BASAL STRESS MEASUREMENTS OF ARTIFICIAL AVALANCHES

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ABSTRACT: Measurements of basal stress of artificial snow avalanches and table tennis ball avalanches in motion were carried out with drag meters at a ski jump and an experimental chute. A mass of snow of which weight was 92 kg at maximum was released at the top of the ski jump slope to produce a snow avalanche. The normal and tangential components of the basal stress exerted on the slope by the avalanches were recorded with a drag meter installed at the lower end of the slope. The basal stress increased rapidly when the head of an avalanche reached the drag meter. The dynamic friction coefficient of the head was relatively small, ranging 0.2 to 0.6. From the middle to the tail of the avalanche, the basal stress decreased and the dynamic friction coefficient increased from 0.4 to 1.0. Basal stress measurements for avalanches of thousands of table tennis balls were also conducted at two points on the experimental chute. The basal stress increased and decreased monotonously during the pass of the avalanches at the upper point. At the lower point, the change in basal stress with time was similar to that obtained for snow avalanches mentioned above. The difference in the basal stress between the two points is probably caused by the change in the structure of the avalanche as it flows down.

KEYWORDS: avalanche, snow, artificial avalanche, table tennis balls

1. INTRODUCTION

The knowledge of the forces exerted on snow avalanches in motion is essential for understanding their dynamic behavior. The stress on the base of an avalanche has been considered as one of the most important forces. Many arguments have been made about it.

However, few studies have been done on direct measurements of basal stress of natural snow avalanches because of its difficulty. Dent et al. (1998) reported a recent successful measurement of basal stress of an artificially triggered snow avalanche in the field. Some laboratory experiments were conducted in relation to basal friction of avalanches (Nishimura 1990). Further experimental study of larger scale is required to obtain sufficient results.

Recently, avalanche experiments using a large number of table tennis balls were proposed as a simulation of snow avalanches (Kosugi et al. 1995). Some dynamic characteristics of table tennis ball avalanches have been analyzed (Nishimura et al. 1997; Keller et al. 1998). It seems that they demonstrate many basic dynamic features of snow avalanches.

In the present study, experiments of snow and table tennis ball avalanches were carried out to measure the basal stress using drag meters.

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2. EXPERIMENTS

2.1 *Artificial snow avalanche experiments*

Avalanche experiments using snow were carried out at the Miyanomori ski jump in Sapporo in a winter season. Figure 1 shows a side view of the experimental set-up. The length and inclination of the slope are 69.5 m and 36 degrees, respectively. A gate was mounted near the upper end of the slope to keep and release snow. On the slope, a groove of 0.8 m in width and 0.3 m in depth was formed. It was covered with polyethylene sheets to reduce the friction.

A drag meter was installed at the lower end

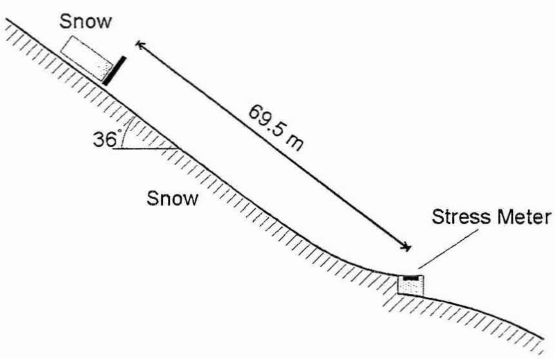


Figure 1. Schematic diagram of the experimental set-up for snow avalanches. Side view.

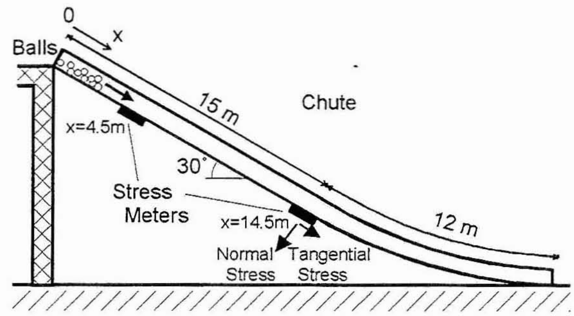


Figure 3. Schematic diagram of the artificial chute. Side view.

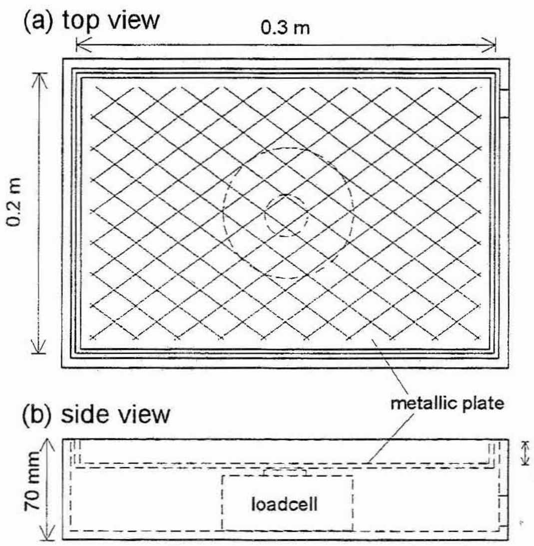


Figure 2. Top view (a) and side view (b) of the drag meter.

of the slope. It was composed of a metallic plate, which was 0.3 m wide and 0.2 m long, and a three-components loadcell as shown in Figure 2. A snow bed of 20 mm in thickness was fixed on the plate. The stress meter was placed horizontally at the same level as the snow surface around it. Electric signals from the loadcell were recorded at a rate of 1 kHz.

Blocks of compacted snow were set at the gate on the slope before the experiments. The density of the snow was 290 kg/m^3. The air temperature was –2 C during the experiments.

2.2 Table tennis ball avalanche experiments

Experiments of table tennis ball avalanches were conducted at the artificial chute, which was designed for snow avalanche experiments, of the Shinjo branch of Snow and Ice Studies. Figure 3 shows a schematic diagram of the chute. It is 27 m long and 1.0 m wide; its inclination is 30 degrees. The lower part of the chute is curved as shown in the figure. The bed surface and the walls are made of glass plates and transparent plastic plates, respectively. The details of the chute are described by Nakamura et al. (1987).

Two drag meters of the same type were arranged on the bottom of the chute. Two high-speed video cameras, taking 200 frames/s, were used beside the drag meters to record the side views of the flow.

3. RESULTS AND DISCUSSION

3.1 Basal stress of artificial snow avalanches

Figure 4 and 5 are results of snow avalanche of which mass released was 46 and 92 kg, respectively, showing normal and tangential stresses and dynamic friction as a function of time. A characteristic change in the basal stress is seen with relation to the position in the avalanche. The basal stress showed an abrupt increase when the head of an avalanche reached the drag meter. The dynamic friction coefficient, the tangential component divided by the normal component of the basal stress, of the head was relatively small, ranging 0.2 to 0.6, though the value shows a large variation in figure 4. From the middle to the tail of the avalanche, the basal stress decreased and the

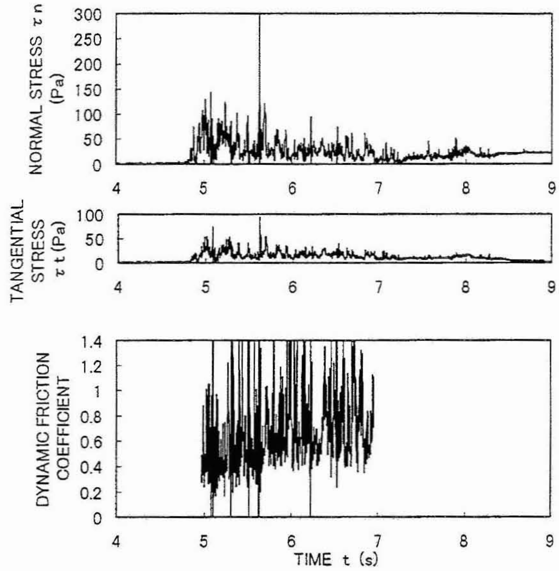


Figure 4. Normal stress, tangential stress and dynamic friction coefficient of a snow avalanche. Mass of snow released was 46 kg.

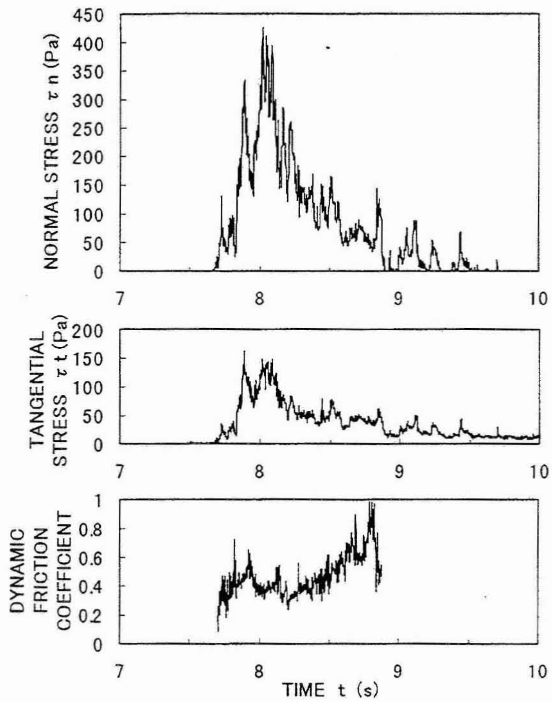


Figure 5. Normal stress, tangential stress and dynamic friction coefficient of a snow avalanche. Mass of snow released was 92 kg.

dynamic friction coefficient increased gradually from 0.4 to 1.0.

Supposing that static pressure balance holds in the middle part of the snow avalanches, its density of can be estimated with the following equation:

$$p = \rho gh, \quad (1)$$

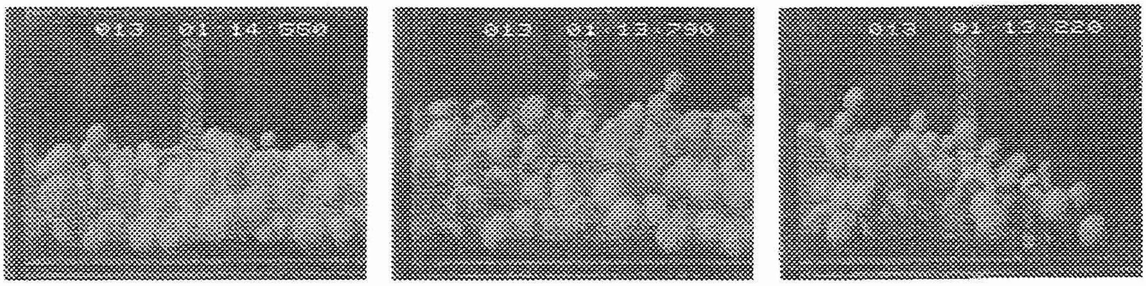
where p is the normal stress, ρ the density, g the gravitational acceleration and h the height of the flow. The density was estimated to be 80 kg/m^3 for the experiment with snow mass of 92kg.

3.2 Basal stress of table tennis ball avalanches

Figure 6 and 7 are side views of an avalanche of 6000 table tennis balls taken by high speed video cameras at the upper and lower drag meters, respectively. The inclination of head at the lower drag meter is larger than that at the upper one, which implies the change in the form, such as formation of the head, during flowing.

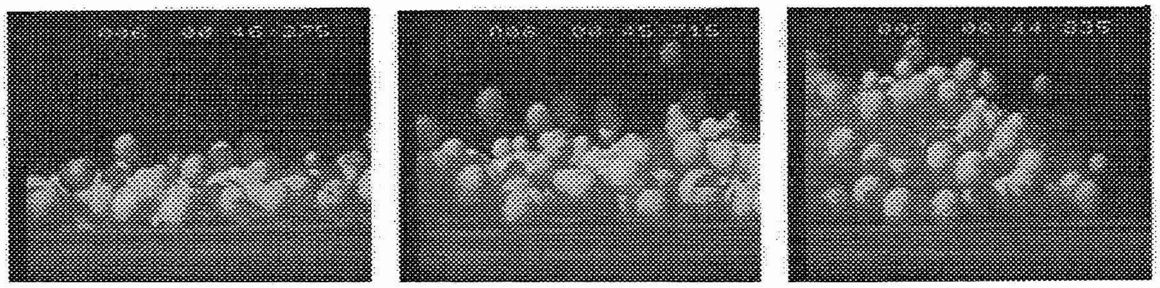
Figure 8 shows normal and tangential stresses and dynamic friction coefficient of the table tennis ball avalanche. The data of left column were obtained by the upper drag meter. The right is from the lower one. The basal stress increased and decreased monotonously during the pass of the avalanche at the upper drag meter. At the lower drag meter, the change in basal stress with time is similar to that obtained for snow avalanches mentioned in the previous section. Distinct peaks exist in the normal and tangential stress records, which probably correspond to the head shown in Figure 7. The difference in the basal stress between the two points is probably caused by the change in the structure or form of the avalanche as it flows down.

The friction coefficient at the upper drag meter is significantly smaller than that at the lower one. This is most likely due to the difference in the velocity and motion of the balls. When the balls are released at the top of the chute, the balls of the upper part of an avalanche begin to flow but those in the lower part can not be accelerated at once. The motion of the balls on the bottom surface is probably rolling in the initial stage of the flow, which results in



(c) tail (b) body (a) head

Figure 6. Side view of a table tennis ball avalanche taken by a high speed video at the upper drag meter. The direction of motion is to right. The diameter of a ball is 38 mm.



(c) tail (b) body (a) head

Figure 7. Side view of a table tennis ball avalanche taken by a high speed video at the lower drag meter. The direction of motion is to right.

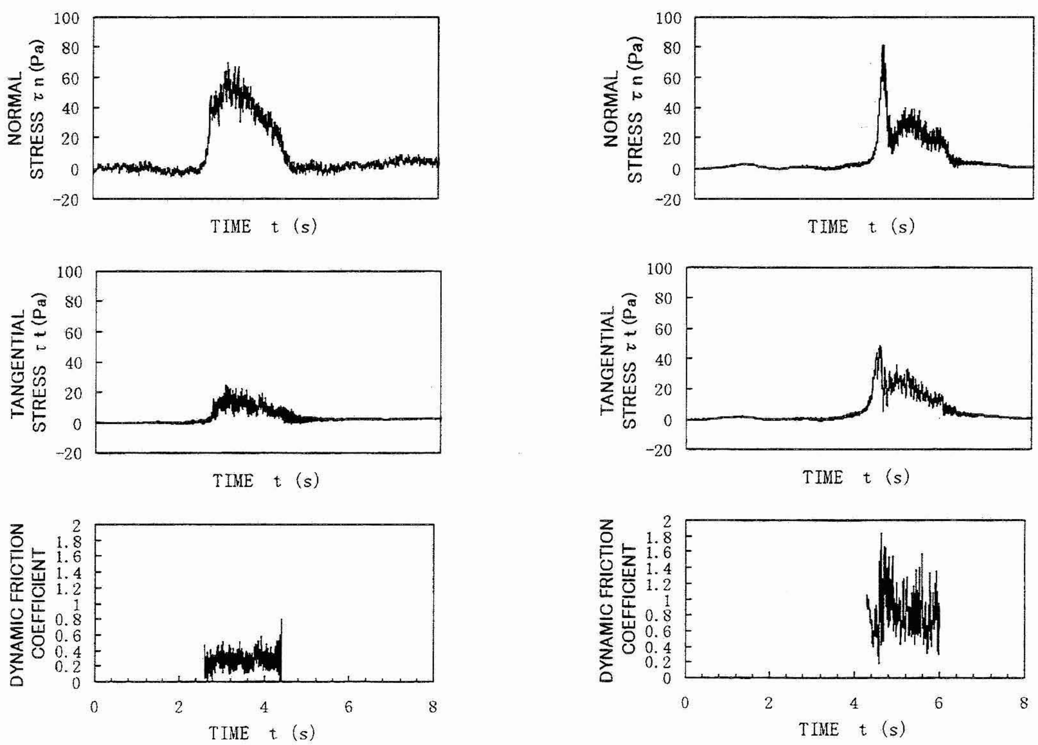


Figure 8. Normal stress, tangential stress and dynamic friction coefficient of a table tennis ball avalanche. The left column shows data obtained by the upper drag meter. The right is from the lower one.

smaller friction. Detailed analysis of the video pictures will provide information about the mechanics of friction.

As a summary, the drag meter presented in this paper showed its efficiency in avalanche research. It will be used in the future studies.

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