Compaction or Removal of Wet Snow by Traffic

P. A. Schaerer

Observations were made of the free-water content of snow on roads and its behavior under traffic. A Tapley decelerometer was used to measure the skid resistance of the snow-covered roads. It was found that snow having a free-water content of less than 15 percent was compacted by traffic and formed a slippery surface on which a deceleration value of 0.30 was measured. Snow with a free-water content between 15 and 30 percent was usually not compacted but remained on the road in a soft, loose state and gave deceleration values of 0.35 to 0.42. The exact behavior depended on other variables such as depth, shape, and size of the grains. Snow with a free-water content of 30 percent was removed by traffic. Deceleration values between 0.40 and 0.50 were measured on this surface, and a value of 0.60 was measured on the bare, wet pavement. The observations confirm that chemicals need to be applied only in an amount sufficient to produce 30 percent melting if a decrease of the skid resistance can be tolerated. A melting of 15 percent would prevent the snow from being compacted into an ice crust but usually would not cause it to be removed by traffic, and thus plowing would be required.

Wet snow deposited on a road and exposed to traffic will either be compacted into a hard and slippery snow-ice layer, remain on the pavement in a loose state, or be removed to the side by the action of vehicles. The condition that develops depends on the properties of the snow and characteristics of the traffic. In 1966, the Division of Building Research of the National Research Council of Canada began to obtain information on whether the snow is compacted, remains loose, or is removed. Observations were made on city streets in Ottawa during one winter, and limited observations were carried out in the following years at Rogers Pass, British Columbia. It was not possible, however, to continue the program in its full extent or to bring it to a stage where final conclusions could be drawn. This paper contains preliminary results only.

Pure snow can contain water in liquid form only if its temperature is 0 C. This water may be formed on the snow as it falls through the atmosphere or it may result from rain or from the partial melting of snow on the road. Snow can also be melted partially by the application of chemicals, and in this case the liquid is a solution. Wet snow that contains chemicals in solution can have a temperature lower than 0 C and is the type of wet snow most frequently observed on roads.

OBSERVATIONS OF SNOW CONDITIONS

There are, on the average at Ottawa, 60 days per winter with snowfalls more than 0.25 cm, and on 5 days the amount of new snow exceeds 10 cm. Plowing during snowfalls usually ensures that snow on roads does not accumulate deeper than 7 cm. The principal observation made during and immediately following snowfalls, either before or after plowing, was to classify visually the state of the snow on the road surface by using the following criteria:

1. Compact snow—Pavement is covered with a sheet of dense snow that does not break or move under the action of the traffic;
2. Loose snow—There is no apparent bond between the snow and the pavement, and the snow is broken into chunks or is a cohesionless mass that moves under the wheels of passing vehicles but is not thrown to the side of the road; and

3. Loose snow removed—The wheels of moving vehicles throw the snow to the side, and loose snow from the road accumulates on the shoulder.

The properties of snow that were measured were free water content, depth, density, temperature, and type of crystals.

Free-water content, F, was determined as the weight of the liquid divided by the total weight (liquid plus solid), expressed in percent.

$$F = 100 \frac{W}{W + I}$$

where

W = weight of liquid (pure water or brine) and
I = weight of ice.

The hot water calorimeter was found to be the most convenient instrument for measuring the free-water content. Because there were significant variations in the free-water content over small distances, it was sometimes necessary to collect in a bucket about 5,000 grams of snow from different spots, mix it, and draw from it 2 to 3 small samples of about 300 grams and melt them in the calorimeter.

The free-water content is the variable that has the strongest influence on the condition of snow on the road. Its effect is discussed in a separate section.

Snow depth on the road was measured by ruler at 10 points selected at random. All observations were made with snow depths between 0.8 and 7 cm. Within this range, depth had no significant influence on whether snow was compacted, remained loose, or was removed by traffic. There appeared to be a change in behavior, however, for very thin layers of snow, 0.2 to 0.5 cm deep.

Layers of this thickness were not removed as readily as snow more than 0.5 cm deep because traffic packed it into the voids of the pavement where it formed a slippery surface. The number of observations on very thin layers, however, was insufficient to draw definite conclusions.

Measurements were made of snow density, but, because density was strongly influenced by the free-water content and varied with location and time, this formation was found to be of little value.

Snow temperature was measured with a shielded glass thermometer. Its value was always consistent with the free-water content, but it appeared to have no direct relation to the behavior of wet snow.

The density of traffic on roads where the observations were made was between 10 and 140 vehicles per hour. Rather than density, the total number of vehicles passing over the snow determined the state of the snow. About one-third of the vehicles were trucks; the reason for this high track ratio is that the observations were made near industrial sites. The speed of traffic was between 30 and 45 km/hr (18 to 27 mph), a normal speed on snow-covered roads in cities.

INFLUENCE OF FREE-WATER CONTENT OF SNOW

Whether wet snow is compacted or removed under the action of traffic depends on the cohesion between the snow grains and their adhesion to the pavement. The study has confirmed that both cohesion and adhesion are strongly influenced by free-water content. Figure 1 shows a plot of observed free-water content against the amount of traffic and the condition of the snow. The values fall into the following 3 zones:

1. Zone A—Initial free-water content less than 15 percent: snow usually compacted on the road;
2. Zone B—Initial free-water content between 15 and 30 percent: snow remains on the the road in a loose condition and is removed by traffic at a slow rate; and

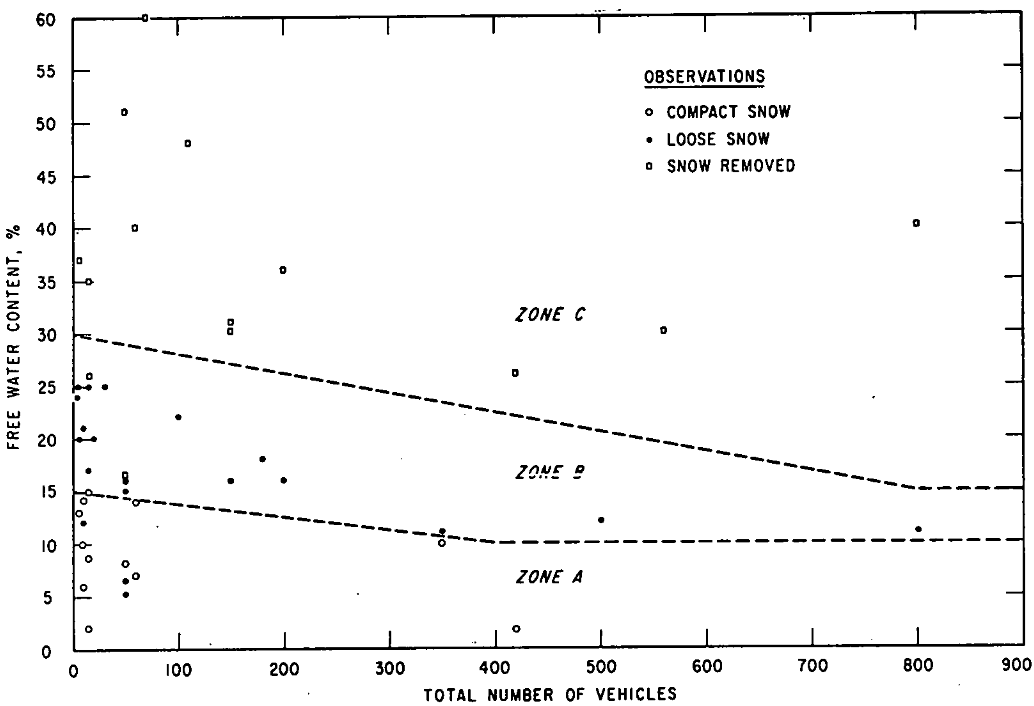

Figure 1. Effect of free-water content and traffic on the compactibility of snow on roads.

3. Zone C—Initial free-water content greater than 30 percent: traffic moves the loose snow to the side rapidly.

The shape of the snow crystals appears to influence the behavior of snow. Rounded grains were moved more readily than needle-shaped or dendritic crystals. This influence is evident only when the snow is fresh. About 2 hours after snow was deposited all the grains had developed a round shape. Zone A in Figure 1 contains observations of snow that was loose and had a free-water content lower than 15 percent. It consisted of graupel and ice pellets.

A similar influence of crystal shape has been reported in measurements of the water-holding capacity of snow. The water-holding capacity is the maximum free-water content that is retained in the snow without producing runoff. de Quervain (1) has observed for dense new snow a water-holding capacity of 20 to 30 percent; for fine-grained old snow, a capacity of 10 to 20 percent; and for coarse old snow, a capacity of 5 to 10 percent. Gerdel (2) reports 13 to 19 percent for new snow and 0.4 to 6 percent for old snow.

The British Road Research Laboratory has recommended for snowfalls the application of 0.0125 lb sodium chloride per inch of new snow, per square yard, per deg F below freezing on roads with a traffic density of more than 50 vehicles per hour, if the resulting wet snow is to be removed by traffic (3). The recommended amount of chemical would produce between 30 and 40 percent melting, which would agree well with the present observations.

OBSERVATIONS OF FRICTION COEFFICIENT

In addition to evaluating the quality of the road surface by observation of the behavior of snow, we took measurements of the friction coefficient. This was determined with a Tapley decelerometer mounted in a light truck driven at a speed of 30 mph

(48 km/hr). Full brakes were applied and the maximum deceleration and corresponding friction coefficient read from the instrument. The results obtained with the Tapley decelerometer are influenced by the type of vehicle and the driver. In order to minimize equipment and human error, the same vehicle and the same operator were used throughout the tests after preliminary experiments had shown that the chosen operator could obtain reproducible results. The Tapley decelerometer, however, was found unsatisfactory for making observations on snow- and ice-covered roads. It was considered that better results could be obtained with a trailer-type, friction-measuring apparatus.

There is usually a great variation in the friction coefficient of roads having apparently uniform snow conditions, depending on whether one or several wheels of the test vehicle happen to be in direct contact with pavement or ice at the instant the brakes are applied. It was found necessary in the present study to make 8 observations on the same road section in order to obtain a mean value that had a 95 percent confidence limit.

More variables influence the friction coefficient than the degree of compaction of snow on the road. Insufficient observations were made to delineate them and establish their relation to friction. Table 1 gives a general picture of the friction coefficients that were observed. All observations were made on roads with asphalt pavement.

TABLE 1

SUMMARY OF OBSERVED FRICTION COEFFICIENTS

Condition of Snow on the Road	Friction Coefficient (percent)
Compacted wet snow	25-30
Compacted dry snow	30-35
Loose, dry new snow on bare pavement	
1 to 5 cm deep	32-38
5 to 10 cm deep	38-43
Loose, wet snow (free-water content 15 to 30 percent)	
1 to 5 cm deep	
Pavement completely covered	33-38
Center bare 2 ft wide	38-46
Center bare 6 ft wide	44-56
Loose, wet snow on bare pavement (free-water content greater than 30 percent)	42-49
Bare wet pavement	60-70

CONCLUSION

Observations of winter road conditions typical of urban areas in eastern Canada indicate that, during light snowfall or after plowing deep snow, chemicals should be applied or pavements should be heated at such a rate that at least 30 percent of the snow is melted. Traffic will move the resulting wet snow to the side of the road. Chemicals should not be applied at a rate that produces less than 15 percent melting, because the resulting wet snow would be compacted into a slippery layer.

It would be useful to continue studies of the friction coefficient of snow- and ice-covered roads in order to determine the influence of different treatments on traffic safety.

REFERENCES

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Formal Discussion

S. F. Ackley

Several points are not clear to me in Mr. Schaerer's paper, and elaboration on these points may aid in the evaluation of the data obtained from either an operational or a research viewpoint. There are a number of difficulties in using hot water calorimetry for the 2-component systems encountered on salted roads, and discussion by Mr. Schaerer on how these difficulties were overcome would be appreciated. Specifically, my questions are as follows:

1. Was the specific heat of pure water (1 cal/gm C) or the specific heat of a salt solution (0.88-0.96 cal/gm C, depending on concentration) used in the calculation?
2. Was the melting point of pure ice or a depressed melting point caused by the presence of salt used in the calculation?
3. Because these contributions are salt-concentration dependent, how was the concentration determined to fix the values of the specific heat and depressed melting points?
4. What was the construction of the calorimeter used for these measurements? Specifically, what was the accuracy of the field temperature measurements, and was the mass of hot water used fairly large compared to the sample size?

My purpose in asking these questions is to allow an assessment of the advantages of this system over density measurements for a similar case. Mr. Schaerer has presented numbers for free-water content with an error of about 1 percent (Fig. 1) in his paper. I have done a "worst case" calculation (assuming a specific heat of 0.9 cal/gm C, a melting temperature of -5 C, 500 grams of hot water in the calorimeter at a temperature of 50 C, and a 300-gram sample of snow plus 30 percent free water at -6 C) and have found that, if the factors I have mentioned are completely ignored, an error of 10 percent in the measured free-water content would be quite possible. Although I do not feel that the numbers given by Mr. Schaerer have this large an error, the range possible for error indicated by the calculation is certainly greater than the 1 percent shown, especially in a field situation. A more complete description of the measurement procedure might give a better idea of the accuracy of the numbers presented and allow a more fair comparison with the density method to determine free-water content.

Schaerer

The observations reported in the paper were made at temperatures between -3 and 0 C, and the concentration of chemicals in the wet snow was usually less than 1.5 percent. Tests were carried out in the laboratory at lower temperatures and with higher concentrations of chemicals. Because of the difficulties mentioned by Mr. Ackley, it was decided not to include in the study these extreme conditions.

For all observations made on salted roads, the amount of sodium chloride or calcium chloride was determined in the laboratory with samples of about 500 grams of wet snow. The snow was melted, and the meltwater was filtered and then evaporated in the drying oven. For some samples the concentration of salt was determined by measuring the electrical conductivity of the solution.

The specific heat of the salt solution was used in the calculation of the free-water content. Because of the low concentration of salt, the specific heat was assumed to be 0.98 cal/gm C. The melting point depression due to the presence of chemical was also considered. A correction was also made for impurities of dust, sand, and rock chips usually contained in the snow on roads. These minerals could amount to 3 percent of the snow; a specific heat of 0.25 cal/gm C was assumed for them.

The calorimeter that was found to be best suited was a wide-neck thermos flask, volume 2,000 cm^3, with a cork stopper. It is most important to work always in the same temperature range and with the same amount of water, which must also be used to determine the heat capacity of the calorimeter. The following are the characteristics of the water and mixture used in our measurements:

Temperature of hot water, 35 C
Temperature of mixture after melting, 5 to 10 C
Amount of hot water, 1,000 grams
Amount of snow, 300 to 400 grams

The temperature was measured with a mercury thermometer graduated in $\frac{1}{10}$ C. The greatest heat loss and possibility of error occurs when the cork stopper is removed and the snow added to the hot water. With some practice this can be done quickly and the error kept within reasonable limits.

The number of observations that could be carried out on the road was too limited to make an evaluation of the influence of all possible errors. It would appear that the variation in the free-water content of the snow on a road produces a greater error than inaccuracies of the calorimetric measurements. The information presented in the paper should only be taken as an indication of the trend in the relationship between free-water content and the condition of the snow. Additional studies must be carried out before a detailed analysis of the effect of traffic on wet snow can be undertaken.

Informal Discussion

Lorne W. Gold

What was the particle size of the salt, in other words, the screen size used?

Schaerer

We have used sodium chloride that meets the specification of the Ontario Department of Highways. Can you tell us what this is Mr. Brohm?

David Brohm

The salt we normally use for highway work is coarse-crushed, maximum size somewhere around $\frac{1}{4}$ in.

Gold

Some European countries use very fine salt, so tests run there would give results that are almost meaningless because there is not a wide range of particle sizes to get down to the interface.

Brohm

Our coarse-crushed salt specification, which is not much different from that commonly used in the United States, does permit a fair amount of fines. It covers a fairly broad band. You cannot really pin it down unless you have an analysis of the salt being used.

M. E. Volz

Apparently there is a great deal of discrimination among definitions of wet snow. Am I correct that your definition is snow with a water content in excess of 30 percent?

Schaerer

Wet snow is any snow that has a certain amount of liquid.

Volz

What amount?

Schaerer

Anything with 1 percent and more.

H. R. Kivisild

I noticed from the graph that traffic intensity has hardly any effect.

Schaerer

The tests were run up to a maximum of 4 hours immediately after snow deposition.

Glenn Balmer

We have made tests with a skid trailer on snow and obtained results very comparable to yours.

Schaerer

Thank you. That is very encouraging.