

Evaluation of Methods Used for Measuring the Slip and Skid Resistance of Permeable Interlocking Concrete Pavement under Winter Conditions

Jeffrey Marvin[1] and Jennifer Drake[2]

[1]MASc Candidate, Department of Civil & Mineral Engineering, University of Toronto, 35 St. George Street, Toronto, ON, M5S 1A4

[2]Asst. Professor, Department of Civil & Mineral Engineering, University of Toronto, 35 St. George Street, Toronto, ON, M5S 1A4

Correspondence e-mail address: jeff.marvin@mail.utoronto.ca

Abstract :

Snow and ice accumulation on pavement surfaces can create hazards for pedestrians (slipping) and vehicles (skidding). These hazards are typically mitigated by winter maintenance practices that remove snow and ice from pavement surfaces, such as plowing, or melt it by applying anti-icing/de-icing products. It has been suggested that Permeable Interlocking Concrete Pavement (PICP), which is a type of permeable pavement (PP) system that infiltrates stormwater and melted snow/ice between concrete pavers, through the joints, into an aggregate base layer and then into the ground below, may reduce the risk of slipping and skidding during winter months [1]. PICP systems have been demonstrated to function during the winter season in cold climates [2], and other PP systems have been shown to provide increased slip resistance during winter conditions due to faster melt rates and increased surface roughness [3,4]. However, the winter safety benefits of PICP have not been rigorously proven or demonstrated. Winter conditions present unique challenges for measuring the surface friction of pavements in the field, as snow and ice can create uneven surfaces, can be spatially and temporally variable, and can be shifted and melted by the friction measuring devices. This paper therefore evaluates the application of two friction measuring devices (Mark IIIB and SlipAlert) to PICP surfaces during winter field conditions in Vaughan, Ontario. Mark IIIB is an American tribometer certified to ASTM F2508 [5] that measures the transitional coefficient of friction by simulating the biomechanical movement of a pedestrian, whereas SlipAlert is a British tribometer adopted by BS 8204 [6] that measures the dynamic coefficient of friction by sliding a small car device across the surface. These two devices were used onin-field PICP surfaces throughout the 2017/2018 winter under surface conditions that include snow, ice, slush, wet and dry. The information provided by thewinter testing of the two devices will help guide future friction measurement practices for PICP such that their potential to reduce winter slip and skid hazards can more easily be evaluated.

Key Words : permeable interlocking concrete pavement; slip resistance; skid resistance; friction; tribometer; snow; ice; stormwater management low impact development

1. Introduction

Permeable Interlocking Concrete Pavement (PICP) is a type of stormwater management practice and permeable pavement (PP) system that uses its joint spaces to drain water from the surface into an aggregate base layer below. Because of this ability to rapid drain surface water, it has

been suggested that PICP may reduce the amount of ice formation compared to traditional impervious pavements, and in turn reduce the risk of pedestrian slipping and vehicle skidding during winter conditions [1]. While PICP has been demonstrated to function during the winter season in cold climates [2],and other PP systems have been shown to provide increased slip resistance during winter conditions due to faster melt rates and increased surface roughness [3,4], the safety benefits of PICP have not been rigorously proven or demonstrated. Additionally, winter conditions present unique challenges for quantifying pedestrian and vehicle safety on pavement surfaces, as most friction measuring devices are not designed to be operated on snowy and icy surfaces. This paper evaluates the applicability of two friction measuring devices, Mark IIIB and SlipAlert, to PICP surfaces when subject to snow, ice, slush and road salt in a controlled outdoor environment. However, an evaluation of the winter slip and skid resistance characteristics of PICP is not included in this paper, as ongoing research on the topic is still being carried out using the two devices.

Mark IIIB is an American tribometer certified to ASTM F2508 [5] that measures the transitional coefficient of friction (COF) by simulating the biomechanical movement of a pedestrian when slipping on a surface. The device is operated by iteratively adjusting the angle of a rubber test foot with respect to the pavement surface until the test foot slips when launched from the device. SlipAlert is a British tribometer adopted by BS 8204 [6] that measures the dynamic COF by simulating the sliding action of a vehicle. The device consists of a small model car with a rubber slider on its bottom and is operated by recording the distance that the car travels over the pavement surface after it is launched down a ramp. The intent of this research is to provide information on the winter usability and challenges of these two devices to help guide future friction measurement practices for PICPunder winter conditions.

2. Methodology

Surface friction was measured using Mark IIIB and SlipAlert throughout the 2017/2018 winter at a controlled outdoor PICP test site located in Vaughan, Ontario, Canada that had no pedestrian or vehicular traffic. The test site consisted of four 2 m by 2 m PICP plots and an asphalt control plot, each receiving de-icing treatments following snow events, as shown in Table 1. The asphalt plot was sloped at 2% to allow for meltwater to drain to a catch basin. Friction measurements were collected on each plot before salting, after salting and at various time intervals until the pavements were dry. Five replicate measurements were collected for each device at different locations on the plots, which provided an overall spatial representation of the entire surface.

Table 1. De-Icer Type and Application Rate for Each Test Plot.

Test Plot	De-Icer	Application Rate
Asphalt Control Plot	Road Salt	Standard (10 lb/1000ft^2)
PICP Plot 1	Road Salt	Standard (10 lb/1000ft^2)
PICP Plot 2	Road Salt	Low (5 lb/1000ft^2)
PICP Plot 3	Road Salt Pre-Wetted with Beet Juice	Standard (10 lb/1000ft^2)
PICP Plot 4	Road Salt Pre-Wetted with Beet Juice	Low (5 lb/1000ft^2)

Mark IIIB and SlipAlert were selected as the friction measurement devices for this study since measurements needed to be collected within a 2 m length, rapidly, with minimal disturbance to surface conditions and with minimal operator error. These criteria eliminated the use of other friction measuring devices that collect long continuous measurements, require a large amount of adjustments or do not easily collect repeatable measurements. The friction devices also needed to represent both pedestrian slipping and vehicle skidding. While many friction measuring devices including SlipAlert represent vehicle skidding by measuring the dynamic COF, few devices such as the Mark IIIB represent pedestrian slipping by measuring the transitional COF. Photos of the Mark IIIB and SlipAlert at the PICP test site are shown in Figure 1.



Figure 1. (a) Mark IIIB; (b) SlipAlert.

3. Results

A sample of the friction measurements collected usingMark IIIB and SlipAlert for one of the salting events (February 5, 2018) is presented in Figure 2. For reference, a minimum dynamic COF of 0.42 measuring using a BOT 3000-E is specified by ANSI A326.3 [7] and a corresponding Pendulum Test Value of 40 specified by BS 8204 [6] for pedestrian safety on indoor flooring. The February 5 event presented in Figure 2 was selected for discussion since it presented the most representative results of this past winter and was not subject to external factors such as positive airtemperatures or salt remains from previous events. As shown in the figure, friction increased on all PICP plots within 30 minutes after salting. A similar increase in friction on the asphalt plot was found only for dynamic friction, as transitional friction was already relatively high prior to salting. The higher initial transitional friction on the asphalt was likely attributed to how the snow was compacted within the asphalt texture, whereas initial snow on the smoother PICP surfaces resulted in significantly less transitional friction.

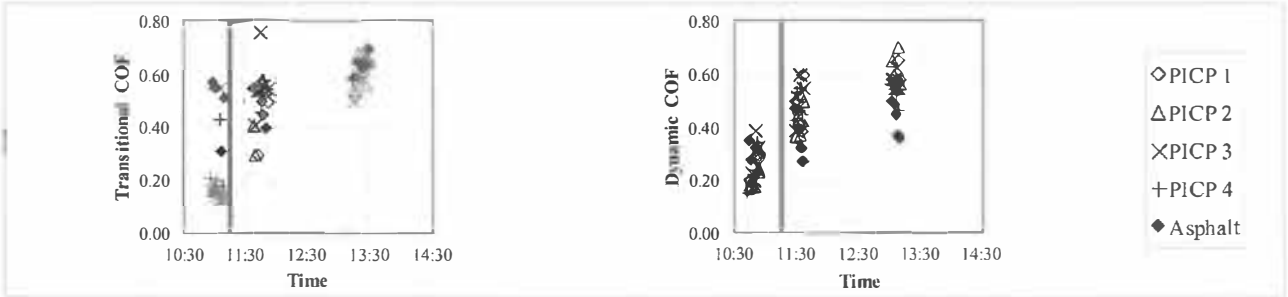


Figure 2. Sample Mark IIIB and SlipAlert friction measurements for February 5, 2018 salting event.

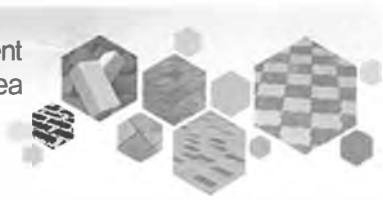
05_ Skid resistance of BP

After salting, transitional friction was similar between the PICP and asphalt plots, whereas dynamic friction was higher on the PICP plots. While snowmelt rates after salting were visually observed to be more rapid on the PICP surfaces during thisevent, this observation was only reflected in the SlipAlert measurements. The discrepancy between surface snow conditions and transitional friction can be partially explained by the presence of salt particles, as the Mark IIIBtest foot was observed to crush the salt particles every time it was launched. The test foot then slid along the resulting thin layer of crushed salt particles whenever a slip occurred. Based on friction measurements collected on dry pavement with salt (not shown), the thin layer of crushed salt was found to impact the PICP surface more than the asphalt surface, as small depressions between the asphalt aggregates were observed where the crushed salt particles would fall into and avoid contact with the test foot. Since all Mark IIIB measurements for the PICP plots were collected on the paver surfaces rather than over the joint spaces, the paver joints had no impact on transitional friction measurements.

While the higher dynamic friction measured on the PICP plots after salting corresponded to visual observations of reduced snow on the surface, the lower dynamic friction measured on the asphalt plot can be partially attributed to SlipAlert being launched on slopes ranging from flat to 2%. Furthermore, no correction was made to these measurements, as adjustment values for using SlipAlert on inclines are only provided for slopes of 3.5% and greater. The slope of the asphalt was not a factor when using Mark IIIB, as the small area needed for Mark IIIB allowed for measurements to be collected along the cross-slope. However, since sloped surfaces are known to increase sliding hazards, the distance travelled by the SlipAlert car can potentially also be used as a metric for quantifying sliding hazards on sloped surfaces.

Snow and ice on the PICP generally melted evenly through the paver joints, whereas melting on the asphalt surface would first occur within the steepest area of its slope, which was then followed by melting at the bottom of the slope next to the catch basin. Because of this, small isolated patches of ice and snow would frequently be present on the asphalt and were sometimes missed by the locations selected for friction measurements. These locations were more commonly missed while using Mark IIIB since the device collects point measurements. Thus, additional measurements (not shown) were collected on the asphalt using Mark IIIBto quantify the hazard of these isolated patches when present, as these patches represent locations where pedestrians could slip on a surface that is otherwise clear of winter hazards. However, some of the isolated thick layers of ice on the asphalt plot could not be accurately measured using Mark IIIB due to unevenness.

Both friction devices were visually observed to disturb the surface conditions of the pavement when snow and slush were present. This was particularly problematic with Mark IIIB, as the test procedure requires launching the test foot at estimated angles until the test foot slips. Each time the test foot was launched on snow or slush, it provided compaction and heat transfer. When the test foot slipped, it pushed the snow and slush away from the point of impact.Because of these disturbances, a good initial estimation of the angle that causes the test foot to slip wasneeded to minimize the number of launches and acquire a representative friction measurement. Furthermore, once a slip occurred, the test location was considered unusable for future measurements. With SlipAlert, the friction measurement is collected by a single launch of the car, causing less disturbance to the surface conditions. However, the area disturbed by SlipAlert is much larger than the area disturbed by Mark IIIB due to the long slidingpath needed for the SlipAlert car. The



compaction, displacement and heating of surface conditions by SlipAlert along its path was therefore more widespread on the test plots. Thus, SlipAlert has the potential to highly disturb surface conditions at single points on the surface, whereas SlipAlert has the potential to disturb surface conditions to a lesser degree but over a larger area.

Finally, friction tests carried out under ice, snow, slush and wet surface conditions ensured that the rubber test foot/slider remained wet for subsequent tests, providing conditions representative of footwear and tires after a snowfall event. However, the rubber test foot/slideralso needed to be lightly wiped to remove collected ice, snow, slush and salt to prevent contamination of subsequent measurements. If a friction test was carried out on a dry surface where the meltwater has drained and evaporated, the test foot/slider first needed to be fully dried.

4. Conclusions

The Mark IIIB and SlipAlert friction measurements collected during the 2017/2018 winter at the PICP test site showed how these devices can be applied to winter surface conditions. Mark IIIB allows for the less common measurement of transitional friction to be estimated, but its measurements take longer to execute, can disturb winter surface conditions and are highly impacted by the presence of salt particles. The device can, however, be successfully applied to winter PICP surfaces if the initial estimate of transitional friction is slightly higher than the final measured value and if salt particles can be avoided during measurement. Mark IIIB also has the advantage of being able to collect spot measurements on isolated patches of ice and snow, as these locations pose safety concerns for pedestrians and vehicles on pavements that have otherwise less hazardous surface conditions.

Unlike Mark IIIB, SlipAlert does not require iterative measurements and can therefore be used rapidly with less disturbance to surface conditions, and SlipAlert measurements are less impacted by the presence of salt particles. SlipAlert can also be used to quantify skiddingdistances on a sloped surface in addition to measuring dynamic friction. Overall, the two devices can successfully provide measurements of transitional and dynamic friction on winter surface conditions for PICP when used in the context of the limitations described above.

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