Measurement of dynamic water-entry value for dry snow

Takafumi Katsushima[1,*], Satoru Yamaguchi[2], Toshiro Kumakura[1] and Atsushi Sato[2]
[1]Nagaoka University of Technology, Nagaoka-city, Niigata, JAPAN
[2]Snow and Ice Research Center, National Research Institute for Earth Science and Disaster Prevention, Nagaoka-city, Niigata, JAPAN

ABSTRACT: In soil physics, many people have discussed about mechanisms of developing preferential flow based on porous media hydraulics. In snow science, there are few studies on the preferential flow though the preferential flow governs a part of runoff process in a snowpack. Dry sand has a water-entry value which is a threshold value of the capillary pressure to start infiltration into dry sand. Water cannot infiltrate in the situation that the capillary pressure at the wetting front is less than the water-entry value. The preferential flow is developed in the upward-negative gradient of the capillary pressure behind the wetting front, which is appeared in the case that the water-entry value is larger than the capillary pressure along the upper moving path of the wetting front. It is thought that the phenomena on the preferential flow in the sand are almost same as these in the snow and the water-entry value of the homogeneous dry snow layer is important to study the preferential flow in the snowpack. In this study, the water-entry values were obtained by measuring the capillary pressure at the wetting front penetrating into the underlying dry snow. The capillary pressure was measured with the high response tensiometers. The measured water-entry values were greater than the air-entry value according to the water retention curve for drying process. The water-entry value with large diameter is larger than one with small. The some paths of the preferential flow were observed in these experiments. On the other hand, the water-entry value was not observed and the preferential flow was not observed in the experiment which used the smaller diameters of snow particles.

KEYWORD: preferential flow, water-entry value, homogeneous dry snow

1 INTRODUCTION

Preferential flow is an important factor of simulating snowpack structures and forecasting wet avalanches. Impermeable dry snow through which the preferential flow can develop is often maintained in the snowpack. Thus, the studies of the preferential flow are important to simulate physical processes of the snowpack(Gustafsson et al., 2004; Katsushima et al., 2008).

The preferential flow is formed on impermeable layers which is usually observed in following three situations; 1) on a coarse-textured impermeable layer under a fine-textured layer (Wakahama, 1963; Marsh and Woo, 1984), 2) on an ice impermeable layer under a snow layer (Langham, 1974), and 3) on a dry snow layer at wetting fronts into a homogeneous dry snow layer (Nohguchi, 1984). The impermeable layer 1) is formed by a capillary barrier due to a difference of the capillary pressure in each of the layers (Wakahama, 1963; Jordan, 1996). And the impermeable layer 2) is explained by water conductivity in the ice layer. The process of the preferential flow 3) is not understood well.

In soil physics, many people have discussed about the mechanisms of developing preferential flow. Dry sand has a water-entry value which is a threshold value of the capillary pressure to start infiltration into the dry sand (Hillel and Baker, 1988; Baker and Hillel, 1990). The water cannot infiltrate in the situation that the capillary pressure at the wetting front is less than the water-entry value. The preferential flow is developed in the upward-negative gradient of the capillary pressure along the upper moving path of the wetting front (Raats, 1973; Philip, 1975). The negative gradient appears in the situations that the water-entry value is larger than the capillary pressure above the wetting front. It is thought that the phenomena on the preferential flow in the sand are almost same as these in the snow and the water-entry value of the homogeneous dry snow layer is important to study the preferential flow in the snowpack. If we could simulate this kind of the preferential flow, it might be able to simulate the infiltration process in the snow layers more realistically.

The objective of this study is to measure the water-entry value, which is not apparent to occurring in snow layers, at the wetting front into the dry snow and we attempt to show the adaptability of the theories in soil dynamics to behaviour of water in snow.

Corresponding author address: Takafumi Katsushima, Nagaoka University of Technology, Kamitomioka, Nagaoka, Niigata, JAPAN;
tel:+81-258-47-1611;
email: katusima@hydro.nagaokaut.ac.jp

2 MATERIAL AND METHOD

Figure 1 shows the schematic diagram of the experimental equipment. All experiments were carried out in a thermostatic bath in a low temperature room where the air temperature was controlled at 0 degree Celsius. The water-entry values were obtained by measuring the capillary pressure at the wetting front (Baker and Hillel, 1990; Geiger and Durnford, 2000).

The snow samples were packed uniformly into an acrylic column with 5 cm diameter in a low temperature room (-20 degree). The column contains an air/water vent at the bottom and 4 small ports at the intervals of 5cm. The upper three ports were used for inserting tensiometers. The port which located in the lowest position was allowed to access air. After packing, the snow temperature of the samples was adjusted near 0 degree. Because the tensiometers cannot measure a change of the capillary pressure when the preferential flow does not contact with a tensiometers, then the previously-wetted snow was set on the dry snow. This wetted snow was obtained by soaking into the water and draining water from the state of the full saturated water content to that of the residual water content. The bottom of the tensiometer, which was inserted in the highest position of the ports, was set into the interface between these dry/wet snow layers. The snow sample of the upper wetted layer was same size distribution as the sample of the lower dry layer. The upper wetted layer thickness was set to 2cm. The water which temperature was kept at 0 degree by using ice was constantly supplied as a point source by a micro tube pump. The capillary pressure was measured with the high response tensiometers (DIK-3180, Daiki Rika Kogyo Co., Saitama, JAPAN) which have small diameter of the porous cup (6mm).

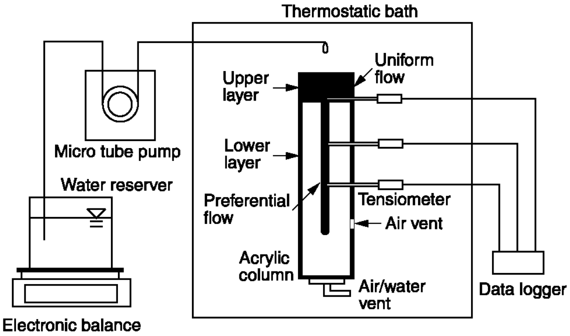

Figure 1 Schematic diagram of the experiment for measuring the water-entry values.

Rounded grains and wet grains which were reserved in a low temperature room (-20 degree) were used for making same snow samples. The grains were sieved several times to separate the size distribution and three types of the samples were made, which were S_S (rounded grains, diameter range is less than 0.25mm), S_M (rounded grains, diameter range is 0.25-0.5mm) and S_L (wet grains, diameter range is 0.5-1.0mm). Table 1 shows the range of the diameter and the averaged dry snow density of each sample. The dry snow densities of the upper layer were almost same as the densities of the lower layer.

Table 1 Properties of the experimental samples.

Sample	Snow type	Diameter range (sieve opening)	Ave. dry snow density Lower layer	Upper layer
		mm	kg m^{-3}	
S_S	Rounded grains	- 0.25	387	386
S_M	Rounded grains	0.25 - 0.5	483	495
S_L	Wet grains	0.5 - 1.0	511	513

The water retention curve (WRC) for drying process was measured using a hanging water column method (Yamaguchi et al., 2009) for comparing between the water-entry value and WRC. WRC was calculated with a model proposed by van Genuchten (1980). WRC for wetting was not measured because experiments of WRC for wetting require long time and the snow particles are changed by wet metamorphism during the experiment. The measured WRC for drying are shown in Figure 2. According to these curves, the air-entry values were about -11 cm in S_S, -14 cm in S_M, and -8 cm in S_L.

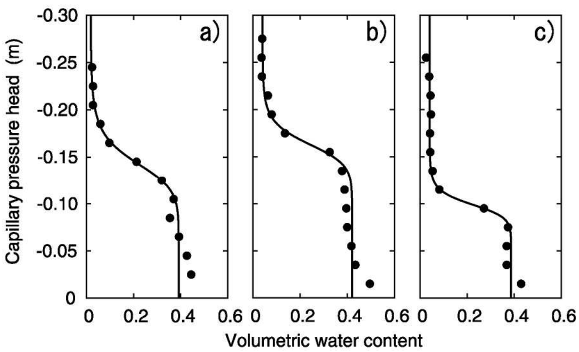

Figure 2 Water retention curve for drying in a) sample S_S, b) sample S_M, and c) sample S_L. Marks indicate the measured water retention data, Solid lines indicate WRC fitted with van Genuchten's model.

3 RESULT AND DISCUSSION

Figure 3 shows the temporal behaviour of the capillary pressure head at the highest position of the port in each sample with three patterns of the supplied water flux. Two different types of the capillary pressure behaviour were observed. In the experiments with the samples

S_S (Figure 3a), the observed values of the capillary pressure were increased and approached to the constant value. And the preferential flow was not observed. On the other hand, in experiments S_M (Figure 3b) and S_L (Figure 3c), the curves of the capillary pressure have the maximum value during the experiments and approached to the constant value. The some paths of the preferential flow were observed in these experiments. The behaviour of the capillary pressure in these experiments is same as the behaviour in sand which has the water-entry value (Baker and Hillel, 1990; Geiger and Durnford, 2000). Then, it is suggested that the peaks of the capillary pressure are the water-entry value due to the impermeable process at the wetting front penetrating into the underlying dry snow.

The gradient of the capillary pressure behind the wetting front is related to the hydraulic conductivity at the wetting front which corresponds to the water-entry value and to the supplied water flux (Hillel and Baker, 1988; Baker and Hillel, 1990). First, we would think the condition of larger supplied flux than the hydraulic conductivity at the wetting front. The capillary pressure increases along the initially wetting curve behind the wetting front and the gradient of the capillary pressure behind that becomes the upward-positive (Geiger and Durnford, 2000). As the result, the water flux at the highest port seems to increase gradually, then the curves of the capillary pressure would become as Figure 3a and finally the capillary pressure approaches to the constant value. Secondly, under the condition of smaller supplied flux than the hydraulic conductivity at the wetting front, the infiltration process becomes the wetting process from the drying process in the upper moving path of the wetting front. The value of the capillary pressure changes to the value belonging to WRC for drying from that in the initially wetting curve (Geiger and Durnford, 2000). The capillary pressure under the drying process is usually less than that under the initially wetting process. Thus, the gradient of the capillary pressure behind the wetting front becomes upward-negative, which is namely under the unstable condition (Raats, 1973; Philip, 1975). The capillary pressure near and behind the wetting front under the condition of wetting process seems to increase before the capillary pressure under the drying process seems to gradually decrease due to the unstable condition where the preferential flow occurs as shown in Figure 3b and 3c.

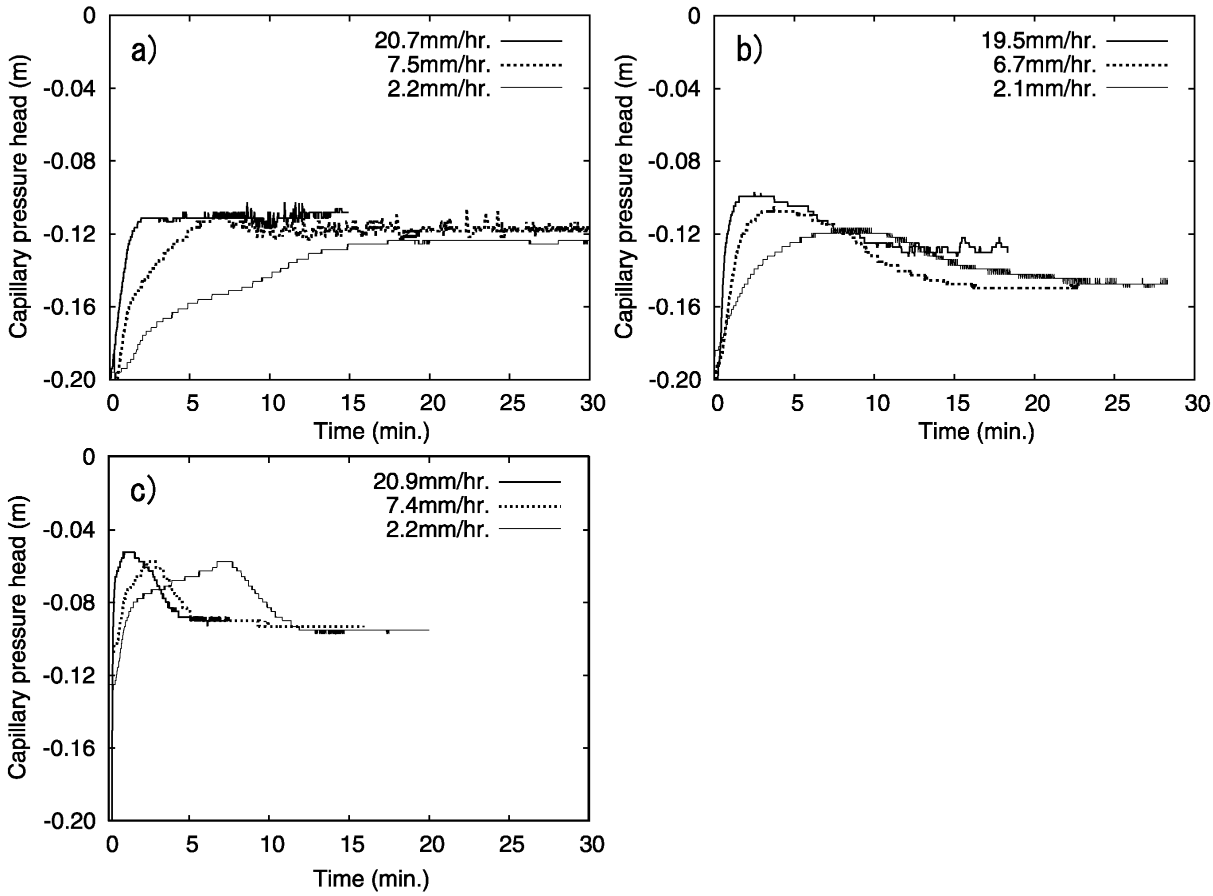

Figure 3 behaviour of capillary pressure head measured in the samples of a) S_S, b) S_M, and c) S_L.

The measured water-entry values were about -10~-12 cm in the experiments with samples S_M and about -5 cm in the experiments with samples S_L. The water-entry value with large water flux and large diameter is larger than one with small. The water-entry values were larger than the air-entry values because the air-entry values read in WRC for drying were about -14 cm with the samples S_M and about -8cm with the samples S_L mentioned in previous section. Glass et al. (1989) and Liu et al. (1994) suggested that the water-entry value is larger than the air-entry value because the infiltration process at the wetting front is under wetting process and the water-entry value is to decide according to the air-entry value of WRC for wetting and the initially wetting curve, which is usually larger than the air-entry value of WRC for drying.

Some results suggesting the similarity between the hydraulic theories in soil and snow were obtained because of the existence of the water-entry value in snow layers. It is thought that it will be enough to simulate this kind of the preferential flow after more experiments will be performed on account of the threshold values of the magnitudes of the supplied water flux and the hydraulic conductivity.

4 CONCLUTION

Water-infiltrating experiments into dry snow were carried out to obtain the water-entry values by measuring capillary pressures at the fixed height of a snow column. The water-entry values were observed in the experiments with large diameter (0.25-0.5 mm and 0.5-1.0 mm) of snow particles. At the same time, some paths of the preferential flow were also observed in these experiments. The magnitude of water-entry value was larger than the air-entry value if the water retention curve for drying process was used. On the other hand, the water-entry values were not observed with small diameter (less than 0.25 mm) and the preferential flow was not observed. It suggests that there may be some similarities between the hydraulic theories in soil media and snow media.

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