Comparison of velocities of the dry and wet snow avalanches at Makunosawa valley in Myoko, Japan

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Abstract: Large-scale natural avalanches of dry and wet snow were occurred at Makunosawa valley in Myoko, Japan. The both avalanches started in the same zone and flew on the same path. The mean velocities of the two avalanches were obtained from the tremor of a geophone and the picture of a video camera. These values were compared with calculated results by Voellmy's approach. The mean velocity of the dry snow avalanche was 43 ms^{-1} and it was 10 ms^{-1} faster than the calculated values of 32 - 34 ms^{-1}. On the other hand, the mean velocity of the wet snow avalanche was 20 ms^{-1} and 10 ms^{-1} slower than the calculated values of 30 - 32 ms^{-1}.

Keywords: Avalanche velocity. Dry snow avalanche. Wet snow avalanche. Makunosawa valley.

1. Introduction

Large-scale snow avalanches have often occurred at Makunosawa valley in Myoko, Japan. Since January 2000, avalanches have been detected by the snow avalanche detecting system (Iikura et al., 2000), a geophone and a video camera, in order to investigate the conditions of avalanche release. The area of Myoko that includes Makunosawa valley is one of the snowy areas, where the northwesterly monsoon conveys heavy snowfalls in winter season. The maximum snow depth is more than 4 m in the valley.

During the two winter seasons from 2000 to 2001, 25 avalanches could be detected. According to the observation results, it was considered that about 80 % of avalanches of Makunosawa valley during cold winter season from January to February were direct-action avalanches, which mainly released by fall of newly deposited deep snow under heavy snowfall (Takeuchi et al., 2001). Among the detected avalanches, the largest one occurred on 4 January 2001. The mean velocity and the runout distance of this dry snow avalanche could be obtained.

On 17 March 2002, large-scale wet slab avalanches occurred. The picture of this avalanche could be taken by the video camera and the mean velocity could be obtained. The runout distance was also measured in the valley.

There are many data of avalanche velocity (for example, McClung and Schaerer, 1993; Schaerer, 1975),

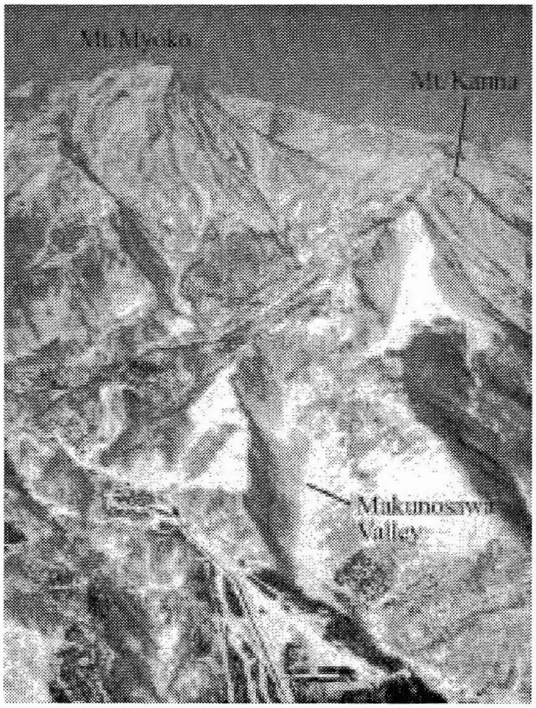

Figure 1: Overview of Makunosawa valley.

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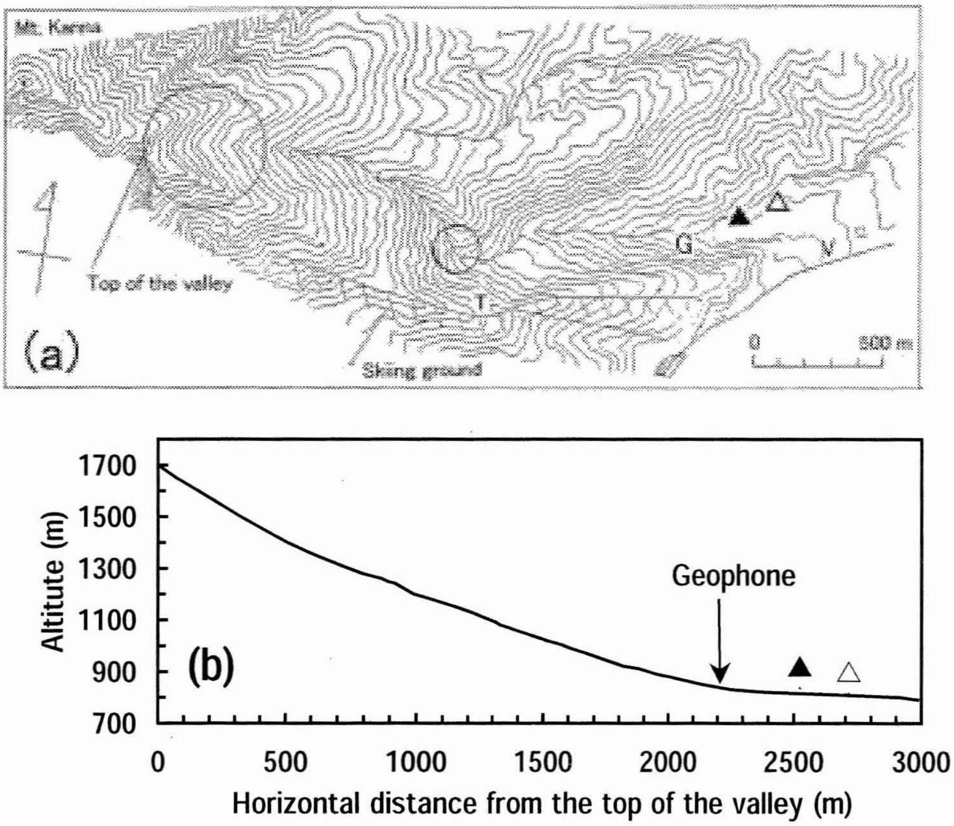

Figure 2: (a) Topographic map of Makunosawa valley. The two circles are the zones taken by the video camera. G: The site of a geophone. V: The site of a video camera. T: The site of air temperature measurement. ▲ and △ are the runout zones of the dry and the wet snow avalanches. (b) Topographic cross section of the valley.

but few field data of natural avalanches of dry and wet snow that started in the same zone and flew through the same path. In this paper, the velocities of the two avalanches are reported comparing with calculated results by Voellmy's approach.

2. Observation site and methods

Overview of Makunosawa valley is shown in Fig. 1. Makunosawa valley faces east and starts near the peak of Mt. Kanna. The topographic map and the sectionaldiagram of the valley are shown in Fig. 2. The altitudes of the starting zone and runout zone are about 1700 m and 800 m a.s.l., respectively and the difference is about 900 m. The distance from the starting zone to runout zone is about 3000 m. The slope of the valley generally increases with the altitude. It is about 35 degrees at the starting zone and less than 5 degrees at the runout zone.

A geophone was set up on the slope of avalanche path (at the point of "G" in Fig. 2(a)) and recorded vertical tremors of the ground motion caused by avalanches from December 2000 to January 2001. A video camera was set up at the point of "V" in Fig. 2(a) in order to record the process of avalanche release and flow. The observation period was from December 2000 to March 2002. Pictures could not be recorded during heavy snowfall and during nighttime. Then, it was difficult to take pictures of avalanches. Air temperature was measured at the ridge of 1100 m a.s.l. (at the point "T" in Fig. 2(a)).

3. Observation results

3.1 The dry snow avalanche on 4 January 2001

A large avalanche occurred and the tremor could be recorded by the geophone at 19:02 on January 2001. This avalanche is called "Avalanche D" in this paper. The tremor is shown in Fig. 3. The maximum amplitude was more than 6000 °C kine. This is much larger than any other tremors due to avalanches (Izumi and Kobayashi, 1986; Tsukuda and Mizoue, 1988; Muramatsu, 1993; Sabot et al., 1998). Unfortunately, picture of video camera could not be taken. When the avalanche occurred, the air temperature was –8.0 ° C at 1100 m a.s.l., and the prior 24 hours precipitation was 47 mm around the runout zone. Stability index of new snow when the avalanche released was computed, using the theory of densification of snow and a regression equation between density and shear strength of snow (Endo et al., 1993). In result, it was found that the stability index at 37 cm from the snow surface became 1.4 and it was smaller than 1.5, which is regarded as a criterion of surface slab avalanche release (Perla, 1977). The snow depth was estimated to about 150 cm. Weak layers were not clear as a results of the snow pit observation on 25 January. Accordingly, it is considered that Avalanche D was direct-action dry snow avalanche, which released by fall of newly deposited snow under heavy snowfall (Takeuchi et al., 2001).

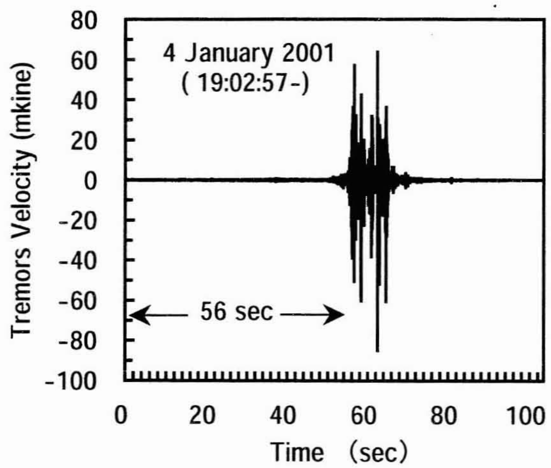

Figure 3: Avalanche tremors detected by a geophone on 4 January 2001.

The runout distance of Avalanche D was found 2900 m (horizontal distance: 2700 m) by following the avalanche track during the melt season in April or later. The debris layer came on the snow surface when the snow depth became about 150 cm. This value roughly agrees with the estimated snow depth on 4 January.

The distance from the starting zone to the geophone is 2400 m. The tremor can be regarded to have started at the same time of the avalanche release. The maximum amplitude can be considered that the avalanche reached the geophone. Then, the time from the starting zone to the geophone was approximately estimated at 56 s as shown in Fig. 3. Accordingly, the mean velocity is calculated at 43 ms^{-1}.

3.2 The wet snow avalanche on 17 March 2002

A large wet slab avalanche occurred on 17 March 2002. This avalanche is called "Avalanche W" in this paper. The process of this avalanche release and flow could be taken by the video camera successfully. Unfortunately on the other hand, tremor could not be recorded because of trouble of the geophone. The avalanche started at the head of this valley of 1700 m a.s.l. According to the photographs, the width and the length of the slab were 100 m and 200 m, respectively. The depth of the slab was estimated at 2-3 m. According to the picture of the video camera, it was found that the entire snowpack of a triangle zone over the steep ground had slipped firstly, and the shock caused the large slab avalanche. The base of the triangle was 30 m long and the height of it was 15 m long. The runout distance was approximately 2700 m (horizontal distance: 2500 m), with a vertical drop of about 900 m. The end of the debris was 70 m wide and the depth was up to 6 m.

A snow pit observation was carried out near the runout zone on 19 March. The snow depth was 270 cm. The upper 120 cm of the snowpack was investigated. These upper layers consisted of wet granular snow. Two weak layers were found out at 40 and 80 cm from the snow surface. Both layers consisted of weak granular snow with large grain size of 1 – 2 mm. The hardness of these layers was smaller than 20 kPa. One of these layers could cause the avalanche. The air temperature at the starting zone was estimated at 4.1° Cduring the avalanche, then the entire snowpack must be wet due to snowmelt. The mean velocity of the avalanche was estimated at 20 ms^{-1} by the picture of the video camera.

4. Comparison of the avalanche velocities

4.1 Calculation method

The velocities of Avalanche D and W were compared with calculated velocities by well-known Voellmy's approach (Voellmy, 1955). The end is to investigate the velocities of dry and wet snow avalanches that started in the same zone and flew on the same path.

According to Voellmy's approach,

$$v^2 = v_{max} - \left(v_{max}{}^2 - v_0{}^2\right)\exp\left(-\frac{2g}{\xi h}x\right) \qquad (1)$$

$$v_{\max}^{2} = \frac{\xi h(\rho - \rho_a)(\sin\theta - \mu\cos\theta)}{\rho} \quad (2)$$

where v_{max} is the terminal velocity of the avalanche, v_0 is the initial velocity, g is the acceleration of gravity, ξ is the coefficient of turbulent friction, h is the flow height, x is distance, ρ is the density of avalanche, ρ_a is the density of air, θ is the slope angle and μ is the coefficient of kinetic or sliding friction. In the case of $v \geqq 10$ (ms^{-1}), μ values are used following Shaerer (1975) convention of $\mu = 5 / v$ (ms^{-1}). In the case of $v <$ 10 (ms^{-1}), μ values were assumed as follows (Japanese society of snow and ice, 2001),

$$\mu = -0.01v + 0.6 \quad (3)$$

The initial value of h for Avalanche D was assumed to be 1 m at most, because this avalanche was considered to be a direct-action avalanche induced by fall of new snow under heavy snowfall, and the smallest stability index was 37 cm under the snow surface by calculation. The h value increased linearly with the distance x and the maximum value was assumed to be 5 - 10 m tentatively. ξ values were selected to fit the runout distance to the field data. When the maximum values of h are 5 - 10 m, ξ values change from 3200 to 1700 ms^{-2}. For Avalanche W, the initial valued of h was 2 - 4 m according to the depth of the slab. The maximum h was 5 m according to the field data of the height of the groove in the runout zone. Then h value for Avalanche W was change from 2 - 4 m to 5 m linearly. ξ values were selected as 2100 to 1800 ms^{-1} to fit the runout distance to the field data.

4.2 Results and Discussions

The variation of velocity for Avalanche D is shown in Fig. 4(a). The dotted lines and the thick line indicate mean velocities by calculation and observation. The value of thick line is 43 ms^{-1} and it is 10 ms^{-1} faster than the calculated mean velocities of 32 - 34 ms^{-1}. Voellmy (1955) assumed the avalanches behave as fluids and the flow is incompressible. Such a fluid model does not consider the internal structural changes during motion. The larger actual velocity of Avalanche D may suggest that it was not a simple flowing avalanche but accompanied by a powder avalanche which can attain higher velocity and run farther than the main deposit (McClung and Schaerer, 1975).

The variation of velocity for Avalanche W is shown in Fig. 4(b). The thick line is mean velocity obtained from the picture of the video camera. The value was 20 ms^{-1} and it is 10 ms^{-1} slower than the calculated mean values of 30 - 32 ms^{-1}. For the both dry and wet snow avalanches, the coefficient of sliding friction (μ) was given as a function of velocity (v) following Schaerer (1975) in this study, in spite of wet snow motion has much higher friction at the sliding surface (McClung and Schaerer, 1993). This may cause that the calculated velocities were larger than the field data of the wet snow avalanche. However, increase of μ value follows decrease of runout distance as well as velocity by using the calculation method of this study. To express the motion of wet snow avalanche at Makunosawa valley, it is a problem how to give μ value to fit both velocity and runout distance for the field data.

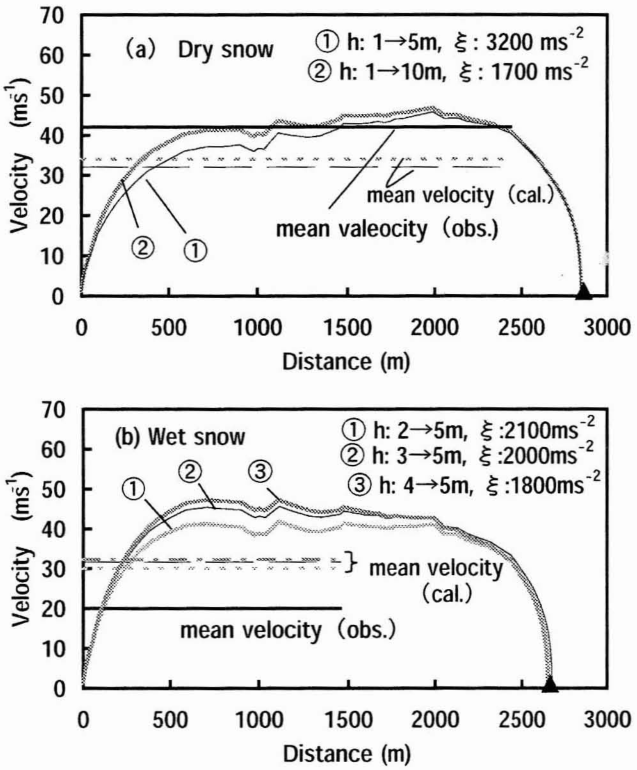

Figure 4: Velocity variations of avalanches. h is the flow depth of avalanche. ξ is a coefficient of turbulent friction. (a) The dry snow avalanche on 4 January 2001. (b) The wet snow avalanche on 17 March 2002.

5. Summary

Large-scale natural avalanches of dry and wet snow were occurred at Makunosawa valley. The both avalanches started in the same zone and flew on the same path. The velocities of the two avalanches were compared with calculated results by Voellmy's approach. The calculated values of velocity could not fit to the field data of the dry and wet snow avalanches, either. But the opposite results were obtained. For the dry snow avalanche, mean velocity by the field data was larger than the calculated values. For the wet snow avalanche on the other hand, it was smaller than the calculated values. This result shows that the type of snow is an important element for avalanche motion as well as terrain.

6. Acknowledgements

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