RESEARCH ON SUDDEN VISIBILITY IMPAIRMENT ASSOCIATED WITH GAPS IN SNOW FENCES

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ABSTRACT: In Hokkaido, which is located in a snowy and cold region of Japan, the development of road snow fences has been promoted. The snow fences are one type of blowing-snow control facilities for securing safe winter road traffic. However, the road sections with snow fences still have sudden visibility hindrances near the ends or open parts of the snow fences, and such visibility hindrances cause traffic accidents. To secure stable winter traffic, establishing measures against the sudden visibility changes at such locations is an urgent task for road engineers. However, the mechanism that results in sudden visibility changes at the end or open parts of the snow fence during blowing-snow and the characteristics of visibility changes that affect vehicular traffic have not been clarified. To clarify the influence of wind velocity changes at the ends and open parts of snow fences on sudden visibility changes and quantitatively clarify the effectiveness of the currently used measures against sudden visibility changes, a wind tunnel experiment using a model snow fence was conducted. This paper reports on the investigations in this experiment. A model fence was created based on a collector snow fence which had been installed as a measure against blowing-snow hazards on a multi-lane road. In the experiment using this model fence, the characteristics of visibility changes, which affect vehicular traffic, were investigated in experiment cases with various wind directions and widths of open parts of the fence. The cases with and without mitigation measures at the locations with sudden visibility changes were also investigated.

KEYWORDS: snow fence, sudden visibility impairment, wind tunnel experiment

1. INTRODUCTION

In winter of Hokkaido, which is located in a snowy and cold region of Japan, road traffic problems, including multiple collision accidents and deep snow on the road that makes vehicles unmovable, occur because of poor visibility and snowdrifts on roads from blowing snow. Blowing snow accounts for 40% of the factors that cause road closures on the national highways in Hokkaido. To address such situation, the installation of facilities, including snow fences, which mitigate blowing snow hazards, has been promoted. However, even in a road section where snow fences have already been installed, accidents such as multiple collisions caused by localized poor visibility have occurred at the ends or open parts of the fences. To secure stable winter road traffic, establishing measures against the sudden visibility changes at such locations is an urgent task for road engineers. However, the mechanism that results in sudden visibility changes during blowing snow at the ends and open parts of a snow fence and the characteristics of visibility changes that affect vehicular traffic have not been clarified. Various engineering attempts to mitigate the blowing snow hazards at the locations with sudden visibility changes have been done. Supplemental snow fences, which are installed with different direction angles from those of the main fences, and snow-break slats with a high void ratio have been used as measures to mitigate sudden visibility changes regarding collector snow fences. However, the effectiveness of such mitigation measures have not been quantitatively clarified. To clarify the conditions at the locations with sudden visibility changes at the ends or open parts of a snow fence, on-site measurements are desirable; however, having steady conditions on-site is nearly impossible.

To clarify the influence of sudden visibility changes at the ends and open parts of snow fences under certain fixed conditions and to quantitatively clarify the effectiveness of actually used measures against sudden visibility changes, a wind tunnel experiment using a model snow fence was conducted.

This paper reports on the investigations in the experiment. A base model fence was created based on a collector snow fence which had been installed and used as a measure against blowing snow hazard on a multi-lane road. In the experiment using this model fence, the characteristics of visibility changes, which affect vehicular traffic, were investigated in the experiment cases with various wind directions and widths of the open parts of the fence. The cases with and without mitigation measures at the locations with sudden visibility changes were also investigated.

2. INFLUENCE ANALYSIS OF THE OPEN PART OF THE SNOW FENCE IN A WIND TUNNEL EXPERIMENT USING A MODEL SNOW FENCE

To clarify the influence of sudden visibility changes at the end or open parts of the snow fence on vehicular traffic, a scale model of a snow fence was created based on a snow fence installed along a road in service. The wind velocities in the area around the open part of the model snow fence were measured in this experiment.

2.1 The experiment apparatus

The wind tunnel experiment apparatus owned by the Civil Engineering Research Institute for Cold Region was used for this experiment (Figure 1). A

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base model on a turntable that is used for adjusting the wind direction angle was set in a test section of the wind tunnel (Figure 2).

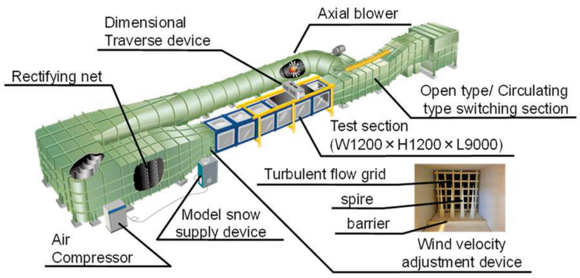

Figure 1: wind tunnel experiment apparatus

Figure 2: The base model and turntable of the experiment apparatus

2.2 Examination for and creation of the scale model

When a study by Miyata et al. (1977) was referenced, it was found that considering the following factors (1) to (3) was necessary in determining the scale of the model.

(1) The similarity law regarding natural winds

The model should be installed within the range of the surface boundary layer (Miyata et al. 1997). The surface boundary layer of the wind tunnel experiment apparatus was 0.4m in height from the bottom surface (Matsuzawa et al. 2013). It was required to set the model within this layer.

(2) Limitations due to the cross sectional size of the wind tunnel

Generally, when a large model is place in a wind tunnel, reproduction of natural winds is negatively influenced by the confining walls above, right and left of the model.

The blockage rate (i.e., the ratio of the cross sectional area of the model to the cross sectional area of the wind tunnel) of 5% or lower is used as a reference index; however, determining the definitive index value has not been possible (Miyata et al. 1997).

(3) Limitations due to the measurement items

In measuring wind velocities, the greater the model scale, the greater the measurement error in the direction of height. On the other hand, if the model is too small, it is physically difficult to handle the model. By considering these factors comprehensively, the scale of the model for this experiment was set as 1/100. There have been many cases of wind tunnel experiments on road snow-control facilities (i.e., snow fences and snowbreak woods) which used models of 1/100 in scale (Matsuzawa et al., 2013; Yamada et al., 2006, and 2007; Yamazaki et al., 2007). The model snow fence was created by using the type of fence which is used on National Highway 337 along the section at KP=74.25. Existing visibility improvement measures are used for the ends and open parts of this fence. The basic data for this fence are as follows:

- Type of snow fence: Collector snow fence (H=5.0m)
- Void ratio of perforated panel (snowbreak slats): 30%
- Widths of open parts: 10m and 20m

The model snow fence was created by using aluminum plates for the snowbreak slats and stainless steel bars for the supports (Figure 3). The snowbreak slats for the parts near the open part of the model were made of ABS resin and created with a 3D printer.

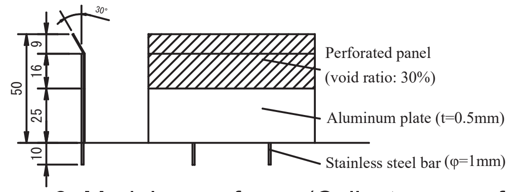

Figure 3: Model snow fence (Collector snow fence)

2.3 Experiment conditions

To simulate natural winds, which increase velocity with the increase in height, the vertical wind velocity profile in the test section of the wind tunnel was set by adjusting the air flows so that they approximated the power law (an exponent of 0.15 was used by assuming the conditions in rural areas (Ohkuma et al. 2008)) (Matsuzawa et al. 2013).

The wind velocity used in this experiment was 7m/s (at H=400mm). This wind velocity was determined based on the wind velocity of approx. 4.5m/s (H=50mm from the ground surface), which had been determined as an optimum wind velocity for reproducing snowdrifts in a wind tunnel experiment using activated clay by Oikawa et al. (2007).

2.4 Experiment patterns

The created model snow fence is shown in Figure 4. The wind direction conditions were set by assuming the perpendicularly incident and obliquely incident winds. The wind velocity measurements were done by placing the model at the angles of 45°, 90°, and 135° to the direction of air flow of the wind tunnel (Figures 4 and 5). The wind direction angle was defined as the angle between the wind direction and the direction of the longitudinal axis of the road.

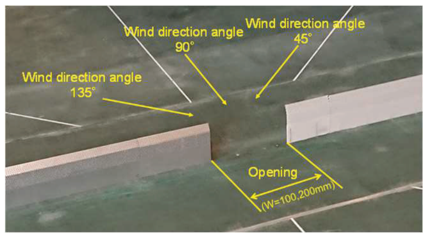

Figure 4: Open part of the snow fence

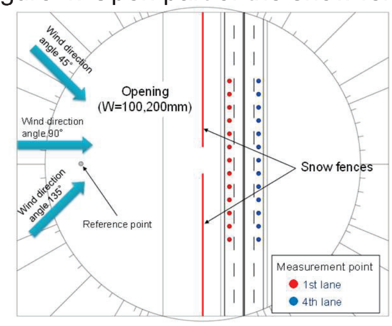

Figure 5: The wind measurement locations

2.5 Measurement method

For wind velocity measurements, a hot-wire anemometer IHW-100 (Kanomax Japan Inc.) was used. In measurements, an I-shaped probe was used. The measurement interval for one time of observation was set as 10ms. A total of 3,072 measurements was done for one location and the measured values were averaged.

To clarify the influence of the open part of the snow fence on the traffic on a four-lane road, the measurement lanes were set as the two outside lanes of the four-lane road. The most windward lane was set as the 1st lane, and the most leeward was set as the 4th lane. Measurements were done along the centerlines of the 1st and 4th lanes. Measurements were done at 13 points on each lane. By setting a central base point on each lane, which was on the intersecting point of the line extended perpendicularly from the center of the open part of the fence and the center line of each lane, 600mm (300m before and after the base point) was set as the measurement line. A total of 13 measurement points were distributed on that line with 50mm intervals (Figure 5). Measurements at each point were done with 5mm intervals for the height from the ground surface up to 100mm, and with 10mm intervals from that point up to 150mm. The reference point for wind velocity in the wind tunnel was set at a point in the center of the cross-sectional area of the wind tunnel and at the windward measurement limit where measurements were not easily affected by the tunnel walls or the model (Figure 5). The ratio of wind velocity measured at each height of each measurement point to the wind velocity at the equivalent height of the reference point was defined as the wind velocity ratio (wind velocity at each measurement point / wind velocity at the reference point), (hereinafter, WVR).

2.6 Results and discussion

From the wind velocity data collected in the experiment, the data points for the height of 15mm, which correspond to the eye level of the driver of a passenger car (1.5m), were extracted. The extracted wind velocity data are shown for each wind direction angle (45°, 90°, and 135°) in Figures 6 to 9. The data for the wind direction angle of 45° are omitted in these figures, because the model was symmetrical and the data for the wind direction angle of 45° are considered to be equal to those for the wind direction angle of 135°. The horizontal axis of the graph indicates the distances of measurement points in the longitudinal direction of the road. Point 0 indicates the base point. Seen from the leeward, the left side points are expressed in minus values, and the right side points are expressed in plus values. The WVRs when the width of the opening was 100mm and the wind direction was perpendicular to the road (wind direction angle of 90°) are plotted in Figure 6. The data points for the 1st lane (i.e., the lane closest to the snow fence) show that the wind speeds were low (WVR of about 0.2) at the areas near the end of the open part, where the collector fence dampens the wind speed, high in the areas near the center of the open part, and about 20% higher at the center of the open part than that at the reference point. On the 4th lane, which was at the most leeward location of the road, the relationship between the variation of WVR and the locations of measurement points relative to the fence opening was roughly similar to those for the 1st lane. The peak value of the data for the 4th lane tended to be lower than that for the 1st lane. It is thought that the wind, which concentrated when it passed through the open part of the fence, diffused as it moved away from the snow fence.

The WVRs, when the width of the opening was 200mm and the wind direction was perpendicular to the road (wind direction angle of 90°), are plotted in Figure 7. On the 1st lane, the curve made by the peak value and the abutting values are almost the same as those for the opening of 100mm in width; however, the width of the peak is broader than that for the 100mm opening. The curve for the 4th lane shows that the peak WVR is higher than that for the 100mm opening, and higher than that at the reference point. It is thought that the wind concentrates when it passes through a wider opening of the fence and diffuses as it moves away from the snow fence; however, the influence of concentrated wind considerably remains at leeward locations on the lane away from the opening.

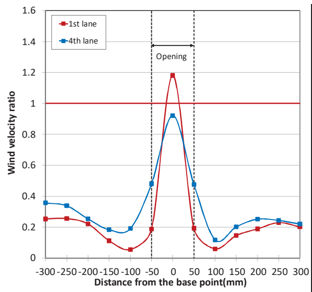

Figure 6: Wind velocity ratio (WVR) (Opening width: 100mm, wind direction angle: 90°)

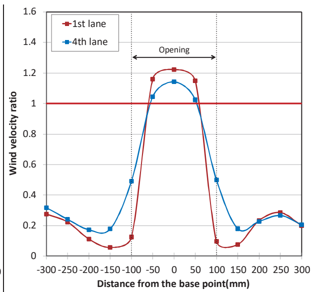

Figure 7: Wind velocity ratio (WVR) (Opening width: 200mm, wind direction angle: 90°)

The relationship between the width of the fence opening and the WVR showed that, in the case of perpendicularly incident winds, the wind speed tended to increase at the area near the center of the opening and the increased wind speed remained at further leeward locations when the opening width was greater.

The WVRs for the wind direction angle of 135° and for the opening widths of 100mm and 200mm are shown in Figures 8 and 9. In the case for the opening width of 100mm (Figure 8), the peak for the 1st lane is at the leeward location (the location which is away from the center of the opening (base point) in the positive direction); however, the peak value of the WVR was about 0.9, which is relatively low compared with those for the perpendicularly incident wind (Figures 6 and 7).

For the 4th lane, the WVRs in the windward locations (those away from the center of the opening in the negative direction) were high. The width of the model fence used in this experiment was made roughly equal to the width of the test section of the wind tunnel when the fence is placed perpendicular to the air flow (i.e., in the case for the wind direction angle of 90°). The reason for the above result shown in Figure 8 was thought to be the presence of gaps between both sides of the model and the test section walls. The gaps on both sides of the model were created when the model was turned 45°. The air flowed through the gaps and influenced the speed of wind that passed the opening.

In the case of an opening width of 200mm (Figure 9), the peak value for the 1st lane was higher than that for the 100mm opening and the influence of higher speed at the opening remained in a broader area than that for the opening width of 100mm. The peak values of the WVR were slightly lower than those for the cases with perpendicularly incident winds. In the 4th lane, the WVRs were high at the measurement points closer to the ends of the measurement point array. Those points were near the lines extended from the ends of the model. Similar to the case with the 100mm opening (Figure 8), the reason for these high WVRs near the end of the model is thought to be the air flow that went through the gaps at the ends of the model. For both cases, the air flow was that of the obliquely incident wind relative to the fence. The air flow in these cases tends to be drawn along the snow fence from the windward direction (the negative side in the figure) toward the opening. The obliquely incident wind directly flows through the opening and then through the gap in the leeward side (the positive side in the figure). It is thought that the wind speed was high at the locations in the plus direction, except for the case of the 4th lane with the 100mm opening. It was found that the wider the opening width, the greater the influence of the opening on the wind speed increase.

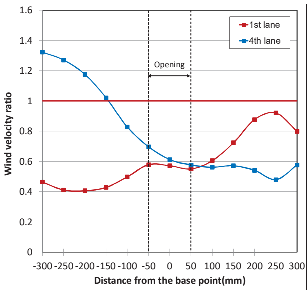

Figure 8: Wind velocity ratio (WVR) (Opening width: 100mm, wind direction angle: 135°)

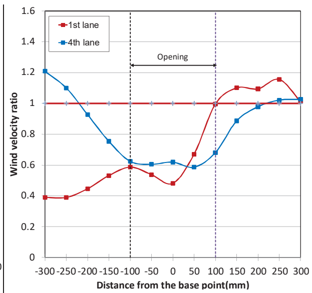

Figure 9: Wind velocity ratio (WVR) (Opening width: 200mm, wind direction angle: 135°)

3. EFFECTIVENESS OF THE MEASURES FOR THE LOCATIONS WITH SUDDEN VISIBILITY CHANGES

Measures against sudden visibility changes in open parts of snow fences have already been taken. Supplemental snow fences have been installed at the ends of the open parts (Figure 11).

In this wind tunnel experiment, we measured wind velocity around the open part of the model snow fence to which a supplemental snow fence was installed.

3.1 *Experiment conditions and patterns*

The experiment conditions were similar to those described in Section 2. The example of installation of a supplemental snow fence in this experiment is shown in Figures 10 and 11.

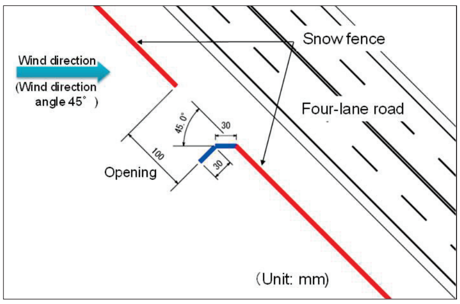

Figure10: An example of installed supplemental snow fence

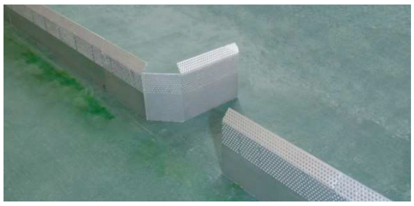

Figure 11: An example of supplemental snow fence installation

3.2 *Results and discussion*

The WVRs for the 100mm opening with the perpendicular wind direction (wind direction angle of 90°) are plotted for the cases with and without a supplemental snow fence in Figure 12. The data for the 1st lane, which was close to the snow fence, show that the peak WVR was recorded at the location closer to the supplemental snow fence (the minus side) than that for the case without the supplemental snow fence. The WVRs were higher for the case with the supplemental snow fence than those for the case without it. The range under the influence of strong wind tended to be broader in the case with the supplemental snow fence than that in the case without it. Generally, the supplemental snow fence is thought to control the flow rate of wind in the horizontal direction. However, it is thought that in this experiment the air flow near the supplemental snow fence was adjusted by it and directed toward the side of the opening with the supplemental snow fence. On the 4th lane, which was at the leeward most location on the road, the relationship between the variation of WVR and the locations of measurement points relative to the fence opening was roughly similar to those for the 1st lane. The peak value of the data for the 4th lane tended to be high.

The WVRs for the opening width of 200mm under the same conditions as the above are shown in Figure 13. In the 1st lane, the peak WVRs and the influence of the supplemental snow fence (with /without) were almost similar to those for the 100mm opening; however, the peaks of the curves show that the ranges under the influence of strong wind were broader than those for the 100mm opening.

The curve for the 4th lane shows that the peak value was higher than that for the 100mm opening. It is thought that the wind that concentrates at the opening diffuses with the increase in the distance; however, when the opening is wide, the influence of the concentrated high speed wind remains in a wider area in the leeward direction. It was found that, in the case of perpendicularly incident wind and with a supplemental snow fence, the location where the peak WVR, which is higher than that for the case without the supplemental snow fence, appears close to the supplemental snow fence.

The WVRs when the wind direction angle was 135° for the 100mm opening are shown in Figure 14, and those for the 200mm opening are shown in Figure 15. In the cases with the 100mm opening (Figure 14), the peak WVR in the 1st lane was lower in the case with the supplemental snow fence than that in the case without it. The WVRs in the range from 100mm to 300mm from the base point are smaller in the cases with the supplemental snow fence than those in the cases without the supplemental snow fence.

In the cases with the 200mm opening (Figure 15), the peak WVR for the 1st lane was even lower in the case with the supplemental snow fence than that in the case without it. The WVR generally tended to be low when the wind flowed through an opening mainly on the side where the supplemental snow fence was installed. The WVRs in the range from 50mm to 300mm are smaller in the cases with the supplemental snow fence than those in the cases without the supplemental snow fence. The reduction effect in the WVRs was greater in the case of the 200mm opening than that in the cases with the 100mm opening. Next, the WVRs when the wind direction angle was 45° for the 100mm opening are shown in Figure 16, and those for the 200mm opening are shown in Figure 17. In the cases with the 100mm opening (Figure 16), the WVRs at and around the peak for the 1st lane were higher in the case with the supplemental snow fence than those in the case without it. The reason for the above is thought to be that the wind was directed toward the opening by the supplemental snow fence and concentrated at the opening.

In the cases with the 200mm opening (Figure 17), the WVRs for the 1st lane were generally low in the case with the supplemental snow fence than those in the case without it. The increase in the WVR under the influence of the supplemental snow fence was not as marked as that in the case with the 100mm opening. It is thought that the influence of with or without the supplemental snow fence was small when the opening was wide.

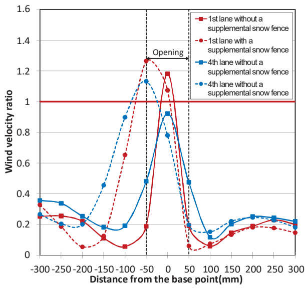

Figure 12: Wind velocity ratio (WVR) (Opening width: 100mm, wind direction angle: 90°)

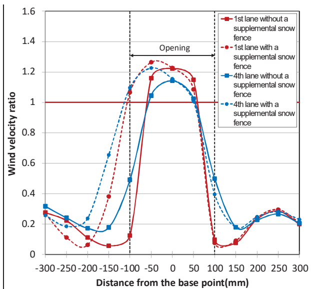

Figure 13: Wind velocity ratio (WVR) (Opening width: 200mm, wind direction angle: 90°)

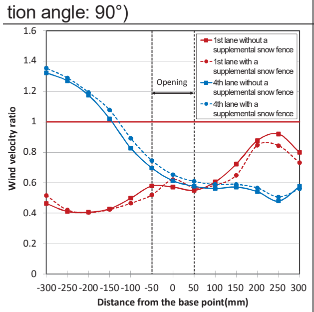

Figure 14: Wind velocity ratio (WVR) (Opening width: 100mm, wind direction angle: 135°)

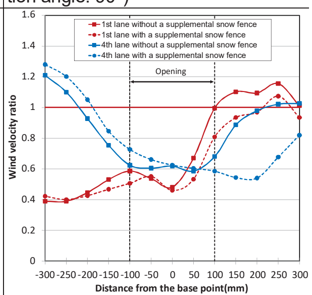

Figure 15: Wind velocity ratio (WVR) (Opening width: 200mm, wind direction angle: 135°)

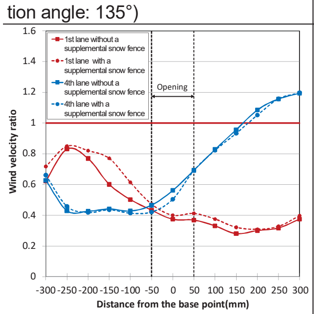

Figure 16: Wind Velocity ratio (WVR) (Opening width: 100mm, wind direction angle: 45°)

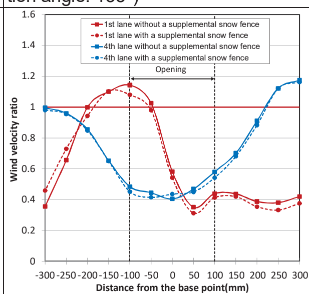

Figure 17: Wind velocity ratio (WVR) (Opening width: 200mm, wind direction angle: 45°)

4. SUMMARY

The characteristics of sudden visibility changes at the end or open parts of the snow fence during blowing snow that affect vehicular traffic have not been clarified. To understand such sudden visibility changes, a wind tunnel experiment using a model snow fence was conducted.

The experiment revealed that when the opening of the snow fence is wide, the WVRs were high and the range on the road under the influence of that strong wind tended to be broad. It was suggested that the wind speed near the open part was able to be reduced by installing a supplemental snow fence; however, when the wind direction is perpendicular to the fence, the supplemental snow fence contributed to increasing the WVR in some cases.

The use of a supplemental snow fence as a mitigation measure for sudden visibility changes at the open part of the snow fence was simulated in the experiment by using a model supplemental snow fence installed orthogonally to the main fence at the end of the opening. Depending on the wind direction and measurement location, the supplemental snow fence strengthened the wind in some cases.

In future studies, further detailed analyses of measurement data in the direction of height will be done to clarify the influence of air flows in the cases of obliquely incident wind, including the air flow through the gaps at the ends of the model and the characteristics of the wind drawn along the fence. We will continue examinations for determining the specification for effective supplemental snow fences.

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