

Final Report FDOT Project BD521-02

Performance Assessment of Portland Cement Pervious Pavement

Report 4 of 4: Performance Assessment of a Pervious Concrete Pavement Used as a Shoulder for an Interstate Rest Area Parking Lot

A Joint Research Program of



Submitted by

Marty Wanielista
Manoj Chopra

Stormwater Management Academy
University of Central Florida
Orlando, FL 32816

Editorial Review by: Ryan Browne

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16. Abstract <p>A pervious concrete shoulder was constructed along a rest stop on Interstate 4 in central Florida. The shoulder was 90 feet long and 10 feet wide. The depth of pervious concrete was 10 inches. A 12 inch deep reservoir consisting of select pollution control materials was used beneath the pervious concrete. The shoulder was monitored over a one year period for wear and stormwater management.</p> <p>The shoulder was monitored for traffic counts recording approximately 500 axles per week. This use included stopping and starting and sometimes the stops were rapid as the truckers did prefer to park on the hard surface pervious concrete area. There was no visual wear noted on the concrete.</p> <p>An embedded single ring infiltrometer was used to monitor the infiltration rates. The rate of infiltration did not decrease with time. The average rates of infiltration over one year were 2.5 inches per hour at a head of zero to one inch; 4.8 inches per hour at a six inch head; and 6.3 inches per hour at a nine inch head. An acceptable rate of infiltration for these designs is 1.5 inches per hour.</p> <p>Water quality leaving the reservoir was about equal to rainwater quality. The amount of water from the collection pipe nearest the edge of pavement was about 50 times the volume from the collection pipe seven feet from the edge of pavement.</p> <p>The demonstration using pervious concrete was considered a success based on wear, water quantity, and water quality considerations. It is recommended for other similar locations.</p>			
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Executive Summary

The infiltration potential of Portland cement pervious concrete has encouraged its use as a stormwater management tool. This study focuses on an infiltration performance and water quality study over a one year period of time. The study site was a shoulder area of a rest stop for Interstate 4 in central Florida.

The shoulder area was part of and adjacent to the truck parking areas of a rest stop. The parking area is considered a watershed because it contributes runoff. The truck parking area is 100 feet long. The total contributing watershed area is 0.20 acres. The length of the pervious concrete adjacent to the parking area is 90 feet and the width is 10 feet. The thickness of the pervious concrete is 10 inches. A 12-inch deep reservoir of sand and tire crumb is compacted to about 90% of the maximum density and is used to support the pervious concrete and to improve the quality of the parking area (watershed) runoff.

Infiltration rates are measured using an embedded ring infiltrometer kit (ERIK) over time. The infiltration rates were consistent over time or did not significantly change. These measures were taken at three different heads, and as expected the higher heads produce higher estimated rates of infiltration. The average rates of infiltration over one year were 2.5 inches per hour at a head of zero to one inch; 4.8 inches per hour at a six inch head; and 6.3 inches per hour at a nine inch head. An acceptable rate of infiltration for yearly volume control and using these designs is 1.5 inches per hour.

The shoulder was monitored for traffic counts. Trucks, primarily tractor trailers, frequently used the shoulder of the rest area when the parking area was congested. On about half of the approximately 80 visits to the site, trucks were seen parked on the pervious concrete pavement. This use included stopping and starting and sometimes rapid stops, the

truckers preferring to park on a hard surface. The traffic counter recorded approximately 500 axles per week. There was no visual wear or raveling noted for the concrete.

Water quantity and quality at the bottom of the reservoir was monitored. Water quality was measured based on dissolved phosphorus, total phosphorus, total nitrogen, and suspended solids. Water quality leaving the reservoir was about equal to rainwater quality. The amount of water from the collection pipe nearest to the edge of pavement was about 50 times the volume from the collection pipe seven feet from the edge of pavement. The water quality at the bottom of the reservoir was found to be better than the runoff water quality.

The demonstration using pervious concrete as a shoulder material at a rest area along an Interstate highway in central Florida was considered a success based on water quantity and water quality considerations. Pervious concrete shoulders should be considered for stormwater management along highways. The infiltration rate, runoff volume reduction, water quality improvement, and structural stability make it a viable option.

Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

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The authors also thank the reviewers of the draft document. They were Michael Davy of Rinker Materials, and students at the University. We wish to give special thanks to two students, namely Erik Stuart who provided construction experience and who with the authors developed the ERIK method of measurement, and Melike Minareci who collected and evaluated water quality samples.

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CHAPTER 1 – INTRODUCTION

Stormwater management methods seek to decrease the runoff from impervious surfaces by reducing the volume and attenuating peak flow which can be done using infiltration. Pervious concrete pavement is a type of porous pavement that can be used as an infiltration practice for stormwater management. It has an open-graded structure and consists of carefully controlled portions of stone aggregate, cement, water, and admixtures. The open-graded structure of the concrete promotes rapid passage of water and allows it to infiltrate underlying soils. A reservoir of select pollution control media can also be added beneath the pervious concrete to remove pollutants. Pervious concrete, already recognized as a best management practice by the Environmental Protection Agency (USEPA, 1999), has the potential to become a popular alternative for dealing with stormwater runoff.

However, a lack of data, particularly with respect to infiltration capacity and water quality, leads to hesitation in using pervious concrete as an acceptable stormwater management practice alternative. An important part of this research involved determining a method for measuring the infiltration rates through pervious concrete sections. Testing included field investigation of pervious concrete parking lot sites that were completed and reported on in a previous report (Wanielista, et. al., January 2007). In this study, eight pervious concrete parking areas, all of which have been operational for an average of 10 years, were investigated for hydraulic infiltration capacity. The results showed that for measuring infiltration over time, the sub base materials had to be included in the cross section. Thus, in this report an embedded ring infiltrometer kit (ERIK) was developed and used.

Shoulder areas along roadways provide an opportunity to use pervious concrete to infiltrate runoff waters. Also, a reservoir beneath the pervious concrete can be built to pass the runoff water, and the material in the reservoir can have the potential for removal of pollutants. Thus, the pervious concrete system (pervious concrete plus reservoir) has the potential to not only attenuate flow and decrease volume of runoff, but to also remove pollutants.

1.1 Objectives

The objectives of this research are:

- 1) Construct a pervious concrete shoulder area on a rest stop adjacent to an Interstate highway in central Florida. The purpose is to determine if this site could be used to support traffic and to visually measure the wear of the pavement.
- 2) Examine a pervious concrete mix with less water content to promote failure and evaluate the feasibility of removal.
- 3) Measure the limiting infiltration capacity of the pervious concrete system. The system is composed of pervious concrete and a reservoir of select materials.
- 4) Measure the water quality of the filtrate as well as the runoff from the parking surface. The filtrate was collected at the bottom on the reservoir and at two distances from the edge of pavement.

1.2 Limitations

The results are constrained by the design of the pervious concrete section and the location and climate of the central Florida area.

1.3 Approach

This report consists of five chapters. Provided in this first chapter is an introduction to the topic and also a description of the research objectives. In chapter two, a review of the current state of pervious concrete and existing research on the topic is presented. The theoretical approach to the measurement of infiltration with laboratory testing is covered in chapter three. In chapter four results and discussion of the data are shown. In chapter five, a discussion, summary, conclusions, and recommendations are presented.

CHAPTER 2 – BACKGROUND

Shoulder areas along roadways are used for safety reasons. These shoulder areas are usually impervious in nature. Thus, the transport of water from the road surface to adjacent stormwater transport and storage occurs. Impervious areas prevent water from infiltrating into the soil underneath. Other examples of impervious areas include rooftops, parking lots, and sidewalks. However, with the use of pervious concrete with a reservoir as shoulder material, the possibility exists to use the shoulders for both water quality improvement and runoff volume and rate reduction and thus the shoulder becomes part of a stormwater management plan.

The addition of impervious shoulder areas on a roadway can increase the hydrologic and water quality impacts to the environment by altering the natural water cycle. The runoff from the impervious surfaces results in at least three main problems: (1) a decrease in groundwater recharge due to lack of infiltration, (2) an increase in the volume of runoff water that has to be treated, and (3) transportation of contaminants, deposited on impervious surfaces, to receiving water bodies. Thus, the introduction of impervious areas has an impact on both surface and subsurface water quantity and quality, in addition to adding to the cost of treating runoff.

From these problems others may arise. Changing natural flow patterns can cause erosion and flooding of naturally occurring channels unaccustomed to handling larger flows of water (Brattebo and Booth, 2003). Furthermore, contaminants including heavy metals (e.g. copper, lead and zinc), nutrients (e.g. phosphorous and nitrogen), and sediment material can travel in runoff water and be deposited in receiving water bodies. These materials severely alter and destroy aquatic habitats, which results in the death of organisms dependent upon that habitat.

Traditionally, runoff peak rates have been controlled and attenuated using storm sewer systems with detention or retention basins (Schluter and Jeffries, 2002). These systems collect the runoff primarily from impervious areas and store the water where it can either infiltrate (retention basin) or be discharged at a controlled rate to a water body (detention basin). Design, operation, and maintenance of these basins are governed by regulations established by state, regional or local government agencies. The size of these basins and the monetary investment in their construction can be lowered if the runoff water is passed through pervious concrete and treated for water quality improvement before entering the ground water.

2.1 Pervious Concrete

There is always an interest in finding new ways to manage stormwater runoff associated with roadways. Porous pavements, an alternative method for stormwater control, represent an innovative method. Types of porous pavements include porous asphalt, pervious concrete, concrete paving blocks, gravel paving systems, and grass paving systems, among others. Porous pavements reduce runoff volume by allowing water to pass through them and to be stored and subsequently be released into the ground. Most porous pavements contain large numbers of pore spaces and allow water to pass through them at a relatively high and sometimes what most would consider a rapid rate.

Pervious concrete used for shoulder areas is the focus of this report. It is a material that consists of open-graded coarse aggregate, Portland cement, water and admixtures. Generally the aggregate is evenly graded to have a size of approximately 3/8 of an inch; sand is omitted from the process leaving the space in between coarse aggregate empty. Typical sections of

pervious concrete have 15 percent to 25 percent void space; some sections may have values as high as 35 percent (Brown, 2003). Most void spaces are interconnected which allows water and air to pass through the section. Newly placed pervious concrete sections have been reported to drain at rates ranging from two to 18 gallons per minute per square foot (Brown, 2003).

Pervious concrete is known to have the advantages of reducing runoff volume and may improve water quality in ground water recharge (Legret et al, 1996). By allowing stormwater runoff to infiltrate, pervious concrete filters sediment and other contaminants that would otherwise make their way to waterways. Similarly, because water can infiltrate through the concrete layer, pervious concrete parking lots and other installations can serve as recharge basins. Other known advantages of pervious concrete include better road safety because of increased skid resistance, road sound dampening, and dampening of the “heat island” effect (Yang and Jian, 2003), (USEPA, 1999), (Brown, 2003).

Pervious concrete also has several potential disadvantages. Those of most concern include perceived cold weather problems, the potential of clogged void spaces, historical high construction failure rates, and the potential to contaminate ground water (EPA, 1999). High construction failure rates are often associated with poor design and contractors who lack sufficient knowledge for proper installation of the product. The two issues or problems frequently expressed to be of greatest concern are the potential of clogged void spaces and credit as a stormwater management practice within stormwater regulations. This research provides data for both issues. However, groundwater contamination is not addressed.

Pervious concrete has begun to receive greater attention as a viable stormwater management practice. The American Concrete Institute has established a committee (ACI

Committee 522, 2006) to determine guidelines for the proper use of pervious concrete. To enhance this document, the committee needs data on the long-term performance of pervious concrete systems. Data are needed on design characteristics, durability, maintenance plans, and effective infiltration rates after years of service.

This information would also be valuable to water management districts in an effort to provide a standard for use of pervious concrete in stormwater runoff control. In Florida, stormwater management criteria are largely developed and implemented by the Department of Environmental Protection (DEP) and the regional water management districts. Currently, only the DEP provides credit for pervious concrete as a stormwater management practice. However, others at the State of Florida regional water management districts levels are considering it as an option. There is provision and national standards that are used on a site-by-site basis using design guidelines to apply for credit (Training Manual, 1998, NRMC, 2004, and FCPA in Pervious Pavement Manual, 2006). It is anticipated that the data of this report will facilitate the application for credit.

There are some tradeoffs between pervious concrete, the most notable of which is cost. The initial cost of pervious concrete can be up to 1.5 times that of other conventional paving methods. This excess of cost is a function of two things. First, pervious concrete is a specialty product requiring experienced skilled labor to install the concrete properly. This specific experience requirement accompanied with low demand drives the price up. Secondly, there is also an extra depth associated with pervious concrete. The extra depth is a function of a couple of factors including a need for extra rainfall storage within the concrete layer and an increased necessary thickness for strength reasons.

Typical concrete strength is around 4000 psi or greater whereas pervious concrete is commonly around 2,000 psi (Ferguson, 2005). A lower compressive strength may require an additional thickness of pavement to help distribute vehicular loading. Normal depth for concrete paving is about four inches while normal thickness for a pervious concrete pavement is six or more inches.

Though there is an expected increase of cost for pervious concrete, that cost can potentially be recouped by the increase in developable area that comes with a decrease in the area required for stormwater management. Other benefits include better traction during wet weather due to free draining pavement, reduction in road noise due to dampening effects in the concrete, and glare reduction at night (Ferguson, 2005), (ACI, 2006).

Pervious concrete has been in existence in the United States for nearly 50 years (Brown, 2003). Though not a widely used product, pervious concrete has been proven effective as a porous pavement in applications such as parking lots, low-volume roadways, and pedestrian walkways. It is necessary to develop standard design, manufacturing, and installation methodology that will establish pervious concrete as a reliable product capable of performing adequately for these uses. Currently there are no regulations or standard design criteria for this technology, thus it is not validated as a presumptive stormwater management method. Pervious concrete has the potential to reduce the amount of, or eliminate the area set aside for stormwater management practices, thus maximizing the amount of land available for development. If a compilation of data shows an agreeable evaluation of long-term performance, this material may become more widely accepted for its beneficial properties. Such information could be used to develop statewide design, construction, inspection, and maintenance requirements within stormwater regulations.

CHAPTER 3 – APPROACH TO INFILTRATION MEASUREMENTS

3.1 Laboratory Experimentation

Prior to creation of a field infiltrometer, it was necessary to assess the operation of a standard infiltrometer. Initial testing was done using a standard double-ring infiltrometer (ASTM D3385-94) on the surface of the concrete similar to the procedure used by Bean and others in 2004. It quickly became apparent that this was an ineffective approach for pervious concrete because of the drastic difference in permeability between the concrete and the underlying soil (initial testing was done on newly poured pervious concrete). Once the infiltrating water moved through the pervious concrete and reached the soil it began to move laterally – See Figure 1. This grossly exaggerated the infiltration rate for the pervious system because it did not take into account the fact that water simply filled up the free pore space adjacent to the double ring infiltrometer and water was not infiltrating into the subsoil nearly as quickly as it appeared.

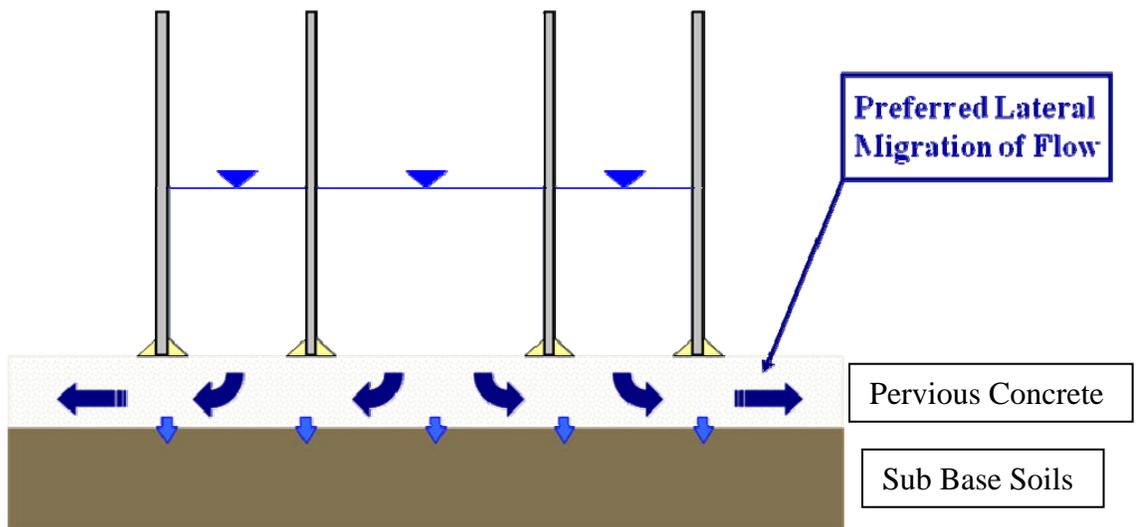


Figure 1 - Double Ring Test on Pervious Concrete

After several of these tests with double-rings on the surface of the concrete, it was decided that it was necessary to treat the pervious concrete – soil interface as a “system”. It was only when the two layers were isolated and one-dimensional flow encouraged, that a more realistic measurement of performance was obtained (See Figure 2).

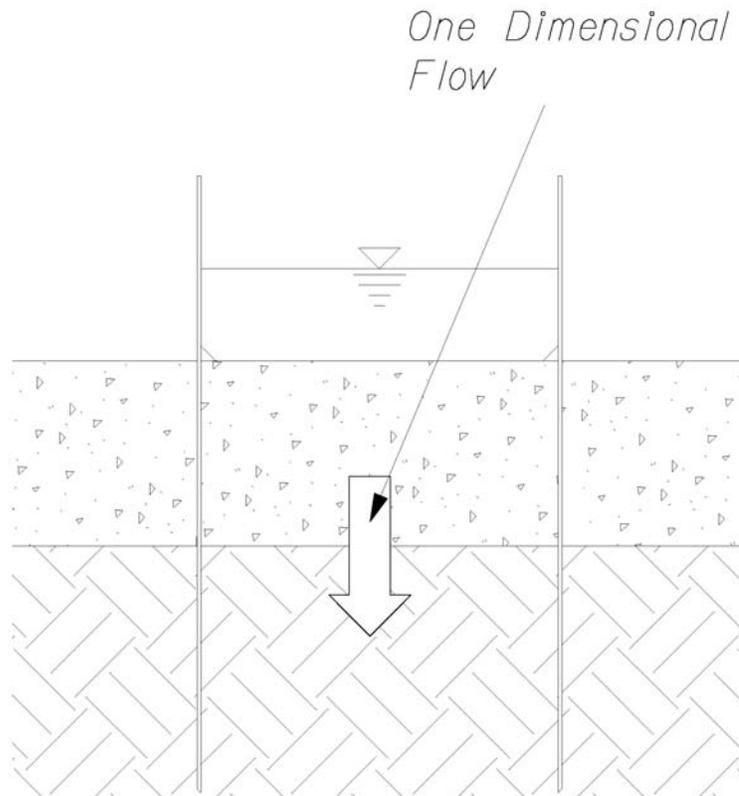


Figure 2 - One Dimensional Flow at Soil-Concrete Interface

For existing pavements, it was decided that a way to approach this was to remove a circular section of concrete using a concrete coring machine (Wanielista, et.al., Jan 2007). A 12-inch diameter core bit was used because it was large enough to provide a “representative area” and small enough to be easily handled. A tube was designed to be inserted around the concrete core and embedded into the underlying soil – a single-ring infiltrometer which

encourages one-dimensional flow through the interface of the pervious concrete and the soil.

Figure 3 shows the dimensions for a single-ring infiltrometer used for existing paving.

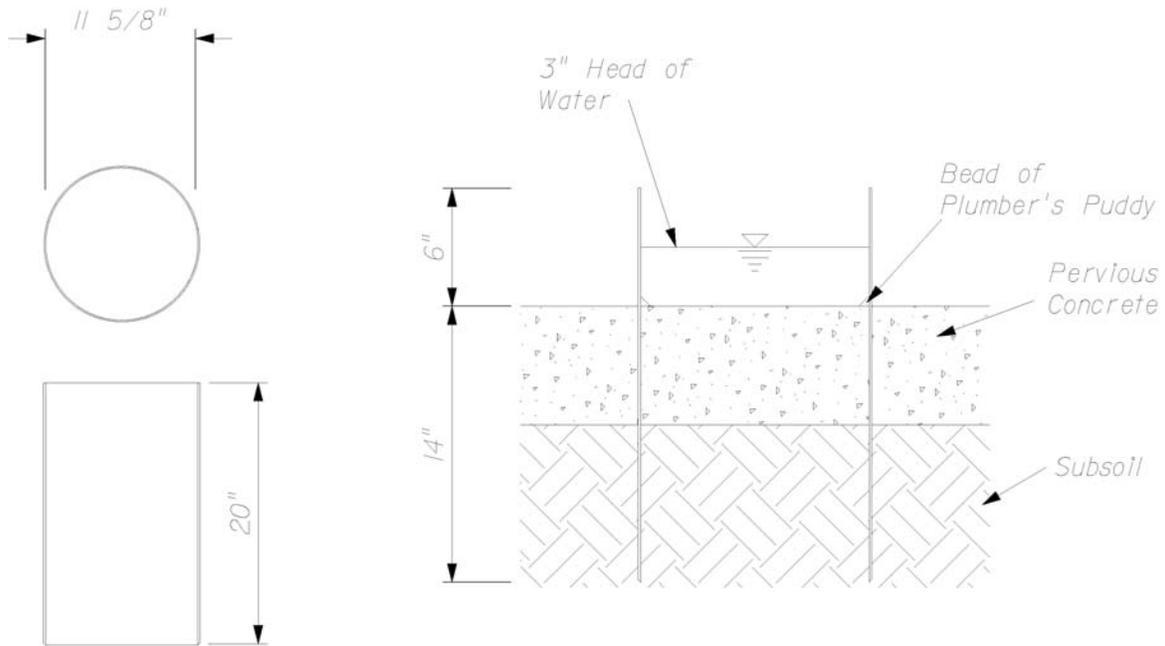


Figure 3 - Single-Ring Infiltrator for Use with Existing Pavements

The testing procedure for the single-ring infiltrometer was much like that for the double-ring test – a specific head was maintained, water was added at specified time intervals, and the amount of water added at each time interval was recorded. The tests were stopped after at least two consecutive time periods after which approximately equal additions of water were added, provided that at least one inch of water over the area was added. One inch is equivalent to the 90% occurrence storm.

Various heads of water are specified by regulations or standard test procedures, so it is important to record the head used with each test results. The head maintained for infiltration

tests was found to be important as the greater the head (up to 9 inches), the higher the infiltration rate relative to a head maintained near the grade (top) of the pervious concrete. From repeated tests on the same section of pervious concrete, the infiltration rate using the embedded single ring varied from a low of about 2.5 inches per hour at a head measured at grade to 1 inch, to a maximum rate of about 7 inches per hour at a head of 9 inches. These rates will also vary among the various field sites.

Embedment depth was determined by several factors – the necessary depth to maintain one-dimensional flow at the concrete soil interface and sufficient length of tube to store at least the water equivalent to mean annual one day storm volume in Florida. At least three inches of pipe above the pavement was maintained to allow for a specific head and to allow for removal of the tube after embedment. The final design called for 14 inches beneath the surface of the concrete and 6 inches of concrete to store at least 4 inches of rainfall at porosities of 0.20 for the concrete and 0.35 for the soil. The mean rainfall depth of the maximum yearly one day storm volume in Florida is about 3.5 inches (Wanielista, et. al. 1991).

Multiple single-ring infiltrometer trial tests were conducted on the test plot. Results from these trials showed approximately two inches of water were added during the course of each testing run, thus exceeding the one inch 90% occurrence storm event. Also, at this rate, and considering the porosity of the soil (assumed 0.35), the wetting front of the infiltrated water would not have passed the depth of the embedded tube during the course of the test. This gave reasonable assurance that 1-D flow was approximated at the soil-concrete interface. It was assumed that other sites visited would have similar soil characteristics and that this

same embedment depth would be sufficient for those cases. Test results for existing sites are given in Wanielista (January 2007).

Removal of the embedment ring was a difficult task. The ring was embedded using compaction force – once embedded, it was lodged so securely that it could not be removed by simply pulling up on the apparatus. Thus, it is recommended that for new construction, the embedded infiltrometer should be part of the construction process.

3.2 Field Testing with an Embedded Ring Infiltrometer Kit (ERIK)

For new construction, an infiltration test device that is embedded into the pervious concrete and the sub base materials at the time of construction would eliminate the need for coring. Also the in-situ embedded infiltrometer would provide initial construction infiltration rate data verification and continued infiltration rate data with time. Thus the concept of the embedded ring infiltrometer with a measurement kit was made, and called ERIK.

The ERIK consists of inner embedded 6 inch diameter pipe, an outer embedded 12 inch diameter pipe, a 2 inch ID graduated “reservoir” cylinder with red marks indicating every inch drop in water level within the embedded ring, and a timing device with a recording pad. The complete set up is shown in Figure 4. On the present model, there are two manually adjusting valves located near the bottom to control flow of water out of the reservoir cylinder. A 6 inch and 12 inch ID PVC pipe are included for the embedment and testing applications. (Note: The 9 inch drop in the reservoir pipe will equal a 1 inch drop in the 6 inch inner testing infiltrometer pipe)



Figure 4 - Embedded Ring Infiltrometer Kit Showing On-Site Measurement

Procedure for using the embedded ring infiltrometer is as follows:

1. Place the inner (six (6) inch pipe) and the outer (nine (9) inch pipe) on the top of the embedded pipes.
2. Apply bead of silicone caulking around bottom of 6 inch and 9 inch test pipes.
3. Allow time for drying or about 15 minutes with the silicone used.
4. Fill rings with water until saturation is reached and check for side leakage
5. Using tape measure, pour water until desired head is reached and mark inside wall of the inner pipe with permanent marker
6. Adjust valves on reservoir to keep a constant head desired in the inner pipe
7. Record time it takes for water level to drop to each marked interval

CHAPTER 4 – RESULTS AND DISCUSSION

4.1 Site Description

The shoulder site selection was based on an area that had potential for runoff water to flow to it and over it with a watershed area at least equal to 4 lanes of traffic or 48 feet. The shoulder site also would be ideal if traffic had the potential to use it.

An interstate rest area was selected because the watershed had a length of flow equal to 100 feet and the slope (about 5%) was toward the shoulder area. The shoulder area was constructed at a standard width of 10 feet and was 90 feet long. The area is along Interstate 4 in central Florida (Figure 5). Also, there was on site evidence that the runoff water was eroding the loose shoulder materials and traffic was using the shoulder area for parking.



Figure 5 - Site Map for Pervious Concrete Shoulder

By constructing the pervious concrete shoulder area, additional parking on a “hard” surface may encourage traffic to use the shoulder area. The use of the pavement would then permit a visual observation of the wear on these surfaces.

4.2 Construction and Mix Specifications

Construction and mix specifications are considered to be a vital part of a pervious concrete pour. Thus care was taken to test some of the construction and mix specifications. The shoulder site was poured with a water mix specification that was low. The section was then removed because it had failed due to loss of surface materials. The removal of the material was not complicated and the 1800 square foot area was removed without any damage to the sub base. The removal process took about 6 hours including mobilization of the field construction crews. The re-constructed product was within specification and performed well with no visual loss of materials. It supported a traffic load on about 500 axle loads per week with a minimum of 305 to 716 axles per week recorded.

The placement and finishing techniques for pervious concrete are different from regular concrete. The equipment used for the shoulder pour is shown in Figure 6.

EQUIPMENT

- A. BACK HOE (lifting)
- B. STEEL ROLLER (compaction)
- C. GROOVER (controlled expansion joints)
- D. VIBRATORY POWER SCREEDER (to "Strike-off" and remove excess concrete)
- E. LUBRICANT (keeps tools clean "a clean tool is a happy tool")

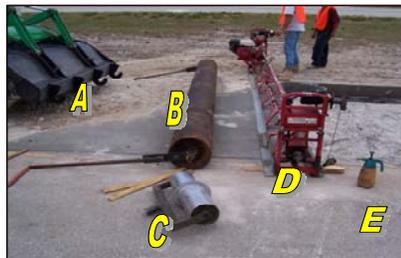


Figure 6 - Pervious Concrete Equipment Used

The following construction and mix specifications were used to provide an acceptable pervious concrete pour and sub base preparation. The contractor selected was one that was certified to install pervious concrete using a national certification program run in the State of Florida by Rinker Materials.

1. Delivered mix must be within 5 pounds per cubic foot of the recommended unit weight. This may vary with design but the unit weight must be specified.
2. Concrete must be stricken off at the form boards (3/8 in this case) and compacted to a level finish grade.
3. A Schedule 40 ten inch steel pipe roller or other comparable compaction device must be used to take the stricken concrete to finish grade.
4. The pervious concrete is covered with an impermeable liner for a period of 7 days to allow proper curing.
5. Curbing should be used to direct water downward.

4.3 Infiltration Rates from Field Testing Using the ERIK

It is important to keep the sub base materials at a compaction level that will support the traffic loads. However, increased compaction will decrease the rate of infiltration. Pitt (2002) reported a limiting soil infiltration rate of about 5 inches per hour for modified compacted sandy soils similar to that used in the reservoir at the shoulder. He used a 4.5 inch head for the test. Soil compaction and site variability are believed to control the rate more than the small head difference between his reported data and the field testing.

Ten limiting infiltration tests were conducted on the finished pervious concrete system to include the rate of movement through the sub base materials. The infiltration tests were run

at three different head conditions: zero to 1 inch, 6 inches and 9 inches. The limiting infiltration rates did not significantly change from one test to another. As expected the higher heads produce higher estimated rates of infiltration. The average limiting rates of infiltration over one year were 2.5 inches per hour at a head of zero to one inch; 4.8 inches per hour at a six inch head; and 6.3 inches per hour at a nine inch head. An acceptable rate of infiltration for yearly volume control and using these designs is 1.5 inches per hour (Wanielista et.al, Jan 2007). This 1.5 inch per hour infiltration rate using the rainfall volumes for central Florida would produce an annual collection effectiveness of at least 80% for level pervious concrete and provided there were no additional off site runoff contribution.

Since the rest area parking does contribute runoff volume to the shoulder area, two collection slotted pipes were placed at the bottom of the reservoir (22 inches below grade) to document the runoff volume and to provide storage for water quality analyses (see Figure 7). A section is shown in Figure 8. The first pipe was located at the edge of the parking area, and the second one seven feet from the parking area edge. The volume of water collected from the edge pipe was at least fifty times greater than that collected from the pipe seven feet from the edge. There was no visible water collected at the edge of the pervious concrete shoulder for the rainfall conditions experience over the one year of measurement (June 2006 – June 2007). The rainfall in this time period was approximately 44 inches. The normal rainfall for the same period is approximately 49 inches. It is estimated that the pervious concrete has infiltrated almost all of the water that was transported to it and all of the rainfall on it.



Adjacent to existing pave
And 7 feet from edge of pave

Separation
Fabric

Slotted pipe to collect
Infiltrated water

Figure 7 - Installation of Collection Pipes for Water Volume and Quality

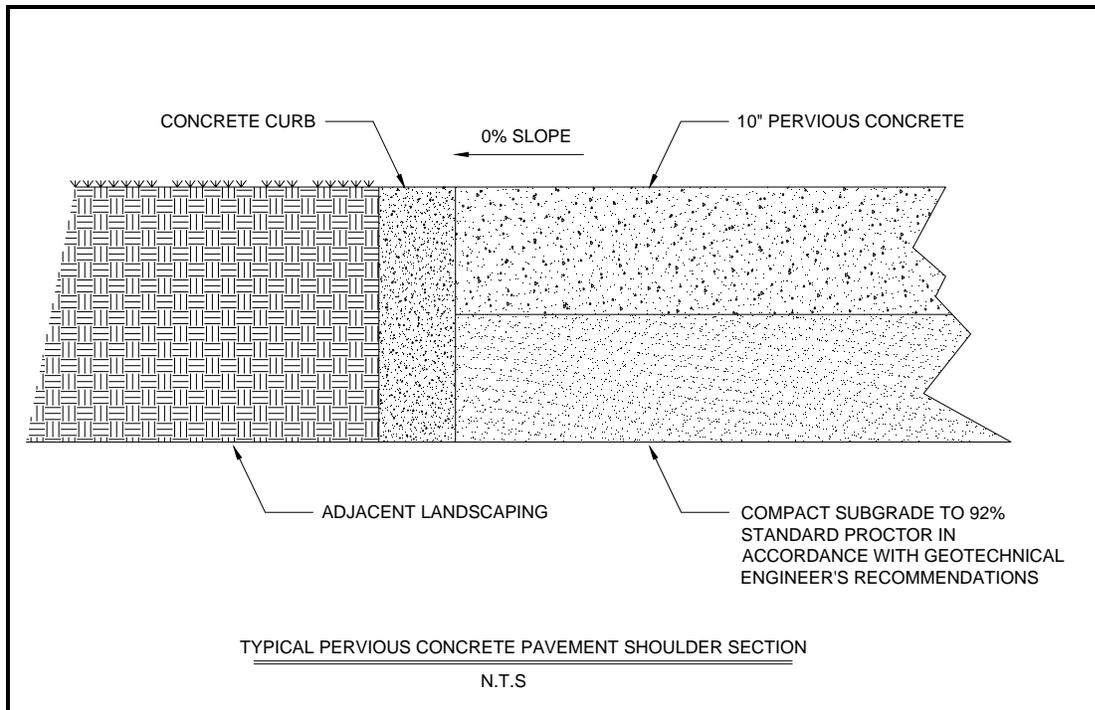


Figure 8 - Shoulder Pervious Concrete Section for I-4 Rest Area

4.4 Water Quality

Water samples were collected from the two slotted sampling pipes at the bottom of the reservoir; one at the edge of pave and the other seven feet from the edge of pavement. Eighteen runoff events were monitored. Not all rainfall events produced runoff to the sampling pipes. A maximum of 53 samples were analyzed from the pipe adjacent to the existing pavement and a minimum of 30 samples from the pipe seven feet from the edge of pavement, because of a lack of water in the pipe seven feet from the edge of pavement. All the data are shown in Appendix A. Table 1 shows the statistical data for all events.

Since orthophosphate and nitrates are dissolved in solution and most likely would be transported in the ground water if not removed, these forms of phosphorus and nitrogen were measured. It was assumed that the particulate fraction would be contained within the reservoir matrix of materials, which was the case when in two samples, the total Phosphorus was about equal to the orthophosphate and the total nitrogen about equal to the nitrate concentration.

Table 1 Rainfall and Reservoir Water Quality Statistics

Statistic	Rain Inches	NO3-N (mg/L)		OP4-P (mg/L)	
		Edge	7 Feet	Edge	7 Feet
number	18	53	32	50	30
maximum	2.80	1.37	0.58	2.26	1.42
minimum	0.20	0.11	0.01	0.04	0.01
Averages	0.55	0.46	0.22	0.46	0.23

The orthophosphate values in the reservoir sampling pipes range from 0.01 to 2.26 mg/L with an average of about 0.46 mg/L in the reservoir sampling pipe closest to the edge of pavement and 0.23 mg/L in the sampling pipe seven feet from the edge of pavement. Rainfall in the area has an average concentration of about 0.2 mg/L (Hulstein, 2005). The nitrate

values in the reservoir sampling pipes range from 0.01 to 1.37 mg/L with an average of about 0.46 mg/L in the reservoir sampling pipe closest to the edge of pavement and 0.23 mg/L in the sampling pipe seven feet from the edge of pavement. Rainfall in the area has an average concentration of about 0.4 mg/L. The reservoir dissolved concentrations are approximately equal to that of rainfall. On the average, comparisons of water quality concentrations at the edge of pavement sampling pipe versus the sampling pipe seven feet from the edge indicated that the reservoir water quality in the sampling pipe seven feet from the edge was better or the concentrations were about 50% lower.

Twenty runoff samples were evaluated for water quality from 10 rainfall events. A secure and non destructive location for runoff sample collection was difficult to sustain because of the truck traffic. The truck traffic initially (for the first four months) destroyed the runoff collection devices. The complete data are shown in Appendix A. The orthophosphate values in the runoff sampling pipe range from 0.22 to 2.65 mg/L with an average of about 1.06 mg/L. The nitrate concentration in the runoff sampling pipe range from 0.22 mg/L to 4.66 mg/L with an average of 1.45 mg/L. These data are compared to the reservoir data for the same rainfall runoff events and a statistical comparison is shown in Table 2.

Table 2 Runoff and Reservoir Water Quality Statistics

Statistic	Rain Inches	Runoff	NO3-N (mg/L)		Runoff	OP4-P (mg/L)	
			Edge	7 feet		Edge	7 Feet
Number	10	20	28	14	20	25	11
maximum	2.80	4.66	1.03	0.58	2.65	2.26	1.42
minimum	0.20	0.22	0.11	0.01	0.22	0.04	0.01
Averages	0.64	1.45	0.45	0.20	1.06	0.60	0.42

Relative to runoff water quality concentration, the reservoir water quality concentration in the sampling pipes was improved. For orthophosphate, the average concentration in the

sampling pipes in the reservoir at the edge of pavement and seven feet from the edge improved by 43 and 61 % respectively relative to the runoff average concentration. For nitrate, the average concentration in the sampling pipes in the reservoir at the edge of pavement and seven feet from the edge improved by 69 and 86 % respectively relative to the runoff average concentration.

CHAPTER 5 – CONCLUSION AND RECOMMENDATIONS

A pervious concrete shoulder was constructed adjacent to a rest area in central Florida. The shoulder width was 10 feet and the length was 90 feet with a 10 inch pervious concrete thickness over a 12 inch deep reservoir. The reservoir was composed of select media consisting of sand and tire crumb and was chosen for strength and pollution control.

The site was monitored over a one year period for infiltration rate and water quality. In addition the use of the shoulder was recorded as axles per week. Visual observation of the surface was also recorded. Infiltration and water quality data were collected and presented over the course of this study and provided evidence that pervious concrete retains an infiltrative capacity, provided proper installation.

5.1 Conclusions

The pervious concrete installation process was demonstrated for a shoulder area. The removal of sections of the pervious concrete was also demonstrated. The removal was relatively easy as the pervious concrete easily separated from the reservoir materials. The pervious concrete by visual appearances is taking the wear of truck stopping, starting and parking. The shoulder was monitored for traffic counts as trucks, primarily tractor trailers who frequently used the shoulder of the rest area when the truck parking area became congested. On about half of the site visits (38 of 80), trucks were seen parked on the pervious concrete, especially in the early morning hours. This use included stopping and starting and sometimes rapid stops as the truckers did prefer to park on a hard surface. The traffic counter

recorded approximately 500 axles per week and nine weeks were sampled. There was no visual wear noted for the concrete.

Limiting infiltration rate measures were estimated for both surface mounted infiltrometers and embedded ones. The embedded ones that also penetrate the sub base materials gave a more accurate accounting of the infiltration rates. During construction of the pervious concrete shoulder, embedded infiltrometers were placed at two locations. Infiltration rates were measured using an embedded ring infiltrometer kit (ERIK). The limiting infiltration rates were consistent for the nine sampling times. These measures were taken at three different heads, and as expected the higher heads produce higher estimated rates of infiltration. The average limiting rates of infiltration for the one year were 2.5 inches per hour at a head of zero to one inch; 4.8 inches per hour at a six inch head; and 6.3 inches per hour at a nine inch head. An acceptable rate of infiltration for an 80 percent yearly volume control and using these designs is 1.5 inches per hour.

Water quantity and quality at the bottom of the reservoir was monitored. Water quality was measured based on orthophosphate (dissolved phosphorus), and nitrates (dissolved nitrogen fraction). Water quality in terms of dissolved phosphorus and nitrates leaving the reservoir was about equal to rainwater quality. The amount of water from the collection pipe nearest the edge of pavement was about 50 times the volume from the collection pipe seven feet from the edge of pavement. The yearly rainfall at the rest area was about five inches less than the yearly average. The rainfall in this time period was approximately 44 inches. The normal rainfall for the same period is approximately 49 inches. The water quality at the bottom of the reservoir was better than the runoff water quality.

5.2 Recommendations

Pervious concrete shoulder areas should be considered for stormwater management along highways. The infiltration rate, runoff volume reduction, water quality improvement, and structural stability make it a viable option.

An embedded ring infiltrometer should be placed in the pervious concrete and about 8 inches into the sub-soil during the construction phase and used for testing infiltration rates in the future.

5.1 Future Research

Strength bearing tests should be performed on the pervious concrete to determine the initial and long term loadings. A section and mix similar to the one used in this report should be used along with others.

The ERIK device was labor intensive and at low infiltration rates was taking several hours to complete with the potential for errors in reading the water column and time. It is recommended that an automated version of the device be developed to minimize human error.

APPENDIX A: Field Data

Table 3 Reservoir Water Quality Data

Date	Rain Inches	NO3-N (mg/L)		OP4-P (mg/L)	
		Edge	7 Feet	Edge	7 Feet
6.09.06	0.53 E	0.48	0.38	0.19	0.14
		0.30	0.21	0.24	0.13
		0.39	0.45	0.19	0.09
6.15.06	0.30 E	0.20	0.22	0.50	0.10
		0.31	0.07	0.68	0.09
		0.32	0.10	0.74	0.26
6.24.06	0.24 E	0.28	0.19	0.54	0.09
		0.39	0.11	0.59	0.20
		0.59	0.11	0.32	0.19
7.08.06	0.75 E	0.65	0.28	0.33	0.04
		1.02	0.23	0.35	0.04
		0.63	0.26	0.25	0.04
7.14.06	0.27 E	0.52	0.30	0.39	0.09
		0.76	0.31	0.31	0.10
		0.47	0.39	0.30	0.07
REPLACEMENT OF PERVIOUS CONCRETE					
9.22.06	0.20 E	0.11	0.27	0.27	0.03
		0.11	0.18	0.18	0.05
		0.12	0.12	0.12	0.10
9.28.06	0.60 E	0.24	*	0.13	*
		0.18	*	0.07	*
		0.18	*	0.15	*
10.05.06	0.41 E	0.42	*	0.12	*
		1.07	*	0.09	*
		1.37	*	0.15	*
11.10.06	0.28 E	0.15	0.14	*	*
		0.15	0.17	*	*
		0.16	0.17	*	*
11.21.06	0.6 E	0.30	0.01	0.32	0.21
		0.31	0.05	0.43	0.28
		0.20	0.06	0.30	0.34
12.16.06	0.41 E	0.74	0.33	0.39	0.08
		0.58	0.14	0.24	0.07
		0.11	0.22	0.28	*
1.11.07	0.28 E	0.17	0.06	0.04	0.05
		0.25	0.08	0.13	0.01
		0.23	0.11	0.45	0.07
1.30.07	0.45	0.66	*	0.34	*
		0.51	*	0.16	*
		0.39	*	0.50	*

Table 3 Continuation of Reservoir Water Quality Data

Date	Rain Inches	NO3-N (mg/L)		OP4-P (mg/L)	
		Edge	7 Feet	Edge	7 Feet
2.05.07	0.68	0.38	*	0.29	0.05
		0.39	*	0.37	*
		0.51	*	0.98	*
2.28.07	0.41	0.53	*	0.81	*
		0.46	*	0.64	*
		*	*	*	*
3.20.07	0.25	0.71	*	0.59	*
		0.36	*	0.68	*
		0.48	*	0.77	*
5.15.07	0.35	0.42	*	0.42	*
		0.50	*	0.55	*
		0.53	*	0.35	*
6.07.07	2.80	1.03	0.37	2.25	1.42
		0.85	0.58	2.26	1.33
		1.00	0.47	1.17	1.07
Average	0.55	0.46	0.22	0.46	0.23
% difference			53		50

- Notes:
1. Reservoirs beneath the pervious concrete were 22 inches down from grade and located at the edge of parking and seven feet from the edge of parking.
 2. There were other rainfall events in the area but none significant enough to produce runoff water in the sampling tubes.
 3. * - Not sufficient water in sampling tubes to perform tests.
 4. E - Rainfall estimated from gages within 4 miles of the site.

Table 4 Runoff and Reservoir Water Quality Data

Date	Rain Inches	NO3-N (mg/L)			OP4-P (mg/L)		
		Runoff	Edge	7 Feet	Runoff	Edge	7 Feet
11.10.06	0.20 E	0.27	0.15	0.14	0.22	*	*
		0.22	0.15	0.17	0.22	*	*
			0.16	0.17		*	*
11.21.06	0.60 E	0.23	0.30	0.01	0.40	0.32	0.21
		0.28	0.31	0.05	0.44	0.43	0.28
			0.20	0.06		0.30	0.34
12.16.06	0.41 E	0.44	0.74	0.33	0.38	0.39	0.08
		0.78	0.58	0.14	0.32	0.24	0.07
			0.11	0.22		0.28	*
1.11.07	0.28 E	3.58	0.17	0.06	1.37	0.04	0.05
		4.66	0.25	0.08	1.19	0.13	0.01
			0.23	0.11		0.45	0.07
1.30.07	0.45	1.29	0.66	*	0.93	0.34	*
		1.92	0.51	*	1.01	0.16	*
			0.39	*		0.50	*
2.05.07	0.66	2.98	0.38	*	1.40	0.29	0.05
		2.71	0.39	*	1.93	0.37	*
			0.51	*		0.98	*
2.28.07	0.41	0.82	0.53	*	1.14	0.81	*
		0.85	0.46	*	1.16	0.64	*
			*	*		*	*
3.20.07	0.25	1.08	0.71	*	1.12	0.59	*
		1.03	0.36	*	0.77	0.68	*
			0.48	*		0.77	*
5.15.07	0.35	1.05	0.42	*	1.09	0.42	*
		0.91	0.50	*	1.09	0.55	*
			0.53	*		0.35	*
6.07.07	2.80	2.04	1.03	0.37	2.65	2.25	1.42
		1.88	0.85	0.58	2.43	2.26	1.33
			1.00	0.47		1.17	1.07
Averages	0.64	1.45	0.45	0.20	1.06	0.60	0.42
% difference compared to runoff			69	86		43	61

- Notes: 1. Reservoirs beneath the pervious concrete were 22 inches down from grade and located at the edge of parking and seven feet from the edge of parking.
2. There were other rainfall events in the area but none significant enough to produce runoff water in the sampling tubes.
3. * - Not sufficient water in sampling tubes to perform tests.
4. E - Rainfall estimated from gages within 4 miles of the site.

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