THE HIGHWAY SNOWSTORM COUNTERMEASURE MANUAL (REVISED EDITION 2011)

M. MATSUZAWA, M. KANEKO, & T. WATANABE
Civil Engineering Research for Cold Region, Public Works Research Institute, Japan
masaru@ceri.go.jp, kaneko-m22ae@ceri.go.jp, 06143@ceri.go.jp
Y. ITO
Snow Avalanche and Landslide Research Center, Public Works Research Institute, Japan
yasu-ito@pwri.go.jp
A. HATAKEYAMA
Hokkaido Regional Development Bureau, Ministry of Land Infrastructure Transport and Tourism, Japan
hatakeyama-a22aa@hkd.mlit.go.jp

ABSTRACT

Snowstorm-induced traffic disturbances in winter remain a serious problem on roads in Hokkaido, Tohoku and other northern regions of Japan. Snowstorms are the most common cause of national highway closures in Hokkaido, accounting for approximately 40% of the annual total. They also have a considerable social impact, as they reduce driving speeds and increase the risk of collisions and other hazards. Accordingly, snow fences, snowbreak woods and other facilities have been established in Japan as blowing-snow control measures on roads. To support the planning, design and maintenance of such facilities, The Highway Snowstorm Countermeasure Manual (draft) was issued in March 1990 under the general editorship of the Hokkaido Development Bureau, which manages national highways in Hokkaido. In March 2011, the manual was revised and issued by the Public Works Research Institute's Civil Engineering Research Institute for Cold Region. The Highway Snowstorm Countermeasure Manual (Revised Edition 2011) consists of four volumes: General Guide, Snowbreak Woods, Snow Fences, and Other Blowing-snow Control Facilities. This paper gives an overview of the manual's revised edition published in March 2011.

1. INTRODUCTION

In snowy cold regions, snowstorms often cause traffic hindrance on winter roads. To address this problem, various snowstorm countermeasures have been introduced. In 1990, the first edition of *The Highway Snowstorm Countermeasure Manual* was published to promote technical criteria for planning, designing and installing snow-control measures. The first edition was published as two separate volumes, *Snow Fences* and *Snowbreak Woods*, and it was issued under the general editorship of the former Hokkaido Development Bureau (currently the Hokkaido Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan). In 2003, the former Civil Engineering Research Institute of Hokkaido (currently the Civil Engineering Research Institute for Cold Region, Public Works Research Institute, Independent Administrative Agency (hereinafter: CERI)) revised the manual and added the *General Guide* volume not only to address snow fences and snowbreak woods but also to address overall snowstorm countermeasures. The printed version of the second edition was published as one book containing these three volumes. CERI published the third edition in March 2011 [1] [2]. The edition contains newly developed technology and knowledge of planning and designing. This paper outlines *The Highway Snowstorm Countermeasure Manual (Revised Edition 2011)* (hereinafter: “the Manual”).

2. CONTENT OF THE MANUAL

The Manual consists of four volumes: "Volume 1: General Guide," "Volume 2: Snowbreak Woods," "Volume 3: Snow Fences" and "Volume 4: Other Blowing-snow Control Facilities." Each volume also contains reference materials (Japanese version only). "Other Blowing-snow Control Facilities" was first included in the third edition. This volume covers snowstorm countermeasures of the road structure, such as drift-control embankments and delineation facilities. These were mentioned in the *General Guide* volume of the second edition. The *General Guide* volume of the third edition covers general information that is common among overall snowstorm countermeasures. The details of snow fences and snowbreak woods are explained in the *Snow Fences* and *Snowbreak Woods* volumes, respectively.

3. THE GENERAL GUIDE

This volume outlines blowing-snow control, such as procedures for establishing plans for blowing-snow control measures; evaluation of the degree of snowstorm danger; the outline of each snow-control facility; and criteria for selecting blowing-snow control measures. The reference materials at the end of the volume include the history of *The Highway Snowstorm Countermeasure Manual*, basic knowledge of snowstorms, reference materials and methods of snow-/ice-related meteorological survey and vegetation growth environment survey. In addition, the reference data include the primary meteorological data at several locations in Hokkaido, Japan, including temperature, wind velocity, snowfall depth, snow depth and the volume of snow settled in snowdrifts.

3.1 Procedure for Formulating a Snow-control Facility Installation Plan

When snow-control measures are planned for a newly constructed road (new routes), schematic survey is first made, followed by the basic survey/analysis and the design condition survey. The blowing-snow control measures are based on the results of these surveys. After such measures are introduced, follow-up surveys are made.

3.1.1 Schematic survey

This is the first survey that is conducted in developing a snow-control facility installation plan on new routes. This survey obtains available meteorological data, such as maps of the distribution snow of volume settled in snowdrifts and records of snowstorm disasters. Using these data and materials, the necessity of blowing-snow control measures is assessed and route of the new road is determined.

3.1.2 Basic survey/analysis

Data on weather and the surrounding environment are gathered and weather observations are conducted to assess the degree of snowstorm danger and to select the proper blowing-snow control facilities. In this survey, blowing-snow-induced traffic hindrances are divided into 1) snowdrifts and 2) poor visibility, and the degree of snowstorm danger for 1) and 2), respectively, is assessed based on the weather conditions and the surrounding environment. When blowing-snow control measures are examined for existing routes, the basic survey is first conducted.

3.1.3 Design conditions survey

Prerequisites to the design of snow-control measures are studied. Such prerequisites include soil surveys, which are relevant to the planting of snowbreak woods and ground surveys, which obtain N-values (JIS A 1219) for designing of snow fences.

3.1.4 Follow-up survey

Follow-up survey is made to verify the snow-control effects of the introduced measure and to check their maintenance and management conditions.

3.2 Assessment of the degree of snowstorm danger

The degree of snowstorm danger is assessed by using a flowchart (Figure 1). The calculated score is classified into four categories. The volume of snow settled in snowdrifts (m^3/m) is the volume of snow accumulated on a unit width of land that is perpendicular to the wind direction. It is widely used for designing snow-control facilities.

Figure 2 to 6 show the typical measures used in Japan. The appropriate measure is selected by using the selection table that gives the feasibility of each measure based on the cross-section of the road, the prevailing wind direction, the availability of land for snow-control measure installation and the number of lanes.

Table 1 gives examples of embankments. For example, the table shows that when the primary aim of the measure is to prevent snowdrift formation, the prevailing wind direction is perpendicular to the road and land for facility installation is secured, the first choice is standard-width snowbreak woods. It is followed by road structure modification, in the order of drift-control embankment, gently sloped embankment, traditional collector snow fence and collector snow fence. Delineation facilities are indicted as “additional measures.” This means delineation facilities can be used together with measures marked “Primary selection” or “Suitable.”

Snowdrift Formation Factors

● Danger factors

(1) Weather conditions

Item	Criteria	Score	
Volume of snow settled in snowdrifts (30 year avg)	20 m^3/m or more	3	
	30 m^3/m or more	6	
	40 m^3/m or more	9	
Angle between the prevailing wind direction and road	Less than 30°	1	
	30 - 60°	2	
	60° or gentler	3	
The max. snow depth (30-year avg)	50 cm or greater	2	
	100 cm or greater	4	
	150 cm or greater	6	
	Total (D1)		

(2) Surrounding environment/road structure

Item	Criteria	Score	
Length of flat land on the windward side	With flat land	3	
	100 m or longer	6	
	300 m or longer	9	
Gradient of cut slope	1:3.0 or gentler	3	
	Total (D2)		

○ Safety factors

Item	Criteria	Score	
Windward woodland, rows of houses or built-up area	10 m or wider	4	
	30 m or wider	6	
Height of embankment	The max. snow depth X 1.3	3	
Roadside snow-piling space	Yes	3	
	Total (S1)		

D1 - S1

When D1-S1>0, (D1-S1)+D2

When D1-S1≦0, (D1-S1)

Pfb

Poor Visibility Factors

● Danger factors

(1) weather conditions

Item	Criteria	Score	
Snowstorm frequency Normal value	20 day or more/year	3	
	30 days or more/year	6	
	40 days or more/year	9	
Snowfall (The max. snow depth) Normal value	300 cm or less (80 cm or less)	3	
	300 cm or more (80 cm or more)	6	
	400 cm or more (140 cm or more)	9	
	Total (D1)		

(2) Surrounding environment/road structure

Item	Criteria	Score	
Site of abrupt topographic change (between cut and fill, along creek)	Small-scale or	2	
	Large-scale or	3	
Gradient of embankment slope	1: 2.0 or gentler	3	
Curve section (radius of curvature)	With a curve	1	
	200 m or less	2	
	100 m or less	3	
Tunnel portal, bridge ends, grade-separate crossings	With at least one of left items	3	
	Total (D2)		

○ Safety factors

Item	Criteria	Score	
Windward woodland, rows of houses or built-up area	Noncontinuous	2	
	10 m or wider	4	
	30 m or wider	6	
Median	Yes	3	
Road lighting	Yes	3	
	Total (S1)		

D1 - S1

When D1-S1>0, (D1-S1)+D2

When D1-S1≦0, D1-S1

Pfv

Pf

History

Item	Criteria	Score	
Instances of traffic suspension due to snowstorm	Once every few years	3	
	Once/year	9	
	A few times a year	15	
Instances of accidents due to poor visibility or the like	Once every few years	2	
	Once/year	6	
	A few times a year	10	
Traffic hindrance under management and maintenance operation	Once every few years	1	
	Once/year	3	
	A few times a year	5	
	Total (C1)		

P

EVALUATION

Rank	Overall score (when only factors are considered)	Evaluation
A	44 or higher (35 or higher)	High degree of snowstorm danger
B	21 - 43 (15 - 34)	Moderate degree of snowstorm danger
C	1 - 20 (1 - 14)	Attention to snowstorm danger required
D	0 or less (0 or less)	Snowstorm countermeasures not required

Figure 1 - Flowchart for degree of danger assessment

Figure 2 - Snowbreak woods: standard-width snowbreak woods (left); narrow-band woods (right)

Figure 3 - Snow fences: traditional collector snow fence (left); collector snow fence (center); blower snow fence (right)

Figure 4 - Snow-control by road structure modification: drift-free cut (left); drift-control embankment (center); gently sloped embankment (right)

Figure 5 - Delineation facilities: snow-pole (left); fixed-post delineator (right)

Figure 6 – Large-Scale Structure: Snow shelter

Table 1 - Selection criteria for blowing-snow control facilities (example of embankment)

Selection criteria / Major countermeasures					Road structure			Snowbreak woods		Snow fence			Delineation facilities	Large-scale structures
Cross-section	Snow-control purposes	Prevailing wind direction	Securing the right of way	Number of lanes	Gently sloped embankments	Drift-control embankments	Drift-free cuts	Standard-width woods	Narrow-band woods	Traditional collector snow fence	Collector snow fence	Blower snow fence		
Embankment	Snowdrift countermeasures	Perpendicular	Feasible	Two or more	Suitable	Suitable	N/A	Primary selection	Unsuitable	Suitable	Suitable	Unsuitable	Additional measure	Suitable
			Unfeasible	Two or more	Unsuitable	Primary selection	N/A	Unsuitable	Unsuitable	Unsuitable	Suitable	Unsuitable	Additional measure	
		Acute	Feasible	Two or more	Suitable	Suitable	N/A	Primary selection	Unsuitable	Suitable	Suitable	Unsuitable	Additional measure	
			Unfeasible	Two or more	Unsuitable	Primary selection	N/A	Unsuitable	Unsuitable	Unsuitable	Suitable	Unsuitable	Additional measure	
	Snowdrift and poor visibility countermeasures	Perpendicular	Feasible	Two or more	Suitable	Suitable	N/A	Primary selection	Unsuitable	Suitable	Suitable	Unsuitable	Additional measure	Suitable
			Unfeasible	Two or more	Unsuitable	Suitable	N/A	Unsuitable	Unsuitable	Unsuitable	Primary selection	Unsuitable	Additional measure	
		Acute	Feasible	Two or more	Suitable	Suitable	N/A	Primary selection	Unsuitable	Suitable	Suitable	Unsuitable	Additional measure	
			Unfeasible	Two or more	Unsuitable	Suitable	N/A	Unsuitable	Unsuitable	Unsuitable	Primary selection	Unsuitable	Additional measure	
	Poor visibility countermeasures	Perpendicular	Feasible	Multiple	Suitable	Suitable	N/A	Suitable	Primary selection	Suitable	Suitable	Unsuitable	Suitable	Suitable
				Two	Suitable	Suitable	N/A	Suitable	Primary selection	Suitable	Suitable	Suitable	Suitable	
			Unfeasible	Multiple	Unsuitable	Suitable	N/A	Unsuitable	Primary selection	Unsuitable	Suitable	Unsuitable	Suitable	
				Two	Unsuitable	Suitable	N/A	Unsuitable	Primary selection	Unsuitable	Suitable	Suitable	Suitable	
		Acute	Feasible	Two or more	Suitable	Suitable	N/A	Suitable	Primary selection	Suitable	Suitable	Unsuitable	Suitable	
			Unfeasible	Two or more	Unsuitable	Suitable	N/A	Unsuitable	Primary selection	Unsuitable	Suitable	Unsuitable	Suitable	

4. SNOWBREAK WOODS

Snowbreak woods are facilities in which trees are planted windward of, or on both sides of, the road to reduce the velocity of wind blowing onto the road and, thereby, to prevent snowdrifts from forming and to mitigate poor visibility. In 1977, the Hokkaido Development Bureau planted snowbreak woods on National Highway Route 12. This marked the beginning of highway snowbreak woods installation in Japan. As of 2012, snowbreak woods on national highways throughout Hokkaido had a combined extension length of about 80 km.

The *Snowbreak Woods* volume describes the woods' width and planting methods. Because it has been over 30 years since the first snowbreak woods were planted, issues of growth management have become apparent. Consequently, the third edition includes the methods for judging the growth of planted trees.

4.1 Basic structure of snowbreak woods

Snowbreak woods are classified into "standard-width woods" and "narrow-band woods" (Figure 2). Standard-width woods are used at road sections where the maximum volume of snow settled at snowdrifts is 20 m^3/m or greater. Standard-width woods are effective for both snowdrift-control and poor visibility improvement (Table 2). Narrow-band woods (woods width: 10 m or less) are used at sections that require measures to mitigate poor visibility and where the volume of snow settled at snowdrifts is less than 20 m^3/m. Figure 7 shows the basic structure of standard-width woods (20-m type).

Table 2 - Maximum Amount of Snow Settled at Snowdrifts, and Required Woods Width

Maximum amount of snow settled at snowdrifts (normal annual average)	Woods width necessary for snow-control	Standard woods width	Standard woods type
20～30 m^3/m	10 m	11.0 m	Standard-width woods (10-m type)
30～50 m^3/m	20 m	23.0 m	Standard-width woods (20-m type)
50 m^3/m～	30 m	32.0 m	Standard-width woods (30-m type)

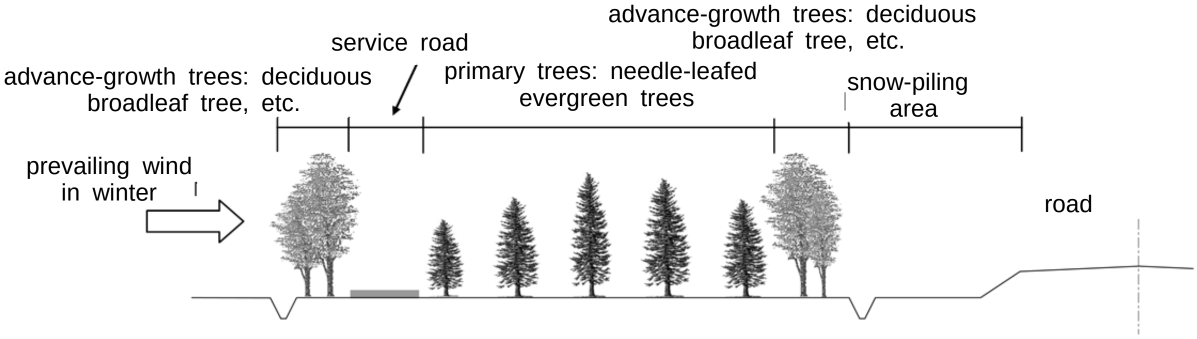


Figure 7 - Basic structure of standard-width snowbreak woods

Standard-width snowbreak woods consist of primary trees and advance-growth trees. Advance-growth trees help primary trees grow by protecting them from winds. In principle, needle-leaved evergreen trees are used for primary trees. Figure 8 shows the standard plan for arranging primary trees, with a row interval of 3.0 m and a tree planting interval of 2.0 m.

Advance-growth trees are planted linearly along the roadside and the opposite side of the band of primary trees. Generally, live willow stakes are used for advance-growth trees, because willows grow fast. In addition, service roads are constructed for the 20-m and 30-m types of standard-width woods.

Narrow-band woods are developed to mitigate poor visibility; the width of woods is less than 10 m (Figure 9). Narrow-band woods consist of primary trees only.

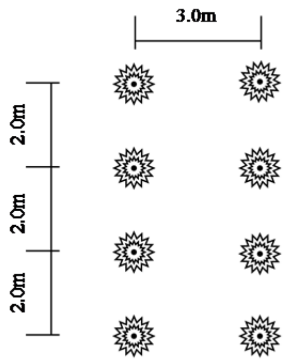


Figure 8 - Plan and arrangement of primary trees

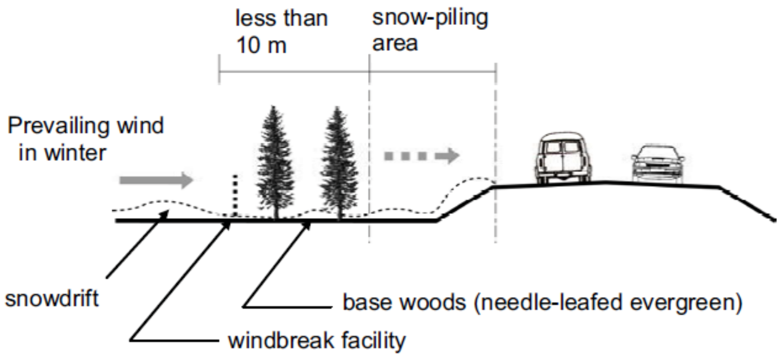
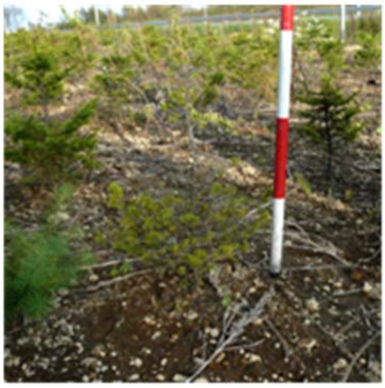


Figure 9 - Basic structure of narrow-band snowbreak woods

4.2 Simplified methods to assess the growth of planted trees

The growth of snowbreak woods needs to be checked and additional trees should be planted, if necessary. Because civil engineers do not have expertise in assessing the growth of trees, a table that facilitates the evaluation of snowbreak woods growth has been developed (Table 3). With this table, which contains photos and drawings, civil engineers are able to evaluate the growth of planted trees based on tree height growth by year and foliage conditions.

Table 3 - Evaluation of growth of snowbreak woods (excerpt from the Manual)

Growth rank	Evaluation	Schematic	Photo
Rank 3 - Growth increase in a year: a few centimeters - Blighted apical or lateral buds on the top?: Yes - Blighted lateral buds on the upper part?: Yes - New leaves?: Yes - Branch on the upper part of the tree has become a main trunk?: Yes - Leaf color: Light green or light brown	- The conditions shows either trees maybe recovering from transplanting damage, or may be experience hindered growth due to other factors. - Measures may be necessary if the leaf color or amount of foliage does not improve.		
Rank 4 - Growth increase in a year: 0 cm - Blighted apical or lateral bud on the top?: Yes - Blighted lateral buds on the upper part?: Yes - New leaves?: No - Branch on the upper part of the tree has become a main trunk?: No. - Leaf color: Light green or light brown	- Blight is regarded as inevitable. In principle, the trees should be replaced.		

5. SNOW FENCES

5.1 Types of snow fences

A traditional collector snow fence has a few fins installed in a space between two posts and has a gap between the ground and the bottom fin (bottom clearance) (Figure 3, left). The traditional collector snow fence is installed to reduce the wind velocity and to cause blowing snow to deposit in front of and behind the fence, so as to prevent suspended snow particles from blowing onto the road and snowdrifts from forming on the road. The installation location of the traditional collector snow fence (distance from the road) is determined by the length of the lee drift, L (m), immediately leeward of the fence (Figure 10). L is given by an empirical equation (Equation (1)). The fence height is given by Figure 11 using the maximum snow depth and the maximum volume of snow settled in snowdrifts at the site.

$$L=(9+0.46P)(H-Hs) \quad \cdots(1)$$

where, P:Void Ratio(%), H:Fence height (m), Hs: Average Maximum Snow depth(m)

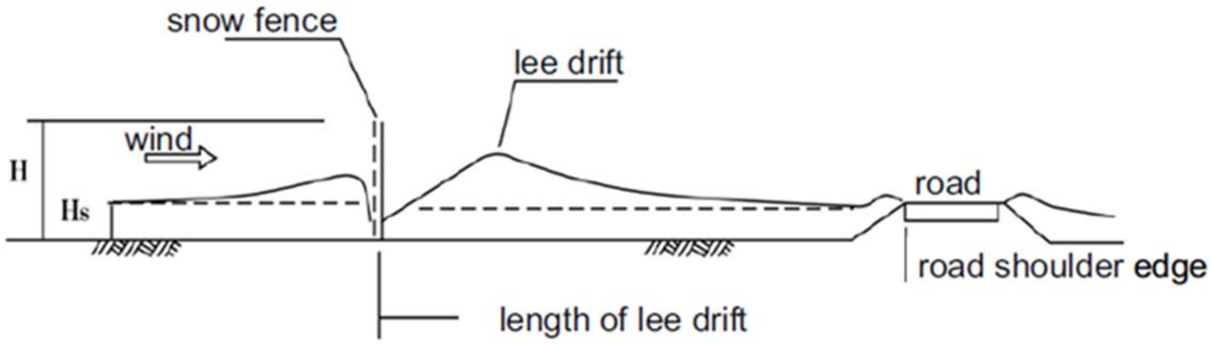


Figure 10 - Length of lee drift for a traditional collector snow fence

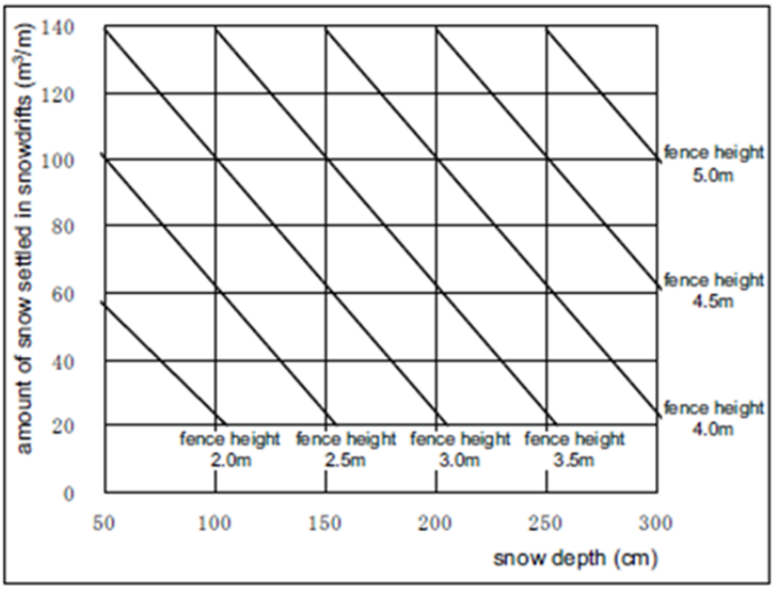


Figure 11 - Height of traditional collector snow fence (void ratio: 25%)

Collector snow fences (Figure 3, center) were developed as a blowing-snow control measure for multi-lane highways. Compared with traditional collector snow fences, they have a greater fence height, a lower void ratio and no bottom clearance. Figure 12 shows the snowdrifts and wind conditions around a collector snow fence. Collector snow fences are typically 5 m high and are installed at 6.5 to 10 m from the road edge.

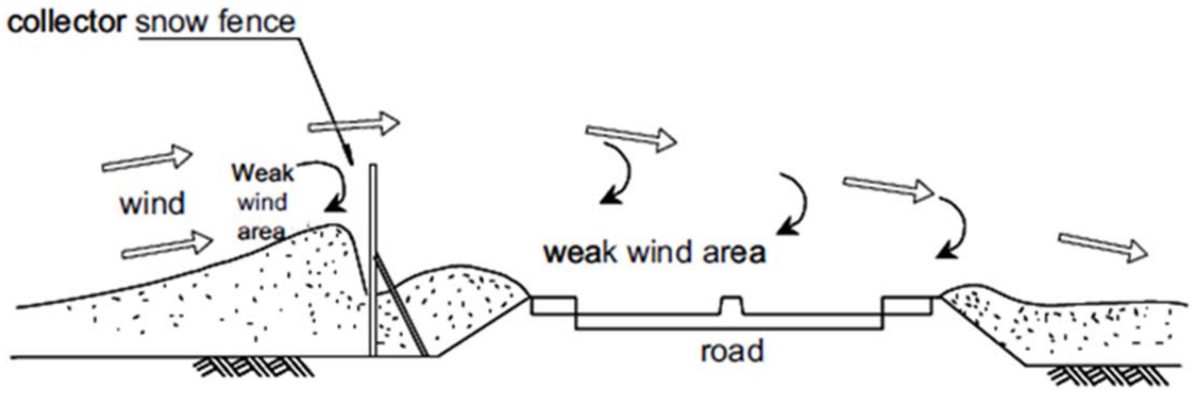


Figure 12 - Snowdrifts and wind conditions around a collector snow fence

A blower snow fence (Figure 3, right) has a bottom clearance of 1 m and a few inclined fins. Blower snow fences prevent poor visibility by directing the flow of drifting snow particles away from the eye-height of drivers. They prevent snowdrifts from forming on the road by blowing snow away, because the fences accelerate the wind near road surface. The fence height is typically 3.5 m. A blower snow fence is capable of blowing away snow for a distance twice as great as the fence height. This is why blower snow fences can be installed only on two-lane roads. When the bottom clearance is filled with snow, the blower effect declines and snowdrifts may form on the road. It is essential to secure the bottom clearance.

In addition to these three types of snow fences, a solid barrier has been developed to prevent snowdrifts and to mitigate visibility hindrance caused by winds that blow up slopes in mountainous regions (Figure 13).

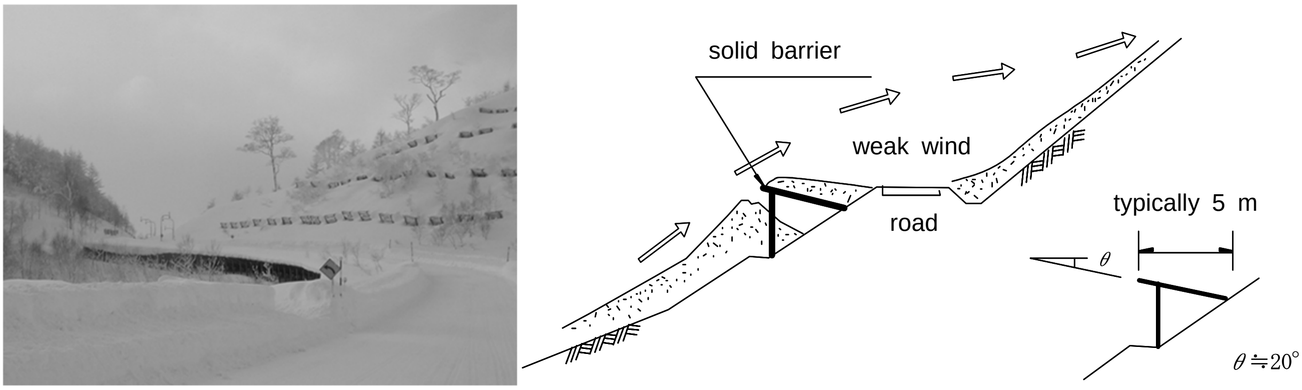


Figure 13 - Solid barrier

5.2 Selecting the appropriate type of snow fence

The *Snow Fences* volume includes a table that gives more detailed selection conditions than the *General Guide* (Table 1). Table 4 is the table from the *Snow Fences* volume. It gives detailed information on the applicability of various snow fences according to the weather conditions.

Table 4 - Applicability of Various Snow Fences according to the Weather Conditions

Weather conditions		Traditional collector snow fence	Collector snow fence	Blower snow fence	Solid barrier
Max. snow depth	Less than 100 cm	Suitable	Suitable	Suitable	Suitable
	100 ~ 150 cm	Suitable	Suitable	CEN*	Suitable
	150 cm or higher	Suitable	Suitable	Unsuitable	Suitable
Wind velocity during snowstorm	Stable and strong	Suitable	Suitable	Suitable	Suitable
	Weak	CEN*	Suitable	Unsuitable	Suitable
Incident angle of prevailing wind	Nearly perpendicular	Suitable	Suitable	Suitable	Suitable
	About 45 degrees	CEN*	Suitable	CEN*	CEN*
	Nearly parallel	Unsuitable	CEN*	Unsuitable	CEN*
	Not constant	CEN*	CEN*	Unsuitable	CEN*
Volume of snow settled at snowdrifts	Less than 40 m^3/m	Suitable	Suitable	Suitable	Suitable
	40 ~ 60 m^3/m	Suitable	Suitable	CEN*	Suitable
	60 m^3/m or more	Suitable	CEN*	Unsuitable	CEN*

(Type of snow fence: Traditional collector snow fence, Collector snow fence, Blower snow fence, Solid barrier)

CEN*: Careful examination needed

6. OTHER BLOWING-SNOW CONTROL FACILITIES

Other blowing-snow control facilities include drift-control embankments and other modified road structures, and delineation facilities.

6.1 Modification of road structures against blowing snow

Snow-control measures by road structure modification include drift-free cuts, drift-control embankments, and gently sloped embankments (Figure 4)

6.1.1 Drift-free cuts

Providing a gradient flatter than 1:3 (gradient: 16.7 degrees) on the slope that lies windward the prevailing wind direction of the road, the drift-free cut mitigates poor visibility and prevents snowdrifts from forming on roads at cut sections. The drift-free cut creates stable snow cornices or snowdrifts on the cut slope, because snow particles carried by the wind settle there.

6.1.2 Drift-control embankments

The embankment height for this type is 1.3 times the average maximum snow depth. Drift-control embankments mitigate the height growth of roadside snow piles and, thus, mitigate poor visibility and snowdrifts on roads caused by windborne snow particles originating from the snow piles.

6.1.3 Gently sloped embankments

The embankment slope of this type is gentler than 1:4 (gradient: 14.0 degrees). It is expected to prevent snowdrifts from forming on roads by reducing the turbulence of wind above the road and to prevent snow particles from being carried by wind because gentle slope embankments eliminate the need for guardrails and, thus, keep the snow pile height at the roadside lower than it would be with guardrails.

6.2 Delineation facilities against snowstorms

Delineation facilities improve drivers' visibility of the road alignment, locations of the roadside and road markings ahead at night and under poor visibility conditions (Figure 5). These facilities do not control snow; they are used only to improve visibility. Delineation facilities are of the following types.
(1) Fixed-post delineators
(2) Light-emitting fixed-post delineators
(3) Snow poles
(4) Light-emitting snow poles
(5) Visual guidance trees
Light-emitting delineation facilities, equipped with LEDs or the like, are adopted in regions that experience heavy snowstorms.

7. CONCLUSION

The *Manual* has been available to the public at the CERI website since March 2013[1)]. The English version of the abridged edition[2)] is also available on the website.

ACKNOWLEDGEMENTS

We would like to extend our cordial appreciation for the efforts and advice provided by the members of the Snowstorm Countermeasures Technology Investigative Committee and officials of the Hokkaido Regional Development Bureau and other relevant organizations, and those who helped us to revise the *Manual*.

REFERENCES

1. The Highway Snowstorm Countermeasure Manual (Revised Edition 2011), Civil Engineering Research Institute of Hokkaido - the Public Works Research Institute (Independent Administrative Agency), March 2011 (in Japanese) (http://www2.ceri.go.jp/fubuki_manual/)
2. Civil Engineering Research Institute for Cold Region: The Highway Snowstorm Countermeasure Manual (Abridged Edition), 2011. (http://www2.ceri.go.jp/fubuki_manual/index_e.html)