Verification testing of the concept selected for full-scale development and eventual production was recommended. The test should demonstrate system performance under extreme operating conditions. Full-scale testing in an environmental chamber was suggested as a low-risk and potentially low-cost alternative to field testing.

ACKNOWLEDGMENT

I wish to thank D.T. Huang, currently with North American Rockwell, for his role in the development of the thermal analysis models and P.H. O'Callaghan for her assistance in exercising the models and developing background information for this paper.

REFERENCES

1. Users Manual: Systems Improved Numerical Differencing Analyzer (SINDA). TRW Systems Group, Redondo Beach, CA, Rept. 14690-H001-RO-00, April 1971.
2. J.J. Brossard and others. Boeing Engineering Thermal Analyzer Program (AS1917). Boeing Aerospace Company, Seattle, WA, Rept. D180-10016-1, Aug. 1970.
3. ASHRAE Handbook and Product Directory of 1976 Systems. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1976, pp. 38.1--38.16.
4. E.M. Sparrow and K.K. Tien. Forced Convection Heat Transfer at an Inclined and Yawed Square Plate: Application to Solar Collectors. ASME Journal of Heat Transfer, Vol. 99, 1977, pp. 507-512.
5. A.M. Neville. Properties of Concrete, 2nd ed. Pitman Publishing Corp., New York, 1973, pp. 428-431.
6. T.C. Barker and others. Personal Rapid Transit System Reports: 1976-1977 Winter Operation. College of Engineering, West Virginia Univ., Morgantown, 1977.
7. D.J. Tighe and others. An Analysis of Airport Snow Removal and Ice Control. Federal Aviation Administration, Rept. FAA-RD-71-20, March 1971.
8. W.J. Kennedy and J.A. Austin, Jr. A Model for Traffic Delay and Its Convenience and Wage Costs. In Snow Removal and Ice Control Research, TRB, Special Rept. 185, 1979, pp. 57-60.
9. B.H. Welch and others. Economic Impact of Snow and Ice Control. Utah Department of Transportation, Salt Lake City, Rept. FHWA/RD-77-20, 1976.
10. C. Thomas and G.I. Thompson. The Value of Time Saved by Trip Purpose. Stanford Research Institute, Menlo Park, CA, Project MSU-7362, Oct. 1970.

*Publication of this paper sponsored by Committee on Winter Maintenance.*

# Wind-Tunnel Analysis of the Effect of Plantings on Snowdrift Control

STANLEY L. RING

**Modern highway design practices have, in general, created an aerodynamic highway cross section that is relatively snowdrift free. However, adjacent topographic features or obstructions may create localized snowdrift-prone locations. One such situation is the grade-separation structure over a freeway. Landscape and maintenance specialists have sought planting arrangements to reduce the problem. To study snowdrift patterns in the field is time consuming and demanding, since control of weather conditions is not possible. The objective of this research was to reproduce the phenomenon of blowing snow in the laboratory wind tunnel, on an appropriate freeway grade-separation three-dimensional model, and to analyze the effect of various plant configurations in minimizing snowdrift accumulations on the pavement. Seventy-seven separate experiments were conducted in the wind tunnel by using 49-μm (0.001 93-in) glass spheres as the particulates to represent snow. Comparisons of snowdrift accumulations versus time were subsequently made to evaluate the effectiveness of various plantings. Similitude relationships were evaluated for relating the model results to known full-scale field conditions. Specific recommendations about plant types, densities, and spatial arrangements are presented for Iowa conditions.**

Blowing and drifting snow has been a problem for the highway engineer virtually since the inception of the automobile. In the early days, highway engineers were limited in their capabilities to design and construct drift-free roadway cross sections, and the driving public tolerated the delays associated with snow storms.

Modern technology, however, has long since provided the design expertise, financial resources, and construction capability to create relatively snowdrift-free highways, and drivers today have come to expect a high-design highway facility that is free of snowdrifts; if drifts develop, drivers expect highway maintenance crews to open the highway within a short time. Highway administrators have responded to this charge for better control of snowdrifting. Modern highway designs in general provide an aerodynamic cross section that inhibits the deposit of snow on the roadway insofar as it is economically feasible to do so.

Maintenance operation policies have called for immediate removal of snowdrifts and have provided the necessary resources. The commitment of snow-removal equipment and personnel for immediate action has, in fact, reduced the concern for natural control of snowdrifting (as through the use of snow fences and the strategic placing of plantings).

Financial limitations and reduced energy availability, however, are now causing administrators to review maintenance policies. Thus, if equipment for rapid snow removal will not be as promptly or readily available in the future as in the past, there will be a renewed interest in the control of snowdrifting by natural means wherever possible.

The Iowa Department of Transportation (DOT) has been concerned with a specific snowdrift-prone location. At certain minor-road grade-separation structures over a freeway in rural areas, when the snow is blown from the same general direction as the minor-road embankment, pressure changes occur and

Figure 1. Effect of variations in backslope on snowdrift accumulation.

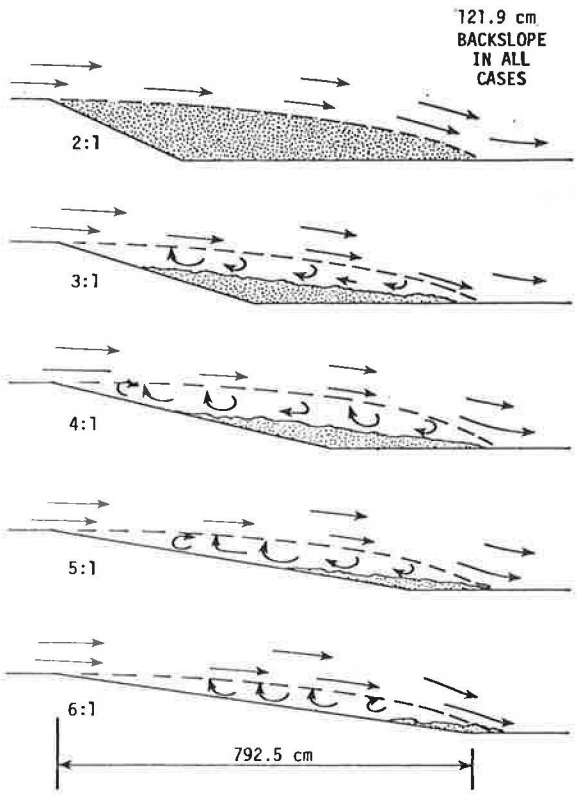



Figure 2. Effect of rounding top and bottom of slope.

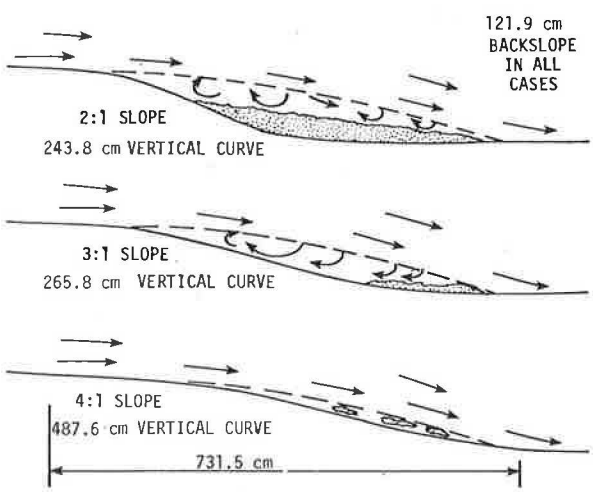
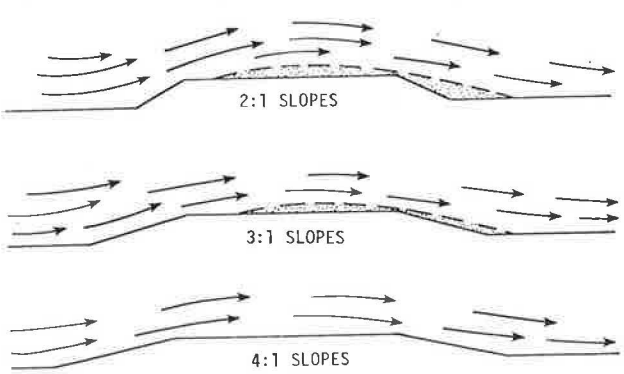



Figure 3. Effect of foreslopes on air flow across roadways.




cause snowdrifts to form. In fact, it is not uncommon for the only snowdrift problems to be in the area under these bridges.

The Iowa DOT contracted with the Engineering Research Institute at Iowa State University to study these snowdrift-prone locations. The research goal was to reproduce the phenomenon of blowing snow in the wind tunnel on an appropriate three-dimensional model and to analyze the effects of strategically placed plantings, or other barriers, in order to make recommendations for the control of snowdrifts.

## STATE OF THE ART

The control of drifting snow can be categorized into three general areas:

1. Design of the highway topography to create an aerodynamic cross section that is self-cleaning,
2. Creation of barriers (snow fences or plantings) in order to create wind-pressure changes and cause the snow to accumulate off the pavement, and
3. Removal of improperly located barriers (guardrail, fences, curbs, and weeds) that create snowdrifts on the pavement.

Some of the earliest research into highway design for snowdrift control was by Finney (1-4). Finney's recommendations were based on wind-tunnel experiments and field observations. He noted that the maximum limits of a snowdrift accumulation on the leeward side of a solid barrier (such as a side ditch cut) would always be at a horizontal distance of 6.5 H, where H is the vertical displacement.

Also, Finney's studies clearly illustrated the benefits of flat foreslopes and backslopes and the rounding of slope junctions. Figures 1-3 illustrate this self-cleaning cross-sectional aspect. Finney's recommendations are generally consistent with modern research results and have been the basis for highway designs for decades.

In recent years Tabler (5-10) has made significant contributions to the science of snowdrift control. His 1975 report (7) is representative of the value of his work. Computer programs based on this work have been developed as an analytical tool for the design of the roadway cross section.

Primarily as a result of Tabler's and Finney's work, the highway engineer can usually predict the downwind shape of a snowdrift that accumulates at a barrier. Generally speaking, a solid barrier will create a maximum downwind length of drift equal to 10 times the height of the barrier. (Note that Finney's earlier laboratory results were 6.5 H.) However, a porous type of barrier (optimum snow-fence porosity is approximately 50 percent) may create a drift length as high as 27 H. It should be emphasized that these shapes are for relatively flat topography. Significant variations can occur for rolling topography.

Systematic investigations into the relationship between plants, snow, and wind were started early in this century. Cornish (11), Bates (12), Burton (13), Finney (3), and a number of studies in the 1940s and later have made significant contributions.

It has been shown that combinations of plants and shrubs can achieve a barrier that has varying degrees of porosity. The degree of porosity determines the length of the leeward drift accumulation. In general, a near-solid barrier plant mass will generate a downwind length of drift equal to 7-10 times the height of the solid mass. Also, a mass in the range of 50 percent porosity can achieve a length equal to 27 times the plant heights.

The primary concern is in selecting plants that

Figure 4. View of the bare model before testing.

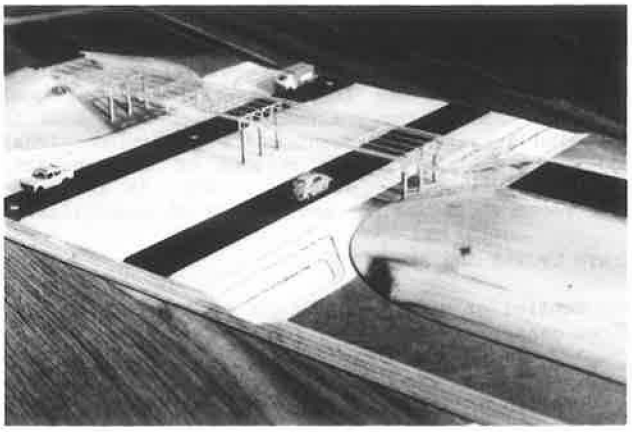
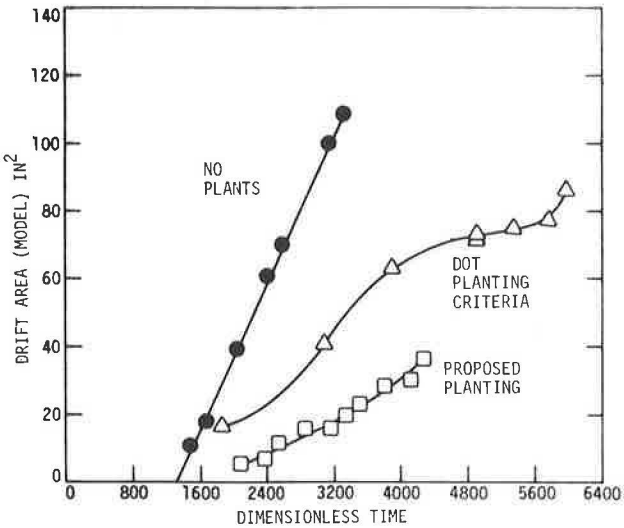


Figure 5. Accumulation of simulated snow as a function of dimensionless time.




are hardy and in predicting the future wintertime porosity. Location of the plants is a function of porosity and height.

It should be emphasized that the capability to predict snowdrift accumulation is influenced by adjacent topography and land features. A grove of trees or farm buildings upwind of the highway may change the quantity of snow available and the wind-pressure level. An upward slope of the topography on the windward side of the barrier will probably increase the volume of snow stored in the drift. A depression on the leeward side of the barrier will also increase the volume of snow accumulated. The final equilibrium profile of the downwind drift probably remains the same, however.

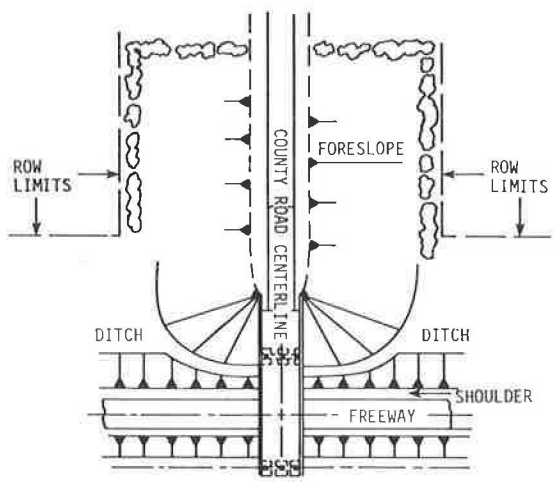
In complex locations, field studies or wind-tunnel modeling may be required to accurately predict snowdrift profiles. Because field studies are time consuming, laboratory modeling is useful if valid predictions can be made from the model results.

## DESIGN OF THE WIND-TUNNEL EXPERIMENT

Two three-dimensional models were constructed on a scale of 1:120 in the horizontal [1 cm = 1.2 m (1 in = 10 ft)]. One model had the same 1:120 vertical scale, and the other had a vertical scale of 1:60 [1 cm = 0.6 m (1 in = 5 ft)]. The purpose of the vertical scale change on the second model was to evaluate the similitude relationships for extrapolation to full scale.

Figure 6. Snowdrifting at grade-separation structure.

Figure 7. Snowdrift-control planting where ROW is constrained.




The models represented a typical freeway design and were accurately machined to scale. The embankment and adjacent area were made of cedar wood; the pavement and bridge were of plexiglas. Shoulder areas were covered with fine sandpaper, and the final-model earth areas were covered with a low-nap velour cloth to simulate ground cover. Figure 4 shows the model before application of the cloth ground cover.

A number of different materials were tested in the wind tunnel to represent plant mass. Tests were first conducted on a flat landscape in order to analyze the experimental drifts in terms of known snowdrift characteristics. The final material selected was a commercial packing material of loosely woven fibers that had many air spaces. Its porosity could be varied by means of compression. This material was found to best reproduce plant-mass snowdrifts in the wind tunnel.

A number of wind-tunnel experiments were conducted to select the material to simulate snow. Two different diameters of finely ground walnut shells and two different diameters and densities of glass spheres were tested in relation to their ability to be picked up and transported according to the snow-transport phenomenon (saltation theory).

Glass spheres of 4.0-g/cm$^3$ (249-lb/ft$^3$) density and 49-μm (0.001 93-in) diameter were se-

lected. The material was placed on the bed of the wind tunnel upwind of the model. Wind-tunnel tests were conducted at 4.4-6.6 m/s (10-15 miles/h), at which speeds the glass spheres were picked up and transported as loose particulates according to the saltation phenomenon of snow transport.

A total of 77 separate wind-tunnel experiments were conducted with the two models; 26 were on the bare model (no plantings), and 51 were with experimental plant configurations for snowdrift analysis. The total wind-tunnel experimental time during these 77 runs was 35 h. The models were rotated to achieve varying wind orientations.

## ANALYSES

Vertical photographs of the snowdrift accumulation and encroachment on the pavement surfaces were taken at specific time intervals in order to evaluate the effectiveness of each alternative. The time-referenced photographs were subsequently enlarged and the encroachment area calculated.

A plot of dimensionless time versus pavement-encroachment area was then prepared as an evaluation tool. Figure 5 represents a comparison of the time for encroachment to occur for (a) the bare model, (b) the standard planting configuration in use by the Iowa DOT, and (c) the planting configuration to be tested.

As would be expected, the plantings function as a living snow fence and cause the snowdrift to accumulate away from the pavement area. Any encroachment on the pavement is consequently delayed in accordance with the distance from snow fence to pavement and the capacity of the snow barrier.

All snowstorms have a finite quantity of snow to transport at any specific location. In many snowstorms the quantity of snow available to accumulate could be stored off the traveled way. Even the storms that carry large quantities of snow could have a significant delay on the time for snow deposits to reach the pavement, if the drift-creating plantings are located far enough to windward and are of suitable height and porosity.

## CONCLUSION

A goal of this research was to determine the suitability of wind-tunnel modeling for reproducing field-observed snowdrifting characteristics through an evaluation of similitude relationships and a direct comparison of modeled drift dimensions with established field-condition drift measurements. The results of the experiments have been shown to correlate well with actual field conditions.

Another goal, based on the testing of various types and configurations of simulated vegetation, was to determine the best design to minimize the deposit of snow on the pavement. The following are recommended:

1. It is important that plantings (or other barriers) be placed some distance away from the freeway. Plantings placed near the bridge may, in fact, cause an increase in snow accumulation on the pavement. Figure 6 illustrates the leeward accumulation on the pavement that results from close barriers.
2. The best planting arrangement in a constrained right-of-way (ROW) situation requires plantings on the minor-road ROW. Figure 7 illustrates this condition.
3. The best planting arrangement in an unconstrained ROW condition provides additional rows of plantings at greater distances from the freeway, as illustrated in Figure 8.
4. Plants selected should generally not exceed 3 m (10 ft) in mature height and should have medium porosity at the lower levels. The type selected depends on soil and moisture characteristics at the

Figure 8. Snowdrift-control planting where ROW is not constrained.

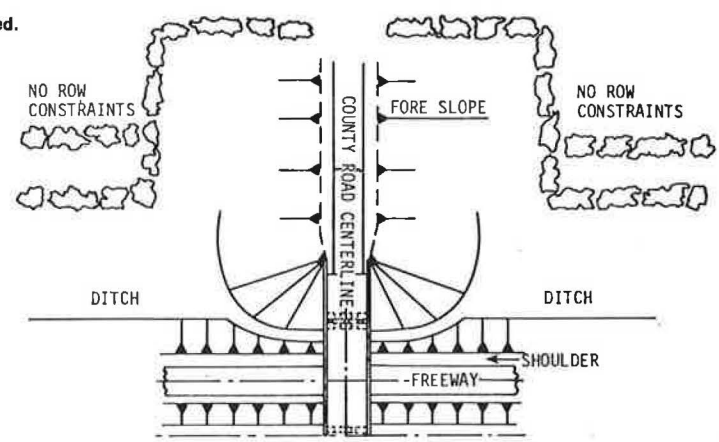



Table 1. Recommended plantings where the ROW is constrained.

| Botanical Name | Common Name | Maximum Height at Maturity (cm) | Number of Rows | Distance Between Rows (cm) | Spacing in Rows (cm) |
|---|---|---|---|---|---|
| Kolkwitzia ambilis | Beautybush | 300 | 2 | 150 | 90 |
| Lonicera xylosteum claveyi | Clavey honeysuckle | 150 | 2 | 120 | 90 |
| Lonicera zabeli | Zabel honeysuckle | 300 | 2 | 150 | 90 |
| Syringa palibiniana | Dwarf Korean lilac | 180 | 2 | 120 | 90 |
| Ligustrum obtusifolium regelianum | Regal border privet | 150 | 2 | 150 | 120 |
| Ligustrum vulgare variegated | Cheyenne privet | 300 | 2 | 150 | 90 |
| Physocarpus monogynus | Mountain ninebark | 120 | 2 | 90 | 60 |
| Rosa rugosa | Rugosa rose | 180 | 2 | 120 | 90 |
| Rosa canina | Dog rose | 270 | 2 | 120 | 90 |
| Spiraea prunifolia | Bridalwreath spirea | 270 | 2 | 120 | 90 |
| Spiraea vanhouttei | Vanhoutte spirea | 180 | 2 | 120 | 90 |

Note: 1 cm = 0.4 in.

**Table 2. Recommended plantings where the ROW is not constrained.**

| Botanical Name | Common Name | Maximum Height at Maturity (cm) | Number of Rows | Distance Between Rows (cm) | Spacing in Rows (cm) |
|---|---|---|---|---|---|
| Juniperus virginiana | Eastern red cedar | 600+ | 2 | 300 | 150 |
| Rhamnus frangula columnaris | Glossy tallhedge buckthorn | 540 | 2 | 240 | 90 |
| Caragana arborescens | Siberian pea tree | 540 | 2 | 300 | 150 |
| Viburnum dentatum | Arrow-wood | 540 | 2 | 300 | 150 |
| Crataegus cordata or C. phaenopyrum | Washington hawthorn | 600 | 2 | 300 | 150 |
| Acer ginnala | Amur maple | 600 | 2 | 300 | 300 |
| Elaeagnus angustifolia | Russian olive, oleaster | 600 | 2 | 300 | 300 |
| Viburnum lantana | Wayfarer tree | 540 | 2 | 300 | 150 |
| Viburnum prunifolium | Blackhaw | 540 | 2 | 300 | 150 |

Note: 1 cm = 0.4 in.

site. For Iowa, Tables 1 and 2 identify suitable plants and their characteristics (honeysuckle is the most practical for normal Iowa conditions).

5. The applicability of guardrail and the type in use should be examined. Moving the guardrail away from the pavement edge improves the potential for snow-free maintenance. Also, the box-beam type may have reduced propensity for creating snowdrifts.

6. A snowdrift-control plan should be implemented at each overhead location at which actual drifting has been observed so that modification of plantings may be made to minimize snowdrifting on the pavement.

ACKNOWLEDGMENT

The research summarized here was supported by the Engineering Research Institute of Iowa State University through funds provided by the Iowa DOT. The participation of the Iowa Highway Research Board is appreciated. The opinions, findings, and conclusions expressed in this publication are my own and not necessarily those of the Iowa DOT or the Engineering Research Institute of Iowa State University.

REFERENCES

1. E. A. Finney. Snow Control on the Highways. Iowa State College, thesis, 1934.
2. E. A. Finney. Snow Control on the Highways. Michigan Engineering Experiment Station, East Lansing, Bull. 57, 1934.
3. E. A. Finney. Snow Control by Tree Planting, Part 6: Wind-Tunnel Experiments on Tree Plantings. Michigan Engineering Experiment Station, East Lansing, Bull. 75, 1937.
4. E. A. Finney. Snowdrift Control by Highway Design. Michigan Engineering Experiment Station, East Lansing, Bull. 86, 1939.
5. R. D. Tabler. New Snow-Fence Design Controls Drifts, Improves Visibility, Reduces Road Ice. Proc., Annual Transportation Engineering Conference, Vol. 46, 1973, pp. 16-27.
6. R. D. Tabler. New Engineering Criteria for Snow-Fence Systems. TRB, Transportation Research Record 506, 1974, pp. 65-78.
7. R. D. Tabler. Predicting Profiles of Snowdrifts in Topographic Catchments. Proc., Western Snow Conference, Coronado, CA, April 1975, Vol. 43, pp. 87-97.
8. R. D. Tabler. Estimating the Transport and Evaporation of Blowing Snow. Proc., Snow Management on Great Plains Symposium, Great Plains Agriculture Council, Bismark, ND, Publ. 73, 1975, pp. 85-104.
9. R. D. Tabler. Snow Control with Road Design and Snow Fences. Technical Institute on Snow Removal and Ice Control, Univ. of Wisconsin, Madison, Dec. 1978.
10. R. D. Tabler. Geometry and Density of Drifts Formed by Snow Fences. Paper presented at Snow in Motion Conference, Fort Collins, CO, Aug. 1979.
11. V. Cornish. On Snow-Wave and Snow-Drifts in Canada. Geographical Journal, Vol. 20, No. 2, 1902, pp. 137-175.
12. C. G. Bates. Windbreaks: Their Influence and Value. U.S. Foreign Service Bull., 86, 1942.
13. V. R. Burton. Snowdrift Prevention and Control on Highways. Engineering News-Record, Vol. 95, No. 19, 1925, pp. 752-754.

*Publication of this paper sponsored by Committee on Winter Maintenance.*

*Abridgment*

# Alternatives to Sodium Chloride for Highway Deicing

STANLEY A. DUNN AND ROY U. SCHENK

**A search has been made for road deicing chemicals to replace sodium chloride (NaCl). The impetus for this search stems from the numerous drawbacks associated with the current extensive use of NaCl as a road deicer. All classes of chemical compounds were reviewed. Deletions were made on the basis of such pertinent criteria as water solubility and freezing-point lowering, corrosion, toxicity, flammability, relative cost or cost potential, and effect on soils, plants, and water supplies. Low molecular weight and high solubility were primary qualifications. Waste products were considered as possible raw-material sources. Two candidate deicers have been selected that, if used, would result in total costs of about one-half those associated with the use of NaCl. Both materials can be made from waste cellulose. Neither is corrosive. One of them, methanol, reacts almost immediately on contact with snow and ice but is less persistent than the other candidate or than NaCl. The other candidate, calcium magnesium acetate (CMA), acts at about the same rate as NaCl in the temperature range of common activity and shows about the same persistence. In strong contrast to NaCl, CMA is a corrosion inhibitor, is beneficial to most soils, and has no potential to harm drinking supplies.**