A Study on the Relationship between the Weather Condition and the Window Glass Damage by Accreted Snow under High-speed Trains

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Abstract—**When a train runs over a snow-covered track at high speed, the snow accreted under the car body may drop and scatter the ballast on the track which causes damages to the railway vehicle as well as the track. Among the various types of damage by the accreted snow under railway vehicle, the window glass damage is most serious in Korea where about 130 broken window glasses are reported per year since the opening of high-speed railway line in 2004.**

In this paper, the window glass damage of KTX train and the weather conditions along the Seoul-Busan high-speed line have been analyzed during the ten years' operation. It has been concluded that the window glass damage of KTX train is related to the weather condition as well as the snow accrete phenomena. The effect of the snow amount and the snow density to the snow accrete phenomena have been investigated and conditions of snowfall which is related to the snow accrete phenomena has been suggested.

Keywords— ***Accreted snow, high-speed trains, broken windows, weather conditions, snow density***

I. Introduction

Railway transportation is known to be robust against weather conditions, which contributes to the punctuality and safety those are very important virtues of railway transportation.

In Korea, the climatic conditions are very harsh with hot summer up to 35℃ and cold winter down to -10℃ normally, therefore the railway transportation is frequently affected by severe weather conditions such as high temperature, strong rain, strong wind and heavy snow.

Since the opening of Korean high-speed railway service in 2004, various climatic problems happened, and the problems caused by the accreted snow under high-speed trains have mostly been noted. When a train runs on the snow-covered track at high speed, the snow is blown away and it accretes to train underbody. The accreted snow on the train repeats to melt and freeze to be as hard as ice and is occasionally detached from train underbody due to the temperature change or impulsive vibration of train body. Finally, the detached snow accrete falls and hit the ballast on the track and causes various problems [1].

Among the problems by accreted snow, the window glass damage is most serious in Korea. Since the year of 2004, total 1312 broken windows are reported which corresponds to about 130 broken windows per year. It is supposed that the window glass break is closely related to the snow accrete phenomena, however the snow accrete phenomena can hardly be examined because the railway operation circumstance in the real field is very hard to access. On the other hands, the snow accrete phenomena is supposed to be affected by the weather condition, especially the characteristics of snowfall.

In this paper, the relationship between the weather condition and the window glass damage have been studied to understand the snow accrete phenomena and its affecting factor among the snowfall variables including the amount of snowfall and the snow density. By calculating statistical correlation parameters between the yearly frequency of snowfall and the yearly number of broken window glasses, the criteria of snowfall variables affecting the snow accrete phenomena as well as the window glass damage have been suggested.

II. Window Glass Damage Analysis

The KTX train, the first-generation high-speed train in Korea is composed of 20 vehicles with maximum operational speed of 300 km/h and. Although the commercial operation of KTX train has been started in the April of 2004, the temporal range of analysis has been set from the January of 2005 to the November of 2014 in order to include hole winter season for every year.

Fig. 1 shows the number of broken window glasses and the total running distance of the KTX trains with respect to years. The numbers of broken window glasses show irregular yearly history while the running distance varies in a relatively narrow range near 400 million km.

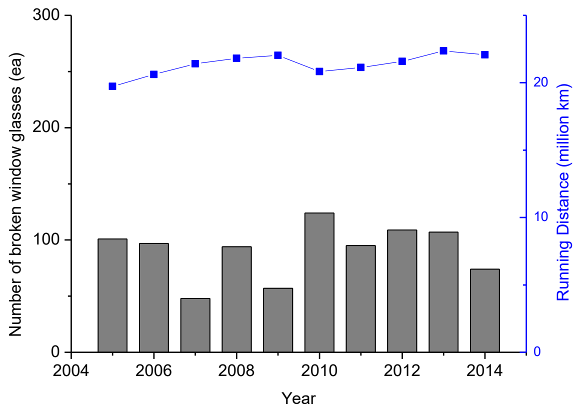


Fig. 1 Yearly history of damaged windows and running distance

The probability of window glass damage is evidently proportional to running distances, therefore the number of broken window glasses have been normalized by the total running distances of KTX train and presented in Fig. 2. Although the effect of running distance has been eliminated, the yearly history of window damage is still irregular from about 2 ea/mil km in 2010 to about 6 ea/mil km, which is suspected to be the effect of weather condition.

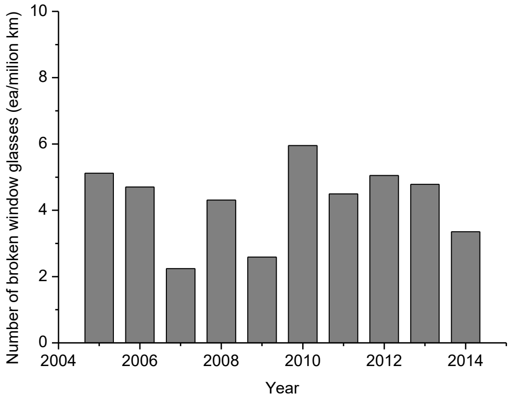


Fig. 2 Yearly history of damaged windows per running distance

III. WEATHER CONDITION ANALYSIS

The weather conditions along the Seoul-Busan high-speed line with about 430km length have been investigated from the year of 2005 to the year of 2014. The number of snowfall days has been counted with various criteria on the amount of daily snowfall(h_s) over 1cm, 3cm and 5 cm have been plotted in Fig. 3, Fig. 4 and Fig 5.

Fig 3 shows the number of snowfall days of each city which have station along the Seoul-Busan high-speed line with respect to the distance from Seoul. Because Seoul is the north bound and Busan is the south bound, the snowfall frequency of the northern cities from Seoul to Daejeon is far larger than that of the southern cities from Gumi to Busan.

The local distribution of snowfall frequency in Fig. 3 cannot be related to the window glass damage property because the location of window break cannot be identified. Nevertheless, we can estimate that the snow accretes take place mainly in the north region during the two and half hours' operation.

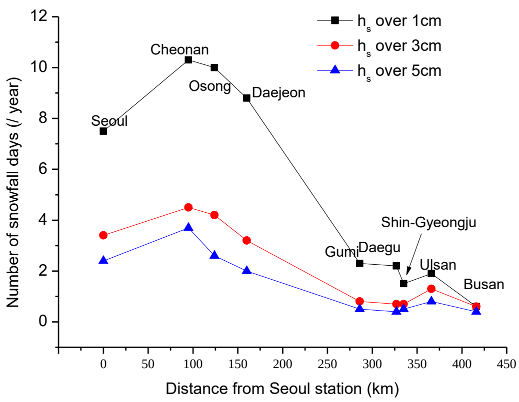


Fig. 3 Snowfall frequency by local positions

Fig 4 presents the number of snowfall days with respect to years from 2005 to 2014. The snowfall frequency in 2010 stands out with 9 times by h_s>1cm and 4 times by h_s>3cm criterion. The snowfall frequency in 2012 and 2005 are also high relative to that in adjacent years. In these outstanding years of frequent snowfall, the number of broken window glasses in Fig. 2 are also large. It is obvious that the more frequent snowfall leads to the larger number of broken widow glasses, however the weak relationship between the snowfall frequency and the window glass damage means that there is another factor that is related to characteristic of snowfall.

The amount of snowfall could be one of the affecting factors to the snow accrete phenomena. A certain amount of snowfall from which the snow accrete phenomenon start to occur could be assumed, therefore restricting a criterion of snow amount to be applied the snowfall frequency could make the relationship between the window glass damage and the snowfall frequency closer. In Fig. 4, the snowfall frequencies are different by criteria on the amount of snowfall. For the snowfall amount criteria of h_s > 1cm, the snowfall frequency in 2005 is far larger than that in 2006, however, the difference becomes quite small when the criteria of h_s > 3cm and h_s > 5cm are applied.

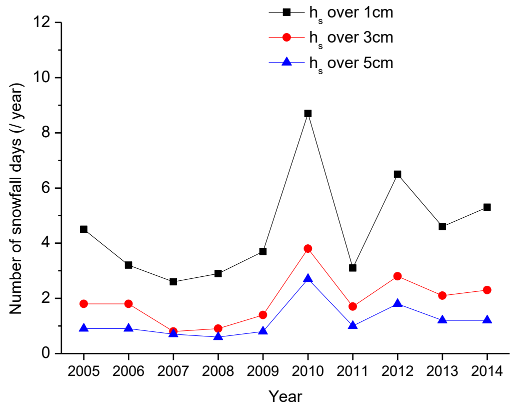


Fig. 4 Snowfall frequency by year

From the experiences of railway operation company in Korea, it is known that too dry snow of which the snow density is very small does not lead to snow accrete to railway vehicle. In this reason, the snow density has been introduced for the affecting factor to the snow accrete phenomena. The snow density could be defined by eqn. (1) which can easily be implemented with usual climatic measurements[2].

$$\rho_s = \frac{h_r}{h_s} \times \rho_w \qquad (1)$$

Where, $h_r$is daily rainfall in mm, h_s is daily snowfall in cm, ρ_w is the density of water in 1,000kg/m^3 and ρ_s is the snow density in kg/m^3.

The number of snowfall days with respect to snow density interval is presented in Fig 5. The snow density shows wide distribution from 40 to 200 kg/m3, however about 70 percent of the snowfall have the snow density from 40 to 100 kg/m3.

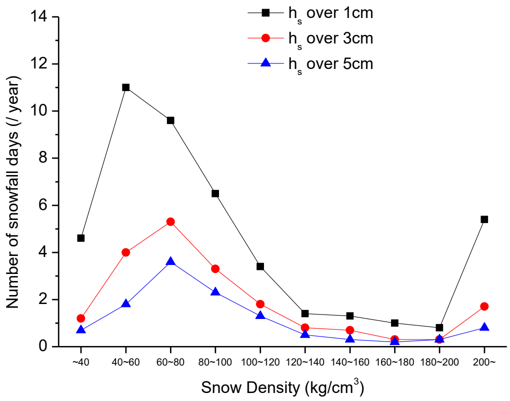


Fig. 5 Snowfall frequency by snow density

IV. CORRELATION ANALYSIS

To yield closer correlation between the window glass damage and the snowfall frequency, the yearly snowfall frequency has been calculated by applying various cut-off criteria on the snow variables in Table 1.

As for the snow amount, five cut-off criteria have been set from 1cm to 5cm with 1cm interval. The snow density has been cut off from 40kg/m^3 to 100kg/m^3 with 10kg/m^3 interval. Consequently, total 35 combination of cut-off criteria have been applied to calculate the snowfall frequency.

TABLE I. CUT-OFF CRITERIA OF SNOWFALL VARIABLES

Snow variable	**Criterion**
Amount of snow	> 1cm
	> 2cm
	> 3cm
	> 4cm
	> 5cm
Snow density	> 40 kg/m^3
	> 50 kg/m^3
	> 60 kg/m^3
	> 70 kg/m^3
	> 80 kg/m^3
	> 90 kg/m^3
	> 100 kg/m^3

To assess the correlation of each cases, $R^2$and adjusted R^2 have been calculated using eqn. (2) and eqn. (3), respectively.

$$R^2 = \frac{SSR}{SST} \quad (2)$$

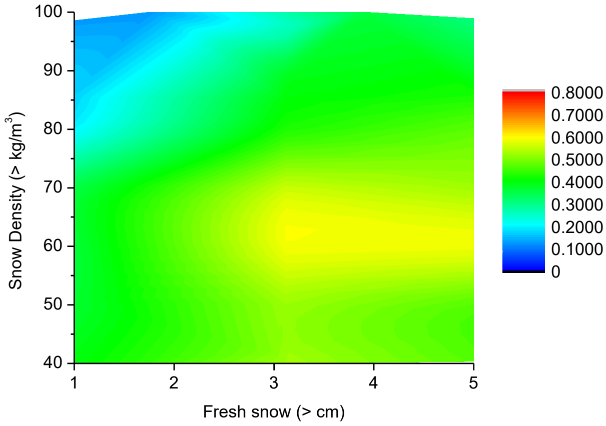
Where, SSR means sum of square regression and SST means sum of square total. R^2 is known as the coefficient of determination which has a value between 0 and 1. It is a measure of consistency of the regression line to linear regression model. R^2 value becomes closer to 1, it means regression model is more relevant[3].

$$\text{adjusted } R^2 = 1 - \frac{MSE}{MST} \quad (3)$$

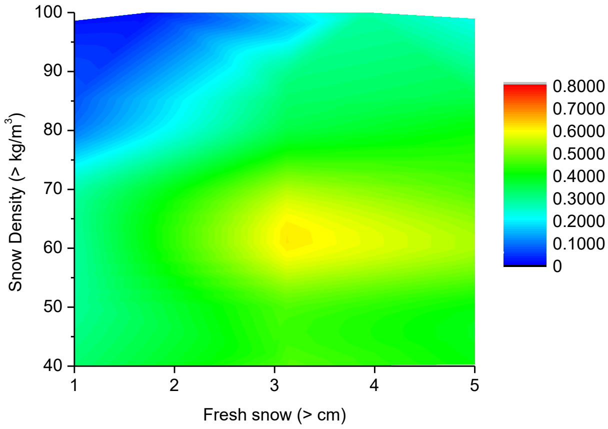
Where, MSE means mean-squared error, MST means mean-square treatment. Adjusted R^2 is a modified form of R^2 which is independent to the number of variables[4].

The calculated values of R^2 and adjusted R^2 have been plotted with respect to weather variable cut-off criteria in Fig. 6 (a) and (b), respectively. As shown in Fig. 6 (a), R^2 is relatively high when the snow density cut-off criterion is set to 60kg/m^3 and the snow fall amount cut-off criterion is larger than 3cm. The adjusted R^2 in Fig. 6 (b) shows similar contour to the R^2 in Fig. 6 (a) except that the former is more distinct.

From the analysis of the correlation parameters R^2 and adjusted R^2, it can be concluded that the criteria of snowfall of h_s > 3cm and ρ_s > 60kg/m^3 yields most close correlation between the window glass damage and the snowfall frequency.



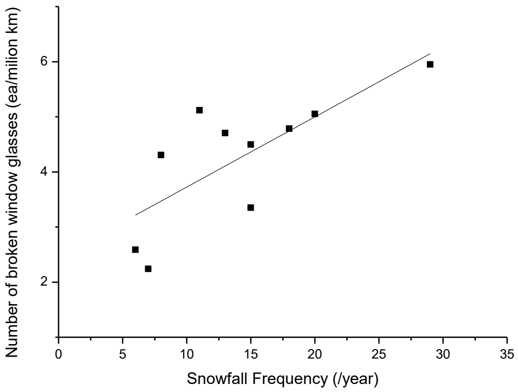
(a) R^2



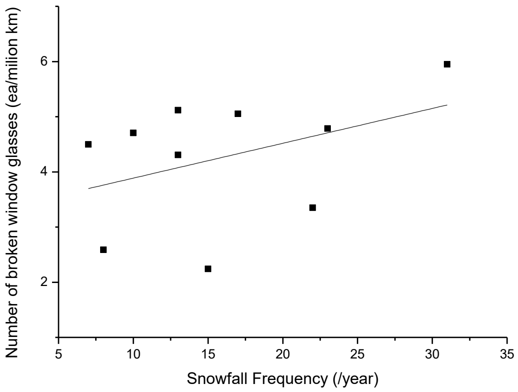
(b) adjusted R^2

Fig. 6 Correlation result with respect to weather variable criteria

The plots of the number of broken window glass with respect to the snow frequency have been plotted for extreme cases. Fig. 7 (a) shows the best fit case with h_s > 3cm, ρ_s > 60kg/m^3 while Fig. 7(b) shows the worst fit case with h_s > 1cm, ρ_s > 90kg/m^3. As is expected by the correlation analysis in Fig. 6, the close relationship is observed between the snow frequency and the window glass damage when the snowfall variable is properly restricted to count the number of snowfalls.



(a) Best fit case (h_s > 3cm, ρ_s > 60kg/m^3)

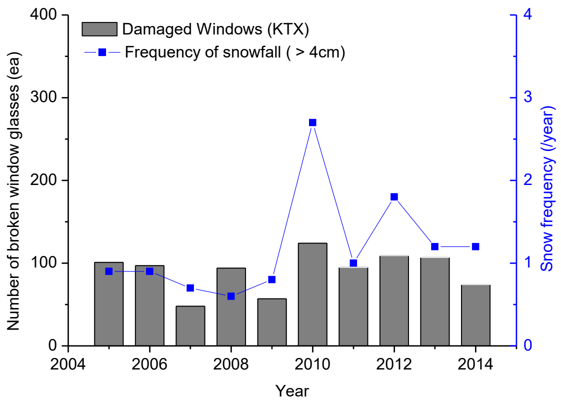


(b) Worst fit case (h_s > 1cm, ρ_s > 90kg/m^3)

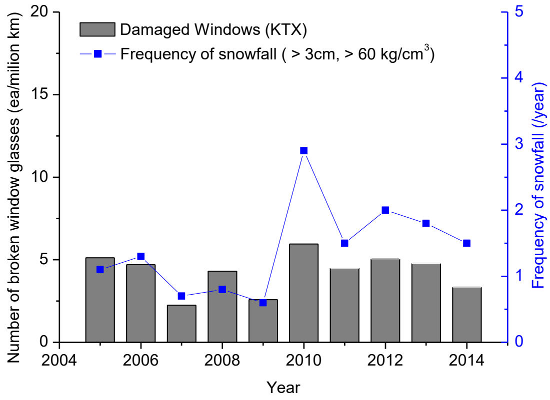
Fig. 7 linear fit result for weather variable criteria

Finally, the yearly trend of window glass damage per running distance and the snowfall frequency over 3cm amount and over 60kg/m^3 snow density has been plotted in Fig. 8 (b) in contrast to that of simple number of wind glass damage and the snowfall frequency over 1cm amount in Fig. 8 (a).

The simple comparison in Fig. 8 (a) shows that the window glass damage is related to the snowfall frequency, however the relationship is somewhat loose. By applying the criteria of h_s > 3cm and ρ_s > 60kg/m^3 to count the snowfall frequency as well as by dividing the number of broken window glass by the running distance of the high-speed train, the relationship between the window glass damage and the frequency of snowfall yields more close correlation.



(a) before criteria has been adapted



(b) after criteria has been adapted

Fig. 8 Yearly trends of the window glass damage and the snowfall frequency

V. Conclusions

In this paper, the window glass damage of KTX train and the weather conditions along the Seoul-Busan high-speed line have been analyzed during the ten years' operation, and the following conclusions have been yielded,

- The window glass damage of KTX train is related to the snow accrete phenomena because the number of broken window glasses is proportional to the days of snowfall.
- Two affecting factors to the snow accrete phenomena have been derived from rational and empirical hypothesis; the snow amount h_s and the snow density ρ_s.
- By restricting the affecting factors to count the snowfall frequency, closer relationship between the window glass damage and the snowfall frequency has been attained.
- Finally, the criteria of h_s > 3cm and ρ_s > 60kg/m^3 are suggested as conditions of snowfall which is related to the snow accrete phenomena.

Acknowledgment

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