FIELD PERFORMANCE OF POROUS PAVEMENTS IN SOUTH CAROLINA

Bradley J. Putman

AUTHOR: Assistant Professor, Department of Civil Engineering, Clemson University, 109 Lowry Hall, Clemson, SC 29634
REFERENCE: *Proceedings of the 2010 South Carolina Water Resources Conference*, held October 13-14, 2010, at the Columbia Metropolitan Convention Center

Abstract. Porous pavements have been used to manage stormwater since the 1980s, but it has only been in the past decade that the use of porous pavements has become recognized as a legitimate stormwater best management practice (BMP). However, porous pavements are considered "high-performance" pavements and require special care during design, installation, and maintenance. If proper techniques are not practiced, then the pavement will not perform as intended.

The functionality of porous pavements can be compromised due to inadequate pavement design, poor mix design, poor installation practices, and clogging to name a few. This paper presents performance summaries of ten porous pavements from across the state of South Carolina with an analysis of causes for poor performance. Performance indicators include infiltration rate, surface distress (e.g., raveling), and structural performance. The knowledge gained from this study can provide guidance for designing, building, and maintaining porous pavements that have a high level of functionality throughout the design life based on local field experience.

INTRODUCTION

As with any pavement, there are several performance criteria for porous pavements. The specific criteria for porous pavements include functional performance, structural performance, and surface performance. The objective of this study was to evaluate the field performance of porous pavements in South Carolina.

Porous pavements are a stormwater best management practice (BMP) and are being considered for use more and more in South Carolina to handle with stormwater issues, especially in commercial locations. While many municipalities accept porous pavements as a stormwater BMP, there are no methods in place to ensure that the pavements are functioning as intended.

The results of this research provide some insight about the performance of porous pavements that need to be considered throughout the life of the pavements to be sure that they are functioning as the stormwater BMP for which they were designed. This information can be used as guidance for municipalities when setting policy; owners when creating construction specifications and when developing long-term maintenance plans; and contractors to properly construct porous pavements.

BACKGROUND AND RELATED WORK

As development and urbanization has increased, natural pervious surfaces have been replaced with impervious surfaces such as roofs and pavements. This reduction in pervious land cover increases the amount of stormwater runoff, which can have negative impacts including sediment transport, erosion, and pollutant transport (Bean et al. 2007). An alternative to traditional impervious pavements is to use porous pavements such as pervious concrete, porous asphalt, or permeable interlocking concrete pavers. Porous pavements allow stormwater to permeate through the pavement surface and then exfiltrate into the soil. By infiltrating through the pavement surface, the quantity of stormwater runoff is significantly reduced and the infiltrate is also filtered by the porous pavement structure in the process (Brattebo and Booth 2003; Sansalone and Buchberger 1995).

Because of all of the potential benefits of porous pavements related to stormwater management, many municipalities have accepted porous pavements as a stormwater BMP. However, it is paramount that the pavements perform as intended. The main performance issue related to porous pavements is clogging of the surface voids. This occurs as sediment accumulates in the voids in the surface of the pavements, which can be minimized with routine maintenance (e.g., vacuum sweeper or pressure washing) (Balades et al. 1995). In fact, removing the material occupying the voids in the 0.6 to 0.8-in. closest to the surface of the porous pavement can substantially regenerate the infiltration capacity of the pavement (Gerrits and James 2002).

A comprehensive study of the surface infiltration of permeable pavements was conducted by Bean et al. (2007). In this study, the researchers evaluated the infiltration performance of 40 sites of various types of porous pavement materials in North Carolina, Maryland, Virginia, and Delaware. During the study, they concluded that maintenance of the porous pavement surface was key to sustaining high infiltration rates. Additionally, they found that it is important to locate porous pavements away from disturbed soil areas where sediment transport will be an issue leading to clogging of the surface voids.

TEST SECTIONS AND PROCEDURES

During this study, ten different porous pavement locations were evaluated in different locations across South Carolina. All of the pavement sections were parking areas, nine of which were pervious concrete and one was porous asphalt. The specifics of each pavement section are discussed later in this section. The evaluations were conducted during the period from March 2009 to July 2010.

The performance of each of the porous pavement sections was evaluated to determine functional, structural, and surface performance. The functional performance was evaluated by measuring the infiltration rate through the pavement surface. Infiltration tests were conducted in accordance with ASTM C 1701 "Standard Test Method for Infiltration Rate of In Place Pervious Concrete" (2009). This procedure was used on both pervious concrete and porous asphalt pavements. Each pavement was divided into sublots and test locations were randomly selected within each sublot.

The structural and surface performance was evaluated by means of visual inspection of the pavement condition. The presence of cracking in the pavement was the primary indicator of the structural performance of the pavement. Surface performance was primarily evaluated by the degree of raveling of the pavement surface. Raveling is identified as loose pavement material that has debonded from the pavement structure.

Test Site A

This test site is the parking lot at an apartment complex in that was expanded in 2005. As part of the expansion, the builders elected to use pervious concrete in the new parking spaces to increase the pervious surface area as required by the city of Clemson. The pavement design consisted of 10-in. of pervious concrete placed over clay.

Test Site B

This is a facility maintained by the City of Greenville, SC Public Works Department. In 2006, the City of Greenville Public Works replaced part of the parking lot at one of their facilities with pervious concrete (7230 ft^2). The pervious concrete is approximately 6-in. thick placed on top of open graded stone base on top of clay subgrade. The parking lot serves passenger vehicles as well as bucket trucks.

Test Site C

This site is a porous asphalt parking lot on the campus of a hospital system in Greenville, SC that was place in October 2007. The porous asphalt is 2.5-in. thick and the base is 9.5-in. of No. 5 stone placed on clay subgrade. The design also included 24-in. infiltration trenches that were 20-ft. wide placed on 50-ft. centers throughout the lot for additional storage.

Test Site D

This site includes 4,291-ft^2 of pervious concrete parking spaces located at the Aiken Department of Public Safety in Aiken, SC that was placed in March 2010. The pavement design consists of 6-in. of pervious concrete placed over a 6-in. base of No. 57 stone and a sandy subgrade. This pavement was constructed as part of the Sand River Headwaters Green Infrastructure Project.

Test Site E

This site consists of a 11,155-ft^2 pervious concrete parking lot at a restaurant in Augusta, GA that was placed in April 2010. The pavement design consists of approximately 4-in. of pervious concrete over 8-in. of crushed stone base and a clay subgrade. The pervious concrete was selected for stormwater management purposes to meet city requirements.

Test Site F

This site is a 9,230-ft^2 city owned parking lot in Aiken, SC that is also a part of the Sand River Headwaters Green Infrastructure Project that was constructed in May 2010. The pavement design is 6-in. of pervious concrete over 6-in. of No. 57 stone over sandy subgrade.

Test Site G

This was a parking lot at a small plaza in Myrtle Beach, SC. The parking areas were pervious concrete (4,620-ft^2) and the drive and entry lanes were conventional concrete. The pavement was constructed in May 2008 and pervious concrete was chosen to satisfy stormwater management requirements of the city.

Test Site H

This site is located at a Myrtle Beach, SC business that installs specialty concrete. The pavement surrounding the building consists of decorative concrete and pervious concrete (6,200-ft^2) that was constructed as a showcase of the products that the company installs. The pervious concrete was also installed for rainwater recovery purposes. The pavement design consisted of 6-in. of pervious concrete over a 6-in. base of No. 57 stone on top of clayey subgrade.

Test Site I

This site is a commercial location having an asphalt parking lot with 6,400-ft^2 of pervious concrete in the perimeter spaces of the lot. The building at the location was expanded in 2009 and so was the parking lot. The

Table 1. Summary of Infiltration Test Results

Site	No. of Tests	Infiltration Rate (in/hr)	% of Locations with no infiltration	Reasons for low or no infiltration
A	11	0 – 365	73	Potential over consolidation during placement, excess water in mix sealing the surface, sediment clogging.
B	6	0 – 999	33	Sediment clogging from adjacent grassy area.
C	12	34 – 509	0	Sediment clogging.
D	11	37 – 1936	0	Excess water in mix sealing surface.
E	18	105 – 2821	0	Excess water in mix sealing surface.
F	16	0 – 3721	6	Excess water in mix sealing surface.
G	6	0 – 797	33	Construction related – potential over consolidation.
H	11	0 – 598	73	Potentially clogged as a result of application of concrete sealer.
I	10	0 – 139	70	Sediment clogging from material wearing off of adjacent asphalt pavement surface.
J	15	0 – 4	93	Severe sediment clogging from adjacent landscaped areas and pavement.

addition of pervious concrete was intended to meet stormwater requirements of the city of Murrells Inlet, SC.

Test Site J

This is an apartment complex in Conway, SC having asphalt parking closest to the buildings and an asphalt drive lane. The perimeter parking areas are pervious concrete (25,212-ft^2 total) that is approximately 6-in. thick over a 6-in. base of No. 57 stone on top of sandy subgrade. The pervious concrete was placed in July 2007 to meet the requirements of the city.

CONCLUSIONS

Functional Performance

A summary of the infiltration results from the evaluation are included in Table 1. It can be seen that the functional performance of these porous pavements varies widely from location to location. Some locations allowed no infiltration at all, while others had infiltration rates in excess of 1000 in/hr. This indicates that all porous pavements are not necessarily "porous." Additionally, in many cases, there was significant variability within a given pavement.

Structural and Surface Performance

The structural and surface performance visual assessments are summarized in Table 2. All of these pavements have performed very well in terms of the load carrying capacity for which they were designed. On the other hand, the presence of raveling was observed in 7 of the 10 pavements included in this study. While the raveling was not always significant and it was generally isolated to individual slabs, it is considered very undesirable from the owner's perspective based on personal discussions with different owners.

Findings

After reviewing the results of the evaluation, there are several conclusions that can be made about the performance of porous pavements. First of all, while the pavement must obviously withstand the traffic loading to which it is exposed, the primary function of a porous pavement is to allow for stormwater infiltration. Based on the pavements included in this study, there were three main causes of low, or no infiltration of the pavements that can all be prevented or minimized: sediment clogging, paste or binder clogging, and over-consolidation.

Sediment Clogging. Clogging of the surface voids resulting from the deposition of sediments transported by stormwater can be detrimental to the functional performance of the pavements. While this is detrimental, it is something that can be minimized with proper landscape design (e.g., material selection and sediment control); maintenance of the adjacent pavement (e.g., sealing of the asphalt surface); and routine maintenance of the porous pavement (e.g., vacuuming and/or pressure washing the surface voids).

Paste/Binder Clogging. Sealing of the surface voids with cement paste or asphalt binder is the direct result of placing a mix having incorrect proportions. For concrete, excessive cement paste results from a mix having too much water. When concrete having too much water is placed and finished, the excess water and cement form cement paste which works its way to the surface during the finishing process. When the paste sets, it seals the surface and creates an impervious surface. This can be identified during placement of the concrete.

In the case of porous asphalt, the surface can be sealed as the result of excess binder, which is what coats the

Table 2. Summary of Structural and Surface Condition Observations.

Site	Structural Condition & Observations		Surface Condition & Observations	
A	Very Good	No noticeable cracking	Good	Minor raveling
B	Very Good	No noticeable cracking	Good/Fair	Moderate raveling
C	Very Good	No noticeable cracking	Very Good	No raveling
D	Very Good	New pavement	Good	Minor to little raveling
E	Very Good	New pavement	Very Good	Very little raveling
F	Very Good	New pavement	Good	Minor to moderate raveling in some areas
G	Good	Few minor cracks at cold joints and one minor crack not at a cold joint	Good	Minor raveling in two small locations
H	Very Good	No noticeable cracking	Fair	Minor to severe raveling depending on location
I	Very Good	One minor crack	Very Good	No raveling
J	Very Good	Few minor cracks at cold joints	Very Good	Very little raveling

aggregate particles and holds the mix together once cooled. Bleeding of the asphalt binder can be the result of high binder content in the mix. Additionally, bleeding can occur when fibers are left out of the mixture. Fibers are typically added to porous asphalt mixtures to prevent binder draindown and to improve the pavement durability.

Over-consolidation. A porous pavement can also be made impervious as the result of poor construction methods that cause the void structure of the pavement to collapse. This typically occurs when the concrete or asphalt mix is over-consolidated. In pervious concrete pavements, over-consolidation occurs as the result of rolling the fresh concrete with too heavy a roller or with too many passes of the roller. It can also occur when the mixture is handled incorrectly (i.e., overworked).

In the case of porous asphalt pavements, over-consolidation can occur for two main reasons. The first is when the pavement is compacted at too high of a temperature. At high temperatures, the mixture will have a relatively low viscosity which can result in over-compaction if it is not allowed to cool to the proper compaction temperature prior to consolidation. The other cause of over-consolidation is too many roller passes or the use of a vibratory compactor during compaction. When this occurs, the void structure in the pavement breaks down.

DISCUSSION

Based on the results of this field evaluation, it is evident that not all porous pavements are in fact porous. This reality should be considered when accepting porous pavements for stormwater management purposes. This could be achieved with the creation of performance criteria that a porous pavement must meet at the completion of construction. These criteria could then become part of the quality control/quality assurance (QC/QA) program during construction. However, even though a pavement functions when initially put into service, the functionality must be maintained throughout the service life of the pavement. This routine maintenance is the responsibility of the owner. Additional criteria could be developed for the porous pavement that would ensure that the pavement functions for its intended service life.

On the other end of this spectrum, one must be aware that obtaining excessively high void contents in the pavement structure, which creates high infiltration rates, could potentially reduce the structural capacity of the pavement. This could in turn, lead to the premature failure of the pavement.

LITERATURE CITED

ASTM, 2009. Standard Test Method for Infiltration Rate of In Place Pervious Concrete, ASTM C 1701. ASTM International, West Conshohocken, PA.

Balades, J.D., Legret, M., and Madiec, H., 1995. Permeable Pavements: Pollution Management Tools. *Water Science Technology*, 32(1):49-56.

Bean, E.Z., Hunt, W.F., and Bidelspach, D.A., 2007. Field Survey of Permeable Pavement Surface Infiltration Rates, *Journal of Irrigation and Drainage Engineering*, 133(3):249-255.

Brattebo, B.O. and Booth, D.B., 2003. Long-term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. *Water Resources*, 37(18):4369-4376.

Gerrits, C. and James, W., 2002. Restoration of Infiltration Capacity of Permeable Pavers. *Proceedings of the 9th International Conference on Urban Drainage*, ASCE, Portland, OR.

Sansalone, J.J. and Buchberger, S.G., 1995. An Infiltration Device for a Best Management Practices for Immobilizing Heavy Metals in Urban Highway Runoff. *Water Science Technology*, 32(1):119-125.