

Surface Friction and Stopping Distance on Icy Roads Mean Values and Sample Variability

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ABSTRACT

Abrasive materials are applied to icy or snow-packed roads to enhance traction in conditions where mechanical removal and chemical de-icing are not effective. A variety of new application methods and equipment were tested in efforts to optimize application rates and to develop end result specifications for winter maintenance.

A test apparatus in a cold room laboratory was used initially to examine a broad range of application methods. Key results were then examined in field situations. The spatial variability of friction on snow and ice covered surfaces was characterized, and measured friction values were compared with stopping distance to determine allowable sampling errors for statistically reliable comparisons between sand types, application rates and methods.

Results suggest that sand application rate had the most significant effect on stopping distance, while sand size gradation had no practical effect.

This information provides a quantitative basis for establishing end result specifications or quality assurance standards for winter maintenance on public roads. Specifications should take into consideration the initial friction values and the variability in friction as well as the rate of improvement with sand application.

INTRODUCTION

Sand is applied to icy road surfaces in Ontario when temperatures fall below approximately -12°C or in the presence of freezing rain, when chemical and mechanical de-icing become ineffective

(Perchanok, Manning and Armstrong, 1991). Approximately one million tonnes of winter sand are used annually on Ontario highways.

The cost of winter sand is a relatively minor component of maintenance operations, but sand application rates and retention of sand on the road after application have an important effect in other ways. The spacing of patrol and material storage yards, the spatial layout of patrol beats and thus the time delay in applying material to icy roads depend on the distances which can be covered by sand spreading vehicles before they have to reload.

A variety of changes to current practice are being evaluated to reduce the cost of sand spreading and other winter maintenance operations. Proposed changes to sand application include relaxing the material specification to increase the number of sources available and reduce supply costs, adjusting the size gradation or spraying the sand with liquid de-icer to improve retention in the presence of traffic, and reducing the application rate to reduce material quantities and also increase the distance covered by each truck. Laboratory and field programs have been conducted to test the effectiveness of these alternative application rates and methods, as shown in Table 1.

Preliminary field test results which were reported previously (Comfort and Dinovitzer, 1996) showed trends in road surface friction related to sand application rate, but were ambiguous concerning the effects of sand size gradation and the effects of pre-wetting. In most cases the degree of scatter in the experimental results made it difficult to interpret the results reliably. The purpose of this paper is to re-examine the experimental variation, and to present

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results from additional experiments using revised experimental procedures.

Table 1. Winter Road Surface Friction Research Program

<p>Comfort & Perchanok, 1995 -friction measured with pendulum device in laboratory tests on compacted snow and bare ice -parameters: sand application rate, size gradation, pre-wetting of sand, sand/salt mix ratio, anti-icing, salt application rate, pre-wetting of salt, test temperature, windspeed and material retention</p>
<p>Perchanok et al, 1995 -friction measured in the field with mechanical decelerometer on packed snow surfaces -parameters: sand application rate, pre-wetting of sand, traffic, temperature</p>
<p>Comfort & Dinovitzer, 1996 -friction measured in the field with electronic decelerometer and with Grip Tester trailer on packed snow and bare ice surfaces -parameters: sand application rate, size gradation, type, pre-wetting of sand, traffic, sunlight, temperature</p>
<p>Comfort, Dinovitzer & McIssac, 1996 -friction measured in the field with electronic decelerometer on packed snow and bare ice surfac's -parameters: sand application rate, size gradation, type, traffic, sunlight, temperature</p>

METHODOLOGY

Initial tests were conducted in a laboratory where the lateral resistance of a pendulum moving against an instrumented, icy or snowpacked surface was measured (Comfort, 1994). Selected laboratory results were re-examined in the field (Table 1) using test surfaces of natural snowpack, man-made snowpack and flooded ice on asphalt highways.

All laboratory and field tests made comparisons between test and control sections. Test areas on a given day were located or artificially prepared so that snow or ice conditions were visually homogeneous with similar shading, pavement irregularity, and exposure to wind and traffic. The control sections were left unsanded throughout the tests and the test sections were treated with sand according to the particular test matrix. Baseline

readings were obtained on all control and test sections prior to spreading of sand or trafficking of surfaces. Details of the test procedures are reported elsewhere (Comfort and Perchanok, 1995; Perchanok et al, 1995; Comfort and Dinovitzer, 1996; Comfort, Dinovitzer and McIssac, 1996). All data reported here are friction factors measured with an electronic recording decelerometer during locked-wheel skids.

Stopping distance is of more practical interest than surface friction to motor vehicle operators, and efforts were made to understand how these two parameters are related. A simple numerical model was developed which relates initial kinetic energy of the test vehicle to the work done by frictional forces while the car comes to rest during a locked-wheel skid (Comfort and Dinovitzer, 1996). This is:

$$d = v^2 / 2gu \tag{1}$$

where: d=stopping distance
 v=initial speed of test vehicle
 g=acceleration due to gravity
 u=friction factor

Laboratory Test Results

The laboratory tests showed mean friction values which are similar to those reported in the literature (Figure 1). Where multiple samples were obtained, the scatter of values during each test condition was large in comparison with differences between test conditions such as application rates or sand types (Comfort, 1994), and environmental factors such as sunlight and traffic could not be replicated in the lab.

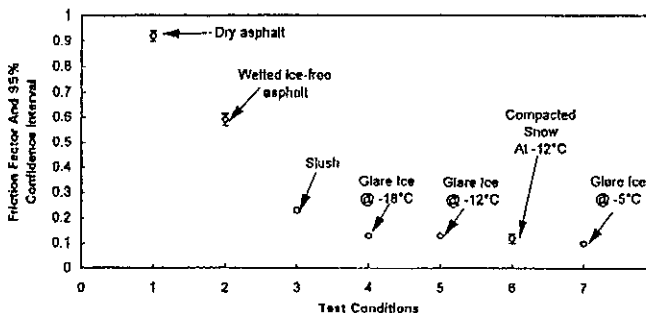


Figure 1. Laboratory friction data (Comfort, 1994)

Phase I Field Test Results

Field tests were undertaken to fully replicate

operational conditions and to provide estimates of the statistical reliability of the results. The layout of the field tests was intended to allow direct comparison of friction values between unsanded, control sections and nearby test sections. Initial results showed that direct comparison was not possible because of:

- a) variations in the baseline, unsanded friction factor between the control and test sections (Figure 2), and
- b) variations in the friction factor of the control sections over the duration of each test due to natural changes in the snow pack and to the effects of traffic (Figure 3).

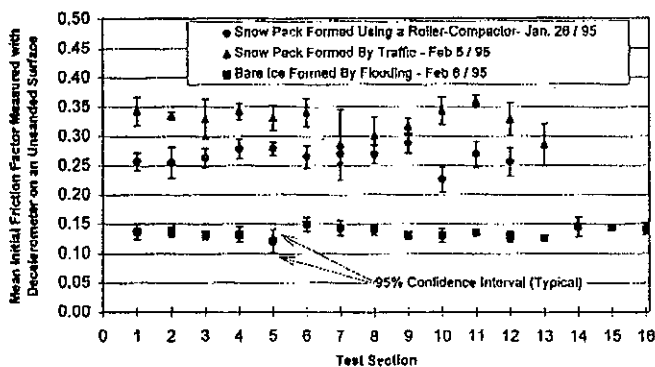


Figure 2. Typical baseline condition friction factors.

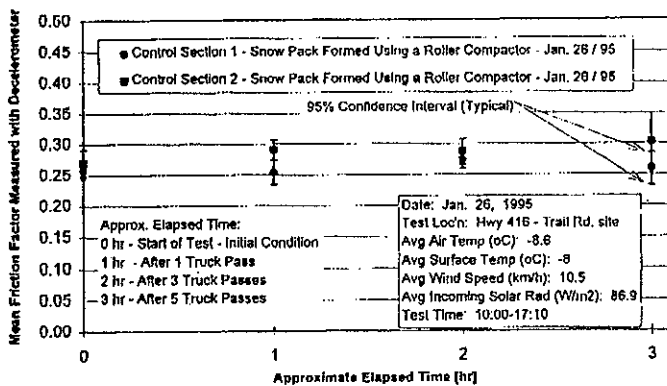


Figure 3. Change in baseline condition during a test period.

Typical examples of the unsanded, baseline friction shown on Figure 2 indicate that differences between baseline values on different tests sections during one test were in some cases significant. For example, initial friction factors on snow pack on sections 11 and 13 on Feb. 5 were significantly different at 95 and 99% confidence levels, as were initial friction values on bare ice on sections 13 and 15 on Feb. 8. This prevented direct comparison of friction factors on the test and control sections and

between test sections.

All measured values of sanded friction were therefore adjusted so that results from different test sections and times on a particular test day could be compared. Measured values on each test section on a test day were referenced to the average value of the control section at the start of that day (Comfort and Dinovitzer, 1996), as :

$$u_{\text{Adjusted}} = u_{\text{Measured}} - du_{\text{Initial}} - du_{\text{Control}}$$

where: u_{Adjusted} = adjusted friction factor for a particular test section and time sequence
 u_{Measured} = measured friction factor at current time
 du_{Initial} = (initial friction factor for test section) - (mean initial friction of control section)
 $du_{\text{Control Section}}$ = mean friction friction of control section at current time sequence.

Even after adjusting the raw data for changes in baseline friction between sections and at successive times during the tests, the large experimental error made interpretation of the results difficult. For example, Figure 4 compares adjusted friction values at various application rates and for three sand types, on packed snow and on bare ice. In both cases trends of increasing friction with application rate are clearly present but are not significant according to the differences between mean values for successive application rates. Trends are also present for the relative friction provided by different sand types but again are not supported statistically.

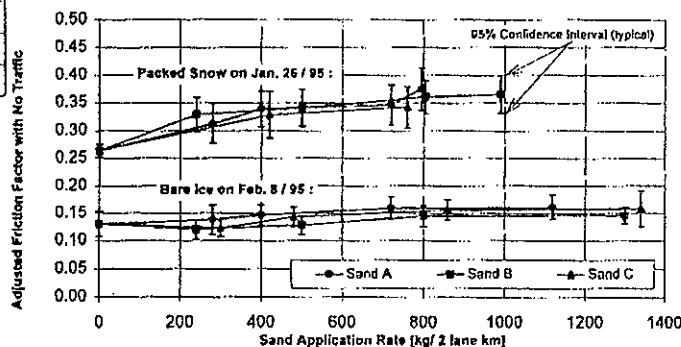


Figure 4. Effect of sand application on friction factor and confidence intervals, 1995.

Data collected in the Phase I experiments provided an understanding of the natural variability of surface friction and stopping distance on icy roads,

and were used to develop criteria for future experiments which would ensure that statistically reliable comparisons could be made. The mean friction factors for packed snow and bare ice were .26 and .12 respectively, with standard deviations of .033 and .021. The difference in samples scatter on the two surface types indicated that different sample sizes should be used on each surface type to achieve equal confidence limits.

The reliability of sample measurements was set at +/- 10% of the mean value within 95% confidence limits, and the 1995 sample variations showed that this required a minimum of 7 samples on packed snow and 14 samples on bare ice. Target sample sizes used in future tests were 10 for packed snow and 20 for bare ice to ensure that the above criteria were met (Comfort, Dinovitzer and McIssac, 1996).

Phase II Field Test Results

Some components of the test program were repeated using a larger number of samples as determined by the stopping distance analysis (Comfort, Dinovitzer and McIssac, 1996). Natural variation between adjacent control and test sections, and between measurements during the test period were again observed (Figure 5), although the confidence intervals were greatly reduced due to the larger sample sizes.

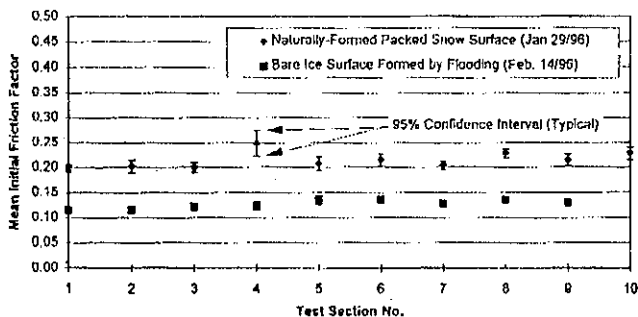


Figure 5. Variation in baseline condition on test sections.

The reduced confidence intervals provided a more reliable model for the increase in friction with sand application rate (Figure 6). In the example shown, differences in friction on packed snow provided by a natural sand (Elk Lake) and a manufactured sand of similar size gradation (B Sand) were not significant at 95% confidence limit, within the range of common application rates. Friction on packed snow increased rapidly with application at

low rates and less rapidly at higher rates, while no significant increase occurred on bare ice at applications below 420 kg/2-lane km.

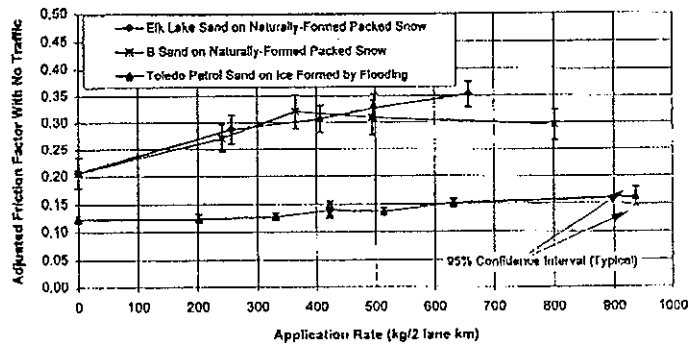


Figure 6. Effect of sand application on friction factor and confidence intervals, 1996.

The confidence intervals of measured friction were used to model the relationship between sand application rate and predicted stopping distance on packed snow and bare ice (Figure 7). The experimental method using different sized samples for the high friction (snow) and low friction (ice) surfaces resulted in similar confidence intervals for the two test conditions.

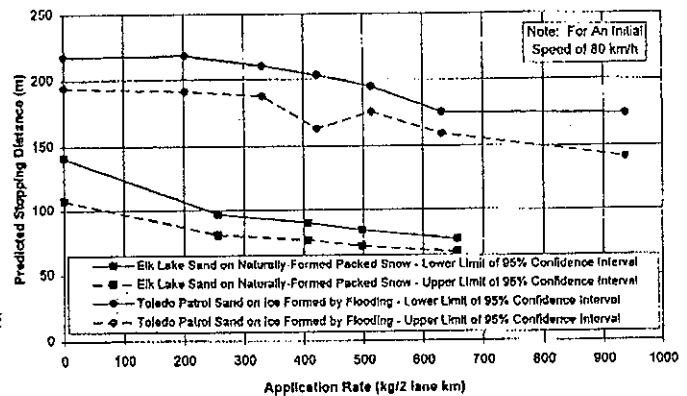


Figure 7. Stopping distance on snow and ice.

Stopping distance on bare ice was very sensitive to sand application rate in the range 200 to 600 kg/2-lane km, while stopping distance on packed snow was sensitive to application in the range 0 to 250 kg/2-lane km, falling only slightly with increasing application rate due to the form of relationship between friction factor and stopping distance. The confidence intervals for friction of sand on packed snow indicate that the variability in friction decreased as sand coverage increased. This suggests that increased homogeneity in sand coverage may be an important secondary benefit of increased sand application in addition to the increase in mean friction factor.

CONCLUSIONS

This study provides a methodology for establishing appropriate sampling characteristics in winter surface friction experiments and provides models for the increase in friction and reduction in vehicle stopping distance resulting from applications of winter sand.

Variability associated with field samples indicates that sample sizes of 10 on packed snow and 20 on bare ice surfaces are appropriate to discriminate differences which are significant within 10% of the mean value of stopping distance.

The observed trends and variability in friction have practical importance for the effect of sand application on stopping distance. In representative examples on snow-packed and ice-covered highway surfaces, the upper and lower 95% confidence limits of friction were associated with predicted, locked-wheel stopping distances of 105 to 154 metres and 190 to 220 metres respectively (Figure 7). Since the relationship between friction and stopping distance is exponential, small improvements in friction on ice have a much larger impact on stopping distance than similar improvements in friction on packed snow surfaces.

Stopping distance on packed snow was most sensitive to sand application rate in the range 0 to 250 kg/2-lane km, while stopping distance on ice was most sensitive to sand application in the range 200 to 620 kg/2-lane km.

Sand type or size gradation within the bounds of the existing size specification had no significant effect on friction or stopping distance.

The relationships between sand application and stopping distance can be used to develop friction-based specifications or quality assurance standards for winter maintenance. Specifications should also take into consideration the natural variability in unsanded friction factor and the effect of sanding on variability in friction as well as the mean value.

ACKNOWLEDGEMENTS

This work was supported by the Research and Development Branch, Engineering Materials Office and Maintenance Operations Office, Ontario

Ministry of Transportation. The authors thank Mr. C. Rogers, Mr. C. Rust and Mr. H. Blaine for discussions and guidance during the project. Significant logistical support was also provided by the Kingston, Ottawa, Thunder Bay and New Liskeard District offices and personnel, and by the Toledo, Kanata, Ignace and Elk Lake patrol offices.

Decelerometer data presented here were obtained with an instrument loaned to the project by Mr. T. Townsend and Mr. A. Mazur of Transport Canada Airports Group.

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