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Developing A Framework for Low-Volume Road Implementation of Pervious Concrete Pavements

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ABSTRACT

Pervious concrete pavement is one of the promising pavement technologies, as it can help overcome traditional pavement environmental impacts, assist with stormwater management, and provide an effective low impact development solution. There are many benefits associated with pervious concrete pavement such as assisting with water filtration, absorbing heavy metals and reducing pollution. The most significant aspect, which draws the attention of environmental agencies and cities and municipalities, is its ability to reduce storm water runoff. Pervious concrete is documented as the paramount solution in storm water management by the United States Environmental Protection Agency. Though it has been used in the southern United States for years, the practice of using pervious concrete is more recent in northern climates where freeze thaw is observed. In Canada, several pervious concrete parking lots have been constructed over the past few years. However barriers exist for implementing the technology, as designers are not always fully informed on the various functional and structural design considerations. In this paper, a framework is developed to identify how pervious concrete can be integrated into low-volume infrastructure. This paper also summarizes the structural performance and drainage characteristics of pervious concrete parking lots constructed in various provinces of Canada, demonstrating the viability of pervious concrete for low-volume northern applications.

1. INTRODUCTION

Pervious concrete pavement is a technology that provides a sustainable, and ecological pavement alternative. The porous nature of the material allows rainwater to percolate directly through the pavement structure and join the natural ground water system, mitigating traditional pavement impacts on natural hydrological cycles and removing the needs for other stormwater management systems. Pervious concrete also provides other benefits such as water filtration [1, 2], heat and noise control [3–5], and heavy metal removal from stormwater runoff [6].

Pervious concrete mixes typically contain single-sized aggregate with locally optimized levels of cementitious binder and water to provide a structure with at least 15% voids [7]. The amount of fine aggregate is limited and optimized to increase the strength while maintaining the required void content to facilitate drainage. This resulting pervious concrete layer is constructed on a clear stone base, which acts as a reservoir layer to store water during infiltrate to the existing subgrade soil. The thickness of the reservoir layer depends upon the characteristics of underlying subgrade soil; a subgrade with a low percolation rate would require a thicker reservoir to maintain a good precipitation rate.

The porous structure of pervious concrete results in lower compressive strength of the material compared to conventional concrete. As a result, pervious concrete is an ideal material for usage in residential streets, walkways, driveways, highway shoulders, and parking lots [3] but not highways or roads with frequent heavy trucks. Literature suggests that roads with Average Annual Daily Traffic (AADT) of 400 or less are considered as low volume roads [8]. But for high traffic volume roads there is no national or American Association of State Highway and Transportation Officials (AASHTO) definition. One of the reasons behind this is as it is a local issue; it varies from agency to agency and depends also on the area of construction. In this paper, roads are classified in four groups:

- Low Volume Road (AADT ≤ 400) [8]
- Moderate Volume Road (400<AADT ≤ 3,000) [9]
- High Volume Road (3,000<AADT ≤ 5,000)
- Very High Volume Road (AADT ≥ 5,000) [10]

Pervious concrete has been used in parts of Europe and warm climates in the United States for several years but its use in the Northern severe cold climates, such as Canada, has been limited [11]. This extreme cold climate presents an extra challenge for pervious concrete and the Centre for Pavement and Transportation Technology, at the University of Waterloo, has constructed and monitored several pervious concrete parking lots across Canada in order to characterize the performance of pervious concrete in cold climates. These sites have demonstrated that pervious concrete is able to withstand low-volume traffic [12, 13]. From these results, a framework is developed for designers to understand where they can apply pervious concrete in their infrastructure and the design process they need to follow.

1.1. Objectives

This paper will present a framework for how to implement pervious concrete into pavement infrastructure in northern regions; given the known performance of pervious concrete, this framework focuses on low-volume infrastructure applications. A summary of the structural and drainage performance of pervious concrete parking lots in northern environments as well as the benefits of applying pervious concrete will also be provided to demonstrate the feasibility of using pervious concrete for low-volume infrastructure.

2. PERVIOUS CONCRETE AND LOW-VOLUME ROAD (LVR)

Pervious concrete pavement is a sustainable pavement technology that is an alternative product for low-volume applications. Almost two third of Canada's public road are either gravel, treated, or of earthen design [8]. Other types of surfacing on low volume roads include Thin Bituminous Surfacing (TBS) treatments such as Cold Mixed Cold Laid (CMCL) surfaces and Bituminous Surface Treatments (BST), chemically stabilized surfaces, and some HMA pavements and concrete pavements [14].

As stated earlier pervious concrete pavement is mostly suitable for low volume traffic roads [3]. To date most of the data available on pervious concrete are from driveways, sidewalks and parking lots. However in this paper only parking lot data has been provided. These data from parking lots can be correlated with low volume roads, as the traffic volume is similar in both cases. Traffic speed and maneuverer pattern is different. It can be assumed that in parking lot most loads are standing, turning and breaking loads, which can affect the pavement structure more drastically. As pervious concrete parking lot is able to withstand this loading, it can be predicted that it would also be durable as low-volume road. In 2011, in Minnesota several test cells of LVR were constructed with pervious concrete with a design life of 10 years. Road reliability was evaluated with the American Concrete Pavement Association (ACPA) StreetPave Software. All of the LVR test section passed with a reliability of 90 [15].

3. BENEFITS OF PERVOIUS CONCRETE IN LOW-VOLUME INFRASTRUCTURE

There are many associated benefits with using pervious concrete pavement compared to the regular low volume roads used in practice.

3.1. Dust Control

Dust is a very common problem and a safety concern with gravel road. Various kinds of treatments should be adopted to avoid this issue [14]. With pervious concrete pavement it can be eliminated easily. Pervious concrete pavement provides a dust free, smooth, and safe surface.

3.2. Drainage Control

To control and facilitate proper drainage is important for all kind of pavement infrastructure. Often in improperly maintained gravel roads, shoulders can be higher than the travelling lane, which causes drainage issues. Roadside drainage and ditches are also important in conventional design [14]. Using pervious concrete pavement can eliminate all this kind of drainage facilities and cut the cost of installation of drainage systems. It also maximizes land uses, as no ditches are required and reduces the likelihood of flooding [16].

3.3. Heat Control

Pervious concrete pavement can minimize heat islands effect and increase reflectivity [16]. The main reason of both of these benefits is attributed to the light grey colour of concrete, whereas the asphalt overlaid low volume road is black in colour. Research indicates that the air temperature in urban areas can be up to 4°C degrees higher than it would be in a rural setting [16]. Another study reported that in hot weather conditions, conventional paving materials can reach of 50°C to 65°C and transmit excess heat to the air above them as well as heat stormwater as it runs across pavements [17]. Porous parking lots have been shown to lower surface temperature and it allows unheated water to infiltrate directly to ground water table minimizing the impact on the aquatic ecosystem [17]. Besides, as urban heat islands effects on humans are of great concern to communities and cities, reduction of urban heat islands is a great benefit to the environment. Besides the quality of heat control of pervious pavement can mitigate the cooling costs of surrounding community.

3.4. Lighting Requirements

The light colour of pervious concrete pavement results in greater reflectivity and reduces the amount of lighting infrastructure required to create the desired brightness of parking lots and paths during evening and night use [16].

3.5. Economic

Pervious concrete pavement is a cost effective sustainable pavement technology. With this pavement, the requirement of stormwater retention ponds or infrastructure such as pipe network can be eliminated. So it cuts the expenses [16,17]. It also reduces property space as well as probability of flooding [17]. The infiltrated water through pervious concrete can be transferred to surrounding gardens and lawns to provide natural moisture and thus can be used in water harvesting system. It limits the expense of watering as well as water demand [16].

4. PARKING LOT FIELD SITES

The six case studies included in this paper were constructed between 2007 and 2011 with varying levels of monitoring. These sites were located across Canada, with the majority being found in Southern Ontario. Figure 1 shows the locations of the six sites being reviewed with general information of each site outlined in Table 1.

4.1 Performance Evaluation

A variety of tests were performed on samples from the six sites, including evaluating the density, void content, compressive strength, modulus of rupture, and permeability. A summary of the density and void content tests can be found in Table 2. Note that Sites 3, 4, and 5 had several different pervious concrete mixtures used in their construction, and these different mixtures are denoted with letters following the site number.

Table 3 shows the compressive and flexural strength values that were measured from samples from each of the sites. This information further demonstrates that in-practice, pervious concrete is a much lower strength material than traditional concrete.

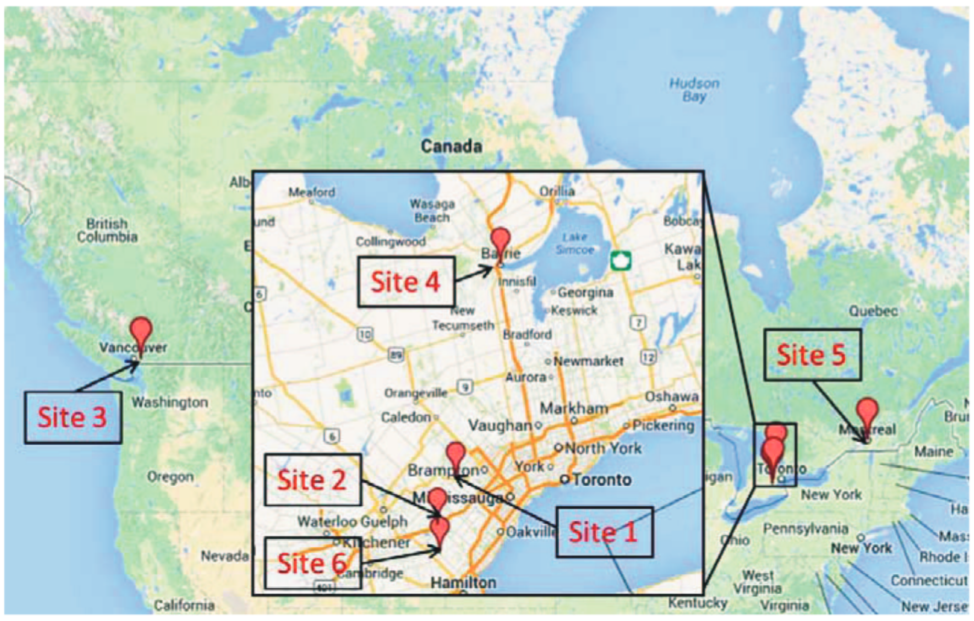

Figure 1. Case Study Locations, modified from [12, 19]

Table 1. Field Site Location and Structural Design [12]

Site	Location	Construction Year	Approx. Area (m^2)	Structural Design PC (mm)	CS (mm)	S (mm)	CTB (mm)
1	Georgetown, ON	2007	630	300	600	–	–
2	Campbellville, ON	2007	1800	240	100	200	–
3	Maple Ridge, BC	2008	100	250	200	–	–
4	Barrie, ON	2008	500	200	300	–	–
5	Montreal, QC	2009	108	200	–	–	200
6	Carlisle, ON	2011	4000	150	–	–	150

*PC represents pervious concrete, CS represents clear stone, S represents stone, and CTB represents cement treated base

Surface distress evaluations were also performed on all of the sites in order to visually inspect the structural performance of the pervious concrete. The information from this for all sites is summarized in Table 4.

Permeability is an important performance characteristic of pervious concrete pavements because without high levels of permeability, the ecological benefits of allowing the pavement structure to act as a natural reservoir are lost. The permeability of Sites 1 through 5 were determined using permeability measuring device (Gilson Permeameter) over up to 4 years are plotted in Figure 2 and demonstrate the longevity of permeability in unmaintained pervious concrete.

Table 2. Density and Void Results from the Field Sites, modified from [12, 20]

Site #	Avg. Density (CSA A23.2-6C, kg/m^3)	Avg. Density (ASTM C1688, kg/m^3)	Void Content (using CoreLok*, %)
1	2011	N/A	18
2	2012	N/A	N/A
3a	1861	N/A	31
3b	N/A	N/A	13
4a	1803	N/A	28
4b	1958	N/A	26
4c	1920	N/A	26
5a	1842	1902	N/A
5b	1996	2025	N/A
5c	1917	1968	N/A
5d	1815	1910	N/A
6-cylinderss	N/A	2249	13
6-cores	N/A	N/A	26

*CoreLok is an equipment that vacuum seals a plastic bag around the pervious concrete sample in the laboratory.

Table 3. Compressive and Flexural Strength Results from the Field Sites, modified from [12, 20]

	28 Day Compressive Strength (MPa)			
Site #	Cylinders (CSA A23.2-3C)	Cylinders (Proctor Hammer*)	Cores	Modulus of Rupture, 28 Days (MPa)
1	21.5	N/A	7.3	1.64
2	22.8/11.8	N/A	7	4.21
3a	31.3	21.3 (10 drops), 30.4 (20 drops)	14.2	N/A
3b	N/A	N/A	N/A	N/A
4a	N/A	8.2 (10 drops)	10	1.5
4b	N/A	9.8 (10 drops)	16	2.0
4c	N/A	8.6 (10 drops)	16.5	1.7
6	28.9	N/A	11.3	5.3

*In all cases, the cylinders prepared with the Proctor Hammer involved the pervious concrete being placed in the mould in two lifts. The number of drops applied to each lift is given beside the results in the table.

The maximum rainfall rate was determined from intensity duration frequency curves from Environment Canada website for the area surrounding each field site [38]. The maximum rainfall rate was similar for each of the five field sites and the highest was selected, 0.0083 cm/sec. The permeability rate results were compared to a maximum rainfall rate. If the permeability results were less than the maximum rainfall rate then the permeability of the pavement was deemed to be inadequate.

Table 4. Surface Condition Evaluation at the Field Sites, modified from [12, 13, 20, 21]

		Distress Types			
Site #	Age (yr)	Ravelling, Joints	Ravelling, Slab	Cracking	Aggregate Fracturing
1	2	M	M	–	–
2	2	S	S	–	–
3a/3b	1	–	M	S	–
4a/4b/4c	1	S	–	–	M
5a	0	–	S	–	–
5b	0	VS	VS	S	–
5c	0	S	S	S	–
5d	0	–	–	–	–
6	1	VS	–	VS	–
6	2	S	–	VS	–
6	3	M	S	S	–

*VS: Very Slight, S: Slight, M: Moderate

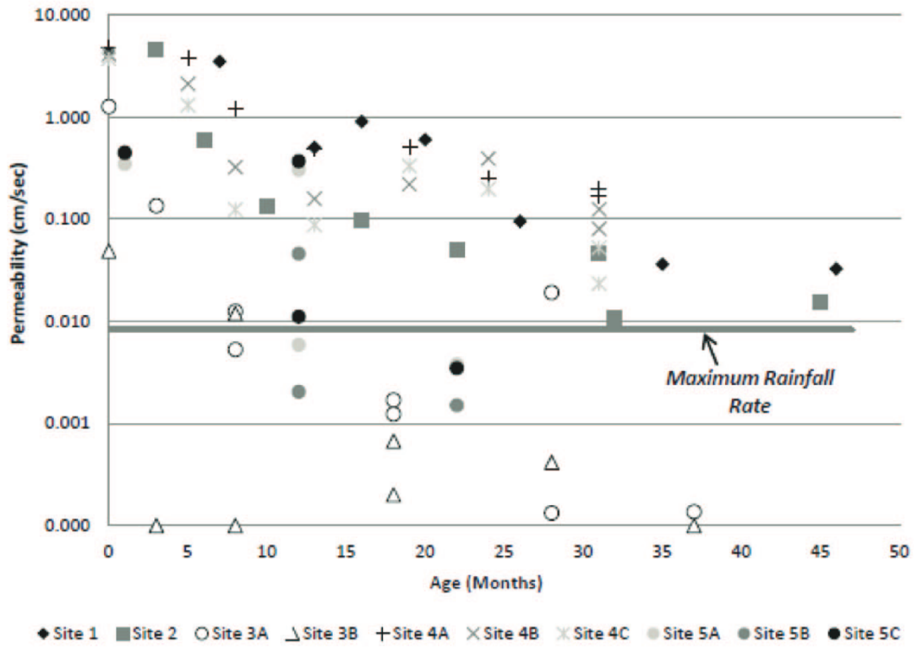

Figure 2. Permeability of Sites 1–5 Over up to 4 Years [3]

4.2. Summary

These field sites demonstrate that pervious concrete is an effective option for the structural design and stormwater management of low-volume infrastructure. The minimal surface damage caused over time and the high maintained permeability show that pervious concrete is very applicable to the design of low-volume infrastructure in northern climates.

5. FRAMEWORK DEVELOPMENT

The proposed framework for pervious concrete implementation in infrastructure is outlined in Figure 3 with descriptions of each step as follows

5.1. Traffic Determination

Within the framework illustrated in Figure 3, there are four levels of traffic considered for the use of pervious concrete pavements.

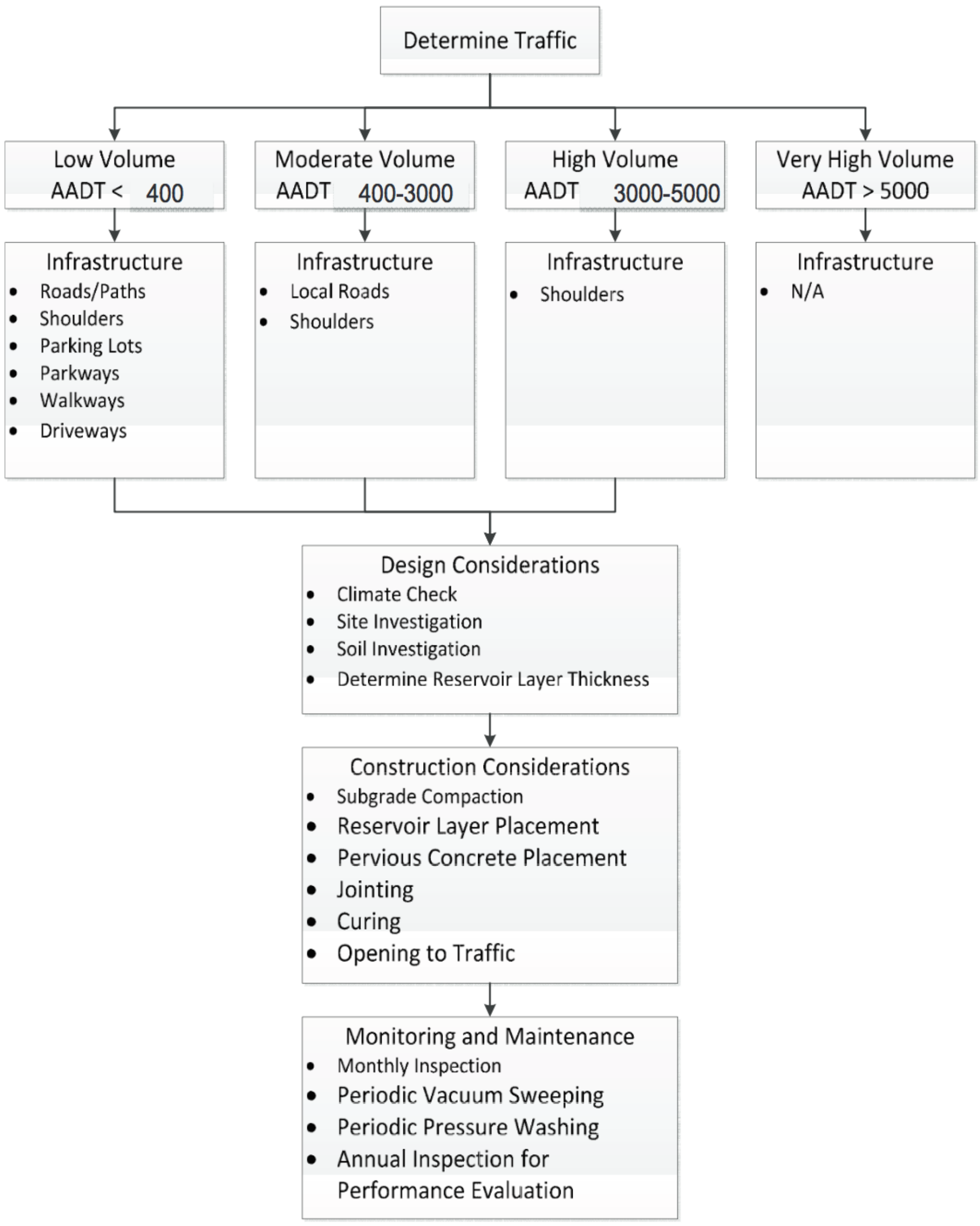

Figure 3. Framework for Pervious Concrete Implementation in Low Volume Road Infrastructure

In traffic determination, the type and level of traffic should be determined according to previous records and recent survey. In general, for low volume road (AADT ≤400), pervious concrete can successfully perform as paths or roads, parking lots, parkways, walkways, driveways, shoulders etc. For moderate volume road (400<AADT≤3000), pervious concrete can be used in the local roads and shoulders. For high volume road (3000<AADT≤5000) pervious concrete pavement can only be used on shoulders. For very high volume road (AADT > 5000), pervious concrete is not applicable due to structural concerns.

5.2. Design Considerations

Under this level all of the important factors for design should be taken into consideration such as climate, site/area, subgrade condition etc. as each of these can influence the performance of the pavement.

5.2.1 Climate check

In which climate pervious concrete will be installed is important. Literature suggests that pervious concrete successfully performs in warm climate [16], and the case studies presented in this paper provides valuable information about the satisfactory performance of pervious concrete pavement in cold climates.

5.2.2. Site Investigation

Next the installation area should be analyzed. Pervious concrete should not be installed in an area with stormwater hotspots such as commercial nurseries, automobile recycling facilities, gas stations and outdoor liquid container storage areas. The runoff from these areas carries high amounts of contaminants, which can pollute the groundwater [22].

5.2.3. Soil Investigation

Soil investigation is the other important step in the design process. Soil strength should be sufficient to provide the pavement the strength to carry the traffic loading. If the California bearing ratio (CBR) of the subgrade soil is less than 4%, then it should be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration [23]. Otherwise compaction to 90% of the Standard Proctor Density is enough to provide with a satisfactory drainage capacity [24]. If the CBR value of subgrade is lower or equal to 3; high clay or silt is present in the soil; water table is shallow or subject to flooding then geotextile should be placed over subgrade. In areas where swelling soil is present, precautions should be taken; cement, additives, membranes etc. should be used to stabilize the soil [25].

In Figure 4 pervious pavement that placed on subbase is presented.

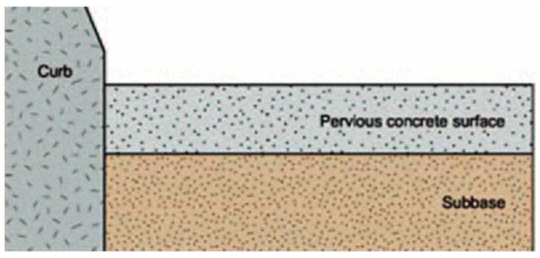

Figure 4. Pervious Concrete Layer Direct on the Subgrade [26]

5.3. External Drainage Requirement

The permeability rate of the subgrade soil does not constrain pervious concrete pavement. If a well-drained soil is underneath, no external drainage is required. Native soil that contain have silt/clay content less than 40% and clay content less than 20% is considered as well drained subgrade. Subgrade soil with minimum permeability rate 0.5 inches per hour is also suitable for construction of pervious concrete. Otherwise if the soil criterion is different or the permeability is lower than the acceptable limit, a reservoir layer or external drainage system is required [23]. Figure 5 represents this type of pervious pavement with draining pipe.

5.3.1 Reservoir Layer Thickness

The main function of the reservoir base layer of the pervious concrete pavement is to work as a detention pond rather than a structural layer. This layer incorporates a storage layer for the percolating water. This layer is generally recommended for pervious concrete in a cold climate with frequent freeze thaw cycles or in the condition when the permeability rate of subgrade soil is low [28]. It typically consists of open graded aggregate with 20%-30% interconnected voids, which can provide water storage capability [25]. Other literatures suggest that open graded clean stone with 20%–40% void space is required in the base layer of pervious concrete pavement [22, 29]. Maximum drainage time for the reservoir layer should not be less than 24 nor more than 48 hours [23].

The typical thickness of this layer is 6", though a detailed hydrological investigation should be done to find out the proper thickness of the reservoir layer depending upon the subgrade soil condition. The detailed hydrological design procedure can be found in [23, 30].

5.3.2 Depth to Water Table

A minimum distance of 2 feet, from the bottom of pervious concrete to the seasonal water table should be maintained [23].

5.4. Construction Considerations

This section provides the detailed procedure of construction.

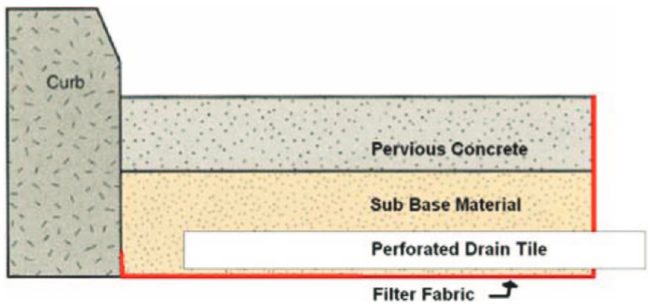

Figure 5. Pervious Concrete with External Drainage Pipe [27]

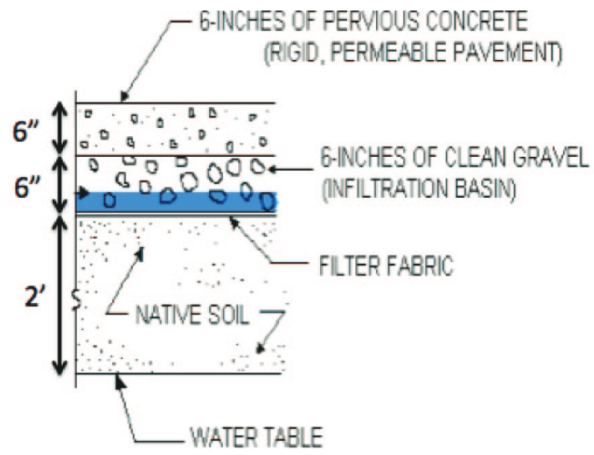

Figure 6. Pervious Concrete with Reservoir Layer [31]

5.4.1 Pervious concrete Placement

The subgrade soil and the reservoir layer should be prepared as described earlier. After preparing those layers, pervious concrete material is placed directly on the base from the chute. Wood/steel forms with shim on the top are used and these are filled with pervious concrete higher (20 mm–25 mm) than the required final thickness. Then typically a vibratory screed is used on the top of the shim to cross off the pervious concrete and then the shims are removed. Following this, a manual weighted roller or a hydraulic vibratory roller is applied to the forms to compact the pervious concrete and to get a level pervious concrete surface [32]. The level of compaction should be optimized to get the maximum drainage. To get the optimum compaction, methods can be followed from [33]:

1. Overfilling the form.
2. Rolling a short 1 m to 3 m section then returning the roller to the initial location.
3. Adding a thin layer of pervious concrete to the previously rolled surface.
4. Rolling the surface again.

5.4.2 Jointing

To control cracking, joints are included into pervious concrete pavement in the similar manner as conventional concrete pavement. The typical joint spacing is twice as the thickness of pavement in feet. For example: a six inch pavement would have a joint space of 12 feet (6" × 2 = 12'). The maximum joint spacing can be 15 feet [34]. Another study recommended joint spacing of 6m up to 13m, which has record of no uncontrolled cracking [35].

Before paving starts, joint locations must be pre-marked. String line can be used for this type of marking. Generally flanged roller or pizza cutters are used to form joints in pervious concrete pavement [33]. All joints should be completed immediately after screed and before curing.

5.4.3. Curing

Curing is one of the most decisive actions for pervious concrete pavement. “If it dries, it dies”, this sentence is very much true in working with pervious concrete pavement. It is recommended to execute curing as soon as possible behind the screed [34]. Typically curing is done by covering the pervious concrete pavement by a 4mm to 6 mm thick plastic sheet. It is recommended to start the curing (cover the pavement with plastic sheet) within 20 minutes of placement from the truck [24].

5.4.4. Timeline for Opening to Traffic

Guidelines for constructing pervious concrete pavement routinely reference that no vehicle traffic should be allowed on the pavement until seven days after construction [33, 35]. The Ontario Ministry of Transportation (MTO) currently requires that pervious concrete not be opened to traffic until a core with a compressive strength of 15 MPa is attained from the site. The minimum curing requirement is seven days.

The Ready Mix Concrete Association of Ontario (RMCAO) requires that no truck traffic use a pervious concrete pavement until 14 days after construction [36]. The Colorado Ready Mixed Concrete Association (CRMCA) requires that pervious concrete pavement not be opened to the traffic until the pavement has reached the equivalent maturity that would have been experienced after 14 days of curing at 21°C at 95% relative humidity [24]. However seven days curing period is followed in most of the cases.

5.5. Monitoring and Maintenance Considerations

Pervious concrete pavement can perform very well with a little regular maintenance. As the porous structure can easily get clogged with sand, dirt, leaves and other debris, it should be kept clean to confirm the drainage functionality. Routine checking of the pavement porosity and infiltration rate can help to maintain its functionality. In general, clogging is limited to the first 1” to 1.5” of the pavement thickness. Periodic and routine vacuum cleaning, sweeping or pressure washing can restore the permeability. Sometimes bleach is added to the pressure washing to remove mold and algae [37]. The literature suggests the following recommendations for maintaining the pavement.

- Monthly inspection to ensure that the pavement is clean of debris, sediments, and dewaters between storms.
- Mow upland and adjacent areas and seed bare areas as necessary.
- Annual inspection to find out the performance and surface distresses. [37]

Ravelling is a common distress in pervious concrete pavement. To find out if the distress is only in the upper layer, so that it is not a structural deficiency, the surface should be swept to remove the loose aggregate. This allows the depth of the raveling to be examined. After sweeping up, the pavement should be monitored if the raveling is going on or has stopped. If the distress goes on and depth is too deep to repair, then it is suggested to replace the complete section or mill that localized section and place a pervious concrete overlay [33].

6. CONCLUSION

The main objective of this paper is to develop a framework to use pervious concrete in low volume road. Overall the state-of-the-art in northern climate pervious concrete field testing has demonstrated that, with diligent design, pervious concrete can be an effective tool available to pavement designers for low-volume applications. All the sites presented in this paper were not under regular maintenance. From the permeability measurement results it is found that permeability reduces with time, as can be expected that without maintenance. With proper maintenance better performance can be obtained. The lower strength and modulus of rupture of the materials do limit the number of heavy vehicles that pervious concrete can withstand, though the slight to moderate surface distresses noted in Table 4 show that it withstands low-volume traffic and freeze-thaw cycling very well. Thus pervious concrete can be a potential alternative for sustainable low volume roads and provide a dust free, smooth, cost effective, and safe alternative to traditional pavements.

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