Estimation Method of Snow Accretion Amount on Train Bogies

Yasushi Kamata[1], Akira Yokokura[2]

[1] *Railway Technical Research Institute, Disaster Prevention Technology Division, Japan*
[2] *East Japan Railway Company, Research & Development Center of JR East Group, Japan*
(Current: *JR East Rail Car Technology & Maintenance Co. Ltd.*)

kamata.yasushi.19@rtri.or.jp, yokokura-akira@ttech.co.jp

Abstract— **Trains operating in snowy areas have snow accretions on their bogies. When the snow drops off from the car, it might damage ground facilities. To prevent such damage, snow removing operations are performed at several stations. We developed a method to estimate the snow accretion amount in the following steps. Firstly snow properties on the railway track was estimated from climatic conditions, secondly the amount of flying snow caused by train passing according to the snow properties and the train speed was estimated. Finally we predicted the snow accretion amount from relationship between amount of flying snow and snow accretion amount.**

Keywords— ***Shinkansen, snow accretion, bogie, flying up snow, estimation method***

I. Introduction

Shinkansen operating in snowy area have snowproof and cold resistant car bodies, like snowplow which is installed on leading car front for removing snow on the track, heaters on doors and glasses for cold and fog proof (e.g.[1, 2]). When train travels on a snow-covered track, the snow on the track flies up and adheres to underfloor equipment and bogies. When such accreted snow falls during train running, ground facilities may be damaged. Especially, Shinkansen has body mount construction or smooth surface construction to protect heavy snow accretion onto underfloor equipment. However, shapes of the car bogies are complicated and then snow accretion easily occurs. At present, snow removing work are performed at several stations to prevent such damages. It is necessary to estimate snow accretion amount accurately and to allocate operators in order to carry out such work efficiently.

In this study, snow accretion amount on sides of the bogies at a Shinkansen station were measured, and estimation method of snow accretion amount on train bogies from meteorological data along the railway line were investigated.

II. ANALYSIS DATA

A. Snow accretion data

We have heavy snow in NorthernEast part of Japan in winter season. We targeted the Akita Shinkansen cars traveling in Tohoku region snowy areas (Fig.1). The amount of snow accretion on the sides of the car bogies were measured at Morioka station by East Japan Railway Company (JR-EAST), whose cars were departed from Akita station without snow accretion. The observation period is from 2006 to 2010 in winter season (from December to March). The snow accretion amount were measured by a device using light cutting method (Fig.2) (e.g. [3]). At the same time, snow accretion image was taken using a Web camera (Fig.3).

B. Meteorological data

Weather data of AMeDAS (Automated Meteorological Data Acquisition System) observation point of Japan Meteorological Agency along Akita Shinkansen line was used for analyzing snow accretion weather conditions. Used AMeDAS points are Akita, Daishoji, Ohmagari, Kakunodate, Tazawako, Shizukuishi, and Morioka (Fig.1).

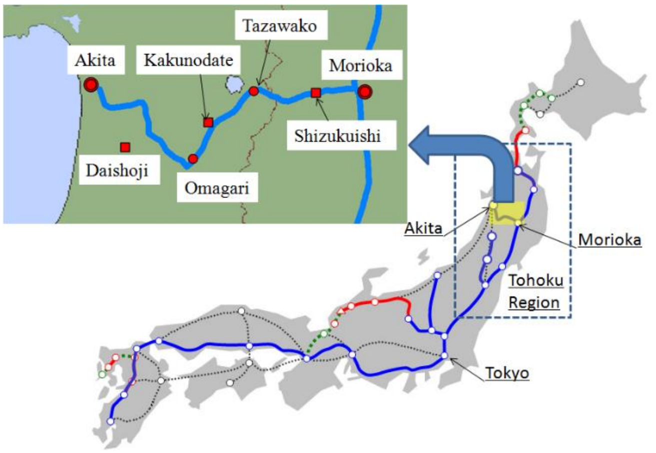

Fig. 1 Shinkansen network in Japan and Akita Shinkansen line.

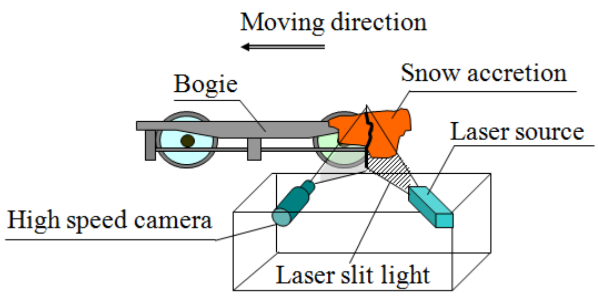

Fig. 2 Schema of snow accretion measuring device.

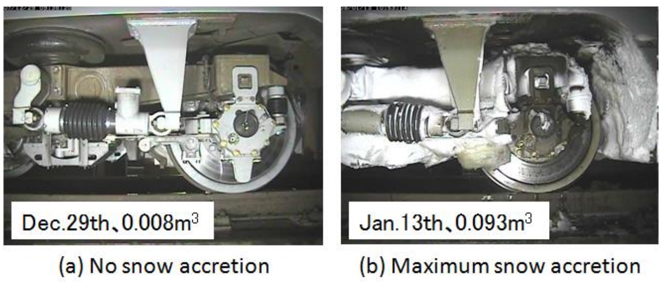

Fig. 3 Images of snow accretion by Web camera.

III. SNOW ACCRETION PROCESS

Fig. 4 shows processes of growing snow accretion to the train. First, snow fall on the tracks. Second, trains travel over the snow covered track. Third, wind induced by train passage make snow on the track to fly up. Forth, flying up snow accumulates to the train bogies.

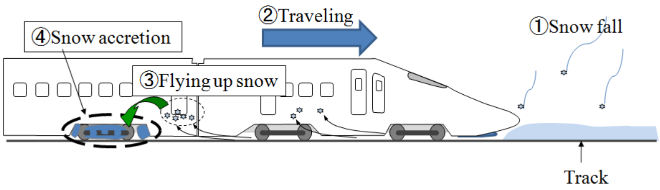

Fig. 4 Process of snow accretion growth.

We developed snow accretion estimation method by analysing along each process of snow accretion growth. Fig. 5 shows the process of the estimation method. First, surface snow density is calculated by surface snow density estimation model from weather information. Second, amount of flying up snow is calculated according to the running speed and the snow surface snow density. Finally, snow accretion amount is calculated from relationship between flying up snow amount and snow accretion amount. Thus, the amount of snow accretion can be calculated from the weather information.

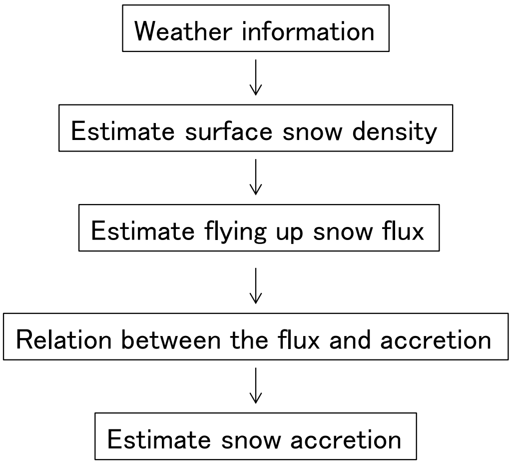

Fig. 5 Estimation process of snow accretion.

IV. ESTIMATION METHOD

A. *Estimate surface snow density*

1) *Surface snow density estimation model*

The amount of snow flying up is large immediately after new snowfall because the bonding force between snow particles is weak. On the other hand, time has elapsed after the snowfall under sunshine and warm temperature, snow density increases due to melting snow and sintering, etc. And then the bonding strength of snow particles at surface layer increases (Fig. 6), and it is considered that the amount of snow flying up decreases.

In our surface snow density estimation model, it is assumed that snow particles on the surface layer will melt due to solar radiation and temperature after snowfall and then the snow density of the surface layer will increase. Unit volume of snow is divided into the composition of ice, water, and voids. Melting occurs at the ice part, so mass change of the ice that affects the density change. We assumed that the melted ice is filled in the void (Fig. 7). So total mass does not change but the volume decreases. Therefore, if the density before snowmelt is ρ_s and the density after snow melting is ρ_{s1}, the density increases due to snow melting is expressed by equation (1).

$$\rho_{s1} = \frac{m}{V'} = \rho_s\left(\frac{\rho_d \times V}{\rho_d \times V - m_M}\right) \quad (1)$$

Here, ρ_d is dry snow density (kg/m^3), V is volume (m^3) and m_M is snow melt mass (kg).

In order to calculate surface snow density by the estimation model, it is necessary to know the mass of snow melt. Snow melt mass is obtained by equation (2).

$$m_M = M \times 10^{-3} \times \rho_w \quad (2)$$

Here, ρ_w is water density (1000kg/m^3) and M is snow melt amount (mm).

The amount of surface snow melt can be obtained by the heat balance method, but many parameters are necessary for calculation. However, in the railway field, calculations applicable to a wide area at short time intervals are required with less weather information. Konya et al. reported a model to estimate hourly snowmelt amount at snow surface from solar radiation and temperature (equation (3)) (e.g.[4]). Therefore, we use Konya's simple snow melt model for our model.

$$M = aK_d + bT_a + c \quad (3)$$

Here, K_d is solar radiation (W/m^2) and T_a is temperature (°C). Coefficients a, b, and c are determined by multiple regression analysis with observation values.

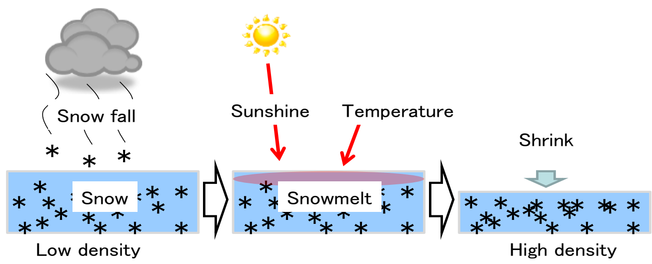

Fig. 6 Images of increasing snow density.

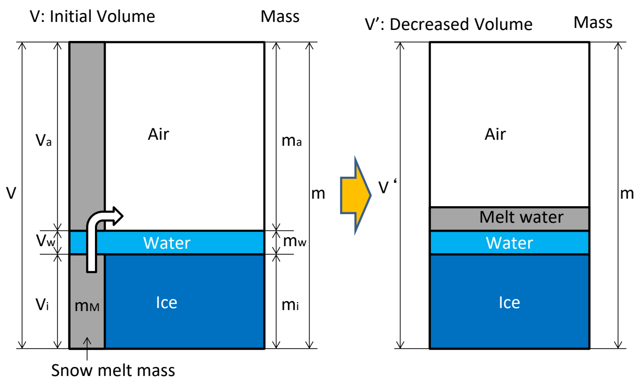

Fig. 7 Concept of surface snow density estimation model in snow composition diagram.

2) Validation of the model

We observed time change of the snow density of 2cm of snow surface layer at the Shiozawa snow testing station of Railway Technical Research Institute (Niigata prefecture, Japan) and the model was verified by comparing the calculated snow density by the model and the observed snow density.

Snow density increased with time after snowfall under solar radiation and temperature change. It was found that change of the calculation value well represents the change of snow density of the surface layer (Fig. 8). As a result, it was shown that the snow density can be estimated by appropriately giving coefficients for estimating the snow melting amount.

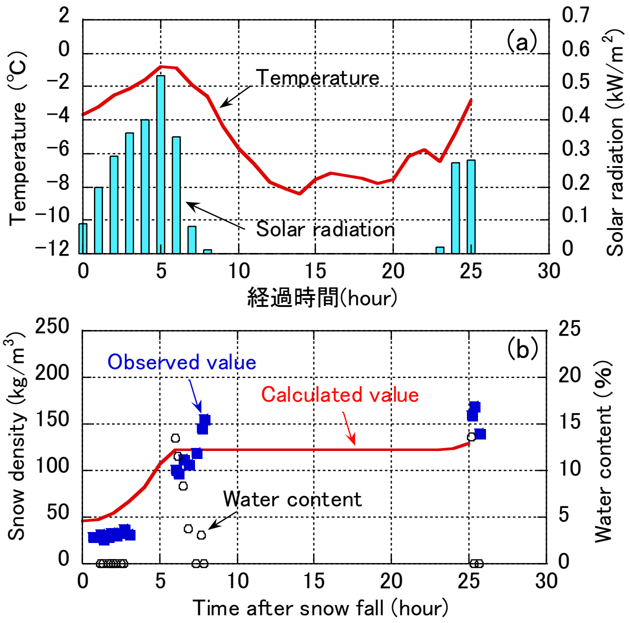

Fig. 7 Comparison of observed value of surface snow density with calculated value by the model.

B. *Estimate flying up snow flux*

In order to investigate the influence of snow density and train passing speed on the flying up snow amount, flying up snow experiments were carried out.

1) Flying up snow experiment

Flying up snow experiments were conducted by snowplow testing device, which is installed at Shiozawa snow testing station. This device is capable of linear motion up to a maximum speed of 40m/s by running a truck pulled by wire rope on a truss beam type guide rail of 60m length. Box model is a rectangular box (200mm in length, 400mm in width, 400mm in height) that simulates an under-floor equipment of a train. It is attached to the truck, and train wind is generated by passing over snow samples to reproduce flying up snow phenomenon (Fig. 8).

Used snow sample was natural snowfall of 150 to 190 mm in thickness. The length in the running direction is 1.8 to 2.7 m. The snow sample was placed so that the distance between the snow surface and the box model was 150mm.

First, surface snow density was measured, and then the model box was run at a set speed. As the amount of flying up snow, mass flux of snow particles on the snow surface (hereinafter "flying up snow flux") was measured using Snow Particle Counter (SPC-S7, Niigata Electric Co., Ltd.).

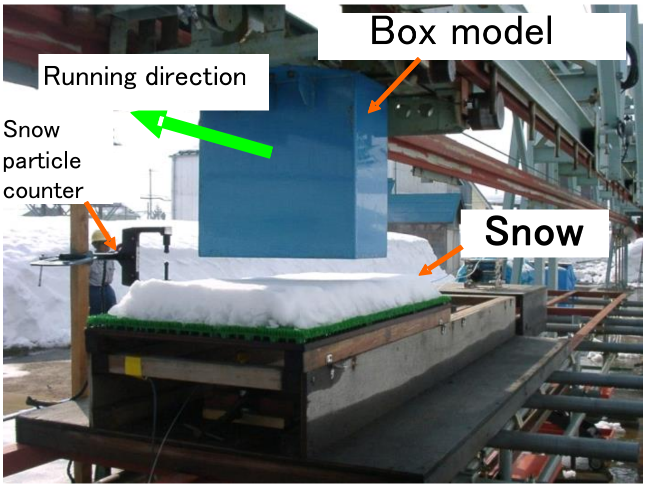

Fig. 8 Situation of flying up snow experiment.

2) Relationship between flying up snow and snow density

The relationship between the flying snow flux and surface snow density is shown in Fig. 9. We show example results of 10m/s and 40m/s in the test speed.

It is found that the flying up snow flux is large when the snow density is low immediately after snowfall, and decreases exponentially as the snow density increases. By formulating such a relationship, the relationship between the snow density and the snow flux was obtained for each speed.

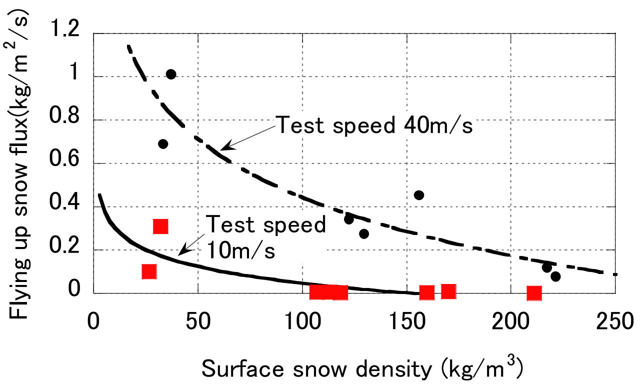

Fig. 9 Relationship between flying up snow flux and surface snow density.

C. *Estimate snow accretion amount*

In order to obtain snow flying up flux during train running, the snow density was estimated from the weather information of AMeDAS observation point between Akita and Morioka, and then flying up snow flux was obtained using the relationship shown in Fig. 9. Train running speed was obtained by reading the average speed between AMeDAS observation point from the driving curve.

The relationship between snow accretion amount and flying up snow flux was determined by comparing the flying up snow flux for each train, which was obtained from the flux for each AMeDAS point, and the snow accretion amount at Morioka Station.

Fig. 10 shows relationship between the flying up snow flux of each train and snow accretion amount. There is a positive correlation between the flux and the snow accretion amount. This relation is expressed as follows.

$$V = 1.11\bar{F}^2 \quad (4)$$

Here, V is snow accretion amount (m^3) and $\bar{F}$ is averaged flying up snow flux (kg/m^2/s).

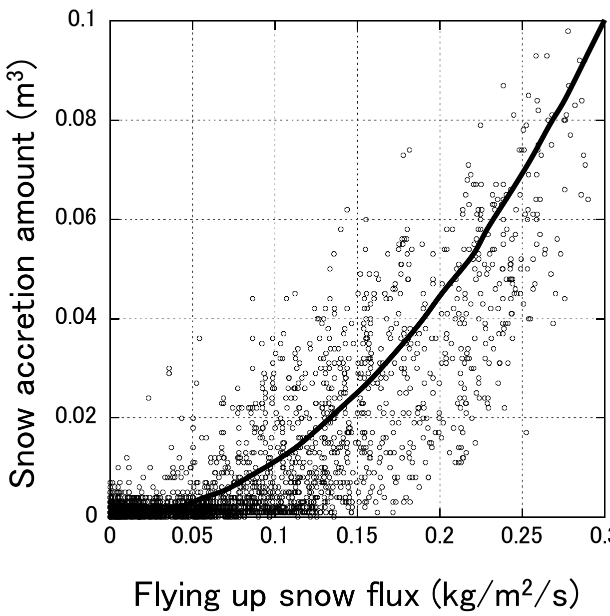

Fig. 40 Relationship between the flying up snow flux of each train and snow accretion amount.

V. VALIDATION OF ESTIMATION METHOD

The procedure to estimate snow accretion amount from the weather information along the railway is shown in the following.

1. Weather information of temperature, precipitation and sunshine are obtained as input data.
2. Snow density of each point is calculated by the surface snow density estimation model.
3. Calculate the flying up snow flux at each point according to the snow density and the train speed.
4. Calculate the average value of the flying up snow flux for each train.
5. Snow accretion amount is estimated from the relationship between the flux and the snow accretion amount.

Fig. 11 shows a comparison of the estimated value obtained by this estimation method with the measured value. The straight line in the figure is the case where the estimated value and the measured value match. Estimated value is consistent with measured value, correlation coefficient was 0.86, and RMSE was 0.008m^3.

In this way, it is possible to estimate the amount of snow accretion on the train bogie from the weather information along the railway.

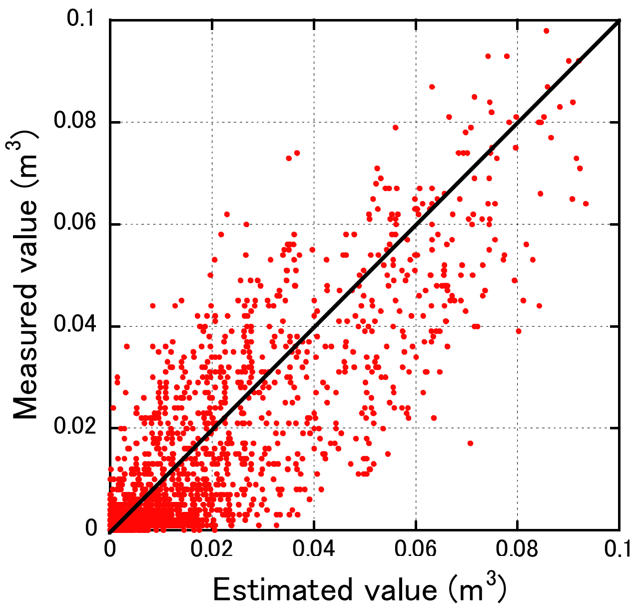

Fig. 51 Comparison of the estimated value of this method with the measured value.

VI. CONCLUSIONS

In order to carry out snow accretion countermeasures such as snow removal work efficiently, we examined a method to estimate the amount of snow accretion growing on the bogie of a train traveling in the snowfall area.

We developed a method to estimate the snow accretion amount from the weather information along the railway

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