by a push gauge (Takeuchi et al, 1998) every 10 cm (or greater to measure all layers).

Snow temperature: measured with a thermistor thermometer every 10 cm.

Density: measured with a 100 cm^3 sampler every 10 cm (or greater to measure all layers).

3 RESULTS

Snow pit observations were conducted on selected dates from January to April 2012 (5 Jan., 25 Jan., 15 Feb., 5 Mar., 26 Mar., and 13 Apr.). The layer structure and snow grain type of each layer of SLP and FLT are shown in Figure 2 and the Change in the Melt Form (MF) ratio (the ratio of the total thickness of the layers comprising the MF to the thickness of all the layers of the snowpack) is shown in Figure 3.

Figures 2 and 3 show clear differences in the layer structure and dominant grain types. Most of the middle and lower parts of the SLP snowpack changed their MF earlier than the FLT snowpack. In addition, the MF ratio was higher for the SLP snowpack than for the FLT snowpack. The average difference in the MF ratio between SLP and FLT was 26%. The largest difference between the MF ratios of the sites was observed on 5 March. The MF ratio for the slope was 99% and that for FLT was 54%.

Observations of the snow pit wall (Figure 4.) suggested that the vertical water channel flow at SLP was less than that at FLT, and the snowpacks were more uniformly affected by water at SLP than at FLT. However, a larger part of the water appeared to flow down into the vertical water channel at FLT than at SLP, which prevented the change in grain type to the MF at middle and lower parts of the FLT snowpack.

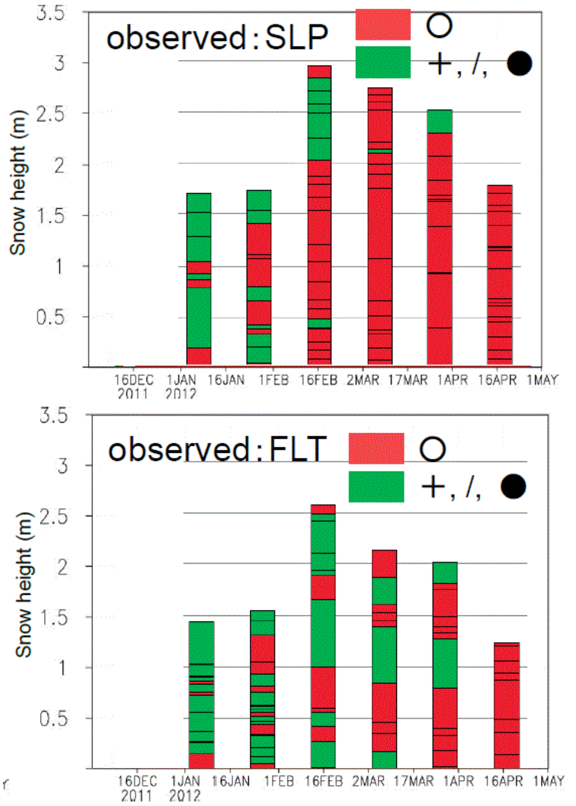

Figure 2. Comparison of layer structure and snow grain type in each layer observed at SLP and FLT.

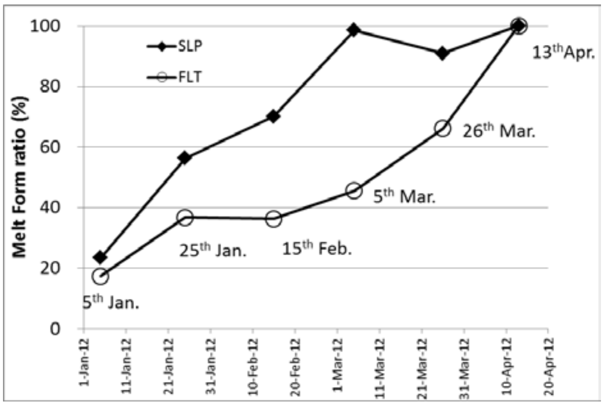

Figure 3. Change in the MF ratios observed at SLP and FLP.

4 ANALYSIS OF THE AMOUNT OF WATEWR FLOWING INTO VERTICAL WATER CAHNNELS

The observations of snow pit walls suggested that differences in the snow layer structure and the MF ratio between SLP and FLT were caused by differences in the amount of water flowing into vertical water channels. To estimate the amount of water flowing into vertical water channels at each site, we used a snowpack model developed by Katsushima et al. (2009) that included a parameterization of the vertical water channel process in a snowpack. The equation for the water retention curve was

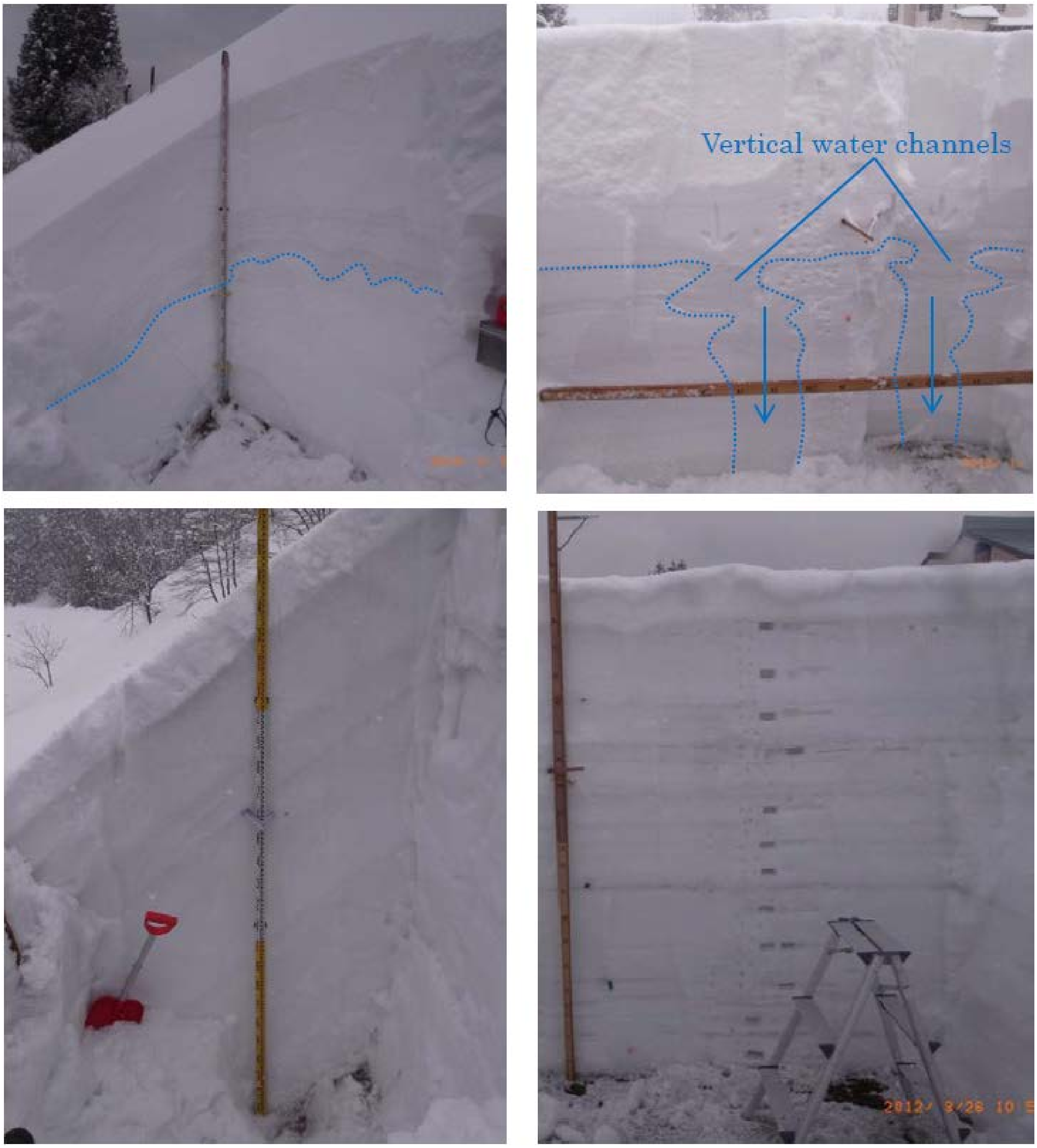

Figure 4. Typical examples of the snow pit walls of SLP (left) and FLT (right): upper, 5 Jan. 2012, and lower, 26 Mar. 2012.

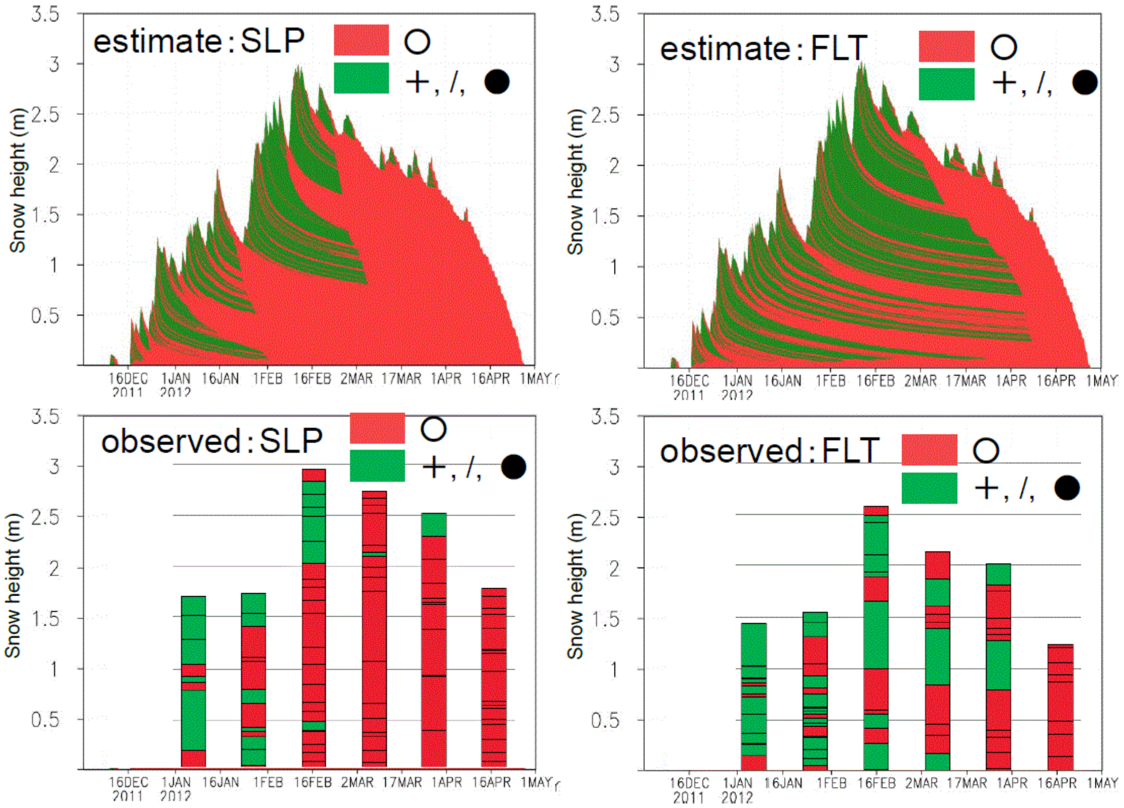

Figure 5. Comparison of estimated and observed layer structures and grain types at SLP and FLT.

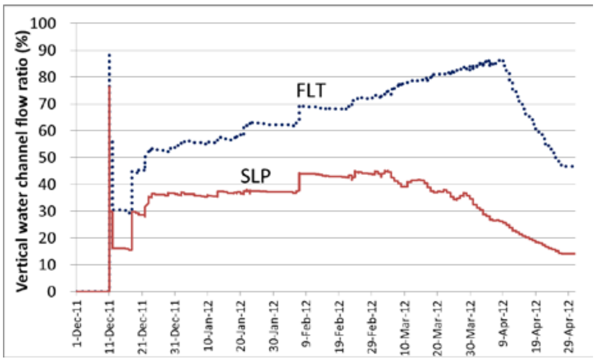

Figure 6. Comparison of estimated vertical water channel flow ratios for SLP and FLT.

changed to that proposed by Yamaguchi et al. (2012). For the calculations, meteorological data (temperature, humidity, precipitation, solar radiation: upward and downward and radiation budget) collected near FLT were used for both SLP and FLT. We assumed that SLP and FLT received the same amount of water supplied by the melting of surface snow and by rainfall. For the model, the amount of water flowing into the vertical water channels was adjusted by comparing the estimated values of the MF ratio with observed values.

Figure 5 compares the estimates by the snowpack model, using the adjusted amounts of water flowing into the vertical water channels for SLP and for FLT, and the observed layer structure and snow grain type at each site. As shown in the figure, the model results well represented the observations when using the adjusted values of water flow into vertical channels for each site.

Figure 6 shows the estimated vertical water channel flow ratio (the ratio of the accumulated amount of water infiltrating the vertical water channel to the total accumulated infiltrated water) for SLP and FLT. The figure shows a notable difference in the vertical water channel flow ratio between SLP and FLT. The vertical water channel flow ratio during the snow-covered period was 14% for SLP and 47% for FLT.

These results support our hypothesis regarding the cause of the differences in the snowpack observed at SLP and FLT.

5 CONCLUSION

To examine differences of the effects of water infiltration of snowpack on flat and sloped sites, we conducted simultaneous snow pit observations on flat land (FLT) and a slope (SLP) and compared the results, focusing on the snow layer structure and snow grain type. We found that the MF ratio was notably higher for the SLP snowpack than for the FLT snowpack. On the basis of snow pit wall observations, we hypothesized that the differences in the SLP and FLT snowpacks were caused by differences in the amount of water flowing into vertical water channels.

To support our hypothesis, we analyzed observational data using a multi-layer snowpack model that included a parameterization of the vertical water channel process in snowpack. The results indicated that the amount of water to flowing into the vertical water channel at SLP needed to be less than one-third of the FLT flow to generate the observed differences in the SLP and FLT snowpacks.

Our results suggest that the amount of water flowing into vertical water channels differed between SLP and FLT. The results also reveal differences in the snowpack structure and snow grain type between SLP and FLT.

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