Visibility Reduction Caused by Snow Clouds on Highways

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Reduced visibility for drivers due to snow and its relationship to safe highway operations have been major concerns of road authorities. Visibility even in calm weather is reduced by airborne snow in clouds created by moving vehicles. A study was conducted using a reflector-type visibility sensor placed on a road median to observe the reduction of visibility. A snow-particle counter was mounted on the roof of a vehicle to measure the size of entrained airborne snow particles while driving through a snow cloud. As the temperature drops, cohesion of snow particles decreases and they are easily blown up from the road surface. Visual range was found to change from hundreds to tens of meters in a short time when a snow cloud formed. Collector snow fences reduce the dissipation of vehicle-generated snow clouds on highways. Poor visibility continued longer in sections with snow fences than in areas with no fences. The number of small snow particles is greater in a vehicle-generated snow cloud than in wind-blown snow. Large vehicles cause large snow clouds, and the extent of a snow cloud depends on vehicle size. Snow particles in a vehicle wake are lifted about to the level of the vehicle's roof. In contrast, average visibility is improved and fluctuation of visibility on a highway is mitigated with collector snow fences in blowing snow conditions. However, a snow fence leads to decreased visibility in snow clouds generated by vehicles. The characteristics of visibility in blowing snow and in vehicle-generated snow clouds on highways are presented.

As the speed at which one drives a vehicle increases, more visual information is needed. However, dynamic visual acuity decreases as speed increases, causing severe problems of poor visibility. Dynamic visual acuity—the ability to recognize moving objects—also declines with age. With an increase in the population of elderly drivers, it is important to ensure that enough visual range is available.

Powdery snow on a highway is blown up in the wake of vehicles driving at high speeds even when the weather is calm and the sky is clear. Studies of the characteristics of visibility due to blowing snow have been carried out in the past. Snow break forests, snow fences, and drift-free road design are countermeasures against blowing snow. However, visibility in snow clouds of vehicles has not previously been studied. In this research, visibility reduced by vehicle-generated snow clouds was observed on in-service highways, and the height and duration of snow clouds leading to poor visibility were analyzed with regard to vehicle size, speed, and highway design. Threshold levels of snow entrainment in the wake of vehicles were studied at different air temperatures and precipitation rates.

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INSTRUMENTATION

In this paper, the term "large vehicles" refers to trucks weighing 8000 kg and buses with passenger capacity of 11 or more. All other vehicles are considered small. The driver's eye level of a small vehicle is 1.2 m above the road surface. Visibility was observed using a reflector-type visibility sensor set on the median of a highway [National Highway Route (NHR) 12]. The visibility sensor was 1.2 m above the highway surface.

The transmissometer-type visibility sensor has a well-established theoretical background (*1*). A comparison of calculated visibility with visual range as sensed by the human eye shows that the transmissometer sensors can be used to measure visibility in blowing snow. The output voltage (V_O) from a reflector-type visibility sensor was compared with the visibility measured with a transmissometer-type visibility sensor (Figure 1) (*2*). Visual range (V) is calculated by Equation 1:

$$V = 26.33\ V_O^{-0.87} \quad (1)$$

THRESHOLD OF SNOW IN WAKE OF VEHICLES ON HIGHWAYS

The cohesion of snow particles on a road surface is destroyed by the mechanical action of vehicle tires and the shear stress exerted in the wake by moving vehicles. Figure 2 shows the threshold condition of blowing snow with precipitation (*3*). Bonding of snow particles tends to increase with temperature. Figure 3 shows the reduction of visibility by vehicle-generated snow clouds in relation to temperature and precipitation. Precipitation increases visibility attenuation in the wake of moving vehicles. As the temperature drops, the cohesion of snow particles decreases, causing them to be blown up from the road surface more readily. A snow cloud generated by a large truck in the passing lane is shown in Figure 4. In this case, the wind was calm soon after precipitation ended, the sky was clear, and the air temperature was −4°C. Although the road had been plowed and the travel lane was mostly bare, a little snow still remained on the passing lane.

The monthly mean air temperature in Hokkaido from December 1 to April 1 typically ranges between −10 and 0°C. The threshold of snow in the wake of vehicles depends on air temperature. Besides real-time meteorological data, forecasts for precipitation and air temperature are available from online meteorological services. If one knows how the threshold for snow entrainment in vehicle wakes varies with air tem-

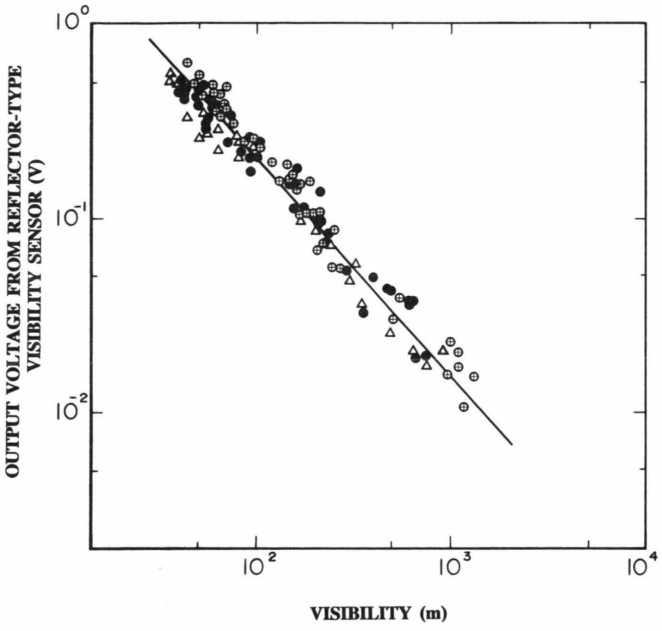

FIGURE 1 Comparison of transmissometer-type visibility output to voltage of reflector-type visibility sensor; $N = 109$, $R = .974$.

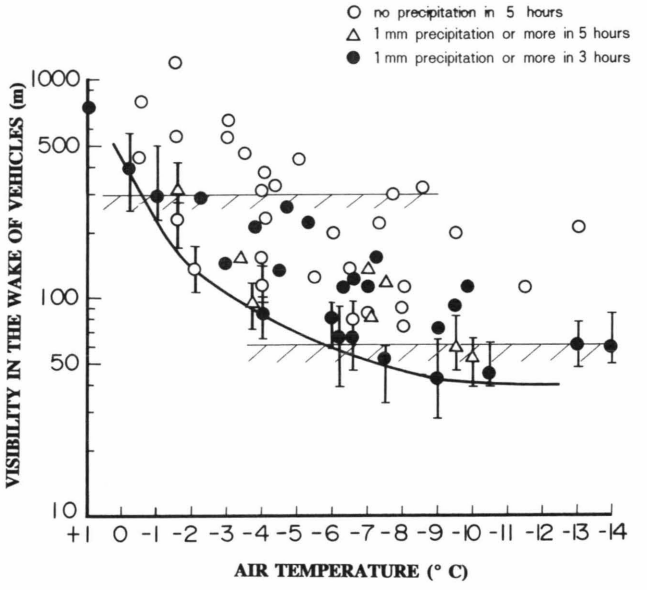

FIGURE 3 Threshold for reduced visibility caused by snow in vehicle wake as a function of temperatures and precipitation rates.

perature and precipitation, it is possible to provide the motoring public with information on adverse conditions caused by vehicle-generated snow clouds.

CHARACTERISTICS OF VISIBILITY ATTENUATION CAUSED BY VEHICLE-GENERATED SNOW CLOUDS

Visual information is indispensable for drivers and becomes more critical as vehicle speed increases. Blowing snow and fog have long been considered the greatest causes of reduced visibility. However, vehicle-generated snow clouds are another important cause of poor visibility. Clouds touching the ground is one type of fog; it causes poor visibility on highways in mountainous areas. The degree of visibility fluctuation due to fog is less than that caused by blowing snow. Figure 5 shows the visibility under foggy conditions observed on a Nakayama mountain pass on NHR 230. Figure 6 shows an observation of reduced visibility due to snow in the wake of a vehicle. Visibility was reduced instantly from more than 1000 to fewer than 100 m. After a vehicle passed the observation point, visibility improved in tens of seconds. Figure 7 shows an observation of blowing snow in Ebetubuto, on NHR 12, where visibility and wind speed changed rapidly.

Visibility is reduced by dispersed snow in the wake of vehicles, not only in blowing snow but also in clear and calm weather. Figure 8 shows the distribution of snow particle sizes on a highway in blowing snow (*left* and *middle*) and vehicle-

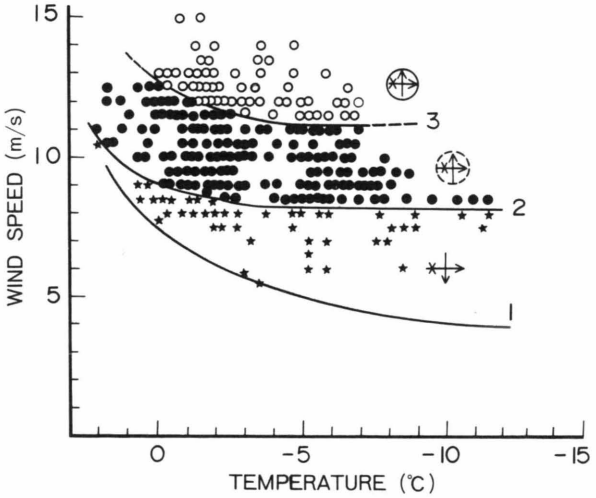

FIGURE 2 Threshold wind speed for blowing snow in relation to temperature.

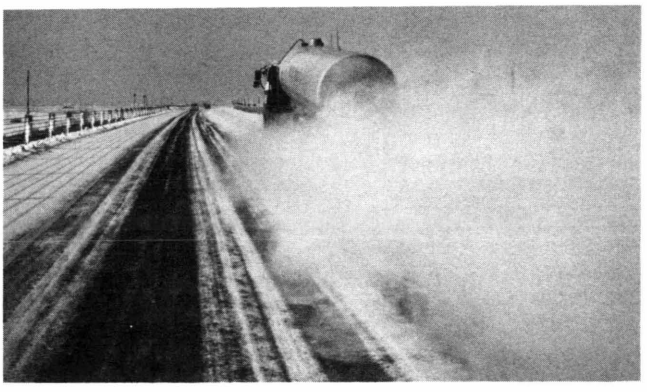

FIGURE 4 Snow cloud generated by large truck on a highway.

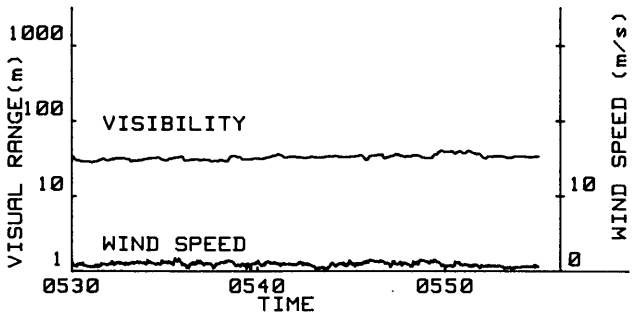

FIGURE 5 Visibility in fog on NHR 230 (Nakayama mountain pass), March 24, 1989.

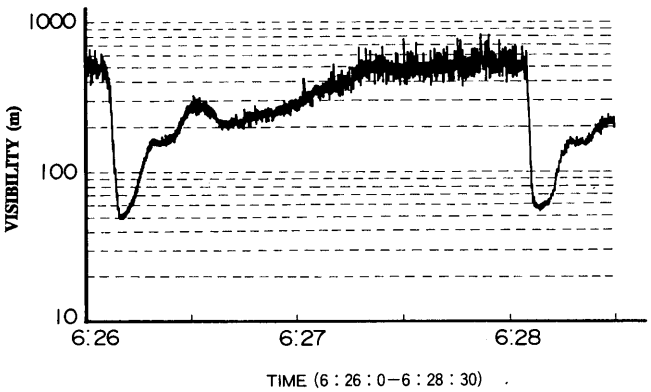

FIGURE 6 Visibility in snow cloud in wake of large vehicle on NHR 12 (Ebetubuto), February 6, 1991.

generated snow clouds (*right*) (*4*). In the vehicle-generated snow clouds, the number of smaller snow particles was greater than that for blowing snow. No particle larger than 250 μm was found.

The wake of a moving vehicle in still air was investigated by Eskridge et al. to predict the dispersion of air pollution along the highway (*5*). They reported the velocity deficit and turbulent energy fluctuation when the wind speed was much less than vehicle speed. The height of the wake (h) behind a

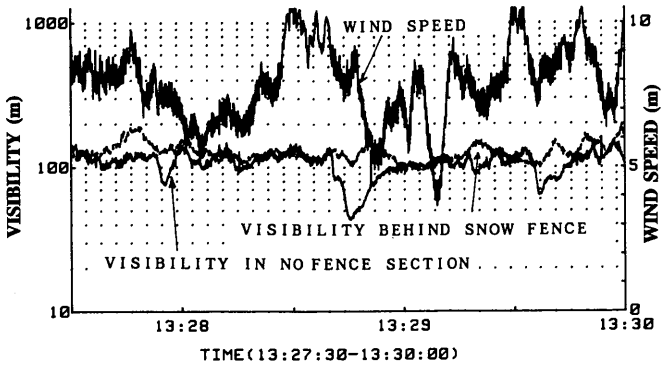

FIGURE 7 Visibility in blowing snow on NHR 12 (Ebetubuto), showing effect of snow fences, February 16, 1991.

vehicle can be derived as

$$h = \alpha \gamma A h (Xh)^{1/4} \quad (2)$$

Suppose a vehicle moves in the X-direction, where A is the cross section of a vehicle, h is the height of a vehicle, and γ is a constant approximately equal to von Karman's constant. Equation 2 is derived theoretically. Snow particles are heavier than the gas used as tracer, and the dispersed area of snow in the wake of a moving vehicle is supposed to be within h.

INFLUENCE OF ROAD STRUCTURES AND VEHICLE TYPES TO SNOW CLOUDS

The diffusion of snow in the wake of vehicles is affected by the geometry of the road and nearby structures. The duration of snow in the wake of vehicles is defined as the period from the time when visibility is reduced below 300 m to the time when visibility recovers to 300 m. Visibility changed by snow in the wake of a large truck showed a duration longer than 60 sec on NHR 12 at a location along a river embankment with a 5-m-high snow fence 10 m upwind. At this location, the embankment and snow fence delayed the diffusion of snow in the wake. For comparison, the visibility measured by a

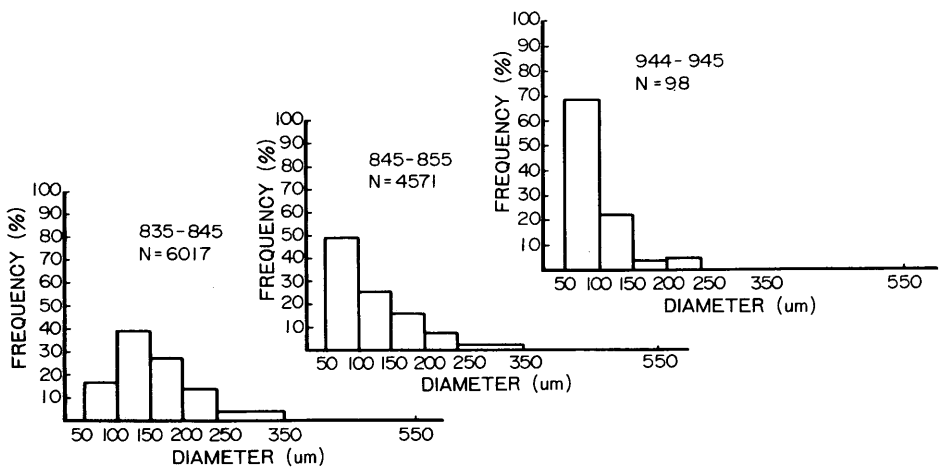

FIGURE 8 Snow particle size distribution on a highway in blowing snow (*left* and *middle*) and in snow cloud (*right*).

reflector-type sensor on the median on NHR 40 shows the duration of reduced visibility to be only about 10 sec (Figure 9). At this location, snow particles in vehicle-generated snow clouds are dispersed more quickly. Figure 10 shows the cross sections of NHRs 12 and 40. During both observations the air temperature was −9.2°C and the wind velocity was below 1 m/sec.

Visibility reduced by snow in the wake of small vehicles was observed on NHR 40 at the same time as the measurements shown in Figure 11 (air temperature of −9.6°C and mean wind speed of 1.1 m/sec). The duration of snow clouds was about 5 sec at the observation point. Minimum visibility was 40 percent greater than that associated with the snow cloud generated by a large vehicle. The larger wakes formed by larger vehicles cause poorer visibility for a longer time than those formed by smaller vehicles.

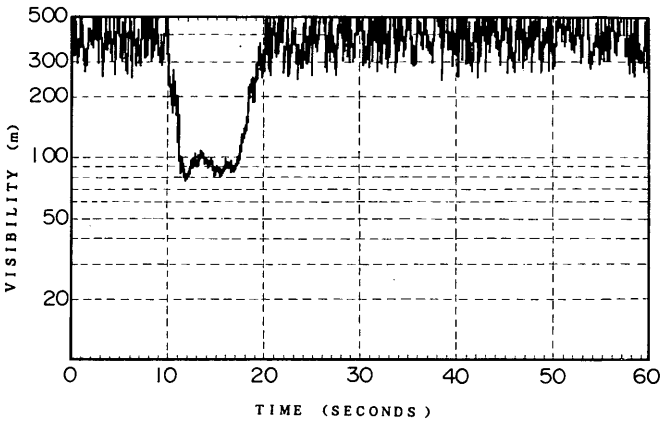

FIGURE 9 Visibility in the wake of large vehicle on NHR 40 (Kaigen).

CONCLUSION

Snow problems such as road closures due to blowing snow have decreased. We can drive at relatively high speeds even during the snow season today. However, traffic accidents during the snow season tend to involve many vehicles. The major cause of such accidents is the diminished visibility due to blowing snow or vehicle-generated snow clouds. Dynamic visual acuity decreases at high speeds and with age. Improvement of visibility in snow conditions is becoming more important with the growing number and proportion of elderly drivers.

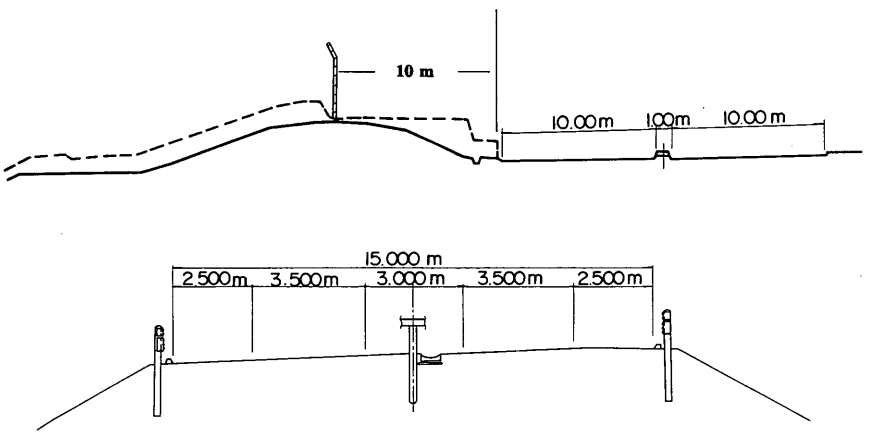

FIGURE 10 Cross sections of NHRs 12 (*top*) and 40 (*bottom*).

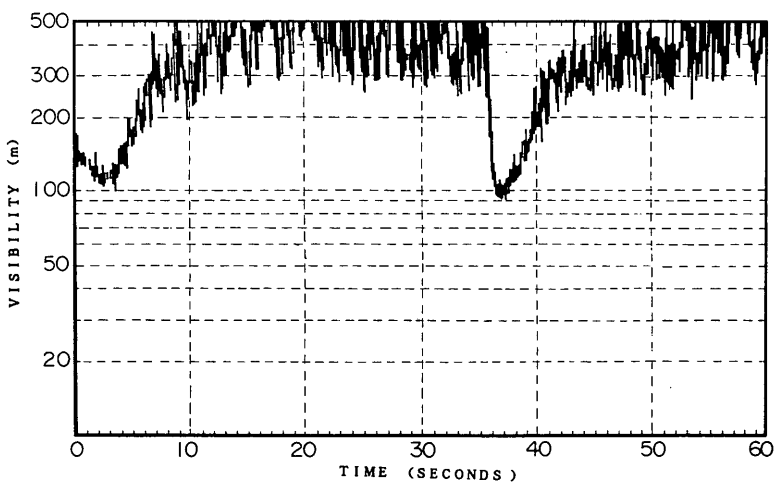

FIGURE 11 Visibility in wake of small vehicle on NHR 40 (Kaigen).

Countermeasures against blowing snow can aggravate the visibility problem caused by vehicle-generated snow clouds. Further studies are under way to determine ways to reduce the visibility problems caused by moving vehicles.

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