Falling Head Test Versus ASTM Standard in Determining Infiltration of Porous Asphalt

by

Fahad Shazad
B.Eng, N.E.D University of Engineering and Technology, Pakistan, 2011

A Project Report Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF ENGINEERING

in the Department of Mechanical Engineering

© Fahad Shazad, 2017
University of Victoria

All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy
or other means, without the permission of the author.

Supervisory Committee

Falling Head Test Versus ASTM Standard in Determining Infiltration of Porous Asphalt

by

Fahad Shazad
B.Eng, N.E.D University of Engineering and Technology, Pakistan, 2011

Supervisory Committee

Dr. Caterina Valeo (Department of Mechanical Engineering)
Supervisor

Dr. Rishi Gupta (Department of Civil Engineering)
Departmental Member

Abstract

Supervisory Committee
Dr. Caterina Valeo (Department of Mechanical Engineering)
Supervisor
Dr. Rishi Gupta (Department of Civil Engineering)
Departmental Member

Porous asphalt has been increasingly used in increased urbanization areas due to its positive environmental aspects. The porous asphalt is used to reduce the amount of runoff from rain water and it also helps to improve the water quality near pavements. Porous asphalt requires maintenance to preserve its effectiveness. A reliable testing method with high repeatability and low error is required to determine the infiltration rate for the porous asphalt. In this project two testing methods, Falling Head Infiltration Device (FHID) and ASTM C1701 Constant Head Infiltration testing, are used to determine the infiltration rate in three samples of porous asphalt of different porosity. For each testing method, a separate device was used to find the method that provides high repeatability and accuracy. Results showed that FHID has high repeatability compared to ASTM C1701 testing method.

Table of Contents

Supervisory Committee ii
Abstract iii
Table of Contents iv
List of Tables v
List of Figures vi
Acknowledgments vii
Dedication viii
1. Introduction 1
  1.1 General Objective and Thesis Layout 3
2. Literature Review 5
  2.2 Research Objective 11
  2.3 Methodology to Achieve Research Objectives 11
    2.3.1 Infiltration Rates Testing Methods 11
    2.3.2 ASTM C1701 - Standard Method for Infiltration Testing of In Place Pervious Concrete 12
    2.3.3 Falling Head Method 13
3. Experimental Setup 15
  3.1 Test Samples 15
  3.2 ASTM C1701 Testing Device 16
  3.3 Falling Head Infiltration Device 17
4. Analysis and Results 19
5. Conclusion and Recommendation 24
6. References 25
Appendix A - Test Results 27
Appendix B - Materials Used for Fabricating Testing Device 29

List of Tables

Table 1 Testing schedule of porous asphalt samples.. 19
Table 2 Infiltration test results of day 1 27
Table 3 Infiltration test results of day 2 27
Table 4 Infiltration test results of day 3 27
Table 5 Infiltration test results of day 4 28
Table 6 Infiltration test results of day 5 28
Table 7 Infiltration test results of day 6 28

List of Figures

Figure 1 Conventional impervious pavement in comparison to permeable pavement 2
Figure 2 NCAT field permeameter of four cylindrical tiers with different diameters 10
Figure 3 Porous Asphalt sample A (middle) and sample B (left) sample C (right) 15
Figure 4 Fibers used in asphalt samples 15
Figure 5 Assembled ASTM C1701 testing setup 16
Figure 6 Gap of 0.5 inch between pavement and open end of the pipe 17
Figure 7 Two components of FHID 17
Figure 8 Inside of assembled FHID 18
Figure 9 Assembled FHID 18
Figure 10 ASTM C1701 Infiltration rate for porous asphalt.. 20
Figure 11 FHID Infiltration rate for porous asphalt... 21
Figure 12 Sample-A Infiltration rate with ASTM C1701 and FHID............................... 22
Figure 13 Sample-B Infiltration rate with ASTM C1701 and FHID............................... 22
Figure 14 Sample-C Infiltration rate with ASTM C1701 and FHID............................... 23
Figure 15 RedGard membrane... 29
Figure 16 2" diameter PVC pipe.. 29
Figure 17 Paint brush 29
Figure 18 Flexible coupling 29
Figure 19 Gorilla tape 30
Figure 20 Plasticine modelling clay 30
Figure 21 5 gallon water bottle 30
Figure 22 2" dia PVC valve 30
Figure 23 Concrete forming tube 31
Figure 24 Hack saw 31
Figure 25 Measuring tape 31
Figure 26 3/4" plywood 31
Figure 27 Fold knife 31
Figure 28 Silicone 31
Figure 29 Teflon tape 32

Acknowledgments

I would like to acknowledge the immense support and guidance provided by my supervisor, Dr. Caterina Valeo for completing the project. I am thankful to my managers Mr. Jason Smith and Mr. Richie Windolf for their assistance and support. Special thanks to my work colleague Mr. Tom Dawson, Mr. Randy Ware and Mr. Nick Mankwald for their ideas that helped me in making a reliable testing device.

Finally, I am grateful to Dr. Rishi Gupta and Dr. Phalguni Mukhopadhyaya for serving as committee member and examination chair respectively.

Dedication

TO MY PARENTS AND SIBLINGS

1. Introduction

In the developed world, most cities are dependent on piping network for storm water drainage. Most of these systems were built in 19^{th} century. The traditional system distributes storm runoff water to sewer systems. These piping system are expensive to develop and maintain. Furthermore, over a long period of time these systems become inefficient and ineffective [1]. Development of permeable pavement system (PPS) has challenged the traditional systems. Permeable pavement principle is to collect, treat and infiltrate the surface runoff to recharge ground water. PPS reduce the dependence and load on traditional piping systems. Permeable pavement allows storm water runoff to infiltrate through the voids in the surface into underlying reservoir [2]. Porous asphalt usually contains 15% air voids and is an environment friendly paving material. In regions of high level of precipitation, permeable pavement is highly effective. The voids in the permeable pavement reduce water runoff which increases the riding safety and quality. Porous asphalt increases the visibility by reducing the reflected light from road surface and decreases hydroplaning. Porous asphalt is mostly deployed in areas which are considered low traffic zone such as parking lots, driveways and sidewalks [3].

The open pores permeable asphalt enables high infiltration rates for water. Slowly the pores of permeable asphalt start to clog with debris and dirt which reduces the effectiveness and permeability. Eventually the pores become completely clogged which changes the permeable pavement to an impervious pavement. To maintain the functionality of PPS, they must be maintained properly. A broom or a leaf blower can be used for clearing surface debris but a rigorous maintenance method like vacuum sweeping or power washing is required to clear deeper pores [4].

Determining the infiltration rates of PPS on a virgin sample are important to properly maintain and ensure long lifespan of permeable pavement system. The infiltration rate in this project is calculated through two different methods. First method is the ASTM C1701- Standard Method for Infiltration Testing of In Place Pervious Concrete [14]. For second method, a falling head infiltration device (FHID) is built in the lab and used for finding the infiltration rate. The devices were tested on three samples of different permeability containing fibers. The performance parameters such as strength, durability, noise level, lifespan, rutting resistance and the water sensitivity of asphalt are greatly influenced by the fibers [5]. The basic difference between conventional pavement and impervious pavement is shown in figure 1. Unlike conventional pavement, impervious pavement allows infiltration, evaporation and reduces the quantity of runoff pollutants.

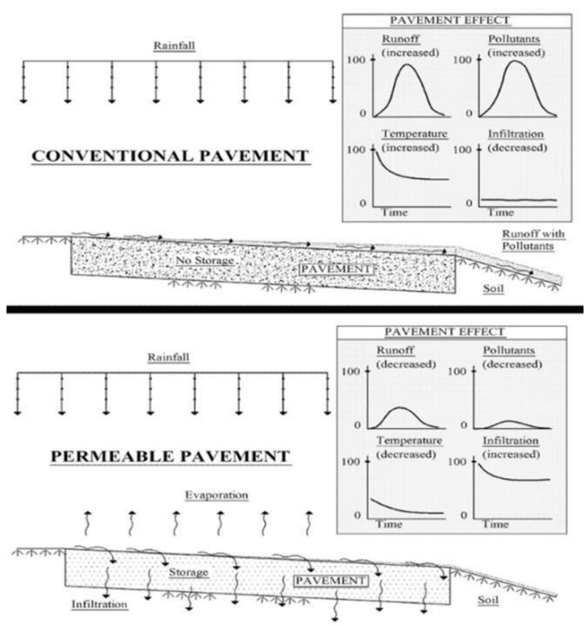

Figure 1 Conventional impervious pavement in comparison to permeable pavement [6]

One of the most common problems of porous asphalt is binder loss by drainage due to reduction in aggregates content. In the first generation of porous pavement high binder percentages were used to maintain better connection among the aggregates, however this lead to hardening issues. Due to environmental concerns, the researchers are looking into different eco-friendly fibers. In porous pavements today a variety of fiber types are used which include cellulose, polymer, mineral, glass fiber, recycled fibers from old tires and carpet fibers [7].

1.1 General Objective and Thesis Layout

The project work has one objective and that is to find a reliable testing method for finding infiltration rate on pervious pavement (asphalt). Previous testing conducted by the students at the University of Victoria showed that the infiltration testing results did not have high repeatability when using ASTM C1701 method. The two main reasons were lack of good sealant between testing ring and pavement and the lack of a good testing device for properly maintaining a constant head. In this project, three different asphalt samples are used for testing. The samples are coarse compared to the traditional asphalt and contain fibers which is a mix of aramid, kevlar and polyolefin. One set of testing is done using the ASTM C1701 standard with the newly designed experimental setup to achieve better repeatability. Second set of testing is done using Falling Head Infiltration Device (FHID) which was fabricated by a student however the device is rebuilt using new techniques that reduced the water leakage to minimal.

Chapter 2 of the report includes literature review of several research papers. The topic of the research and the methodology used for achieving the test results are summarized in this chapter.

Chapter 3 consists of the designing and fabrication of testing device and experimental setup.

Chapter 4 provides details of the experiments conducted for finding the infiltration rates, results and analysis.

Chapter 5 concludes the findings of the infiltration testing with the two methods and recommendation for future work.

2. Literature Review

Kuldip Kumar, Joseph Kozak, Lakhwinder Hundal, Albert Cox, Heng Zhang and Thomas Granato reported the measured in-situ infiltration performance of permeable pavers, permeable concrete and permeable asphalt over a four year period since construction of a parking lot. The infiltration rates were measured by using ASTM C1701 method. The decline in infiltration rates after one year of use was marginal however between two to four years, the infiltration rates declined significantly due to clogging of pores either by shear driving and degrading of permeable surfaces or dry deposition of particles. The permeable asphalt section had an area of $1311m^2$ with 38 parking slots. All slots in the permeable asphalt were always full throughout the working days during the year. During winter, snow from the parking lot was removed and de-icing salt which contained a mixture of chloride salts of sodium, calcium and magnesium was used as in a normal parking lot. The porous asphalt section consisted of open-graded asphalt of 10 cm layer over an open graded fill base 30 cm deep consisting of CA-7 aggregate above native soil. LINQ 180 EX separation geotextile separated aggregate base from subgrade native soil. Spray water followed by sweeping was used for asphalt maintenance twice annually. The overall infiltration performance depends on the permeability of the surface. During first year the average infiltration rate for porous asphalt was 31.1 mm/s. The infiltration rate declined during next three year and was 30.6 mm/s, 24.4 mm/s and 9.1 mm/s. The results showed that only marginal declines in infiltration rates was noted after one year of usage after which the decline accelerated. In the fourth year, the infiltration rate for porous asphalt had declined as much as 70% in parking slots. At the end of four year study the physical condition of permeable asphalt had declined but the infiltration rate was still approximately 380 times higher than most rainstorm events impacting the study area and no runoff flow was observed at the parking lot [8].

Bin Yu, Liya Jiao, Fujian Ni and Jun Yang launched a five year tracking programme to collect performance data of porous asphalt section paved in Yan-Tong highway in Jiangsu Province of China. The results from the field performance of the test section were used for validating and improving porous asphalt design. The investigation covers permeability, roughness, rutting and skid resistance on truck lane, passing lane and passenger vehicle lane. The highway has three lanes per direction with a speed limit of 120km/h. The 17km porous asphalt section lies in heavy traffic corridor which opened for traffic in November 2005. The meteorological data from January 2006 to July 2009 shows the temperature exceed 30^{o} C in summers. The annual precipitation ranges between 990-1060 mm with 120 rainy days per year. The porous asphalt section had limestone aggregate in the middle and bottom layers and basalt aggregate in the surface layer. The permeability of porous asphalt section was investigated on the truck and passenger vehicle lane. The Subgrade and Pavement Testing Method for Highway Engineering (JTJ059-95) (Research Institute of Highway Ministry of Communication, 1995) was followed for testing. The tests were replicated at each spot for three times to assure reliability. The amount of water (ml) penetrated into the porous asphalt within 15 sec were reported for the results. At the end of five year investigation the permeability of passenger vehicle lane was in better condition with efficiency of 600-1000ml/15s whereas the permeability of truck lane was less than 600ml/15sec. The permeability of the porous asphalt increased initially then decreased with peak values occurring between 15 and 18 months after construction. The results of field investigation showed that the permeability and noise reduction merits associated with the porous asphalt reduced substantially with time [9].

Ian Anderson, Mark Suozzo and Mandar M. Dewoolkar evaluated hydraulic parameters and long term infiltration monitoring and cleaning operations of pervious concrete with 3/8'' aggregate. The study compared methods to determine infiltration rate in the field to the laboratory measurement of hydraulic conductivity. The objective of the investigation was to determine relation among single ring, double ring and falling head infiltration rate in the field and compare the field methods to hydraulic conductivity measurement in the laboratory. Two facilities were monitored for changes in infiltration rate over time in Vermont, USA. The facilities have 6'' layer of porous concrete with 34'' gravel sub-base. The infiltration rates with single and double ring infiltrometer were determined in accordance with ASTM C1701. A ring of 12'' diameter was used for single ring method; however, for double ring infiltrometer a second ring of 24'' was placed around the 12'' inner ring. The falling head infiltrometer device had a 2'x2'x3/4'' base with a circular hole attached to a 4'' internal diameter stand pipe and the infiltration rate was calculated by measuring the time taken for the top level to drop from 15'' to 3'' above porous asphalt. A linear correlation of 1.0 : 1.8 : 1.5 : 9.0 was found among hydraulic conductivity, single ring, double ring and falling head infiltrometer testing. The effectiveness of various cleaning methods was also evaluated. Cleaning methods effectiveness for average restoration rates was 10% for hand vacuuming, 21% for street sweeping, 30% for vacuum truck cleaning, 85% for pressure washing and 100% for combined pressure washing and cleaning. The falling head method used higher head value compared to ASTM method which increased the amount of lateral flow resulting in inflated infiltration rates. The difference in geometry resulted in different infiltration values. The 4'' diameter of falling head infiltrometer is smaller than the 12'' diameter of single ring infiltrometer; as a result the ratio of perimeter to area is higher for falling head compared to single ring infiltrometer.

It was observed that the lateral flow is influenced by the ratio of perimeter to area, thus the falling head infiltrometer had higher infiltration value. The correlation between single ring and falling head method was consistent over a wide range of infiltration values which suggests that the falling head can be used to predict infiltration values obtained from the ASTM C1701 single ring method [10].

Márcia Lopes Afonso, Marisa Dinis-Almedia and Cristina Sena Fael investigated the performance of porous asphalt mixture with cellulosic fiber additive. The investigators used a double porous layer to improve runoff and reduce clogging problems. Two mixtures with and without cellulosic fibers were produced containing fine and coarse aggregates. Four different mixtures were produced (1.Porous asphalt without fibers, with fine aggregate 2.Porous asphalt without fibers, with coarse aggregate 3.Porous asphalt with fibers, with fine aggregate 4.Porous asphalt with fibers, with coarse aggregate) and they were evaluated for the performance under stiffness, permeability, water sensitivity and deformation testing. Test results suggested that the porous asphalt with fine aggregate is more likely to have water presence than mixture with coarse aggregate since coarse aggregate have more air voids [7].

Robert A. Brown and Michael Borst conducted a research project to measure the water balance for quantifying the evaporation from a lined permeable pavement section. The pervious concrete (PC), porous asphalt (PA) and permeable interlocking concrete pavers (PICP) were used in the investigation. All infiltrating water was captured by an impermeable liner installed in four 11.6 m by 4.74 m sections 0.4 m below the surface. The area ratio between impervious areas to permeable pavement was 0.66:1. The water level for 24 months was measured in the collection tanks. The researchers concluded that the evaporation increased during the warmer months and the average cumulative evaporation was about 5.2% of the total rainfall for permeable pavement. Cumulative evaporation from pervious concrete, permeable interlocking concrete and porous asphalt was ranging from 6.5–7.6%, 3.9–5.8%, and 2.4–5.6% of the cumulative rainfall, respectively. The difference in evaporation between PICP and PA was not significant whereas porous concrete has the largest cumulative evaporation [11].

Hui Lin, Masoud Kayhanian and John T. Harvey compared permeability measurement of permeable pavements using ASTM C1701 and National Center for Asphalt Technology (NCAT) permeameter methods. The study was conducted to compare the results obtained from field testing on a variety of permeable pavements. Six different permeable pavement surfaces types included pervious concrete, porous asphalt and permeable interlocking concrete pavers. Silicone gel was used as sealing material for testing. Through the comparison it was found that both methods (NCAT and ASTM) are effective in measuring the permeability of all pavement types. The permeability measured through ASTM C1701 method was 50-90% (75% on average) lower than those measured with NCAT. The reliability and accuracy of the measured permeability is dependent on the permeameter cylinder diameter, use of larger diameter produced less variation in results. The NCAT method uses falling head principle. The NCAT method was never published; however it is widely used in assessments of pervious asphalt and thin layers of open graded asphalt. The testing procedure requires filling water in the cylinder in tier 4 or in tiers 3, 2 or 1 and measure the time required to drop the height of each of the permeameter tiers. The testing device is shown in figure 2. The coefficient of permeability also known as saturated hydraulic conductivity, K_s can be calculated by using equation 1 [12].

$$K_s = \frac{al}{At}\ln\left(\frac{h_1}{h_2}\right) \quad \text{............ Equation 1}$$

Where;

K_s= saturated hydraulic conductivity, cm/s

a = inside cross-sectional area of inlet standpipe, cm^2

l = thickness of the permeable porous asphalt or pervious concrete pavement, cm

A = cross-sectional area of tested pavement, cm^2

t = average elapsed time of water flow between timing marks (t_1-t_2), s

h_1= hydraulic head on pavement at time t_1, cm

h_2 = hydraulic head on specimen at time t_2, cm

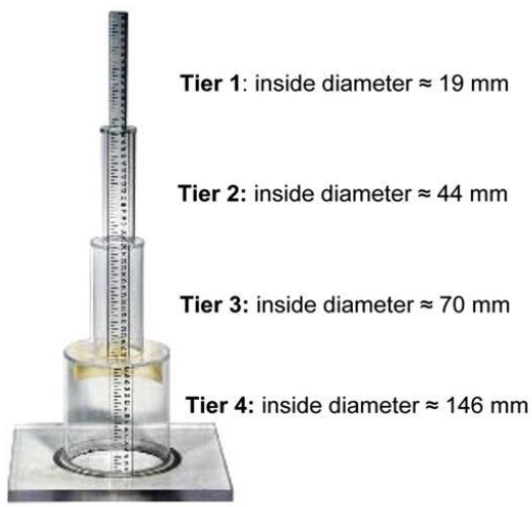

Figure 2 NCAT field permeameter of four cylindrical tiers with different diameters

2.2 Research Objective

The objective of the research is to make a reliable testing method that could be used on different porous pavement to determine the infiltration rate. The porous pavements become clogged with dirt and debris overtime and hence require maintenance. A reliable infiltration test would help to build a maintenance schedule.

2.3 Methodology to Achieve Research Objectives

Infiltration rates of permeable pavement are high when they are first installed. The infiltration test procedure used in the past has been inconsistent and the variation in results is very large. Most test procedures are based on using single or double ring infiltrometer test. Ring infiltrometer was originally designed to determine the hydraulic conductivity in soils. For high hydraulic conductivity single ring infiltrometer are commonly used. A falling head or constant head method can be used for pavement with high infiltration rate.

2.3.1 Infiltration Rates Testing Methods

Most standards for testing the infiltration rate are based on ASTM D3385 [13] which were primarily developed for testing on soil. Since soil has much lower infiltration rate compared to permeable pavement therefore ASTM D3385 cannot be used on highly pervious pavement. There is currently no standard to test infiltration rate on permeable pavement however ASTM C1701 and ASTM C1781 have been developed for infiltration testing on porous concrete and porous interlocking concrete pavers, respectively. These standards are very similar except for the fact that ASTM C1781 specifies where to place the ring on the interlocking pavers.

2.3.2 ASTM C1701 - Standard Method for Infiltration Testing of In Place Pervious Concrete

The ASTM C1701 standard is a constant head method that requires a ring of 12'' diameter to be adhered to the pavement surface, pouring a known mass of water onto the pavement, maintain a constant head between 0.4 – 0.6 inch and recording the time taken for water to disappear from top of the surface. The testing method requires a user to pre-wet the surface using 8 lb. of water. If the time taken for water during pre-wetting is less than 30 sec, use 40 lb. of water for infiltration testing. During pre-wetting, if the time taken for water to infiltrate completely into the pavement is greater than 30 sec, use 8 lbs of water. The infiltration rate is calculated using equation 2.

$$I = \frac{KM}{D^2 t}$$ ………………. Equation 2

Where;

I = Infiltration rate (in/h)

M = Mass of infiltrated water (lbs.)

K = 126870 [(in^3.s)/(lb.h)] (needed to convert recorded data to the infiltration rate)

t = Time required for measured amount of water to infiltrate (sec)

D = Inside diameter of infiltration ring (in)

The limitation to this standard is that the next test cannot be performed before 24 hours have elapsed since the last precipitation or last test. However, if two tests are conducted on same day at the same location the infiltration rate can be calculated as the average of the two tests.

The ASTM testing method is highly user dependent as maintaining the constant head between such a small ranges (0.4 - 0.6 inch) is very challenging. Achieving a high repeatability with low error in ASTM C1701 testing is difficult.

2.3.3 Falling Head Method

The FHID method was also used to determine the infiltration rate on same samples. With FHID, same quantity of water is used and the testing ring size is also 12’’ as used for ASTM C1701 testing. However, with falling head infiltration test all the water is dumped onto the permeable pavement at once instead of maintaining constant head above the surface. This method leads to a lower time taken by water to disappear which translates to high infiltration rates. A 12’’ concrete forming tube was used to make falling head infiltration device. The device consists of two sections. One section fits within the 12’’ section and sits on top of the bottom surface of outside section. The surface where the two section meet is made out of plastic sheets and rubber. The plastic sheets and rubber are bonded together using caulking glue. The plastic sheet and rubber had three holes cut of identical size and pattern. When the top section is rotated the holes align and close, allowing the water to be filled in the inner section. After filling water, the inner section could be rotated either clockwise or anti-clockwise to release water for infiltration testing. The inside and outside of the forming tube was covered with water proofing and crack prevention membrane to prevent the forming tube from becoming wet and soggy.

The ASTM C1701 standard doesn’t specify the falling head for water onto the pavement. The actual total falling head with FHID was 11 inches. A soft modeling material plasticine was used as sealing material. The use of plasticine provided excellent sealing between the pavement and the testing ring. Plasticine is easy to form into a role which was placed around the outside of testing ring and gently compressed to make a seal. It is very easy to remove plasticine from porous pavement. Using plasticine amount of water leaking in lateral direction was negligible (few drops of leakage only). The testing method with FHID is similar to ASTM which requires a user to pre-wet the surface using 8lb of water. Unlike ASTM standard where water used for infiltration testing is 40lb if the pre-wetting time is greater than 30 seconds, the FHID method doesn't require 40lb of water even if the pre-wet timing is less than 30 seconds. With 40lb of water the initial head is very high which forces the water to flow underneath the sealant and the water comes out of the pavement on the other side of the testing ring. FHID requires entire quantity of water to be dumped onto the porous pavement at once. The difference in filtration rates between 8lb to 40lb of water is upto 8 times which is unrealistic for same sample. Therefore the time taken for pre-wet during FHID is not much of importance except for the fact that pre-wetting brings different samples of the pavements to same initial testing conditions.

3. Experimental Setup

3.1 Test Samples

Infiltration tests were performed on three asphalt samples (A, B and C) which were received from a local paving company located in Vancouver Island.

Figure 3 Porous Asphalt sample A (middle) and sample B (left) sample C (right)

Each test sample was approximately 3 feet by 1.5 feet in size. On each sample only one location could be selected for testing. The relatively flat surface for 12inch diameter test ring was found to be right in the middle of the sample hence this location was selected for testing. Each sample had a different porosity and contained fibers as binders.

Figure 4 Fibers used in asphalt samples

3.2 ASTM C1701 Testing Device

The equipment used for ASTM C1701 testing are a 12’’ diameter and 9’’ high fiber reinforced plastic (FRP) ring, wooden stand, 5 gallon water bottle, 2’’ diameter pipe, PVC valve, flexible coupling and a gorilla tape. Building the testing setup starts with placing the FRP ring onto the porous pavement. After placing the ring on the sample the ring was adhered to the pavement using plasticine. The wooden stand is placed on top of the pavement to support a 5 gallon water bottle. After placing the bottle upside down on top of the stand the piping is connected to the valve on the bottle.

Figure 5 Assembled ASTM C1701 testing setup

The length of piping is selected carefully such that when the experimental setup is assembled on the field, the gap between the pipe and the asphalt is approximately 0.5’’.This can easily be done by field measuring the distance between the valve and asphalt to calculate the required length of pipe. The pipe was field cut using hacksaw.

Figure 6 Gap of 0.5 inch between pavement and open end of the pipe

This gap of 0.5 inches is maintained strategically since with the above setup when the valve is full opened the device will maintain the level automatically between 0.4 to 0.6’’.

3.3 Falling Head Infiltration Device

Two 12 inch diameter sections made of concrete foaming tube were built for the falling head infiltration device. The sections were made such that one section could fit inside the other section. The other equipment used for FHID includes a wooden stand, 5 gallon water bottle, 2 inch dia pipe, PVC valve, reducer and gorilla tape.

Figure 7 Two components of FHID

The component on the right in above figure sits on top of the porous asphalt whereas the component on the left fits inside the component that adheres to asphalt. The contact area between the outer ring and asphalt is sealed by using plasticine.

Figure 8 Inside of assembled FHID

After assembling the FHID, the inside component is rotated to close the window. This allows the water to stay in the inner section until the test starts. The concrete foaming tube was coated with water proofing membrane which made it reusable.

Figure 9 Assembled FHID

4. Analysis and Results

The testing on each sample could only be performed 6 days due to time constraints. Alternate day were selected for one method of testing for each sample as shown in the table 1.

Table 1 Testing schedule of porous asphalt samples

Sample	Type of Testing Conducted					
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
A	ASTM	FHID	ASTM	FHID	ASTM	FHID
B	FHID	ASTM	FHID	ASTM	FHID	ASTM
C	ASTM	FHID	ASTM	FHID	ASTM	FHID

For ASTM C1701 as well as falling head testing pre-wetting with 8lb of water was performed before the test stage. The test results over a period of 6 days are shown in the table 2 to 7 in the appendix A.

The tests results shown in the tables (2-7) of appendix A are for the testing conducted on three samples (A, B, C) over a period of 6 days. The rest period between the tests is 24 hours approximately. Figure 10 shows the infiltration rate using ASTM C1701 on each sample over 6 days period.

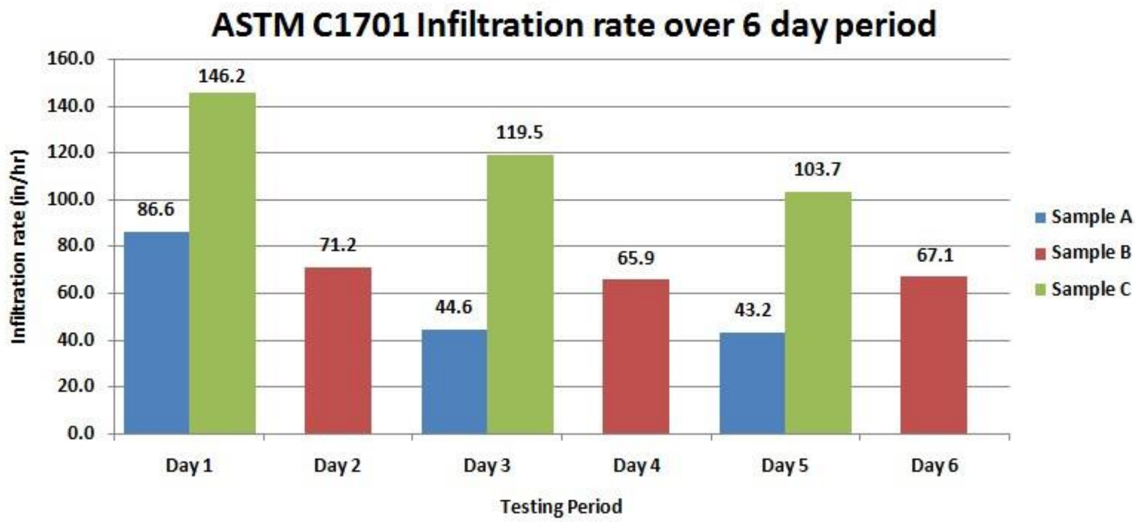

Figure 10 ASTM C1701 Infiltration rate for porous asphalt

The result shows that the infiltration rates for sample A and C were high on first day of testing but it stabilized during the next two testing. The infiltration rates of sample B which started on 2 day can be seen to have less variation. The reason for such a behavior of the asphalt could be that on day 1, the samples not only let the water infiltrate through the pores but the voids and open spaces inside the sample hold some of the water and the fiber binders also absorbed negligible quantity of water. Since fibers are in very small quantity therefore it can be estimated that the amount of water the sample holded is significant. In case of sample B the infiltration rate remain very stable, this is because the sample B is tested for FHID on day 1 hence the sample is already wet from previous day of testing. Therefore, the infiltration rate has good repeatability for sample B. The variability in results is likely due to the height of the pipe which is ideally set at 0.5 in but in the field testing this height varied slightly during each test which resulted in variable head of water.

While ASTM C1701 testing was conducted on one set of sample the other set of samples were tested with falling head method. The results of FHID on three samples over a period of 6 days are shown in figure 11.

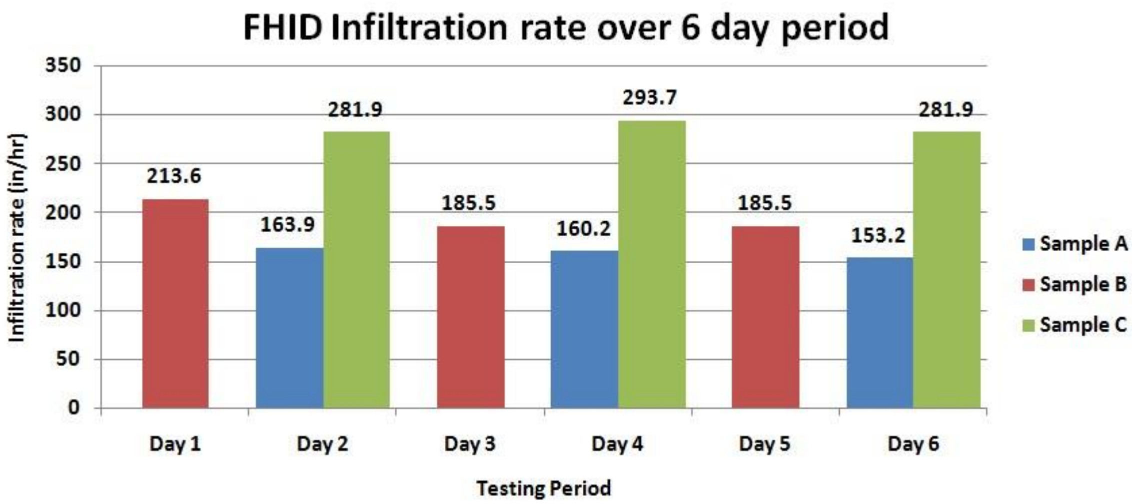

Figure 11 FHID Infiltration rate for porous asphalt

The testing with FHID showed very promising results with good repeatability. The tests on day 2 onwards showed very similar result. There was some difference noticed in sample B values which showed a high infiltration rate on day 1 compared to later tests. Again this is because when the sample B was first tested the asphalt was dry and holded some of the infiltrated water in the voids and holes which affected the test and resulted in higher infiltration rate on day 1.If the infiltration rates from figure 10 and 11 are compared it can be seen that the infiltration rates with FHID method were found to be much higher when compared to ASTM C1701 standard. However the high infiltration rates with FHID are not a major concern as the consistency and repeatability in values over time for same location is more important.

The ASTM C1701 standard for is basically derived from ASTM D3385 [12]. The ASTM D3385 is designed for the determination of infiltration rate of soil. Soil has strong capillary action; the pre-wetting in ASTM C1701 is incorporated to adjust for capillary action in concrete. Collected data for pervious asphalt was analyzed to see if pre-wetting in needed in asphalt samples at all.

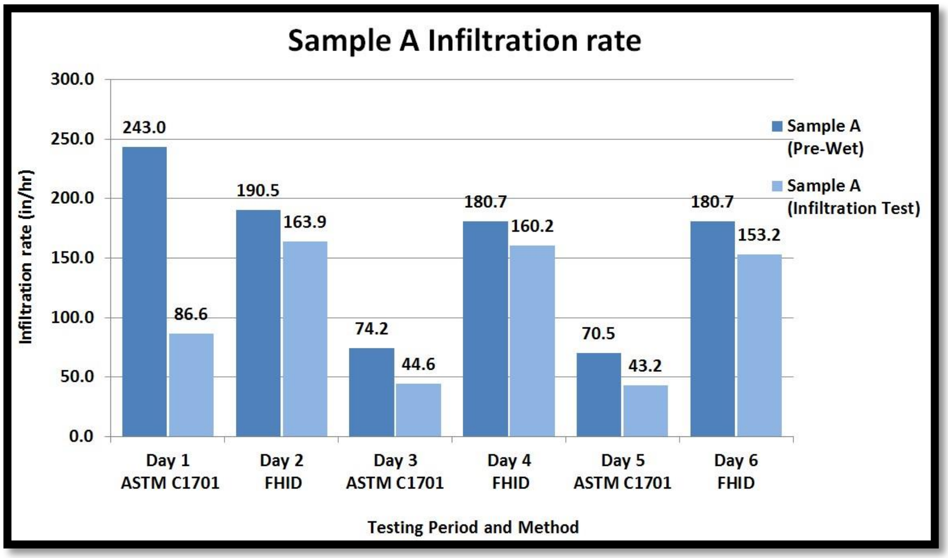

Figure 12 Sample-A Infiltration rate with ASTM C1701 and FHID

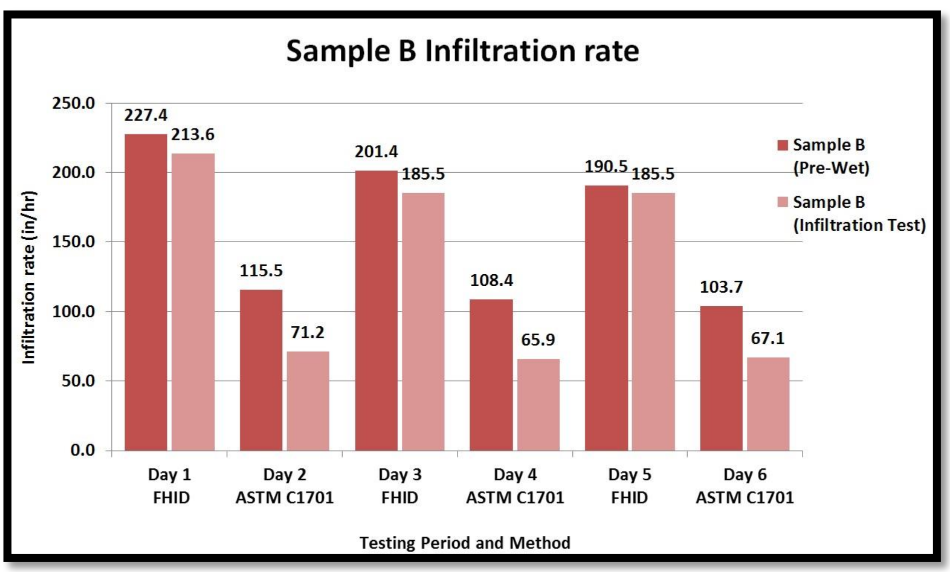

Figure 13 Sample-B Infiltration rate with ASTM C1701 and FHID

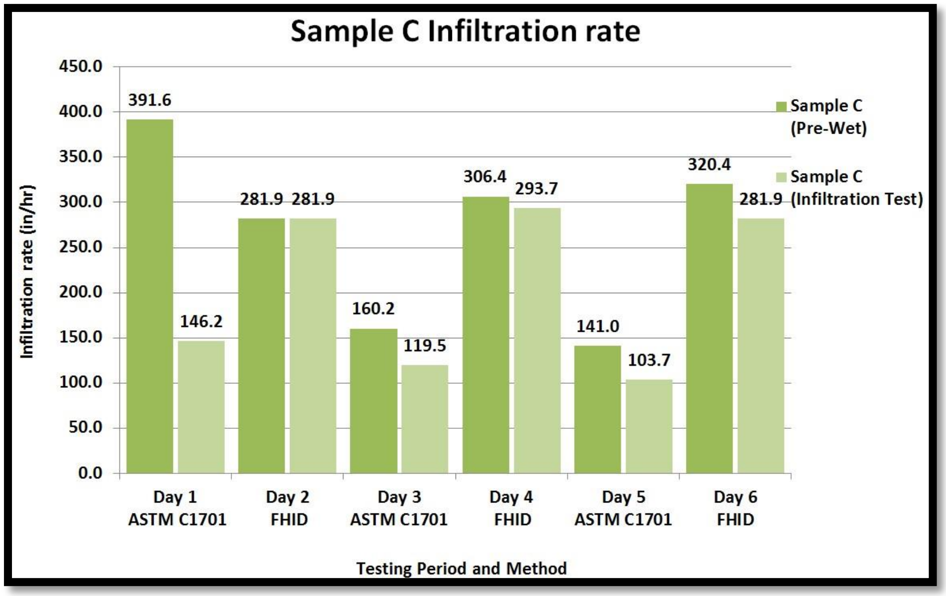

Figure 14 Sample-C Infiltration rate with ASTM C1701 and FHID

The capillary action is not as significant in porous asphalt as it is in soil. However test results suggest that pre-wet helps bring the asphalt to same initial testing conditions. The infiltration test performed after the pre-wet produced very similar result but the pre-wet time varied mostly, especially on first day of testing. Therefore when determining infiltration rates through ASTM C1701, it is recommended to perform pre-wetting before performing the infiltration testing. When using FHID on sample B the difference in results between pre-wetting and infiltration testing was not significant even on the first day of testing. Therefore with FHID it is totally up to the user to either choose pre-wetting or not as it doesn’t affect the results by a great deal.

5. Conclusion and Recommendation

The test results showed that the falling head device produced more consistent results compared to the test conducted using ASTM C1701. The use of plasticine as sealant had a huge impact on the accuracy and repeatability of results. The plumber's putty which is suggested in ASTM standard and used by several investigators does not provide sufficient sealing. The result showed that falling head method is simple and easy to use for determining infiltration rate. Among the three samples, Sample C was found to have the highest infiltration rate followed by sample B and sample A. Pre-wetting of the sample is suggested when ASTM C1701 method is used, the results with FHID were highly consistent so pre-wetting is not required. Since the test samples were not in situ, the results may vary when the same sample is in situ. Since the samples are placed on wooden pallets few inches off the ground there is relatively lower resistance to flow of water. The FRP ring used for conducting the ASTM C1701 tests was very stable and thus the sealant could be compressed much harder to the ring to achieve good seal. The components of FHID were made from concrete forming tube with water proofing membrane which helped the device retain its shape. If water proofing membrane is not used, it is recommended to use FRP or poly vinyl carbonate or steel for making the components of FHID.

6. References

[1] Miklas Scholz, Piotr Grabowiecki, “Review of permeable pavement systems”, Institute for Infrastructure and Environment, School of Engineering and Electronics, The University of Edinburgh, Scotland, UK, 2006

[2] Permeable Pavement, Version 1.8, March 1, 2011 (Available online: http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec7PERMEAB LEPA VEMENT.html)

[3] Cesare Sangiorgi, Shahin Eskandarsefat , Piergiorgio Tataranni, Andrea Simone, Valeri Vignali, Claudio Lantieri, Giulio Dondi, “A complete laboratory assessment of crumb rubber porous asphalt”, D pt. of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, V.le Risorgimento 2, 40136 Bologna, Italy, 2016

[4] R.J. Winston, W.F. Hunt, A. Al-Rubaei, G. Blecken, M. Viklander, “Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate. The effects of street sweeping, vacuum cleaning, high pressure washing, and milling” Journal of Environmental Management”, vol. 169, pp. 132-144, 2016

[5] Yanping Sheng, Haibin Li, Ping Guo, Guijuan Zhao, Huaxin Chen and Rui Xiong, “Effect of Fibers on Mixture Design of Stone Matrix Asphalt”, School of Materials Science and Engineering, Chang’an University, Xi’an 710064, China, 2017

[6] J. Sansalone , X. Kuang and V. Ranieri, “Permeable Pavement as a Hydraulic and Filtration Interface for Urban Drainage”, Journal of Irrigation and Drainage Engineering, Vol. 134, No. 5, October 1, 2008

[7] Márcia Lopes Afonso, Marisa Dinis-Almeida , Cristina Sena Fael, “Study of the porous asphalt performance with cellulosic fibres”, Centre of Materials and Building Technologies, University of Beira Interior, 6200-358 Covilhã, Portugal, 2016

[8] Kuldip Kumar, Joseph Kozak, Lakhwinder Hundal, Albert Cox, Heng Zhang, Thomas Granato, “In-situ infiltration performance of different permeable pavements in an employee used parking lot - A four-year study”, Monitoring and Research Department, Metropolitan Water Reclamation District of Greater Chicago, 6001 West Pershing Road, Cicero, IL, USA, 2015

[9] Bin Yu, Liya Jiao, Fuji n Ni & Jun Yang, "Long-term field performance of porous asphalt pavement in China", School of Transportation, Southeast University, Sipailou #2, Nanjing 210096, People's Republic of China, 2014

[10] Ian A. Anderson, Mark Suozzo and Mandar M. Dewoolkar, "Laboratory and Field Evaluations of Pervious Concrete", University of Vermont Transportation Research Center, TRC Report 13-007, October 2013

[11] Robert A. Brown and Michael Borst, "Quantifying evaporation in a permeable pavement system", U.S. Environmental Protection Agency, 2890 Woodbridge Ave., MS104, Edison, USA, 2015

[12] Hui Li, Masoud Kayhanian, John T. Harvey, " Comparative field permeability measurement of permeable pavements using ASTM C1701 and NCAT permeameter methods", Department of Civil and Environmental Engineering, University of California, Davis, CA, USA, 2013

[13] ASTM, "ASTM D3385 - Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer", ASTM International, West Conshohocken, PA, 2009

[14] ASTM, "ASTM C1701 – Standard Test Method for Infiltration Rate of In Place Pervious Concrete", ASTM International, West Conshohocken, PA, 2009

[15] Google image search, www.google.com/

Appendix A - Test Results

Table 2 Infiltration test results of day 1

DAY 1	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	ASTM		FHID		ASTM	
Pre-wet	8	25 sec	8	31 sec	8	18 sec
Test 1	40	5 min 1 sec	8	33 sec	40	3 min 31 sec
Test 2	40	8 min 32 sec	8	33 sec	40	4 min 30 sec
Average infiltration time	6 min 47 sec		33 sec		4 min 1 sec	
Infiltration Rate (in/hour)	86.6		213.6		146.2	

Table 3 Infiltration test results of day 2

DAY 2	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	FHID		ASTM		FHID	
Pre-wet	8	37	8	1 min 01 sec	8	25 sec
Test 1	8	43	8	1 min 22 sec	40	35 sec
Test 2	8	43	8	1 min 56 sec	8	25 sec
Average infiltration time	43 sec		1 min 39 sec		25 sec	
Infiltration Rate (in/hour)	163.9		71.2		281.9	

Table 4 Infiltration test results of day 3

DAY 3	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	ASTM		FHID		ASTM	
Pre-wet	8	1 min 35 sec	8	35 sec	8	44 sec
Test 1	8	2 min 25 sec	8	38 sec	8	55 sec
Test 2	8	2 min 50 sec	8	37 sec	8	1 min 02 sec
Average infiltration time	2 min 38 sec		38 sec		59 sec	
Infiltration Rate (in/hour)	44.6		185.5		119.5	

Table 5 Infiltration test results of day 4

DAY 4	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	FHID		ASTM		FHID	
Pre-wet	8	39 sec	8	1 min 05 sec	8	23 sec
Test 1	8	43 sec	8	1 min 32 sec	40	35 sec
Test 2	8	44 sec	8	2 min 02 sec	8	24 sec
Average infiltration time	44		1 min 47 sec		28 sec	
Infiltration Rate (in/hour)	160.2		65.9		293.7	

Table 6 Infiltration test results of day 5

DAY 5	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	ASTM		FHID		ASTM	
Pre-wet	8	1 min 40 sec	8	37 sec	8	50 sec
Test 1	8	2 min 31 sec	8	38 sec	8	1 min 05 sec
Test 2	8	2 min 55 sec	8	38 sec	8	1 min 10 sec
Average infiltration time	2 min 43 sec		38 sec		1 min 08 sec	
Infiltration Rate (in/hour)	43.2		185.5		103.7	

Table 7 Infiltration test results of day 6

DAY 6	Sample A		Sample B		Sample C	
	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed	Quantity of water (lbs)	Time elapsed
Testing Method	FHID		ASTM		FHID	
Pre-wet	8	39 sec	8	1 min 08 sec	8	22 sec
Test 1	8	46 sec	8	1 min 38 sec	40	32 sec
Test 2	8	45 sec	8	1 min 52 sec	8	25 sec
Average infiltration time	46 sec		1 min 45 sec		25 sec	
Infiltration Rate (in/hour)	153.2		67.1		281.9	

Appendix B - Materials Used for Fabricating Testing Device

Figure 15 RedGard membrane [15]

Figure 16 2'' diameter PVC pipe [15]

Figure 17 Paint brush [15]

Figure 18 Flexible coupling [15]

Figure 19 Gorilla tape [15]

Figure 20 Plasticine modelling clay [15]

Figure 21 5 gallon water bottle [15]

Figure 22 2'' dia PVC valve [15]

Figure 23 Concrete forming tube [15]

Figure 24 Hack saw [15]

Figure 25 Measuring tape [15]

Figure 26 3/4'' plywood [15]

Figure 27 Fold knife [15]

Figure 28 Silicone [15]

Figure 29 Teflon tape [15]