Aerodynamic Snow Fences to Control Snowdrifting on Roads

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This paper describes some problems of snowdrifting control on roads in open terrain. Some of the relationships between geomorphological-climatic factors and snow fences as snowdrifting control devices are discussed. The aerodynamic-snow mechanics aspects of snow fences and flow processes of air-snow currents across dense and permeable snow fences are described, rough calculations are made for spacing of snow fences, and difficulties in theoretical analyses of aerodynamic snow fences are discussed. The paper also suggests additional studies that are needed to improve the effectiveness of snow fences. These include studies of geomorphology and climate of regions prone to snowdrifting, aerodynamics of snowdrifting, and aerodynamic-snow mechanics of various kinds of snow fences and their components.

Clearing and protecting streets, highways, and airfield runways, taxiways, and service roads from snow are undisputed necessities for unimpeded, year-round operation of transportation on the ground, especially during, and even for some time after, snowstorms.

Discussion of snow removal practices on roads is beyond the scope of this paper. Snow removal by mechanical means has been adequately discussed by others (1, 2, 3). This paper only discusses the protection of roads against snowdrifts, viz., snowdrift control in open terrain. Some of this discussion pertaining to snowdrifts on roads may also be applicable to winter maintenance of airfield runways.

SNOWDRIFTS

During snow periods with heavy winds there is a tendency for the snow to drift. Frequently snowdrifts on roads bring vehicular transportation to a complete standstill. The magnitude of snowdrifts depends, among other things, on the quantity and nature of snow and the velocity of the wind. The wind may pick up snowflakes from a snow blanket on a field adjacent to a road. It is known from fluid mechanics that the velocity of the air current, viz., snow-laden wind, is reduced by an obstacle in the way of the wind. Any obstacle that brings about a reduction in the velocity of the air current carrying snow will cause some of the snow to be deposited in a heap, commonly known as a drift. Such obstacles may be grass, brush, shrubs, trees, fences of all kinds and built-up areas, variation in the relief of the terrain on both sides of the road, embankments, fills, cuts, position of the road, roadside snowbanks created by snowplowing, and many other physical obstacles. Thus, under certain combinations of meteorology, aerodynamics and physical terrain, such as wind obstacles along the road, decrease the velocity of the wind blowing across the road enough to cause snow to accumulate and to pile up on the roadway. This affects the traffic on the road adversely, or may even render the road impassable. Therefore, prevention by control of drifting snow or, rather, reduction of the perils of snowdrifts so far as is physically possible and economically feasible involves a judicious introduction of drift control devices to reduce the wind velocity at or near the roads and runways.

REMEDIAL MEASURES FOR SNOWDRIFT CONTROL

Some of the common remedial measures used to control drifting and accumulation of snow on roads are removal of objectionable obstacles (fences, trees) that may cause

snowdrifts; planting of rows of trees to serve as wind barriers; planting of areas of trees to serve as snow accumulation "reservoirs"; proper road and alignment design in drift-prone areas; and erection of artificial snow fences. Experimental studies of wind-breaking and snowdrift control by tree-planting have been performed and described by Finney (4).

Each of these remedial measures has its advantages and disadvantages. For example, the "natural" snow fence fits in very nicely with the timely trend toward improvement and beautification of the roadside and highway appearance. Effective as it may be in drift prevention, the natural fence, however, also has its inherent disadvantages.

1. It may require a wide right-of-way;

2. It is relatively expensive in respect to planting, growing, and maintenance;

3. It takes many years (about 6 to 8) to grow a hedge and about 15 years to grow some species of trees; and

4. Once planted, it is impossible to shift and erect the natural fence against the changing direction of the winds.

Artificial snow fences as snowdrifting control devices have proved to be a practical, effective, and relatively inexpensive means both here and abroad for reducing the wind velocity and thus protecting roads and railroads from snowdrifts.

The principle involved in using snow fences is their proper erection at some distance away from the road on its leeward side. In front of the windward side and behind the fence (on the leeward side), snowdrifts are formed where snow is deposited and stored before it can reach the road. The proper distance from the pavement edge to the snow fence varies from approximately 75 to 100 ft. The actual distance must be determined in accordance with local conditions, of course. From practical experience this distance is an empirical function of the height of the fence. For example, in some regions, by method of trial and adjustment, snow fences are placed from 6 to 15 to 20 times the height of the fence from the point where snowdrifting is to be avoided, viz., from the edge of the pavement. Fences are placed parallel, perpendicular, or at an angle to the road, depending on the direction of the prevailing wind.

FACTORS INVOLVED IN PLACING OF SNOW FENCES

As simple as the problem of placing the snow fence might appear superficially, in reality it is not that easy. The position of the snow fence involves not merely its height, but also meteorological and hydrological conditions of the locality such as fluid mechanics of the snow-laden air current; aerodynamics of the snow fence; physical properties of the air, snow, and the fence itself; snow mechanics (5); the theory of snowdrifting (6); and effective drainage facilities for removing snow meltwater as quickly as possible during thawing periods (the road must be "dry" even in wet weather). It is also essential that the drainage be kept warm to prevent freezing; geomorphology of the terrain, topography, and possibly some other factors must be considered. Continuous study of weather trends would disclose the regimen and "detours" of the prevailing winds and snowstorm paths. The properties of snow of interest are density, specific gravity and hardness, temperature and moisture content, cohesion, plasticity, viscosity, and shear strength. Thus snow mechanics is of interest not only in avalanche studies, forestry, military operations, snow sports, and snow densification but also in snowdrifting control and research.

From this short review it may now become apparent at once that the problem of placing the snow fence for proper functioning and the theory on which proper functioning of such a fence is based are anything but scientifically simple. This problem is tricky to solve satisfactorily. It may be said at this point that this is one of the examples where winter service road maintenance men intuitively and correctly recognized very early and utilized with reasonably practical success the snow fence as a snowdrifting control device before science and engineering were able to supply the logic. All these factors call for an experimental study for the development of an aerodynamic snow fence as an effective snowdrifting control device. The kinds of snow fences used by the various highway departments are described in their highway maintenance manuals, in the Highway Engineering Handbook (7), and elsewhere (2, 8, 9, 10). Paper snow fences have been used successfully in Michigan (8, 9). However, in this discussion, all snow fences are classed as solid or impervious to snow, and open or pervious to snow.

If a snow fence contains horizontal or vertical gaps (voids) or "pores" between adjacent boards, pickets, or paper stripes, the snow fence is open, or permeable to snow. The perviousness of a snow fence may be characterized by its "void ratio" or by its "density ratio." The void ratio is a number that shows the proportion of void (open gaps) to solid areas in the frontal portion of the material or obstacles. Density ratio is the ratio of the frontal area of the snow fence material to the total frontal area of the fence (including open gaps).

THE FUNCTIONING OF A SOLID, IMPERMEABLE FENCE

The fundamentals of the theory of snowdrifting have been dealt with by Dyunin (6) and others. Unfortunately, there has been very little technical explanation of the functioning of both solid and permeable snow fences. The approach followed so far in the development of methods of snowdrifting control has been empirical. The theoretical aspects of this problem have received very little attention in the past. It is for this reason that research on aerodynamic snow fences is suggested here.

The following is an approximate description of the functioning of snow fences, based on observation.

When a fluid such as a horizontal, snow-laden air current meets and flows about an obstacle perpendicular to the flow such as a dense, impermeable snow fence, it tends to flow around the top of the fence. The velocities of the current on either side of the fence have different magnitudes. The streamline pattern of the air current normal to the blunt, impermeable snow fence is shown in Figure 1. On the windward side of the fence the velocity of the current, v_W , is greater than that on the leeward side, v_L .

Aerodynamic studies indicate that upon flowing around the sharp edge of the upper end of the vertical plate (fence) a separation of the streamline pattern takes place; the snow-laden air current is torn off and deflected, and whirls or eddies of the air-snow mixture set in on both sides of the dense fence, hurling and whirling along the dead,



Figure 1. Snowdrifting at an obstacle-initial phase of performance of a dense snow fence, and snow accumulation in wind-cam zones.



Figure 2. Final phase of performance of a dense snow fence.

deposited snow. Large drag forces develop there, eddying and carrying away the loose masses of snow (dissipation of energy of the air-snow fluid). When the momentum of the eddies becomes large enough, the eddies break away, allowing another to form, and this process repeats itself.

In the wake (leeward side) of the air-snow current behind the obstacle, the local pressure is greatly reduced. With the decrease in velocity of the air-snow current here and because of the eddying (reduced pressure and suction whirl shown in Figure 1), the snow falls out from the air current and deposits in the relatively calm forefield (snow field) or snow storage area. The heavy snow flakes fall out first.

If the forefield is wide enough, the air current is relatively free of snow when it sweeps across the road. Thus the drifting spends itself and becomes less and less severe as it peters out. Among the properties of snow it appears that viscosity of the air-snow mixture is the root of the drag problem in snowdrifting. The snowdrifting process continues for as long as the snow fence is effective in reducing the velocity of the wind.

The picking up, the transport of snow flakes by the air current, and the formation of snowdrifts begin on the average at a wind velocity from 4.5 to 8.0 m/sec. ⁵ The average unit weight of a loose, powdery snow at calm varies from 60 to $100 \text{ kg/m}^{3^{\circ}}$. A denser, wind-deposited snow, depending on its moisture content, may have a unit weight from 250 to 370 kg/m³¹.

Observations made of air-flow currents indicate that the bulk of the snow mass is carried by the lower part of the wind current. The densest air-snow current is approximately 2 m above the ground surface, and about 90 percent of the snow is carried within the lower tens of centimeters, and about 80 percent within the lower 4 centimeters. This explains why no high snow fences are in use. The height of snow fences is usually from 1.5 to 2 m (about 4 to 6 ft).

When the drift is built up to the top of the fence, it is said that the fence is filled or saturated (Fig. 2). A dense snow fence produces especially strong suction and thus short, thick drifts. But the consequence of this is that such a fence soon becomes saturated and thus ineffective. Because of this disadvantage, dense snow fences have seldom been used so far.

THE FUNCTION OF A PERMEABLE FENCE

If a snow fence has voids or gaps, its aerodynamics is more complex than that of a dense fence. The performance of a horizontally pervious fence in its initial phase is shown in Figure 3. The dotted line indicates the final phase of the performance of the snow fence when filled. The principal advantages of a pervious snow fence over a dense



Figure 3. Performance of a horizontally pervious snow fence.

one are less material, light weight, and much greater width of snow drifting and eddying area, the snow storage area between the pervious fence and the road. Also, here the volume of the accumulated snow is greater than that around a dense fence. The effectiveness of the permeable snow fence depends on the void ratio, of course.

From this discussion one already should have gathered that the functional intent of a snow fence is not the prevention of drifting of snow. On the contrary, the function of the snow fence is to facilitate purposive drifting and deposition of snow in an area away from the roadway, i.e., in the area between the fence and the highway. Hence, the term "control of snowdrifting" is used. The real purpose of the snow fence is thus to reduce the velocity of the snow-laden air current, thus facilitating the fall-out and achieving the wind stream and the deposition of the snow before it is carried to the road. Such a function of the fence is continuous for as long as the fence remains effective in reducing the velocity of the wind or air current.

SNOWDRIFTING ON FILLS AND IN CUTS

The width of the snow storage area at a fill or cut of a road also depends on the steepness of the fill. At steep slopes, 1:1 to 1:2, the snow is swept across the road and, depending on the character of the wind and snow, is deposited partly on the pavement, partly on the shoulder, and partly on the leeward slope of the road. This also requires an effective drainage system to carry away the meltwater of snow quickly. With gentler slopes of low fills (less obstruction) from about 1:3 to 1:4 or flatter, the wind should carry the snow up the slope and across the pavement and deposit it on the leeward side of the slope (1). The trend in cross-sectional design concerning snowdrifting is toward the use of 1:5 slopes. Flattened slopes and the rounding of slope junctions facilitate the flow of the air-snow current; thus the deposition of the snow is controlled to some extent. Also, gentle slopes render a more stable fill than those with steeper slopes. Up to now, the rounding of slope junctions has not been practiced widely enough.

Because the streamlines of the wind (air-snow current) over the road on a low fill are squeezed closer together, there results an increased wind velocity across the pavement. Therefore, the snow is swept across and away and deposited next to the road on its windward side.

As to the cuts, during severe snowstorms, there forms in deep cuts a perfect, closed whirl-drum of air-snow mixture (Fig. 4). With a ratio of width, W, of cut at its top to depth, D, of less than 4:1 [(W:D)<(4:1)] and at a wind velocity intensive enough, the eddying motion carries the snow out from the cut in such a way as to free it of drifted snow. A ratio larger than 4:1 may result in partial or complete drift in the cut.

Hence, from the viewpoint of aerodynamics, height of fill, curved slopes of fills and cuts, and depth of a cut would have an effect on the drifting regimen of snow.

Sometimes heavy drifts on roads are formed as a result of maintenance operations such as snow removal. For example, the first, thin cover of snow on the pavement may



Figure 4. Perfect whirl-drum in a cut.

become riffled ("washboarded") by traffic or from plow lines. These act as snow retardants and accumulators. After snowdrifting has begun, the drifts on the pavement increase rapidly.

VOLUMETRY OF SNOW FENCE DRIFTS

The slopes of the volume of the accumulated snow on both sides of the saturated snow fence may be used for practical purposes in calculating approximately the necessary height, h, of the snow fence as a function of the vertical cross-sectional area, A_s . For example, assume that there is a saturated snow fence-terrain system as shown in Figures 5 and 6. The calculations are as set forth in examples 1 and 2 that follow.

Example 1

The snow fence is set back from top edge of slope (Fig. 5). The total cross-sectional area A_s of accumulated snow is

$$A_{S} \approx \Delta BC + \Delta ABC + \Delta DEF \tag{1}$$

or

$$\mathbf{A}_{c} \approx (0.5)(8h)(h) + (0.5)(10h)(h) + (0.5)(1.5)(d^{2}) = (0.5)[(18)h^{2} + (1.5)d^{2}]$$
(2)

The height of the snow fence is

$$h = \frac{1}{6}\sqrt{4A_{\rm s} - 3d^2}$$
(3)

The position of the snow fence must be at a distance L = (10)(h) - (1.5)(d) from the edge F of the cut.

$$L = (10)(h) - (1.5)(d) = \frac{10}{6} \sqrt{4A_{s} - 3d^{2}} - (1.5)(d^{2})$$
$$= \left(\frac{1}{2}\right) \left[\left(\frac{5}{3}\right) \sqrt{4A_{s} - 3d^{2}} - (3)(d^{2}) \right]$$
(4)



Figure 5. Saturated snow fence-terrain system with fence set back from top edge of cut.



Figure 6. Saturated snow fence-terrain system with fence at top edge of cut.

The specialization of Eqs. 2 and 3 is as follows:

1. When there is no cut, then d = 0 (level terrain), and the needed height of the snow fence is

$$h = \frac{1}{3} \sqrt{A_s}$$
 (5)

Also, the width of the snowdrift storage area, L, on the leeward side of the fence for such a case, is

$$L = (10)(h) = \frac{10}{3} \sqrt{A_{\rm s}}$$
 (6)

2. When there is no snow fence used, then the allowable depth, d, of the cut free of danger of the drifting of snow is calculated by Eq. 2 as

$$d = 2\sqrt{\frac{A_s}{3}}$$
(7)

i.e., at such a depth, d, no snow fence is needed.

Example 2

The snow fence is at the top edge of the slope (Fig. 6). The total cross-sectional area of accumulated snow is

$$(0.5)(8h)(h) + (0.5)(1.5d)(d) + (1.5)(d)(h)$$

 $(0.5)(8)(h^2) + (0.5)(1.5)(d^2) + (3/2)(h)(d)$ (8)

The height of snow fence is

$$h = \frac{3d}{16} \pm \frac{1}{16} \sqrt{64A_{\rm s} - 39d^2} \tag{9}$$

The specialization of Eq. 9 is as follows:

A_S ≈ =

1. When d = 0 (no cut), then

$$h = +\frac{1}{2}\sqrt{A_{\rm S}} \tag{10}$$

2. When h = 0 (no fence), then

$$d = \frac{4}{3} \sqrt{A_s}$$
(11)

i.e., at such a depth of cut, no snow fence is needed.

SNOW FENCE AND DRIFTING CONTROL STUDIES

Because in a particular environment each kind of snow fence performs differently, it is here suggested that scientific studies of their effective functioning should be pursued along the following lines: the geomorphologic-climatic aspect; the aerodynamics of snowdrifting; and the aerodynamic-snow mechanics aspect of the function of various kinds of snow fences and their components.

THE GEOMORPHOLOGIC-CLIMATIC ASPECT

Snowdrifting on a road is decisively influenced by the form of the geomorphology of the terrain, hydrology, and climatic conditions during winter in the region concerned. Therefore, to perform a thorough investigation along these lines and to plan snowdrifting control facilities, one must learn and know the causal connections between the various elements in question. These studies include the following:

1. The relationship between the land form (geomorphology) and the prevailing wind regimen (intensity, direction, duration, wind gaps, and wind jets) should be understood.

2. Hills, valleys, ridges, depressions in the ground surface, woods, fills and cuts, snow banks, as well as open spaces affect the wind regimen and hence the regimen and control of drifting of snow. These obstacles cause a change in the angle of direction of the wind thus changing the snowdrifting regimen. For example, fills up to about 9 m in height may cause a reduced velocity of the air-snow current across the roadway thus bringing about snowdrifts on the pavement.

3. Highway fills or cuts may change the wind and snowdrifting regimens as compared with those prior to such construction.

4. Possible danger to soil erosion and frost action problems in soil because of melting snow along the highway must be considered prior to road construction.

5. Frozen soil may be the cause of a 100 percent runoff. This may tax the drainage facilities and cause flooding of roads and runways.

6. Part of the study of the climatic conditions should include wind profile measurements. Such data may help also in laboratory research using terrain-road models.

7. A snowdrifting warning service should also be investigated.

These and other multiple climatic factors and their resulting phenomena also bring to the fore the question whether wind (snow) protection of roads is always advisable. Under certain conditions such protection may turn out to be disadvantages or even dangerous to motorized traffic. However, whatever the situation, the highway alignment must fit in properly geomorphologically, hydrologically, and climatically with the terrain in respect to drainage conditions, wind regimen, and aesthetic appearance of the road-terrain system. Also, the road should lie beyond the leeward limit of the drifting area of snow.

THE AERODYNAMIC-SNOW MECHANICS ASPECT OF A SNOW FENCE

The functioning of snow fences depends on their physical and aerodynamic properties and on those of the wind. In other words, the snowdrifting control depends on the shape of the fence contour, i.e., height and density of the fence; size and smoothness or roughness of the surface and edges of the pickets; drag coefficient of the fence and its components; nature of the gaps; density, viscosity, elasticity, and temperature of the compound fluid air-snow; and the fundamental properties of streamline separation.

The aerodynamic prototype of a dense fence is the fluid flow around the top of a vertical, flat rectangular plate of small height. Here the flat plate is the simplest possible aerofoil section. On a blunt object the boundary layer (contour of the dense fence) of the air-snow current causes the streamlined flow to separate from the leading edge of the fence and thus causes a reduction in velocity of flow, decrease in pressure behind the point of separation, and eddies. The phenomenon of separation becomes a very important factor in determining the characteristics of the fluid flow about the snow fence, calling for a study of the mechanism and fundamental properties of the separation. The results of such a study depend critically on the assumptions of potential streaming and whether the surface of the fence is smooth or rough, and whether the leading edge is blunt, sharp, or rounded.

The analytical studies become even more difficult with permeable fences. The flow past the individual vertical pickets and/or horizontal boards and paper ribbons, the separation of flow at the top of the fence and along the contours of the gaps, and the mutual influence from the adjacent pickets or gaps in the fence bring about a very involved streamline pattern, flow separation, and consequently a very complex eddy regimen. All these phenomena present great computational difficulties for a single, solid, vertical plate, and even greater difficulties for a permeable snow fence.

Because the snow fence problem does not lend itself to a satisfactory analytical treatment, it is suggested that aerodynamic snow fence studies should be performed experimentally in the laboratory as well as in the field, along with geomorphological and climatic studies of the region in the context of effective snowdrifting control on roads and airfields.

SUMMARY

1. The theoretical aspects of methods of control of snowdrifting have received very little attention in the past.

2. The phenomenon of snowdrifting is curbed by the erection of snow fences along roads for the purpose of controlling snowdrifting on them.

3. Snow fences are helpful, but where the country is hilly they are not always effective.

4. A discussion of the function of dense and permeable snow fences is given in this paper.

5. The need for knowing the geomorphological and "wind climate" factors in conjunction with snowdrifting control by means of snow fences is here brought to the fore.

6. Snowdrifting control systems must be designed and adjusted to local snow conditions.

7. The performance and effectiveness of snow fences can be learned from the following scientific and experimental studies: geomorphologic-climatic conditions; aerodynamics of snowdrifting; and aerodynamic-snow mechanics of various kinds of snow fences and their components.

8. The highway alignment must fit properly geomorphologically and climatically in the terrain with respect to drainage, snowdrifting control, and aesthetic appearance.

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REFERENCES

- Wells, N. M. Landscaping. In Highway Engineering Handbook, 1st Ed. (Woods, K. B., ed.), McGraw-Hill, 1960, -p. 28-11.
- 2. Recommended Practice for Snow Removal and Treatment of Icy Pavements. HRB Current Road Problems, No. 9-3R, 3rd rev., Jan. 1954, pp. 5-19.
- Knobel, A. Snow-Clearance Problems on Swiss Roads. Proc. Institution of Civil Engineers, London, Vol. 8, Paper 6246, Nov. 1957, pp. 199-210.
- 4. Finney, E. A. Snow Control by Tree Planting. HRB Proc., Vol. 16, 1936, pp. 119-134.
- 5. Minsk, L. D. Snow and Ice Properties Pertinent to Winter Highway Maintenance. Highway Research Record 94, 1965, pp. 28-44.
- Dyunin, A. K. Fundamentals of the Theory of Snowdrifting. Technical Translation 952 (Belkov, G., tr.), National Research Council of Canada, Ottawa, 1961.
- Whitton, R. M. Highway Maintenance. In Highway Engineering Handbook, 1st Ed. (Woods, K. B., ed.), McGraw-Hill, 1960, pp. 27-1 to 27-66.
- 8. Downey, B. R. Paper Snow Fence Installations 1951-1952. Highway Research Abstracts, Vol. 23, No. 6, June 1953, pp. 40-48.
- 9. Broughton, W. C. Paper Snow Fence Installations 1952-53. Technical and Research Division Rept. 199, Dec. 15, 1953.
- Pugh, H. L. D., and Price, W. I. Snow Drifting and the Use of Snow Fences. Polar Record, Vol. 7, No. 47, Jan. 1954, pp. 4-23.
- Longley, R. W. Snow Depth and Snow Density at Resolute Northwest Territories. Jour. Glaciology, Vol. 3, No. 28, Oct. 1960, pp. 733-738; Tech. Memo. 66, Associate Committee on Soil and Snow Mechanics, National Research Council of Canada, Ottawa, Dec. 1960.