Performance evaluation of Porous Rubber Pavement (PRP) in the Canadian climate

Tamanna Kabir
Ph.D. Candidate, Department of Civil and Environmental Engineering, University of Waterloo

Abimbola Grace Oyeyi
Ph.D. Candidate, Department of Civil and Environmental Engineering, University of Waterloo

Hanaa Al-Bayati
Ph.D., Post Doctoral Fellow, Department of Civil and Environmental Engineering,
University of Waterloo

Susan Tighe
Ph.D., PEng, FCAE, FCSCE, Deputy Provost and Associate Vice-President Integrated Planning and Budgeting, Norman W. McLeod Professor in Sustainable Pavement Engineering,
University of Waterloo, Ontario, Canada

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Abstract

Permeable pavements are becoming popular in North America, especially in the last decade. Permeable pavements are considered as a low environmental impact design and beneficial for best stormwater management practice. Porous Rubber Pavement (PRP) is a comparatively new addition to this type of pavement, which is currently utilized on low traffic areas and pedestrian walkways as a surface material. PRPs have been used as a surface wearing course for abating the road noise in a few European and Asian countries. The constituents of PRPs are stone aggregates, crumb rubber from recycled tyres, and polyurethane as the binder. As a new pavement material in North America, its performance has not yet fully quantified for this climatic condition. Because of its higher permeability (27% to 29% of voids), this material can be highly beneficial for preventing hydroplaning, glare, spray and splash on the road surface during surface runoff. Also, as a result of its flexible nature, it has de-icing capability by deformation of ice on its surface layers. As part of an extensive study on PRP material, an initial field performance evaluation was conducted on a commercial parking lot located in Kitchener, Ontario, Canada. In this study area, PRP was used as surface material. This paper presents some results obtained during these investigations with a focus on surface roughness, permeability and surface distress of PRP pavements. Two equipment, SurPRO and Dipstick, were employed to investigate pavement roughness in terms of the International Roughness Index (IRI). The average IRI of the PRP surface was found to be 10 m/km. The average infiltration rate was found to be 30836 mm/h. Ravelling (disintegration of material from the surface) was the significant surface distress observed during visual distress evaluation. Though the PRP shows widespread benefits in terms of environmental and safety issues, there is an opportunity to improve its performance as a pavement material after a thorough evaluation, which can make PRP a good candidate for the low impact pavement surface. Thus, this investigation can be the basis for the future improvement of this material.

Keywords: Porous Rubber Pavement, Stormwater management, Roughness, Permeability, Surface distress

Introduction

With the building of roads, parking lots, driveways and other similar kinds of structures, impermeable surfaces are expanding in cities. These impermeable surfaces are leading towards increased volumes and rates of stormwater runoffs along with accumulation and wash-off from a variety of contaminants. While conventional impermeable paving materials interrupt the natural hydrological system by replacing the natural soil surface, permeable pavement can reduce surface runoff, maintain the underground water table and improve water quality by its filtering capability. Along with the beneficial attributes of permeable pavements for best stormwater management practice, they have widespread environmental and safety benefits (Schaus, 2007).

Permeable pavements have become more common in North America over the last decade. The most common permeable types of pavement in the North American cold climatic region are pervious concrete, porous asphalt and permeable interlocking concrete pavers (Drake, Bradford, Seters, & MacMillan, 2012; Hein, 2014). Porous Rubber Pavement (PRP) is a comparatively new addition to these types of pavements. This material consists of rubber aggregates, granite aggregates and polyurethane as a binder and is proportioned in to attain a very high content of interconnected air voids. PRPs can have a very large percentage of interconnected air voids. This percentage can be up to 40% depending on the variation in the percentage of different components and compaction effort applied during placement (Wang et al., 2017). Besides, the use of a substantial amount of crumb rubber makes PRP a highly elastic material. Because of its very permeable nature, PRP pavements could be remarkably beneficial for preventing hydroplaning, glare, spray and splash on the road surface during surface runoff. Additionally, both permeability and elasticity contribute to better tire-road noise reduction performance than other types of conventional pavements (Kalman, Biligiri, & Sandberg, 2011; Persuade, 2015). Also, as a result of its flexible nature, it has de-icing capability by deformation of ice on its surface layers, which can reduce snow accumulation on the pavement surface in winter (Wang et al., 2017).

In North America, PRPs are used on low traffic roads and pedestrian walkways as a surface material. It should be noted that this application is in limited areas only like, pathways, driveways, patios, playgrounds etc. However, as a pavement material, its performance is still unexplored for the North American climate. Till to date, no research has been found in the literature that investigates PRPs for North America. Thus, the properties of PRPs and their performance as a pavement material are still not fully quantified and understood.

Scope

The main objective of this study is to provide information on the current performance of existing PRPs which will inform decisions that will enable the improvement of PRPs for the Canadian climate as a pavement surface material for low trafficked areas. This paper presents part of a field investigation, which is a portion of a wide-ranging research. Particularly, surface roughness, infiltration capability and visual distress evaluation from existing PRP pavement are analyzed.

Methodology

The paper is based on the analysis of the in-situ field performance of PRPs in terms of surface roughness, infiltration capability or permeability and surface distress. For surface roughness, the SurPRO walking profiler and Dipstick were used. Using NCAT permeameter, the permeability of the test surface was investigated. Surface distress was evaluated following The Ontario Ministry of Transportation (MTO) 's SP-024 manual.

Test equipment

SurPRO is an effective device for measuring surface profile and roughness characteristics of any placed surface. SurPRO uses a rolling inclinometer and measures longitudinal and transverse profiles of a travelled surface (Multipurpose Surface Profiler Operating Manual, 2014). The instrument can be operated at a constant walking speed up to 2.5 mph (Nazef, Mraz, Scott, & Whitaker, 2008). Inclinometers of the SurPRO determine the elevation changes between its two wheels and produce profile data of the surface (Pickel, 2018). Then using ProVAL software, this profile data is converted into IRI value of the tested surface.

The Dipstick is another inclinometer-based profile measurement device, which is traditionally used for profile verification (Karamihas, 2005). The instrument is supported by two legs, which are 305 mm (12 in) apart from each other. Two digital displays at the two ends of the instrument read the elevation of the leg relative to the other leg. The operator walks along the pre-marked surface by alternately pivoting the instrument about each leg (Nazef et al., 2008; Pavement Tools Consortium, 2019). The International Roughness Index (IRI) is calculated automatically from the recorded measurements.

NCAT Asphalt Field Permeameter was used to determine the water infiltration rate. This equipment has four tires of clear plastic. The bottom tire has the largest cross-section, and cross-section reduces gradually for upper tires. Permeameter needs to be sealed temporarily at the surface. Then, a given mass of water is poured into the ring, and the time required for the total water infiltration is recorded. To follow the test standard ASTM - C1701/C1701M, the diameter of the bottom tire is considered. According to test standard ASTM - C1701/C1701M – 17a, at least three test points are recommended for a test area of 2500 m^2. Since the infiltration rate from each point is valid for the localized areas, to determine the infiltration rate of the entire site, the average value should be taken (ASTM C1701/C1701M−17a, 2017). The test points need to be selected in such a way that the first point is near the corner where pores can be clogged, the second point in the middle of the surface, and the third point near the edge where soil or debris can be transported easily (Valeo & Gupta, 2018).

Surface distress evaluation

Following The Ontario Ministry of Transportation (MTO)'s SP-024 manual for condition rating of flexible pavements, surface distress is assessed (Chong, Phang, & Wrong, 2016). According to the manual's guideline, a visual inspection should be conducted to identify different types of distresses. Afterward, the severity and density of those distresses are categorized according to the guideline. Measurements of those distresses are also taken during the inspection along with photographs for future reference. Surface distress evaluation helps to rate the surface condition and evaluates its ability to provide expected service to the users (Chong et al., 2016).

Material properties

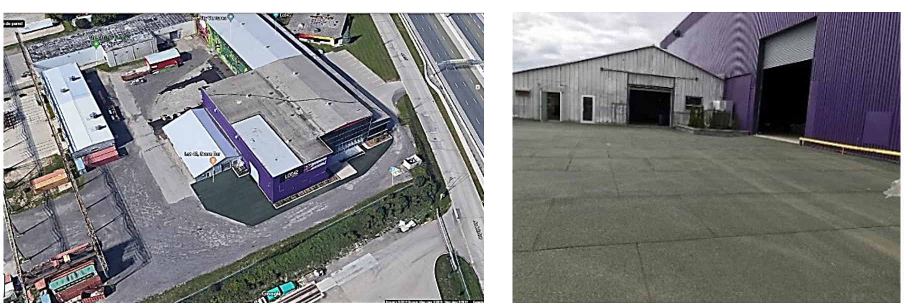
In most of the current practices in North America, PRP consists of 45.25% of recycled tires, 45.25% of stone aggregates and 9.5% of polyurethane binder by weight. Typically, it contains 27% to 29% interconnected voids by volume. Crumb rubber chips of the consistent size of approximately 6.35mm (1/4") to 9.5mm (3/8") are usually used for PRPs. For stone aggregates, cleaned and kiln-dried stone aggregates of the consistent size of 9.5 mm (3/8") to 19 mm (3/4") are used. Usually, granite is used to avoid water absorption by aggregates, which is detrimental for bonding with polyurethane binder (Porous Pave Inc., 2017). Polyurethane binder is a polymer where carbamate (urethane) links join organic units. Moist cured polyurethane binder is solid at room temperature. In this study area, a B5HN polyurethane binder was used.

Study area

Field tests were conducted on a commercial driveway and parking at Kitchener, ON (otherwise referred to as Study area), as shown in Figure 1 and Figure 2.

Figure 1: Study area

The field test was conducted on October 24, 2019, from 10.00 am to 1.00 pm. At that period, the temperature was $11^{o}C$, and humidity observed 66%.

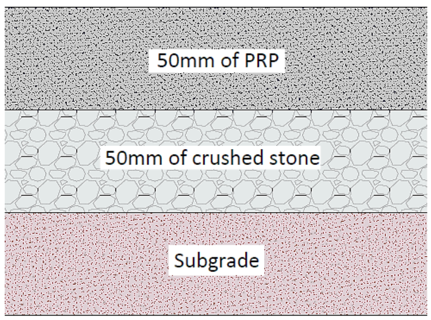


(a) Google earth view of the site *(b) Front view of the site driveway after construction*

Figure 2: Photos of the study area
Source: After construction photo, Porous Pave Inc

This parking lot was constructed between July and August of 2017. Within a year of construction, ripples or corrugation was observed on parts of the parking lot. So, the damaged part was cut and replaced by new material using the same construction techniques.

In this study area, 50mm (2") of PRP material was used over 50mm (2") of the clean crushed stone subbase. For the PRP surface, a typical standard PRP mix was used. Both structure and mix design are shown in Figure 3. The adjacent areas outside the driveway area consisted of either concrete or crumbled asphalt. Figure 4 shows the detailed plan of the study area with surrounding structures. Heavy traffic areas on the PRP pavement are highlighted with the hatch on the detailed plan.



(a) Structure of study area

Components	% by weight
Rubber Granules	45.25
Granite Aggregates	45.25
Polyurethane binder	9.5

(b) Components in mix

Figure 3: Structure of the pavement in the study area

Figure 4 shows a paved area with PRP by bold black lines. The pavement material of the surrounding area is also shown here. Points P-1 to P-20 indicates the points that were tested within the PRP area. Points 'P-e-c' indicate the edge points, where outside of the edge is concrete pavement. Points 'P-c' and 'P-ca' indicate the points that are on the concrete surface and crumbled asphalt surface, respectively. The typical traffic type in the study area is delivery trucks and passenger cars.

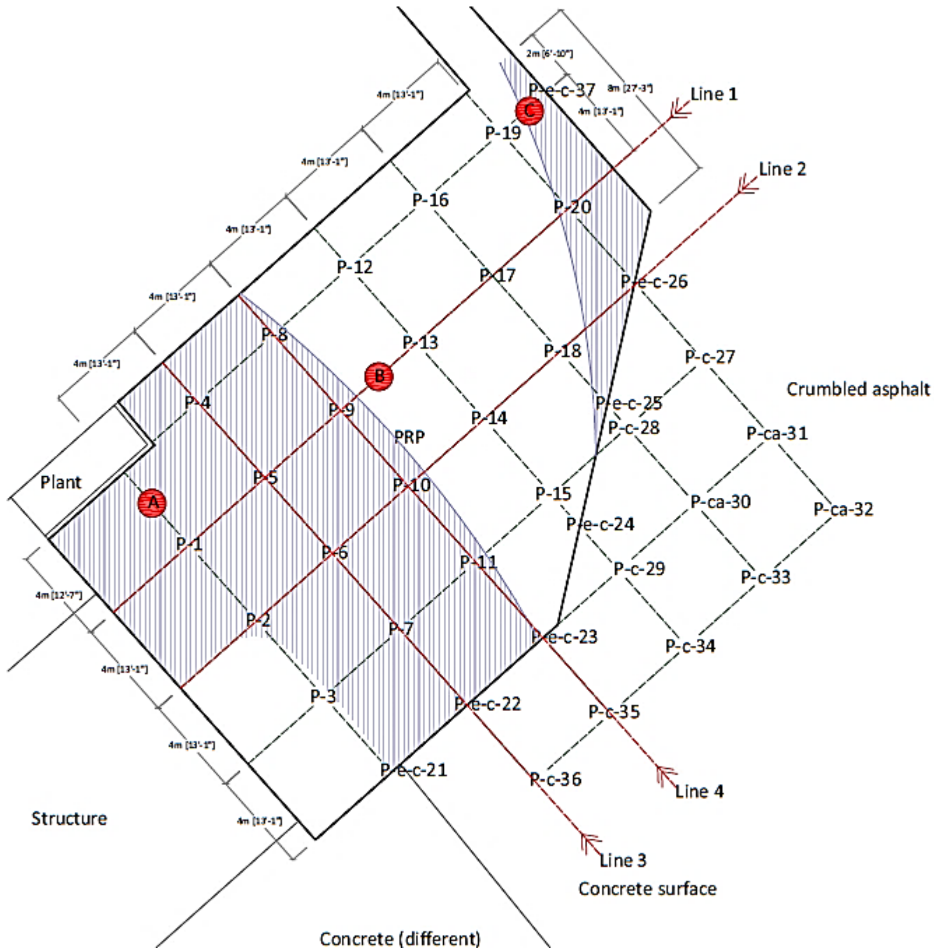


Figure 4: Detail plan of the study area

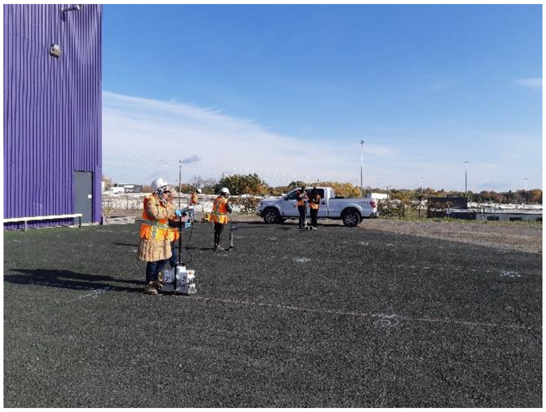
Figure 5 shows the preparation of the study area for testing according to the plan shown in Figure 4.

Figure 5: Site preparation for testing according to plan

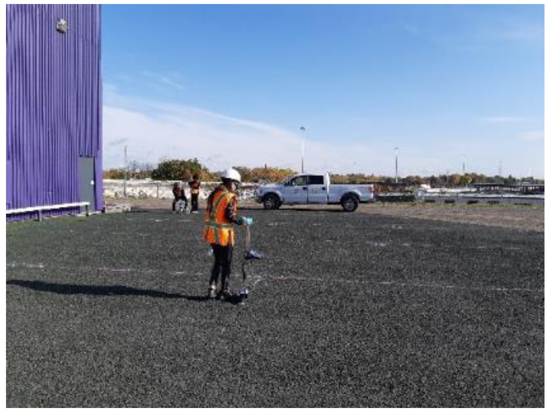
Results

Roughness evaluation

The roughness of the PRP surface at the study area was evaluated by using two equipment, i.e. a walking profiler (SurPRO 2000) and Dipstick, as shown in Figure 6.



(a) SurPRO 2000



(b) Dipstick

Figure 6: Surface roughness evaluation

IRI value is an indication of surface roughness. Figure 7 can be used for interpretation of the IRI values obtained from field testing. Where an IRI value of 0 m/km signifies absolute smoothness and 8 m/km represents a rough surface of an unpaved road (Sayers & Karamihas, 1998).

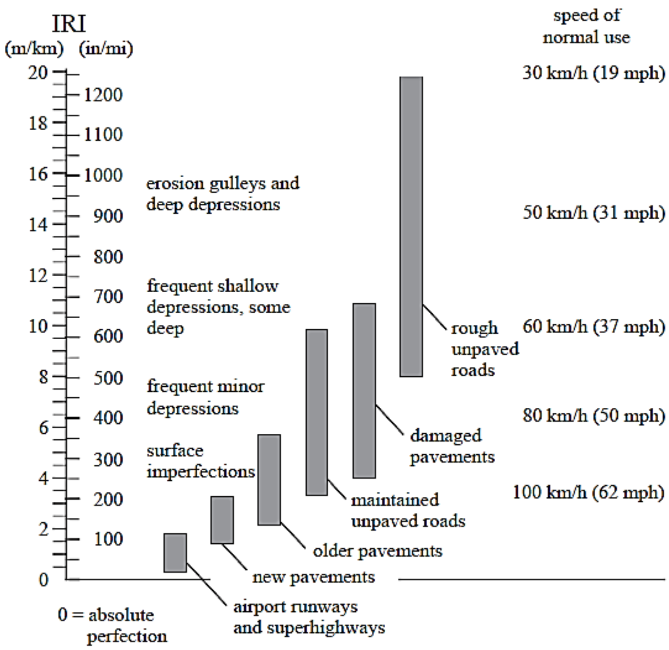


Figure 7: Pavement condition indication by IRI
Source: (Sayers & Karamihas, 1998)

As shown in Table 1, for both SurPRO and Dipstick, the same lines on the pavement surface were used. Tested lines can be identified in Figure 4 using Table 1.

Table 1: Location points for SurPRO and Dipstick testing

	Line 1	**Line 2**	**Line 3**	**Line 4**
SurPRO and Dipstick line connects	P-1, P-5, P-9, P-13, P-17, P-20	P-2, P-6, P-10, P-14, P-18, P-26	P-4, P-5, P-6, P-7, P-22	P-8, P-9, P-10, P-11, P-23

Both types of equipment give a very high average IRI value for the pavement surface, which is 10 m/km. SurPRO results showed a higher standard deviation, whereas Dipstick results showed more consistent values. Higher standard deviations for SurPRO data could be due to continuous measurements and the presence of surface distress. However, ANOVA analysis indicated that there was statistically no significant difference between the results from both types of equipment (P-value 0.6). The average IRI for each line was also high. Probably under traffic loading, settlement occurred in the base layer. Besides, the construction method, which was not fully mechanized, may have caused unevenness on the surface. For line 3, the average IRI was higher than the rest of the lines. The reason could be that the line fell on the high traffic area, according to Figure 4 (hatched area). Also, it could be the attribution of transverse cracking, depression, severe ravelling observed during surface distress evaluation along that line, as shown in Figure 10 and Table 5. Unfortunately, there was no initial IRI evaluation performed for the pavement immediately after construction to serve as a baseline for comparison with current IRI values, however, it is assumed that these values were lower than what is currently observed due to the nature of distresses that presently exist.

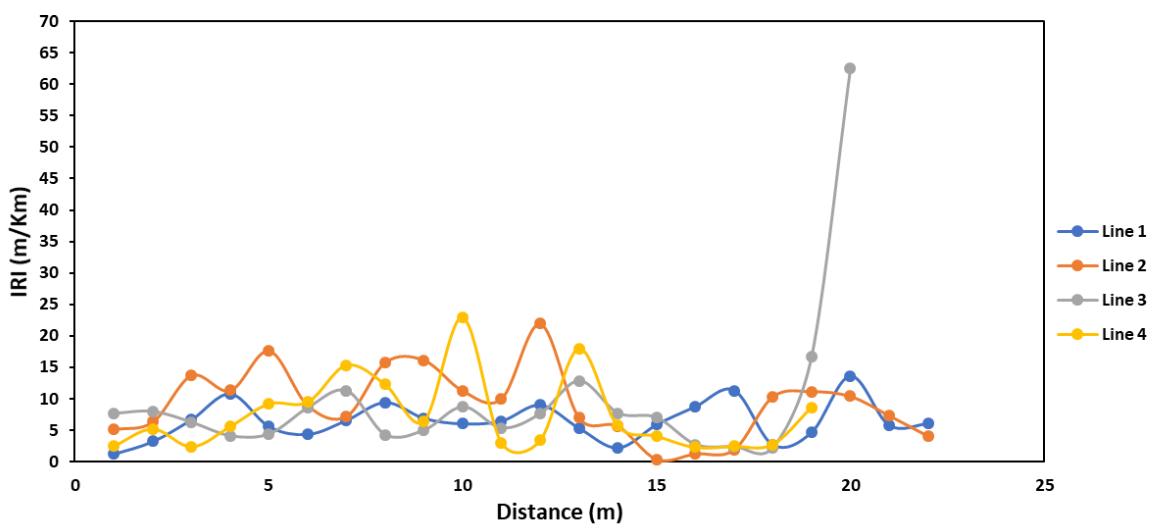


Figure 8: IRI result obtained from SurPRO

Table 2: Result from SurPRO

Line	Average IRI (m/km)	Standard deviation
1	6.52	3.24
2	9.18	5.67
3	13.41	20.55
4	8.68	6.21

Table 3: Result from Dipstick

Line	Average IRI (m/km)	Standard Deviation
1	7.56	0.23
2	10.25	0.10
3	15.77	0.07
4	8.93	0.83

Permeability Test

NCAT Asphalt Field Permeameter was used to determine the permeability of the surface at the study area, as shown in Figure 9. According to the test standard ASTM - C1701/C1701M − 17a, three points were selected for testing; A, B, and C. Point A was close to point P-1, as marked on the surface before the test. Point B was on the connecting line of the point P-9 and P-13. Point C was very close to the point marked as P-19 (see Figure 4). The points' locations are also given in Table 4. The test area of the study was around $397.78m^2$, for which testing three points was considered sufficient. Since the infiltration rate from each point is valid for the localized areas, the average value should be taken to determine the infiltration rate of the entire site (ASTM C1701/C1701M−17a, 2017). In some cases, if the adjacent areas are unsaturated water may spread to the adjacent areas. However, during this test, it was found that due to very high permeability, the water did not spread under the plate, instead, it immediately passed through the material.

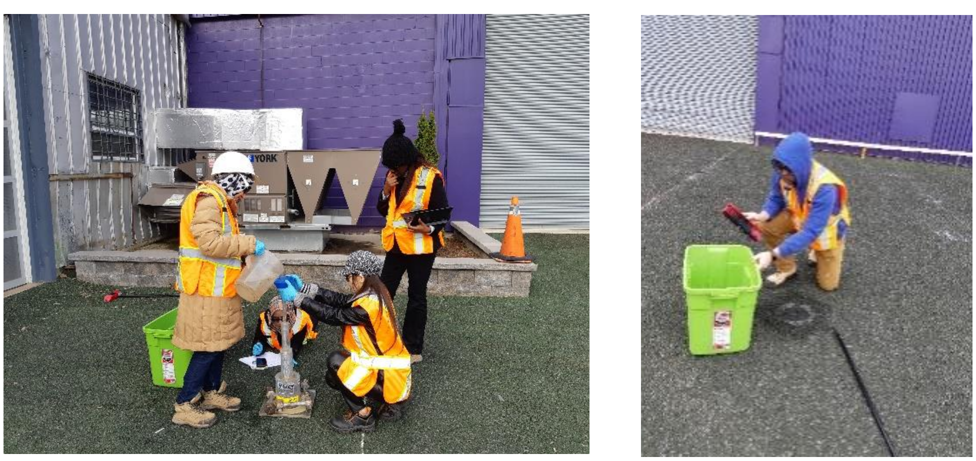


Figure 9: Permeability testing in the study area

The result of the permeability test is presented in Table 4. Point A and B showed a higher infiltration rate compared to point C. Since point C is close to the edge of the pavement surface, the probable reason could be the clogging of pores by debris. The average infiltration for the surface was 30836 mm/h. The intensity duration frequency data for short duration rainfall shows that the maximum rainfall rate observed for Canada was 298.8 mm/hr (Environment Canada, 2019; Henderson, 2012). The permeability rate of this pavement surface was much higher than this value. So, the permeability rate seems to be adequate for the study area. However, no hydrological design was considered during the construction which would ensure that pavement's storage or reservoir layer is thick enough to store rainwater for a given period of time and then slowly dissipate it to the subgrade soil. Thus, it was not possible to evaluate the hydrological design of this pavement.

Table 4: Result from Field Permeameter

Point's name	**Infiltration rate, I (mm/h)**
A (Close to P 1)	35508
B (Between P 9 and P 13)	32085
C (Close to P 19)	24915
Average	30836

Surface distress evaluation

There was no adverse structural issue observed during the distress survey. The major concern was ravelling (Figure 10, Figure 11 and Table 5). Most of the PRP surface was affected by ravelling. Lack of adhesion between crumb rubber aggregates and stone aggregates might have contributed to this abrasion loss. Another possible reason could be the rate of compaction or the compaction effort. During construction, only little compaction effort was applied, which may increase the probability of ravelling on the pavement surface. Besides, the turning movement of vehicles may also have contributed to this ravelling. Other than that, very slight rutting and longitudinal cracking were observed. Slight rutting could be the result of a settlement in the base layer. Sometimes for permeable pavements, water infiltration may deteriorate the situation.

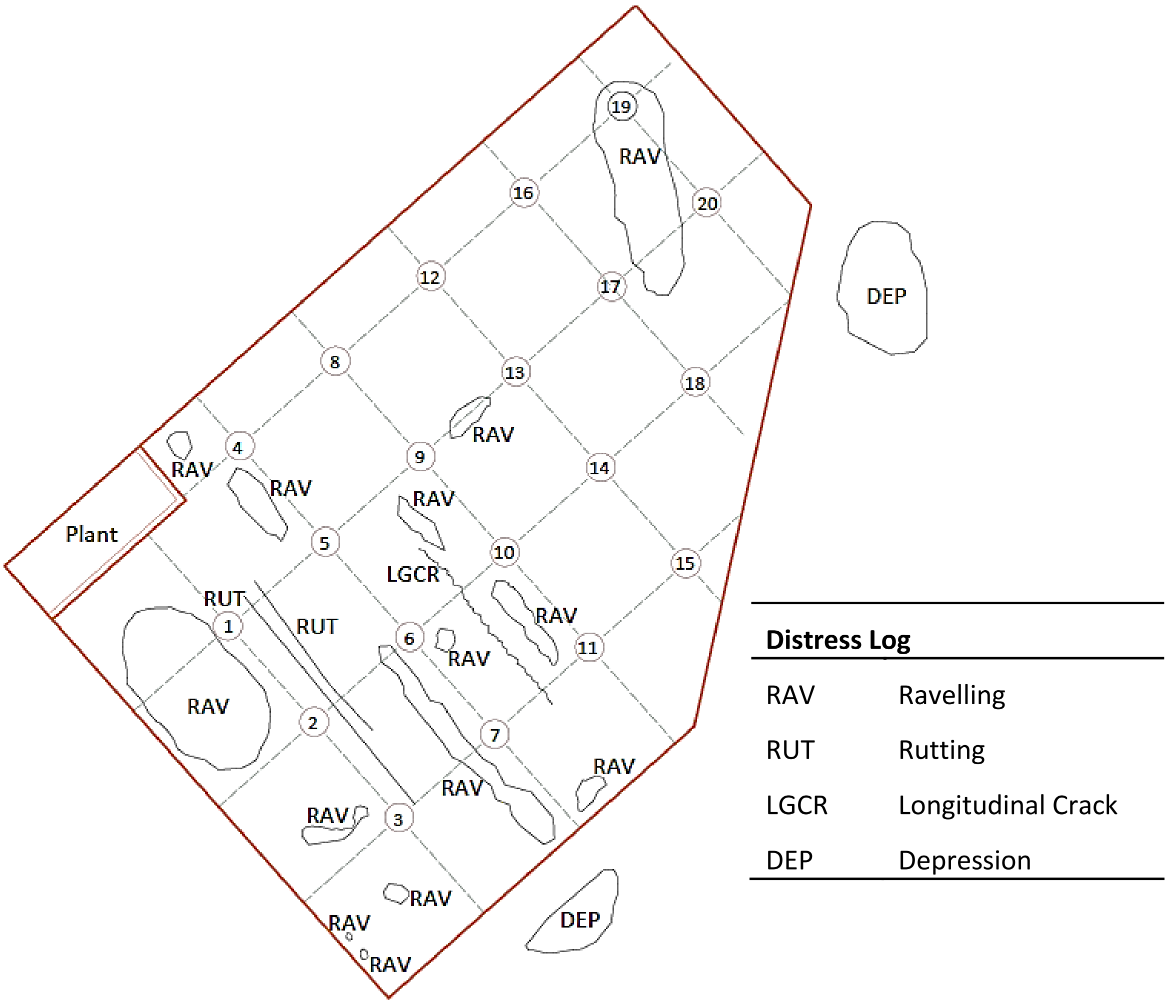


Figure 10: Surface distress mapping for the study area

(a) Ravelling *(b) Rutting*

Figure 11: Surface distress at the study area

Table 5: Surface distress evaluation of Site 2

Section	Distress manifestation	Distress type	Severity	Extent	Description
Study area	**Surface defects**	Ravelling	3 (Moderate)	20 to 50% pavement surface affected (Frequent)	Having a pock-marked appearance. Shallow disintegration of pavement surface on most of the area.
		Ravelling	4 (Severe)	<10% of surface area (Few)	Disintegration with low severity potholes. Mostly in the heavy traffic area.
	Permanent deformation	Rutting	1 (Very slight)	< 10% area affected (Few)	Barely noticeable, less than 6 mm. Measured rutting is 2 mm.
		Rutting	2 (Slight)	< 10% area affected (Few)	6 to 13 mm without a single longitudinal crack. Measured rutting is 8 mm.
	Cracking	Longitudinal crack	2 (Slight)	< 10% area affected (Few)	Single crack from 3 mm to 12 mm. Measured 4 mm.

Conclusion

This paper investigates the performance of the existing pavement surface constructed with Porous Rubber Pavement. The study area was located at Kitchener, ON. The result of surface roughness, permeability and distress evaluation are presented and analyzed in this paper. The roughness of the pavement surface was evaluated by using the SurPRO walking profiler and Dipstick. Results from both types of equipment were compared to validate the result. NCAT permeameter was employed for permeability testing. Surface distress was evaluated by visual inspection. The result can be summarized as,

- The IRI value found from SurPRO was between 6.52 m/km to 13.41 m/km, and for Dipstick, this value was between 7.56 m/km to 15.77 m/km. There was statistically no significant difference between the results from the two equipment. The average IRI value was found to be 10 m/km.

- IRI value found higher under the wheel path, heavy traffic areas and areas where visible surface distresses were observed. Settlement in the base layer and construction method is probably contributing to the high IRI value. Besides, severe ravelling could also have contributed to the higher IRI value.

- The average infiltration rate found for the pavement surface area was 30836 mm/hr, which is significantly higher than the highest rainfall rate in Canada.

- Most visible surface distress for the PRP surface area was ravelling. Moderate to severe ravelling was found all over the study area.

- Lower compaction effort and less adhesion between rubber and stone aggregate were probably contributing to this ravelling or abrasion loss of PRPs.

Porous Rubber Pavement can be a potential alternative to the existing permeable pavement material in Canada. Preliminary investigation shows that its current performance in terms of permeability is adequate to reduce the surface runoff during the heavy rainfall incidents. However, uneven surface or higher surface roughness may affect the riding comfort and maintenance activities. Since this material has typically been used mainly for slow traffic areas like parking lots, and driveways, its higher surface roughness may not affect the safety issues associated with high speed. However, further roughness evaluation is required to assess initial roughness and its progression over time. Also, severe ravelling is a concerning issue that is directly impacting material's durability. This study is only providing initial insight about the PRP material which can support the future detailed study and the improvement of the material property. Since performance evaluation in this study was application as a parking lot material, further study could look at improving the PRP material to accommodate higher traffic and speeds.

References

ASTM C1701/C1701M−17a. (2017). *Standard test method for infiltration rate of in-place pervious concrete.* (Standard No. C1701/C1701M−17a).ASTM.

Chong, G. J., Phang, W. A., & Wrong, G. A. (2016). *Manual for condition rating of flexible pavements - distress manifestation.* (Technical Report No. SP - 024). ON, Canada: Ministry of Transportation, Highway Standards Branch, Material Engineering and Research Office.

Drake, J., Bradford, A., Seters, T. V., & MacMillan, G. (2012). *Evaluation of permeable pavements in cold climates.* (Research report No. Final Report). Downsview, Ontario: Toronto and Region Conservation Authority.

Environment Canada. (2019). Engineering climate dataset, IDF - version 1.00. Retrieved from ftp://client_climate@ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/archive/IDF_v1.00/

Hein, D. K. (2014). Permeable pavement design and construction case studies in North America. Paper presented at the *Transportation Association of Canada 2014 Annual Meeting,* Montreal, Quebec. Retrieved from https://www.researchgate.net/publication/290946871_Permeable_Pavement_Design_and_Construction_Case_Studies_in_North_America/citations

Henderson, V. (2012). *Evaluation of the performance of pervious concrete pavement in the Canadian climate* (Doctor of Philosophy).

Kalman, B., Biligiri, K. P., & Sandberg, U. (2011). Project PERSUADE: Optimization of poroelastic road surfaces in the laboratory. Paper presented at the *Inter. Noise 2011 - September 4-7,* Osaka, Japan.

Karamihas, S. M. (2005). *Critical profiler accuracy requirements.* (Draft Final Report No. UMTRI-2005-24). Michigan: The University of Michigan Transportation Research Institute.

Multipurpose Surface Profiler Operating Manual. (2014). *SurPRO 3500.* (Operating Manual No. Revision 8).Cherry Systems Research.

Nazef, A., Mraz, A., Scott, S., & Whitaker, J. (2008). *Evaluation of SurPRO as a reference device for high-speed inertial profilers.* (Research Report No. FL/DOT/SMO/08-512). FL: Florida Department of Transportation (FDOT).

Pavement Tools Consortium. (2019). Pavement interactive - reference desk. Retrieved from https://www.pavementinteractive.org/reference-desk

Persuade. (2015). PoroElastic road SUrface: An innovation to avoid damages to the environment. Retrieved from http://persuade.fehrl.org/

Pickel, D. J. (2018). *Precast concrete inlay panels: Rehabilitation strategy for high-volume highways in Ontario* (Doctor of Philosophy in Civil Engineering).

Porous Pave Inc. (2017). *Porous pave.* (Porous Pave product and project information). Grant, MI: Porous Pave, Inc.

Sayers, M. W., & Karamihas, S. M. (1998). *The little book of profiling - the basic information about measuring and interpreting road profiles*. Michigan: University of Michigan.

Schaus, L. K. (2007). *Porous asphalt pavement designs: Proactive design for cold climate use.* (Unpublished MSc). Waterloo University, Waterloo, ON, Canada.

Valeo, C., & Gupta, R. (2018). Determining surface infiltration rate of permeable pavements with digital imaging. *Water, 10*(133) DOI:10.3390/w10020133

Wang, D., Liu, P., Leng, Z., Leng, C., Lu, G., Buch, M., & Oeser, M. (2017). Suitability of PoroElastic road surface (PERS) for urban roads in cold regions: Mechanical and functional performance assessment. *Journal of Cleaner Production, 165*, 1340-1350.