10th International Conference on Concrete Block Paving
Shanghai, Peoples Republic of China, November 24-26, 2012

Potential Application of ASTM C 1701 for Evaluating Surface Infiltration of Permeable Interlocking Concrete Pavements

David R. Smith, Technical Director
Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270, Herndon, Virginia 20171 USA
Tel +01-703-657-6900; Fax: +01-703-657-6901 Email: dsmith@icpi.org

Kevin Earley, Director of Commercial Sales & LEED® Green Associate
Nicolock Paving Stones
3025 Fairhill Drive Collegeville, Pennsylvania 19426 USA
Tel; +01-631-774-6431 Email: kearley@nicolock.com

Justin M. Lia, P.E., President, LEED® AP
4Site Engineering, PLLC
58 Janet Street Port Jefferson Station, New York 11776 USA
Tel: +01-631-828-6123; Fax: +01-631-791-5655 Email: jlia@4siteli.com

Summary

Permeable interlocking concrete pavement (PICP) has seen increased use for stormwater management and low impact development (LID). Surface infiltration is a key performance indicator for surface cleaning using vacuum equipment. This paper provides background on the development of test methods for measuring surface infiltration of permeable pavements. Among those test methods is the single ring infiltrometer described in ASTM C 1701 *Standard Test Method for Infiltration Rate of In Place Pervious Concrete*. This test method was initially developed to measure surface infiltration of PICP and concrete grid pavements in 2004, and approved and published by American Society for Testing and Materials (ASTM) in 2009 as a test method only for pervious concrete.

Research on surface infiltration testing from PICP sites in Long Island, New York, USA confirms that ASTM C1701 test method is suitable for measuring the surface infiltration rate of PICP. The post-construction pavement surface infiltration results demonstrated an average rate of 1.4 x 10^{-3} m/sec or greater. Test results are also referenced from United States Environmental Protection Agency (US EPA) surface infiltration testing that used a modified version of ASTM C 1701 at a permeable pavement research facility in Edison, New Jersey, consisting of PICP, pervious concrete, and porous asphalt.

Modifications to ASTM C 1701 are proposed that include use of (1) modeling clay to seal the ring to the pavement in hot weather; and (2) graduated bucket(s) to determine the mass of infiltrated water, and (3) a means to determine placement of the test apparatus on the paving pattern. Graduations on the buckets can eliminate the use of a scale on the test site to determine the infiltrated water's mass. In addition, changes to C1701 are proposed to reference an emerging ASTM surface infiltration test method for PICP and clay pavers for comparative purposes.

Key Words: permeable interlocking concrete pavement. surface infiltration testing. permeable pavement, pervious pavement.

1. Background

There are several ways to assess infiltration of rainfall and runoff into permeable pavements. In ascending cost order they include: (1) visual inspection during or immediately after a rainstorm for ponding; (2) measuring surface infiltration on sampled small areas; (3) generating synthetic rainfall and runoff for a distinct rain event which often involves a rain simulator; and (4) continuous monitoring of rainfall and surface runoff usually over a period years.

The PICP and pervious concrete pavement industries elected to use method (2) i.e., sampling and testing the surface infiltration rate of small areas across a larger pavement for acceptance testing of newly constructed pavements as well as for assessing in-service surface infiltration. This test method is formalized in ASTM C 1701. The test method was proposed by the pervious concrete industry. The selection of this testing approach is likely due to the speed and economy of conducting tests in this manner.

2. PICP Surface Infiltration Testing with ASTM C 1701

Initially approved by ASTM in 1975, ASTM D 3385 *Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer* is a test method for assessing soil infiltration rates between 10^{-4} and 10^{-8} m/sec. In 2004, ASTM D 3385 was tried by Bean (Bean 2007) while evaluating surface infiltration of PICP, concrete grid and pervious concrete pavement sites in North Carolina, Virginia, Maryland, and Delaware. Figure 1 shows the double ring infiltration testing device. He moved to a single ring infiltrometer due to high surface infiltration rates of the permeable pavements tested and the volume of water required for maintaining hydraulic heads within the rings.

Figure 1. Double ring surface infiltration device used by Bean in 2004.

Bean reports test results from 14 PICP sites using a single ring device sealed with plumber's putty to the pavement surface. He measured values between 1.1×10^{-2} m/sec and 4.4×10^{-6} m/sec on PICP. The lowest values were due to clogging from fines, i.e., sediment on the surface. Values between 1.9×10^{-2} and 3×10^{-5} m/sec were measured on pervious concrete, again with the lowest values due to clogging from fines.

Bean's use of a single ring device is similar to that used for ASTM C1701 *Standard Test Method for Infiltration Rate of In Place Pervious Concrete* which uses a single ring infiltrometer sealed to the pavement surface. Developed from Bean's research, this test method consists of a 300 mm diameter ring, plumber's putty to seal the ring to the pavement surface, water (typically provided in 19-20 liter buckets) and a stopwatch (found on most cell phones).

ASTM C 1701 is recommended for acceptance testing and in-service performance of PICP by the Interlocking Concrete Pavement Institute (Smith 2011). A minimum infiltration rate acceptance for new construction of 7×10^{-4} m/sec is recommended. The same rate is recommended for acceptance testing of pervious concrete pavement in a New York State Department of Transportation specification (NYSDOT 2011) and a draft specification by Caltrans (California Department of Transportation).

3. PICP Infiltration Tests in New York

To further demonstrate the utility of this test method for PICP, results from two sites from 4Site Engineering in 2010 and 2011 are provided (Lia 2011 and Lia 2011b). Both sites are in Lindenhurst, New York, the first being an 880 m^2 parking lot at a building materials supply store. The paving units were 120 x 225 x 80 mm thick with 13 mm joints filled with a stone gradation conforming to ASTM No. 9 stone per ASTM D448 *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*. For ASTM No. 9 aggregate, stone sizes range from 4.75 to 0.30 mm. According to *The Aggregate Handbook* (NSA 1991), this material has a hydraulic conductivity of at least 3.5×10^{-3} m/sec.

The paving units and jointing material were installed over 40 mm thick ASTM No. 8 bedding stone. This aggregate is slightly larger in size than the ASTM No. 9 stone in the paver joints. This bedding stone was placed over a 100 mm thick ASTM No. 57 base over a 675 mm thick subbase of ASTM No. 3 stone. ASTM No. 57 base ranges in size from 25 to 2.36 mm and ASTM No. 3 is 50 down to 12.5 mm.

The design storm required for infiltration by the local municipality is equivalent to a storage volume of 40 mm in a 24-hour period or a 90% rainfall event as defined by the New York State Stormwater Management Design Manual. Figure 2 illustrates the test site with the ASTM C1701 test apparatus.

Figure 2. ASTM C1701 test apparatus at a building supply store parking lot

Both test locations in Lindenhurst used plumber's putty to seal the metal ring against the pavers as shown in Figure 2. On both sites, the jointing stones are removed between the joints under the ring and filled with plumbers putty to further direct the water downward. Removal of the jointing stones can be done with a putty knife and screwdriver. A key consideration on locating the ring is to frame the paver joint pattern within the ring. This framed area should represent the percentage of open area in the overall surface to best characterize surface infiltration. Besides characterizing the overall permeable jointing pattern, this location can reduce the time and effort required to remove jointing stones and filling the joints with plumber's putty.

After pre-wetting, ASTM C 1701 test method was conducted three times over the first 11 months of service that resulted in an average infiltration rate of 2.025 x 10^{-3} m/sec or 287 in./hr. Table 1 provides the test data for three test locations.

Table 1. PICP test results for a building supply parking lot in Lindenhurst, New York, in m/sec

Date	Test Location 1	Test Location 2	Test Location 3
21 October 2010	1.5 x 10^{-3}	2.1 x 10^{-3}	2.5 x 10^{-3}
21 October 2010	1.3 x 10^{-3}	2.5 x 10^{-3}	2.2 x 10^{-3}
4 April 2011	2.3 x 10^{-3}	2.4 x 10^{-3}	2.4 x 10^{-3}
4 April 2011	2.4 x 10^{-3}	2.3 x 10^{-3}	2.5 x 10^{-3}
2 November 2011	1.8 x 10^{-3}	1.6 x 10^{-3}	1.7 x 10^{-3}
2 November 2011	1.7 x 10^{-3}	1.6 x 10^{-3}	1.7 x 10^{-3}

Another test using ASTM C1701 was conducted at a 600 m^2 PICP parking lot at a public library in Lindenhurst, New York. The paving units were 200 x 200 x 80 mm thick with 13 mm wide joints filled with ASTM No. 8 stone. The paving units and jointing material were installed over 40 mm thick ASTM No. 8 bedding stone. This was placed over a 100 mm thick ASTM No. 57 base and a 150 mm thick subbase of ASTM No. 3 stone over a highly permeable soil subgrade. Figure 3 illustrates the test site with the ASTM C1701 test apparatus.

Figure 3. ASTM C1701 test apparatus at a public library parking lot

After pre-wetting (i.e., applying water without measurements) the ASTM C 1701 test method was conducted in April, 2011 during the first months of service that resulted in an average infiltration rate of 3.8 x 10^{-3} m/sec. Table 2 provides the test data.

Table 2. PICP test results for a public library parking lot in Lindenhurst, New York, in m/sec

Date	Test Location 1	Test Location 2	Test Location 3
4 April 2011	3.4×10^{-3}	3.5×10^{-3}	4.6×10^{-3}
4 April 2011	3.4×10^{-3}	3×10^{-3}	4.8×10^{-3}

4. US Environmental Protection Agency Infiltration Testing

In fall of 2009, the US Environmental Protection Agency opened a 110-car parking lot for staff at their Edison, New Jersey, National Risk Management Laboratories. The parking lot was designed to evaluate the long-term performance of PICP, pervious concrete and porous asphalt. The parking facility is illustrated in Figure 4 with the three permeable pavement surfaces each approximately 530 m^2 for car parking. The research objectives and parameters for this multi-year monitoring project are shown in Table 3.

One objective listed is measuring surface infiltration to assess maintenance cleaning methods. To gain a better understanding of surface cleaning required, one half of the parking lot is vacuumed swept twice a year and the other half is not. Surface infiltration measurements are measured monthly in both areas with a modified version of ASTM C1701 to characterize the clogging potential of each surface and when cleaning might be required.

Figure 4. Pervious concrete (light colored parking area on left), PICP (center) and porous asphalt (right) at a test facility at US EPA laboratories in Edison, New Jersey

Table 3. US EPA research objectives and parameters measured at the Edison, New Jersey, permeable pavements research facility

Monitoring Objective	Parameters Measured
Hydrologic performance	Volume, exfiltration rate
Water quality performance	Soils, indicator organisms, metals, nutrients, organic compounds
Urban heat island effects	Net radiation, infrared radiation, temperature
Maintenance effects	Surface infiltration rate, visual assessment
Use	Car counter, visual assessment
Infiltrating water parameters	Water depth, reduction and oxidation reactions, pH, conductivity, chloride

Instead of using plumber's putty to create a seal between the ring and the pavement surface, neoprene is used on the ring and it is pressed into the pavement surface with plastic buckets weighted with stones. This accelerates set up, measurements, and clean up. Figure 5 illustrates the apparatus. All other aspects of the test method appear to be similar to ASTM C1701 (Borst 2010).

Figure 5. Modified ASTM C1701 using neoprene seal on the porous pavement (Borst 2010)

Borst reported infiltration rates for the initial months of the parking lot's surface (Borst 2010). There was no difference between maintained and unmaintained area surface infiltration rates, likely due to the newness of the surfaces. The unweighted means for pervious concrete were 1.1 x 10^{-2} m/sec), PICP at 6.6 x 10^{-3} m/sec and porous asphalt at 5.6 x 10^{-4} m/sec. The report does not mention if the stones are removed from between the pavers in the PICP and filled with neoprene or plumber's putty.

5. Proposed Changes to ASTM C 1701 Testing Procedures

Jennifer Drake, a doctoral student with the University of Guelph is conducting a series of surface infiltration tests on PICP and pervious concrete sites in Ontario, Canada using ASTM C 1701 as well double ring test methods. She is also investigating water volume and pollutant removal from these pavements. Her observations regarding both pavement types are that they require regular vacuum sweeping in order to maintain surface infiltration rates. She noted at an October 2011 presentation in Ontario (Drake 2011) that for hot weather (over 30° C.), non-oil base modeling clay works better than plumber's putty as the latter material becomes viscous, stringy, and difficult to handle. The modeling clay molds quickly and creates a seal between the ring and pavers.

ASTM C 1701 currently requires that the mass of infiltrated water be determined so that value can be entered into a formula that calculates the surface infiltration rate. This can require bringing a scale to the site to weight before and after mass of the water dispensed usually from buckets. A bucket or other suitable container(s) with graduations related to the mass of water could obviate a scale on the site while still providing the mass of water dispensed during the test.

6. Conclusions

The most common permeable pavement surfaces are pervious concrete, PICP and porous asphalt. There are millions of square meters of each in service. ASTM C 1701 is an inexpensive and rapid test method for measuring surface infiltration by simulating a small hydraulic head on the surface test area like those generated by intense rain storms and contributing runoff. Data and experience from Bean, Lia, and Drake confirm that C1701 is suitable for testing the surface infiltration of PICP and Bean extends its use to successfully testing concrete grid pavements. Borst reports using a modified version of C 1701 to test PICP, pervious concrete, and porous asphalt as part of a nationally visible evaluation of these pavements.

In order for contractors, stormwater agencies and project owners to better understand performance of maintenance needs of all permeable pavements, ASTM C 1701 should be revised to address PICP, concrete grid pavements, and porous asphalt testing. Chopra 2010 and Vancura 2010 demonstrate that permeable pavements can experience a reduction in their surface infiltration rates especially if not maintained with vacuum sweeping. Broadening the application of ASTM C 1701 to characterize the surface infiltration of more than just pervious concrete enables an objective comparison of the performance other pavement systems designed to reduce stormwater runoff.

ASTM C 1701 test method is within the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates. The development of a separate test method with results comparable to ASTM C 1701 is proceeding in ASTM Committee C15 on Manufactured Masonry Units. This committee has jurisdiction over concrete and clay paving units as both materials are used to build permeable segmental pavements. When ASTM Committee C15 approves the test method, there is logic in revising ASTM C 1701 to reference the new test method for PICP and concrete grid pavements.

Along these lines, proposed changes include the following:

- Addition of a note that references in ASTM C 1701 to a new test method (when approved by ASTM Committee C 15) that yields comparable test results.
- As a substitute for plumber’s putty, optional use (non-oil base) modeling clay while testing in hot temperatures with material specifications.
- Optional use of graduated containers to determine water volume and mass for dispensing water. This could eliminate the use of a scale on the test site.
- Inclusion of test procedures for PICP and concrete grid pavements including a description centering the ring over concrete paver/grid patterns and joints.
- Precision and bias statements for the above.

7. References

Bean 2007. Bean, E.Z., Hunt, W.F. and Bidelspach, D.A., “Field Survey of Permeable Pavement Surface Infiltration Rates,” *Journal of Irrigation and Drainage Engineering*, American Society of Civil Engineers, Reston, Virginia, pages 249-255, May/June 2007.

Borst 2010. Borst, M., Rowe, A. A., Stander, E. K. and O’Connor, T. P., *Surface Infiltration Rates of Permeable Surfaces: Six Month Update (November 2009 through April 2010)*. Water Supply and Water Resources Division, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, Edison, New Jersey, August 2010.

Chopra 2010. Chopra, M.B., Stuart, E., Wanielista, M.P., “Pervious Pavement Systems in Florida – Research Results,” in *Proceedings* of Low Impact Development 2010: Redefining Water in the City, pages 193 – 206, American Society of Civil Engineers, Reston, Virginia.

Drake 2011. Drake, J., "Permeable Pavement Monitoring at the Kortright Centre for Conservation & Maintenance Testing on Established Permeable Pavements," presentation given at the Kortright Centre, Toronto and Region Conservation Authority, Toronto, Ontario, October 4, 2011.

Lia 2011. Lia, J. M., "Post Construction Surface Testing of the Nicolock Eco-Ridge Permeable Interlocking Concrete Paver Installation (PICP) at the Century Building Materials Facility Hamlet of Lindenhurst, Town of Babylon Suffolk County, New York," report form 4Site Engineering, Port Jefferson Station, New York, October 22, 2010, April 4 and November 2, 2011.

Lia 2011b. Lia, J. M., "Post Construction Surface Testing of the Nicolock SF-Rima Permeable Interlocking Concrete Paver Installation (PICP) at the Lindenhurst Public Library," report form 4Site Engineering, Port Jefferson Station, New York, April 4, 2011.

NSA 1991. *The Aggregate Handbook*, National Stone Association, Washington, DC.

NYSDOT 2011. ITEM 502.010700OD – Pervious Portland Cement Concrete, New York State Department of Transportation, Albany, New York, September 23, 2011.

Smith 2011. Smith, D.R., *Permeable Interlocking Concrete Pavement – Design Specifications Construction Maintenance,* Interlocking Concrete Pavement Institute, Herndon, Virginia, October 2011.

Vancura 2010. Vancura, M. and Khazanovich, L., *Performance Evaluation of In-Service Pervious Concrete Pavements in Cold Weather*, Department of Civil Engineering University of Minnesota, December 2010.