Some rules on the migration and deposition of snow in Western Siberia and their application to control measures

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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 a barrier 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 barriers, 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 encountered in engineering practice. The Division is pleased to offer to Canadian engineers the information contained in this technical translation on observations made on drifting snow in Siberia, and its application to snow fence design. This report is the fourth on Russian investigations on snowdrifting that has been published in the National Research Council Technical Translation series. The other three are: "Vertical Distribution of Solid Flux in a Snow-Wind Flow", by A.K. Dyunin, "Fundamentals of the Theory of Snowdrifting", by A.K. Dyunin and "On the Construction of Snow Fences", by A.K. Dyunin and A.A. Komarov.

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Robert F. Legget
Director

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Title:	Some rules on the migration and deposition of snow in western Siberia and their application to control measures (Nektorye zakonomernosti perenosa i otlozheniya snega v raionakh Zapadnoi Sibiri i ikh ispol'zovanie v snegozaderzhanii i snegobor'be)
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SOME RULES ON THE MIGRATION AND DEPOSITION OF SNOW IN WESTERN SIBERIA AND THEIR APPLICATION TO CONTROL MEASURES

This paper gives the results of experimental investigations on the transfer and deposition of snow at barrier and methods are suggested for increasing the efficiency of snow control measures.

The study of transfer and deposition of snow near barriers is of great importance in perfecting existing control methods and finding new ones. Knowledge of the laws governing transfer and deposition of snow should help in making a sound choice of the type and size of snow fences and also to arrange them in the proper way depending on various factors. Moreover, knowing the physics of the transfer and deposition processes should help fundamentally in solving problems of retaining snow on adjacent fields which is a fundamental part of the problem of combatting snowdrifting.

It should be noted that up to the present time the control of snowdrifting has frequently been approached from a rather narrow scientific point of view. Research workers of the Automobile and Railroad Transport Industries, who study problems of combatting snowdrifting, do not take into account agricultural requirements whereas research workers of agricultural institutes in their design of means of retaining snow do not take into account the interests of automobile and railroad transport. This difference of approach in solving such closely connected problems do not give positive results and do not correspond to the principles of our socialist economy.

In 1953, Professor G.D. Rikhter, Doctor of Geographical Sciences, advanced the idea of a complex solution to the problem of snowdrifting control[6]. The essence of his method is that the control of snowdrifting at railroad tracks and automobile roads should be done at some distance from the roads, mainly in the adjacent territories. In fact, snow transferred to railroad and automobile roads is not only useless but frequently is harmful, since on melting the water may have a deleterious effect on the earth fill or base of the road. At the same time snow retained on adjacent fields could help to improve agricultural crops.

In developing the idea of Professor G.D. Rikhter this report makes an attempt to elucidate some rules on the transfer and the deposition of snow in regions of western Siberia and to suggest some measures towards improving the efficiency in combatting the transfer of snow.

The first investigations on the nature of snow transfer were carried out in 1913 by the well-known Russian engineer N.E. Dolgov. He established that snow transfer begins when wind velocity at the height of the weather vane exceeds 8 m/sec. N.E. Dolgov drew the important conclusion that most of the snow is transferred in the lower stratum of the snow-wind flux at the height of 10 - 20 cm(1). Later in 1930 - 1934 observations on the migration of snow were carried out by the Vodenyapinskaya Snegozashchitnaya Stantsiya TsNII MPS Central Research Institute of the Ministry of Transport(3).

As a result of the work of this station during the course of two winters it was established that most of the snow (up to 95%) is transferred in the lower stratum of the atmosphere at the height of not more than 20 cm above the surface of the ground (Table I).

Observations of the Vodenyapino Station also showed that between the total quantity of snow which is transferred in a two-metre layer of air and that transferred at the surface, there is a stable relationship from which one can determine the total quantity of snow transferred in the two-metre layer by measurements at the surface. This relationship can be expressed by the following formula

$$q = a \cdot i \qquad (1)$$

where q is the total snow flux in a layer 200 cm high in g/cm per minute;

i is the snow flux at the height of 1 cm in g/cm^2 per minute;

a is the experimental coefficient which varies from 4.8 to 5.0 (mean 4.9).

Since 1948 experimental investigations on snow transfer were carried out by the Central Research Institute of Railroad Transport Industry(5). On the basis of these investigations the following relationship was established between wind velocity and the amount of snow transferred per unit time:

$$q = CV^3$$

where q is the total snow flux in a layer 2 m high in g/cm per minute

V is the wind velocity in m/sec measured at the height of 11 m

C is a coefficient equal to 0.0129.

The formula of D.M. Mel'ink, derived from the assumption that q is proportional to the force of the wind, was checked with many examples. At the present time it can be considered established that the flux of the snow-wind current depends on wind velocity not less than to the third order of magnitude.

The processing of blizzard metring observations of the Transport-Power Institute of the West Siberian Division of the Academy of Sciences USSR, using the method of least squares, showed that the total snow flux over an unlimited area is expressed by the following empirical formula

$$q = 0.0065V^{3,5} - 0.4 \qquad (3)$$

q is the total snow flux in a layer 2 m in g/cm per min (without taking into account blizzard metring errors)*

V is the wind velocity in m/sec measured at the height of 1 metre.

The results of blizzard metring observations are shown in Fig. 1.

To elucidate the relationship between the amount of snow transferred and various factors, during the course of two winters we carried out blizzard metring observations under varying conditions. Observations showed that the snow flux depends not only on wind velocity but on a number of other initial conditions, the chief of which is the size of the snow-collecting area and the nature of the adjacent locality.

From experience in combatting snowdrifts it is known that where there are open fields in front of snow fences one observes the greatest amount of snowdrifting. On the other hand, where there is vegetation snowdrifting may be much less. However, up to the present time it has not been established what should be the minimum snow-gathering area necessary to produce a maximum snow deposition at the barrier. It is usually considered that in an open place snow is transferred over considerable distances covering tens of kilometres but in fact, as will be shown below, the distance over which snow is transferred is limited.

P.I. Sarsatskikh considers that the distance over which snow is transferred for the south-eastern regions is approximately 1.0 km(4). To support this view he gives the following computation: the volume of snow retained by barriers on a level plain is equal to 180 m^3/pm**. The quantity of snow transferred by the wind is taken to be 80% of the total quantity of snow fallen. Knowing the thickness of the snow cover one can readily calculate the distance over which snow has been transferred which, for conditions of the European part of the USSR, according to P.I. Sarsatskikh, does not exceed 1.0 km. The method of Sarsatskikh for determining the dimensions of the

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* Concerning errors in blizzard metring and the derivation of a general theoretical formula for the motion of solid particles in a fluid flow, see the paper by A.K. Dyunin, Vertical distribution of solid flux in a snow-wind flow, Trudy Transportno-Energeticheskogo Instituta, (4): 49-58, 1954. (NRC TT-999).

** Translator's Note: m^3/pm - metres cubed per linear metre.

snow-gathering area is not without defects. The main defect is that the density of the snow at the barriers and in the open field is taken to be equal, whereas it is different.

The dimensions of the snow-collecting area can be defined more fundamentally in the following way. Let us suppose the total quantity of snow deposited at the barrier during the winter to be equal to Q_1. The snow is deposited at the barrier as a result of being transferred from the adjacent snow-collecting area. The quantity of snow can be determined by the formula

$$Q_2 = \frac{i}{1000} L\Theta$$

where Q_2 is the quantity of snow transferred throughout the winter from the adjacent snow-collecting area in kg/m;

- i is the quantity of precipitation during the winter in mm;
- L is the distance over which the snow has been transferred in m;
- Θ coefficient of snow transfer equal to the ratio of the quantity of transferred snow to the quantity of snow fallen.

From the equation $Q_1 = Q_2$ we obtain

$$L = \frac{Q_1 \cdot 1000}{i\Theta} \text{ m.} \tag{5}$$

In the formula (5) the magnitude Q_1 is expressed in kilograms of water per 1 pm of barrier. In practice, the volume of snow lying at the barrier (V) is expressed in m^3/pm (cubic metres per running metre); here $Q_1 = \delta$, where δ is the density of snow in t/m^3.

Substituting in formula (5) the quantity of snow expressed in m^3/pm we obtain

$$L = \frac{v\delta \cdot 1000}{i\Theta}. \tag{6}$$

Taking the average snowfall from the data of adjacent meteorological stations, the volume of snow measured at the snow fences, the coefficient of snow transfer $\Theta = 0.7$ and the density of snow $\delta = 0.35$, we obtain with formula (6) the following value for the length of the portion over which the snow was transferred for some regions of western Siberia (Table II).

Thus the length of the portion over which the snow is transferred is not limitless and depends mainly on velocity and duration of the blizzard, the amount of snowfall through the winter and the snow transfer coefficient depending on topography and the presence of vegetation.

As shown by approximate calculations (Table II) the length of the portion over which snow is transferred for regions of western Siberia varies from 1 to 3 km.

To support the notions expressed above concerning the size of the snow-gathering area, over a three-year period we carried out observations on the character of snow transfer and deposition in a system of land conservation forest strips (Fig. 2). In front of strip no. 1 there is a level area extending over several tens of kilometres without obstacles, i.e. the snow-collecting area is unlimited. In front of strips no. 2, 3 and 4 the length of the portion over which snow is transferred can be considered approximately equal to the spaces between the strips. Up to 80% of the snowfall in this region is transferred and is deposited at the forest strips. The direction of prevailing winds with respect to the strips in the winter is perpendicular or approximately so.

From the shape and volume of the snow deposit one can see that regardless of the large difference in the size of the snow-collecting area the magnitude of the deposits accumulated through the winter at all three strips, with the exception of the first strip, is approximately the same (Fig. 2). Some difference in the volume of snow deposits can be explained by the difference in the construction of the strips themselves and partially by the microrelief of the adjacent areas. Thus field observations show that the length of the snow-collecting area from which snow is transferred to the barrier is limited to specific distances.

Knowing the dimensions of the snow-collecting area one can use a more fundamental approach in considering methods of retaining snow on the adjacent fields. Since the length of the snow-collecting region for western Siberia is 2 - 3 km the snow-retaining devices should be constructed at the above-mentioned portions of territory adjacent to the roads being protected. The retention of snow at regions located beyond the limits of the snow-collecting area from the objects being protected, i.e. roads, is not an expedient way of combatting the snowdrift problem.

The magnitude of snow transferred is also affected by temperature and the nature of the surrounding topography. From data of many years of meteorological observations in western Siberia the air temperature during blizzards is on the average -10 to -20°C. Towards the end of winter, blizzards are observed at temperatures from 0 to -5°C. To establish the effect of air temperature on snow flux we carried out blizzard metring observations at temperatures from 0 to -5°C, which showed that at these temperatures the quantity of snow transferred per unit of time decreases by a factor of 1.5. The snow is less mobile and one observes the adhesion of snow to the snow fence itself.

As regards the topography of the region and the state of snow cover which also have an effect on snow flux, it should be noted that the overwhelming mass of snow in the steppe regions of western Siberia is removed by the wind. I.V. Zykov characterizes the snow cover in the Siberian forest-steppe region by stating that as soon as the wind velocity exceeds 10 m/sec, and particularly beyond 15 m/sec, snow is completely removed from open fields where there is no grass or stubble(2). After the snow has been removed, where the soil is friable or loose, dust storms begin. Thus during the winter extensive areas of the fields are several times laid bare and therefore one cannot speak of snow cover in terms of a constant value(2).

Above, some rules were considered for snow transfer and the effect of the main factors governing the transfer of snow.

Knowing the rules governing snow migration one can approach the deposition of snow at barriers and at the same time suggest some measures that might increase the efficiency of snowdrift control measures. From Fig. 3 one can see that an increase in wind velocity by the magnitude of ΔV causes an increase in snow flux by Δq; and conversely one can assume that with a decrease in wind velocity by the value of ΔV the snow flux will decrease by Δq. This indicates that the quantity of falling snow considered as part of the snow-wind flow between the two cross-sections perpendicular to the wind direction is equal to the difference in snow flux at these cross-sections brought about by a decrease in wind velocity. This principle was suggested by Professor A.Kh. Khrgian in 1934 in a paper entitled "On the effect of small profiles of railroad tracks on snowdrifting"(7). However this suggestion was not confirmed in practice.

To check this working hypothesis we carried out blizzard metring observations to check the intensity of snow migration on an open area and behind barriers which reduce the velocity of the wind.

The results of observations are shown in Fig. 3, which indicates the snow flux on an open area without barriers and behind barriers. The processing of experimental data made it possible to establish that the dependence of snow flux on velocity beyond fences is the same as in the open area. Consequently the processes of migration and deposition of snow from a snow-wind flux are reversible processes when there is a change in wind velocity.

Thus if the total snow flux at a given cross-section is expressed by the relationship $q_1 = f(V_1)$ and at another $q_2 = f(V_2)$ where $V_2 < V_1$, the quantity of snow deposited can be expressed as a difference of total snow fluxes, i.e.

$$\Delta q = q_1 - q_2 = f(V_1) - f(V_2). \tag{7}$$

Substituting in expression (7) the values of total snow fluxes according to formula (3), we obtain

$$\Delta q = 0.0065(V_1^{3,5} - V_2^{3,5}) \qquad (8)$$

where Δq is the difference of total snow fluxes or the quantity of deposited snow in a unit of time;

V_1 is wind velocity before reaching the barrier;

V_2 is wind velocity after being reduced.

To give a practical confirmation of the relationship (8) we carried out experimental observations of snow deposition at two fences having a height of 2.0 m arranged at a distance of 40 m from each other (Fig. 4). Each fence row was of open-grid construction with 25% density, which reduced wind velocity by 25%.* The average wind velocity during the time of the blizzard was approximately 12 m/sec. With these initial data the volume of snow deposition is theoretically, according to formula (8), 70% beyond the first fence and 23% beyond the second fence (these percentages are taken of the total snow transferred by the wind). Part of the snow - about 7% - as seen from the calculation, is not retained in this case by the fences and is transferred beyond their limits. The calculation data were confirmed by field observations, which showed that beyond the first fence the mean volume of snow deposited was 74% and beyond the second fence 19% of the total quantity of snow transferred, and the value of snow not retained by the fences is taken approximately to be within the range of 7%.

From a comparison of theoretical and field data it is seen that the difference in volumes of snow deposition is insignificant and that the results of experimental observations confirm the theoretical calculation.

From an analysis of relation (8) and experimental observations one can make the following conclusions:

1. The quantity of snow deposited out of a snow-wind flow when the wind velocity is decreased depends on the difference between at least the cube of the initial and final velocities; consequently a relatively small decrease in wind velocity facilitates the deposition of a substantial quantity of snow. For example, if the wind velocity is reduced by the factor of two, the total snow flux is reduced by more than a factor of eight.

2. Snow is deposited at barriers when there is a very small decrease in wind velocity due to the barrier and is observed when the wind velocity away

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* The 75% indicates the relation of the area of open spaces to the total area of the fence.

from the barrier is more than 5 - 6 m/sec, i.e. snow deposition is unavoidable with any decrease in wind velocity.

3. The greatest quantity of snow is deposited beyond the initial decrease in velocity, although the decrease may be small, with further decrease in wind velocity by succeeding barriers, for example, the second and third rows of fences, the quantity of snow deposited decreases.

On the basis of these results one can make a number of practical suggestions to increase the efficiency of snow control measures.

1. In designing single-row fences there is no need to try to reduce the wind velocity beyond the fence to the zero point. It is completely sufficient to create a situation in which the wind velocity would be reduced to 3 - 4 m/sec, i.e. a velocity at which there would be no noticeable snow migration.

2. In constructing multiple fences, such as a series of parallel barriers as well as the planting of forest strips, the design at the present time is to have each row of fence operating independently and reducing wind velocity as much as possible (up to 80 - 85%) of that over the open fields. From an analysis of the rules governing snow transfer and deposition it follows that the most effective operation of a multiple-row fence would occur if the snow-wind flux would fall under the joint influence of all the rows of the fence. From this it would be expedient to build each succeeding row of fence with an increase in open space between, but designed so that the velocity of the wind would be reduced evenly, and beyond the last row it should not exceed 3 - 4 m/sec, at which snow transfer is not observed.

3. As regards retaining snow on the fields by means of mobile fences, it should be noted that with grid-type fences one should try to have 20 - 25% density in the framework and built to a height of 1 m. With such dimensions a wide, flat snow cover is formed reaching the height of the fence and extending away about 25 to 30 times the height of the fence. This is the most favourable arrangement as far as distribution of snow on the field is concerned. Let us recall that at the present time in protecting railroads the fences usually have 25 - 50% density, which form short, high walls or drifts. Having a more open type of grid work for the fence not only facilitates a more rational distribution of snow on the fields but also reduces the expenditure of material and labour.

4. Since the length of the snow-collecting area from which the snow is transferred to the fence is limited, snow retention as a measure of combatting snowdrifting can be effective on the fields adjacent to the roads up to a width of 2 - 3 km, i.e. the area over which the snow may be transferred.

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Table I

Distribution of the quantity of migrating snow by height

Layer in cm	Quantity of migrating snow in %
100-200	1.0
50-100	1.2
30-50	1.2
20-30	1.4
10-20	6.0
0-10	89.2
Total.......	100%

Table II

Dimensions of the snow-collecting areas

Location	Volume of snow deposited m^3/pm	Snowfall throughout the winter mm	Length of the portion over which snow is transferred m
	Winter of 1950-51		
A	260	70	1920
B	240	53	2280
C	150	35	2140
	Winter of 1951-52		
A	270	81.5	1670
B	230	75	1520
C	170	50	1700
	Winter of 1952-53		
A	315	137	1150
B	450	77	2900
C	240	59.3	2000

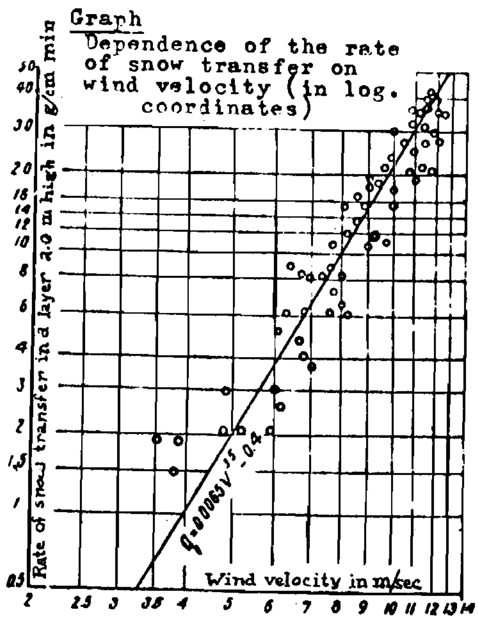


Fig. 1

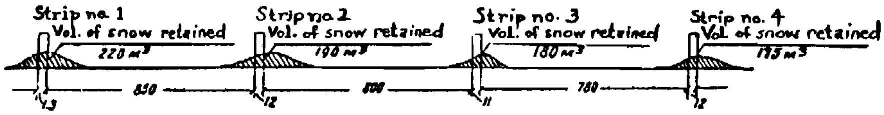
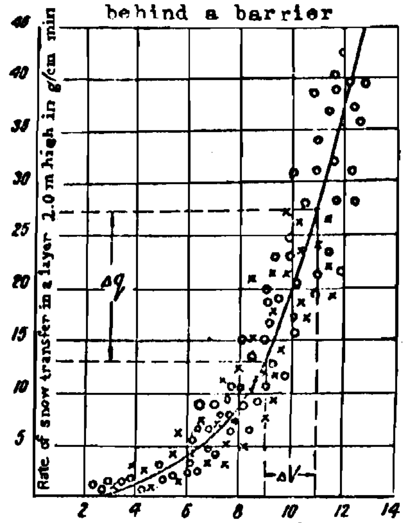


Fig. 2

Distribution of snow at parallel forest strips

Dependence on the rate of snow transfer on wind velocity in an open area and behind a barrier



Wind velocity in m/sec
(at a height of 1.0 m)

Fig. 3

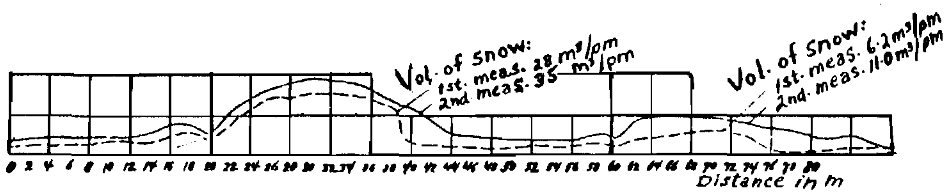


Fig. 4

Profile of snow deposits in a two-line fence with open spaces in the grid comprising 75%