On the construction of snow fences

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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/20331399
Technical Translation (National Research Council of Canada); no. NRC-TT-1103, 1963

PREFACE

Snowdrifts can be a major source of disruption in the operation of transportation services and a general nuisance in the normal wintertime activity of a community. Such drifts are formed whenever a wind, strong enough to transport horizontally a significant amount of snow, encounters an obstacle which forces it to deposit some of this snow. The usual approach taken in defending an area or structure against snowdrifting has been to locate the structure properly so that the drift problem will be a minimum and to erect obstacles, such as snow fences, to control where the snow will be deposited. The approach taken in the development of these defences has been largely empirical. Attention has been directed primarily to the character of the air flow with little attention being given to the material transported. In some circumstances, it would be an advantage to have a more complete defence against snowdrifting than is now available. In their attempts to develop this defence, engineers are giving more consideration to the theoretical aspects of the problem and in particular to the relationships between the air flow and the snow being transported.

It is one of the responsibilities of the Snow and Ice Section of the Division of Building Research to collect and make available information required for the solution of snow and ice problems. The present paper, translated from the Russian, is a contribution to the theory of snowdrifting. This paper will give to the reader an appreciation of some of the factors to be considered in the theoretical description of blowing snow and its deposition as snowdrifts.

The paper was translated by Mr. G. Belkov of the Translations Section of the National Research Council Library, to whom the Division of Building Research wishes to record its thanks.

Ottawa
November 1963

R.F. Legget
Director

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1103

Title:	On the construction of snow fences (O konstruktsii snegovykh shchitov)
Authors:	A.K. Dyunin and A.A. Komarov
Reference:	Trudy Transportno-Energeticheskogo Instituta, (4): 111-118, 1954
Translator:	G. Belkov, Translations Section, N.R.C. Library

ON THE CONSTRUCTION OF SNOW FENCES

Summary

This report notes the defects of existing snow fences and a sound argument is presented for improving the construction of fences with reduced density of the lower part and which do not have to be moved so often.

Movable fences are widely used on railroads in the Soviet Union and particularly on the roads of Western Siberia where more than 50% of the total places subject to drifts are protected by them[1,2,5]. Therefore the question of improving the construction of existing movable fences is of great importance.

Snow fences were invented 90 years ago by the Russian engineer, V.A. Titov. Attempts by a number of specialists to make improved types of fences were unsuccessful and the construction of standard fences at the present time does not differ essentially from those which were used in the seventies of the last century.

One of the defects of standard fences (Fig. 1) is their small snow-gathering ability before they are moved for the first time, being 25 - 30 m^3/pm* when the wind is perpendicular to the fence. A great defect of lattice-type fences is that they are unreliable for protecting roads from snowdrifts. During strong winds the fences are filled in during one or two blizzards and sometimes even after several hours, which constitutes a danger for roads where continuous traffic is required. The moving of fence lines during a blizzard is exceedingly difficult and sometimes impossible.

The rapid filling in of the fence is explained by the fact that the peak of the steep snow wall formed behind the fence line is in direct proximity to the fence (Fig. 2).

In order to prolong the time taken to fill in the fence one has to "move" the snow wall away from the fence line. On the basis of simple theoretical considerations one can easily formulate conditions which would fulfill this requirement.

For solving the problem posed we use the formula found by means of dimensional analysis for determining the weight of snow flux in a unit of

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Translator's note:

* m^3/pm - metres cubed per running metre.

time over a unit of front length of the fence:*

$$Q = \psi (v_1 - v')^3 \ g/m \ sec, \quad (1)$$

where ψ - the coefficient which is, generally speaking, variable. For average, most probable conditions, it can be considered constant and equal to 0.255 $\frac{g \cdot sec^2}{m}$.

v_1 - the averaged translational velocity of the wind at the height of 1 m in m/sec.

v' - critical velocity in m/sec at a height of 1 m which for loose snow blown by the wind is equal to 2.71 m/sec.

The main factor influencing the magnitude of the snow flux is the longitudinal surface velocity of the wind. Therefore the main characteristics of a snow fence must be considered to be the curve of reduction in surface wind velocity in the area where the fence is effective. Such a curve for any new construction of a snow fence can be obtained from simple field wind measurements or by using an appropriate model in a wind tunnel. In analyzing these curves one should be governed by specific conditions. For the first let us consider the conditions related to the ability of the fence to resist being filled in.

If the field velocity of the wind in front of the fence is equal to w and behind the fence to v, in the area protected by the fence for each unit of time and for each unit of width of the fence, according to formula (1), the following amount of snow will be deposited (under the same initial conditions):

$$\Delta Q = \psi \left[(w - v')^3 - [v - v')^3 \right]. \quad (2)$$

If one knows the equation of the curve showing reduction in wind velocity $v = f(l)$, where l is a length plotted from an arbitrary point on the surface of the ground parallel to the wind, one can readily determine the increase in the height of the snow deposit Δh for a unit of time at any point of the area protected by the fence:

$$\Delta h = \frac{1}{\sigma} \left| \frac{d \Delta Q}{dl} \right| = - \frac{3\psi}{\sigma} (v - v')^2 \cdot \frac{dv}{dl},$$

where σ is the density of the snow deposit in g/m³.

The location of the maximum accretion of snow of the initial snow deposit, i.e. the location of the peak of the snow wall formed at the beginning of snow drifting, can be determined from the equation:

$$\frac{d\Delta h}{dl} = - \frac{3\psi}{\sigma} (v - v') \left[2 \left(\frac{dv}{dl} \right)^2 + (v - v') \frac{d^2 b}{dl} \right] = 0$$

* See paper by A.K. Dyunin "Solid flux of snow-bearing air flow" (NRC TT-1102).

hence

$$\frac{d^2v}{dl^2} = -\frac{2\left(\frac{dv}{dl}\right)^2}{v-v^1}. \qquad (3)$$

The case v - v' = 0 corresponds to the minimum Δh since when v = v' snow transfer is equal to 0 according to the definition of the critical velocity v'.

At the point of the maximum of Δh, v should always be greater than v'. Consequently the second derivative of v over l is essentially a negative value. Therefore the peak of the snow wall would correspond to the convex part of the curve representing the decrease in velocity from the point of initial decrease to the point of its inflexion which is approximately at a distance of 2 metres from a standard fence (Fig. 3). In fact the peak of the snow wall forms somewhat further from the fence (Fig. 2), which apparently is explained by a number of other factors not taken into account by formula (3).

Hence it follows that with a more gentle slope of the curve representing decrease in wind velocity, the wall forms farther from the fence. This is the fundamental condition in designing snow fences that will not be filled in.

The second condition involves the greatest possible decrease in wind velocity beyond the fence. Let v in formula (2) correspond to the point of maximum decrease in velocity. Let us determine the value of v from the condition of maximum initial snow deposition,

$$\frac{d\Delta Q}{dv} = -3\psi(v-v^1)^2 = 0$$

hence

$$v = v_{min} = v'.$$

The upper limit of the minimum possible velocity is defined by what percentage of snow transferred beyond the limits of the zone affected by the fence should be considered insignificant. Usually in engineering calculations errors of the order of 5% are neglected. Thus if one considers a snow fence that decreases snow flux by at least the factor of 20 to be efficient, to define the upper limit of v_{min} we have the inequality following from formula (1):

$$\frac{(v_{min}-v')^3}{(w-v')^3} \leqslant 0.05$$

hence

$$v_{min} \leqslant 0.3684w + 0.6316v'.$$

Assuming $v' = 2.71$ m/sec we will have

$$v_{min} \leqslant 0.3684\, w + 1.71.$$

Table I gives the ratio of $\frac{v_{min}}{w}$ at various values of wind velocity w.

Assume that the average $v_{min} < 0.5$ w. Combining this condition with the one obtained earlier $v_{min} = v'$, we will have for the definition of the minimum velocity of the surface wind beyond the fence the following inequality

$$v' \leqslant v_{min} < 0.5w. \qquad (4)$$

This is the second condition in designing an efficient snow fence.

In this paper we will restrict the discussion to these two conditions which are common to all types of fences. As can be seen from Fig. 3, in using normal standard fences only the second condition is observed, and v_{min} is equal to 30 - 35% of the field velocity, i.e. considerably less than 0.5 w.

The curve of the surface velocities rises sharply at the fence line and as a result the peak of the initial snow deposition is too close to the fence and the fence is quickly filled in (see Fig. 2).

Interesting suggestions published recently by the Snow Control Laboratory of TsNII MPS and by P.I. Sarsatskikh, research worker at DorNII (ref. 1,2,6) indicate a way of meeting the second condition.

The Snow Control Laboratory of TsNII suggested raising a normal fence by a height of 0.5 m above the surface of the ground. This measure greatly increases the kinetic energy of the surface stratum of wind directly beyond the fence and consequently results in flattening of the curve of reduction in velocity. On the basis of experiments in placing models of elevated fences in a wind tunnel at the Transport-Power Institute of the West Siberian Filial of the Academy of Sciences it has been established that the second condition is satisfied if the fence is raised by not more than 0.5 m. Thus the suggestion of TsNII fully corresponds with the conditions of designing snow fences which explains the good results of field experiments(2).

Experimental observations carried out by us on the Tomsk Railroad showed that the recommendations of TsNII justified themselves completely. However, the elevation of the fence has an effect only up to the time of the first movement of the fence after which it is taken off the posts and subsequently operates as a standard fence. To retain the effect of an elevated fence in a heavily drifting region can only be done with high posts which would permit a gradual lifting of the fence as it is being filled in, always leaving an open space underneath.

From the same considerations one can alter the construction of the fence by decreasing the density of its lower part.

This was the approach taken by engineer P.I. Saratskikh who suggested a fence for protecting automobile roads with horizontal slats and variable density which increases with height. But this type of fence has not been widely used because it is not stable and frequently the horizontal slats break, particularly the lower slats, when they are being removed from the snow(4).

We suggest a different construction of fence with vertical slats and decreased density of the lower part (Fig. 4).

The suggested fence differs from the standard in that every second vertical slat is cut off in the middle and the lower ends are fastened to two additional horizontal slats 1 m in length.

Models of such fences were tested in wind tunnels and it was established that the curve representing the decrease in velocity has a more gentle slope in comparison with the curve for a standard fence. Here the minimum surface velocity beyond the fence does not exceed 45 - 48% of the open field velocity (Fig. 3), i.e. inequality (4) is fulfilled.

During the winter of 1952-53 in an experimental portion of the Tomsk Railroad observations were carried out on the operation of the fences. On an open area perpendicular to the direction of the prevailing wind two lines of fence were set up - one being a standard fence and the second having reduced density in the lower part. The results of observations are shown in Fig. 5 and Table II.

The fences were set up in the middle of December 1952 and were not moved till the end of winter. The wind velocity reached 12 - 13 m/sec at a height of 1 m.

As can be seen from Fig. 5 and Table II the volume of snow deposited beyond both types of fences was approximately the same but their operation was quite different. Whereas with a normal fence in January of 1953 more than a third of the height was filled in and required immediate moving of the fence, the fence with the reduced density in the lower part was not filled in by the end of winter. The peak of the snow wall was more than twice as far from the fence as that of the standard fence and the total snow deposit reached 94 m^3/pm without it being necessary to move the fence.

In addition to the volume of snow deposited and the manner in which the fence is filled in, there is some interest also in the question of the amount of snow transferred beyond the limits affected by the fence. Special blizzard metering observations were carried out at a distance of 17 and 27 m from the fence line and it was established that the flux of snow beyond the fence was decreased on the average by a factor of 20 for both types of fences.

In order to find the amount of snow transferred beyond the area affected by the fence during the formation of the snow wall on March 10, 1953, a control line consisting of standard fence was set up along side the line of new fence. It was found that by March 25 the control fence collected 25 m^3 of snow per pm which is approximately equal to the difference between the snow deposition on March 25 and March 10 behind the experimental snow fence lines. Consequently the amount of snow transferred beyond the zone affected by the fence did not vary essentially towards the end of winter by comparison with the initial period of operation of the fence.

The fence design with decreased density in the lower part and consisting of vertical slats is much stronger and more stable than that suggested by P.I. Sarsatskikh, however they are not as strong in their resistance to bending along the vertical plane as the standard fence. Let us determine the maximum wind velocities at the surface at which one can use the new type of fence without reinforcement.

For calculating the normal force component of the wind we used the formula of A.A. Bogorodetskii[3], which takes into account the shock effect of the wind,

$$N = [1.25 + 0.6(1 - k)]\, F_{\kappa} \cdot \frac{\rho v^2}{2}\ kg, \tag{9}$$

where k - coefficient of the density of the fence contour which in our case was taken to be 0.5 for the upper half of the fence and 0.25 for the lower half;

F - total area of the fence considering its outer contour;

ρ - mass density of the air $\frac{0.37\ \text{kg sec}^2}{\text{m}^4}$

when T = -10°C and atmospheric pressure is 750 mm;

v - mean wind velocity which to retain a safety factor we assumed to be equal along the entire contour and being equal to the mean velocity at the height of 1 m.

The resistance moment of the fence is

$$w = n\frac{bh^2}{6},$$

where n is the number of lower vertical slats, b and h are the width and thickness of the slats.

The moment arms are determined from the location of centres of gravity of the upper and lower halves of the fence (1.5 m and 0.5 m) without taking into account the depth to which the fence is immersed in the snow.

Let us assume n = 7, b = 0.07 m and h = 0.015 m.

Then the maximum normal bending stress for the lower part of each vertical slat running the full height of the fence will be

$$\sigma = \frac{2 \cdot 0.0685v^2 \{[1.25 + 0.6(1-0.5)] \cdot 0.5 \cdot 1.5 + [1.25 + 0.6(1-0.25)] \cdot 0.25 \cdot 0.5\}}{\frac{7 \cdot 0.07 \cdot 0.015^2}{6} 10^4} \cong$$

$$\cong 1.01v^2\ kg/cm^2.$$

A similar calculation for a standard fence gives

$$\sigma = 0{,}62v^2\ kg/cm^2.$$

Consequently a fence with reduced density in the lower part is weaker than a standard fence by 39%.

The maximum permissible wind velocity with the permissible bending stress for pine of 120 kg/cm² is,

$$v_{max} \simeq \sqrt{\frac{120}{1.01}} \simeq 11 \ m/sec.$$

For a standard fence it is

$$v_{max} = \sqrt{\frac{120}{0.62}} \cong 14 \ m/sec.$$

When the wind velocity is greater than 11 m/sec the fences must be either reinforced by diagonal members, as we did in the experimental section, or strengthened by attaching two additional slats to the two outer vertical slats up to 2/3 of their height.

In the winter of 1953-54 two methods of snow control using the new type of fence will be tested on a portion of the Tomsk's railroad:

1. Movement of the fence when it has been filled in up to the top of the snow wall and using a reinforced construction.

2. Raising the fence on posts as the snow wall grows. In this case additional reinforcement of the fence will not be required.

During the test it is intended also to establish the best distance of the fence from the road being protected and to elucidate the function of the new fence when the wind is blowing at an angle.

Results

The suggestion of the All-Union Research Institute of Railroad Transport and the Transport-Power Institute of the West Siberian Filial of the Academy of Sciences USSR for improving the operation of snow fences greatly decreases the number of times the fence has to be moved in areas subject to extensive drifting.

The fence recommended by the Transport-Power Institute provides some economy in material and makes it possible to use lumber mill waste products extensively.

The use of fences with improved snow control properties can reduce the total expense of snow control and also facilitate continuous operation of railroads through the winter, which is particularly important for railroads of the Ural and West Siberian regions.

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Table I

Open field velocity w m/sec at the height of 1 m	$\frac{v_{min}}{w}$
10	0.539
12	0.510
14	0.49
16	0.475
18	0.463
Average	0.495

Table II

Type of fence	Volume of snow deposit at fences in m^3/pm on the following dates				
	27/XII-52	16/I-53	21/I-53	10/III-53	25/III-53
Standard	23	41	56	65	95
	Transfer of fence required				
With reduced density in lower part	24	42	59	66	94

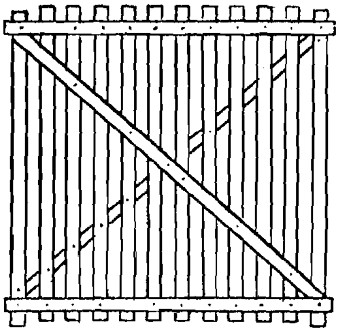


Fig. 1

Normal fence

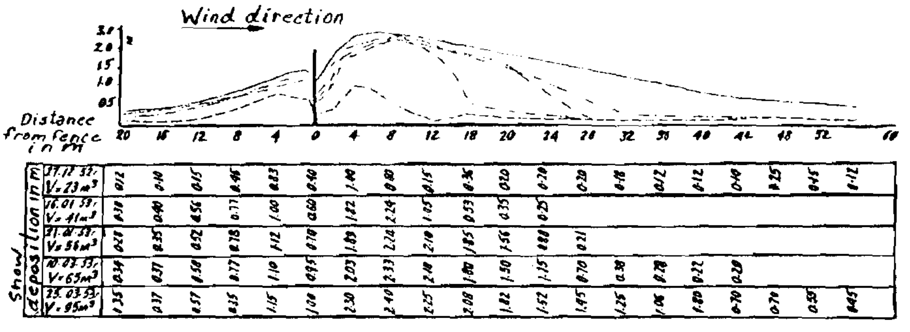


Fig. 2

Snow deposition at a normal fence

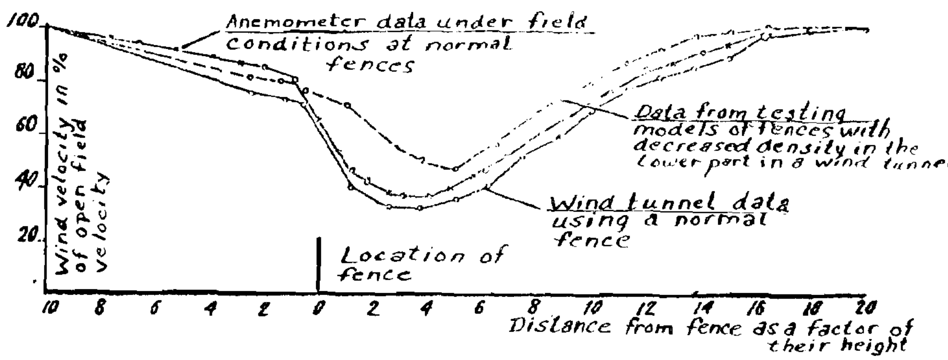


Fig. 3

Curves showing wind velocities from wind tunnel data and anemometer measurements

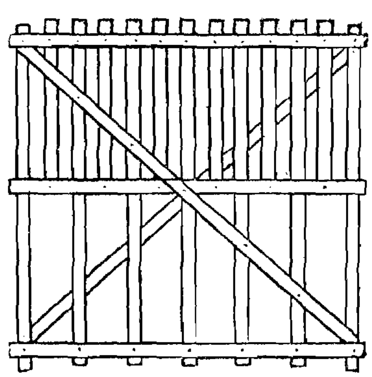
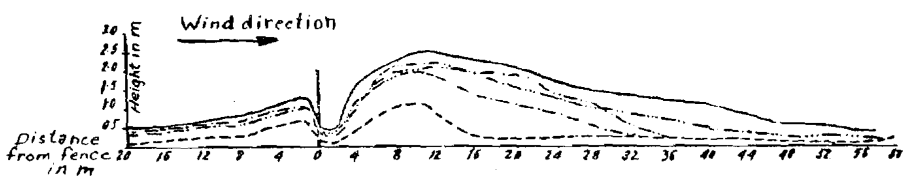


Fig. 4

Fence with reduced density in the lower part



Snow deposit	20	16	12	8	4	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56
27 12 52г. V=24м³	0.16	0.17	0.28	0.29	0.53	0.31	0.45	1.00	0.73	0.24	0.16	0.23	0.28	0.22	0.20	0.18	0.14	0.10	0.10	0.10
16 01 53г. V=45м³	0.35	0.41	0.54	0.64	0.92	0.40	1.07	1.95	1.81	1.35	1.08	0.87	0.50	0.25						
21 01 53г. V=58м³	0.32	0.43	0.52	0.59	0.89	0.40	1.07	2.08	2.12	1.95	1.85	1.39	1.12	0.52	0.20					
18 03 53г. V=66м³	0.40	0.50	0.55	0.55	0.74	0.40	1.22	1.87	2.06	1.93	1.55	1.20	1.03	0.88	0.70	0.45	0.35	0.22	0.35	0.25
20 03 53г. V=94м³	0.40	0.50	0.54	0.83	1.10	0.36	1.70	2.14	2.50	2.33	2.10	1.79	1.47	1.34	1.18	1.15	0.35	0.50	0.57	0.40

Fig. 5

Snow deposit at fences with reduced
density in the lower part