# Study on the model to estimate the snow property of the slope snowpack

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ABSTRACT: To ensure the safety of train operations for full depth avalanche, it is important to estimate the stability of the slope snow. And then, it is necessary to evaluate the dynamic balance between the driving force of snowpack and the strength of bottom of snowpack. These are known that it is concerned with snow properties. Therefore, in this study, we have developed a model that can estimate density and snow depth using only AMeDAS weather data. Compared with calculated values by this model and observed values, it was found that good agreement of snow depth and density of the bottom of snowpack.

KEYWORDS: Stability of the slope snowpack, physical properties, AMeDAS weather data

# 1. INTRODUCTION

In the railway fields in Japan, there are heavy snowfall regions (e.g. 2m depth or more). In those regions, a large amount of snowmelt occurs on snow surface in an early spring. And then, since the slope snowpack becomes unstable, a train has a possibility to be damaged by full-depth avalanche. Therefore, countermeasures such as track patrol and train operation control for full-depth avalanche are carried out when high temperature rise or heavy rainfall has occurred. These countermeasures are often based on empirical rules which are determined from the past disaster records. In order to carry out such countermeasures effectively and efficiently, it is important to establish a method based on the objective criteria to evaluate the stability of the slope snowpack.

Stability of the slope snowpack can be evaluated by the ratio between the driving force (the overburden load on the snow) and the supporting force (the strength of snowpack) (Maeno and Fukuda. 2000). This ratio is called stability index (SI) and widely used for estimating stability of slope snowpack (Perla. 1997). Based on this idea, if the driving force increases due to a large amount of snowfall, or the supporting force decreases due to the snowmelt, the slope snowpack becomes un-

\* Corresponding author address: Ryota Sato, Railway Technical Research Institute, Hikari-cho 2-8-38, Kokubunji,Tokyo,JAPAN; tel: +81-42-573-7264; fax: +81-42-573-7398; email: sato.ryota.70@rtri.or.jp stable. It is known that the driving force and the supporting force are dependent on the snow properties (McClung et al.,1993). In this study, we examined the construction of an estimation model of snow properties.

## 2. OBSERVATION

Snowpack properties and weather data obtained at the Shiozawa Snow Testing Station (Minami-Uonuma, Niigata,Japan) during the winter of 2014 / 15.

As snowpack observations, snow type, snow depth, density, water content, hardness, grain size, and snow water equivalent were observed. Observation was carried out by flat point and two artificial embankments for 5 days (Jun.21st, Feb.18th, Mar.9th, Mar.20, and Apr.2nd) (Fig.1). There are



Fig.1 Observation points in the Shiozawa Snow Testing Station

two artificial embankments, one has the slope length of 8m and the inclination of 20 ° (hereinafter, referred to as small embankment), the other has the slope length of 13m and the inclination of 35 ° (hereinafter, referred to as large embankment). Both artificial embankments have a southeast slope and northwest slope (hereinafter referred to as each small southeast, small northwest, large southeast, large northwest).

The weather condition of temperature, humidity, precipitation, snow depth, wind speed, air pressure and solar radiation (hours of sunshine) were observed every ten minutes during the same period.

#### 3. DEVELOPMENT OF SNOW PROPERTY MODEL

As considering for application of a model to the slopes along railway lines, it is desirable to build a model to use easily available weather data (such as AMeDAS (Automated Meteorological Data Acquisition System) of the Japan Meteorological Agency). In this study, we reviewed the past research (Endo et al. 2004, Suizu 2002) and carried out snowpack and weather observations. And then, by using these results, we have constructed a model that can estimate the snow property every one hour.

#### 3.1 <u>Overview and calculation flow of the snow</u> property model

Figure 2 shows the concept of the snow layer formation of the snow property model we developed. This model configures one snow layer (t, j) in every one hour regardless of the presence or absence of snowfall. "*t*" represents the time, and "*j* "represents the layer number at "*t*". Calculations can be continued up to time "*n*". The largest "*j*" at time "*t*" is the snow surface layer  $(t, j_{max})$ .

Calculation flow is shown in Figure 3. This model could calculate values of the snow temperature Ts(t, j), the snow density  $\rho(t, j)$ , and the snow layer



Fig.2 The concept of the snow layer formation of the snow property model



Fig.3 The calculation flow of the snow property model

thickness h(t, j) at all snow layer.

### ①Snowfall Ps [mm]

From precipitation *Pr* [mm] data, rain/snow distribution was distinguished based on air temperature  $T_a$  [°C]. In this research, the precipitation when *Ta* was below 1 °C was categorized to snowfall. On the other hand, the precipitation when *Ta* was over 1 °C was categorized to rain. Snow surface (*t*, *j<sub>max</sub>*) becomes a layer having a mass when there is snowfall (*Ps* > 0). On the other hand, If there is no snowfall (*Ps* = 0), snow surface (*t*, *j<sub>max</sub>*) is apparent layer without a mass.

②Snow temperature Ts [°C]

The snow temperature Ts [°C] at snow surface layer (t,  $j_{max}$ ) is equal to air temperature Ta [°C]. The snow temperature of under layers were determined to be the average value of the three layers ((t-1,j),(t-1,j-1) and (t,j+1)) (Suizu 2002). For example, snow temperature of snow layer (4.3) in Figure2 is average of the layer (3.3), (3.2), and (4.4).

3 Mass of snow layer W [kg/m<sup>2</sup>]

Mass of the snow layer (t, j) is equal to mass of snowfall [kg/m<sup>2</sup>]. The Change of mass due to snowmelt is calculated by outflow of snow bottom (4).

#### (4) Outflow of snow bottom $M_b$ [mm]

Snow melt is calculated by heat balance on the surface of snowpack. The weight equivalent to snow melting heat quantity flows out from the bottom layer (t, 1). Therefore, the snow layer above

the bottom layer does not cause mass change due to snow melt. On the other hand, if there is the snow layer below 0  $^{\circ}$ C, a weight equivalent to snow melting heat quantity in consideration of the heat loss quantity for rising the snow layer to 0 $^{\circ}$ C is flows out from the bottom layer (Kurihara et al. 2011).

### (5) Density $\rho$ [kg/m<sup>3</sup>]

The initial density [kg/m<sup>3</sup>] of the snow surface(t, jmax) is calculated as a function of temperature. The under layers are calculated density in consideration of the densification by the overburden load based on the viscosity compression theory (Endo et al. 2004).

#### 6 Thickness h[m] and snow depth Hs [m]

The thickness h [m] of each layer is estimated by dividing the mass by the density. The total snow depth Hs [m] is obtained by summing up the thickness of each snow layer.

#### 3.2 Estimating method density and snow depth

In the case when a snowfall *Ps* (t) > 0, the snow surface (*t*, *j*<sub>max</sub>) is judged as the new snow layer, and then initial density  $\rho_{initial}(t, j_{max})$  is given by the equation (1). The equation (1) was obtained from the results of snowpack observation at Shiozawa Snow Testing Station.

$$\rho_{initial}(t, j_{max}) = 66 \exp\left(0.052 \times T_{a}(t)\right) \tag{1}$$

On the other hand, the layer (t, j) below the snow surface layer is compacted by its own weight and the overburden load, and then density increases with the passage of time. Densification of these due to each layer was estimated from the viscous compression theory (Endo et al. 2004). According to the viscous compression theory, snow density considering densification  $\rho$  (t, j) is given by the equation 2 for distinguished case : the case1,  $\rho$ (t-1, j) > 200 kg / m<sup>3</sup>; the case2,  $\rho$ (t-1, j)  $\leq$  200 kg / m<sup>3</sup>.

$$\rho(t-1, j) > 200,$$
  

$$\rho(t, j) = \rho(t-1, j) \times (1+3.44 \times 10^5 \exp(-0.0958 \times T_s(t,j)))^{-1} \times \exp(-0.0253 \times \rho(t-1, j)) \times (L(t, j))$$

$$\rho(t-1, j) \leq 200, \\ \rho(t, j) = \rho(t-1, j)^{3.69} \times 3.69(1.78\exp(-0.0958 \times T_s(t, j)))^{-1} \\ \times (L(t, j))^{1/3.69}$$
(2)

where  $\rho(t, j)$  is the density of snow layers at the time "*t*", and L(t, j) [N/m<sup>2</sup>] is overburden load on the

layer (*t*, *j*) at the time "*t*". For this model to determine the snow property every one hour, the overburden load is the summed value per hour. Overburden load L(t, j) is given by the equation 3 (Kominami et al. 1998).

$$L(t, j) = 9.81 \times (\sum_{j=j+1}^{jmax} L(t, j) + \frac{1}{2} W(t, j) + P_s(t)) \times 3600$$
(3)

where W(t, j) [kg/m<sup>2</sup>] is a mass of snow layers, 9.81[m/s<sup>2</sup>] is gravitational acceleration, and 1/2*W* (*t*, *j*) is the own weight of the j layer.

Thickness h(t, j) can be obtained by the equation (4).

$$h(t,j) = W(t,j) / \rho(t,j)$$
(4)

By integrating h(t,j) from j = 1 to j = jmax, it is possible to found the snow depth Hs(t) by the equation (5)).

$$Hs(t) = \sum_{j=1}^{J_{max}} h(t, j)$$
(5)

#### 4. RESULT

#### 4.1 <u>Comparison of observed values and</u> <u>calculated values</u>

The snow depth and the density of the snowpack were calculated by using the snow property model. By comparing the data observed in 2014/15 year with the calculated values by the model. (snowpack observation was carried out on Jun.21st, Feb.18th, Mar.9th, Mar.20, and Apr.2nd in 2015). As a result of comparing calculated values by the model of the snow depth and the observed value throughout 2014/15 years (Fig.4), our model could reproduce snow depth from early winter to snowmelt season.

Comparison of calculated values by the model and observed values of snow density at flat snowpack is shown in Figure 5. As a result, it can be seen



Fig.4 Comparison of observed values and calculated values of snow depth at flat snowpack



Fig.5 Comparison of observed values and calculated values of snow density at the flat snowpack





that the model good agreement with observed values. However, there is an underestimate part. So, we compared with the observed values and the calculated values by the model of the vertical distribution of the density on Mar.10th (Fig.6). As a result, although good agreement in the lower part, the calculated values was found to be smaller than the observed values in the upper part (especially the upper part more than 160cm). This trend was also same at the other day. In addition, the RMSE (root mean square error) of all the layers of the snowpack shows a slightly larger value of 129kg / m<sup>3</sup>. On the other hand, RMSE of the lower layers (50 cm or less) are 32 kg/m<sup>3</sup>, it was found that it is possible to estimate the density within the 10% error for the lower layer.

As cause of underestimation the density of the upper layer, because this model calculates the snowmelt water (snow bottom runoff) flow out from bottom layer, this model does not consider of process that snowmelt water generated from snow surface to penetrate. For this reason, mass change due to the snow melt at the upper layer does not occur, and then the snow density of upper layer is remained small. Therefore, it must be considered to develop this model that to be able to estimate the changes of the mass in the vertical direction of the snow layers due to penetrate snowmelt water (and the rain).

#### 5. APPLICATION OF THE MODEL TO SLOPE SNOWPACK

This model could calculate snow depth and density of flat snowpack. Next, we examined the applicability of the slope snow.

#### 5.1 <u>Comparison of snow properties between the</u> <u>flat and the slope snowpack</u>

In order to find the difference of snow properties between the flat snowpack and the slope snowpack, observation results of flat, small embankment (southeast slope, northwest slope) and large embankment (southeast slope, northwest slope) were compared. Figure 7 represents the relationship of density at the same snow depth between the flat and each slope. According to Figure 7, although there are slight variations, the density of flat snowpack and the density of slope snowpack at the same snow depth show almost the same values in spite of the aspect and inclination. Therefore, the estimation method of this model could apply to slopes snowpack.

It was found that the snow depth was significantly different between the flat and the slope (Fig. 8). As this reason, it was considered that snow melting







Fig.8 Comparison of observed values of snow depth at flat and each slope

heat and precipitation per unit area were difference between the flat and slope.

The concept of snow melting heat and precipitation in slope snow are shown below. A solar radiation is known that a large contribution to snow melting heat (Kondo, 1996). Since solar radiation to slope snow varies depending on the aspect and inclination (Fig.9), the maximum value and the time change of snow melting heat in the snow surface is different from the flat snow.

Differences precipitation per unit area of the slope and flat, it was decided to take into account the projected area of the slope. Although unit area of precipitation in flat is  $1m^2$ , a projected area is  $1/\cos\theta m^2$  in the slope of inclination  $\theta$  (Fig.10). Thus, precipitation amount per unit area  $(1m^2)$  in



Fig.9 Solar radiation at slope



Fig.10 Projected area at slope



the slope is smaller than the flat by this ratio. Therefore,

#### 5.2 <u>The Method of Estimating the snow melting</u> heat and precipitation per unit area at slope

In this model, it was decided to use the snow melting heat quantity estimation method that takes into account the inclination and aspect of the slope. In addition, using the value obtained by correcting the amount of precipitation in the flat with a projected area by inclination  $\theta$  as precipitation of the slope.

### 5.3 Calculate to snow depth of slope

The snow depth at a small embankment (southeast slope, northwest slope) and large embankments (southeast slope, northwest slope) were calculated. As a result of comparing the calculated values and the observed values obtained from snowpack observation of 5 days, there is a difference of 0.3m from 0.06m, it tended to underestimate observed values (Fig.11). However, the variation is small, and then it was able to be estimated with good accuracy irrespective of the aspect and the inclination.

# 6. CONCLUSION

To estimate the stability of the slope snow, it is necessary to evaluate the dynamic balance between the driving force and the snow support force of snow. It is known that those forces are dependent on snow property. So, we have developed a model that can calculate the density and snow depth of snow using only AMEDAS (Automated Meteorological Data Acquisition System) weather data.

As a result of comparing calculated values and observed values, it was found that the model can be calculated with good accuracy of snow depth and density of snow bottom for slope snowpack. Further, since the driving force and the supporting force of the snowpack is affected to them, it is considered to be estimated by using this model. From now on, we advance the calculated accuracy of this model and use this model to calculate the mechanical balance of the slope snow.

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