Porous Concrete Pavement Construction: Opportunity for Alternative Drainage Methodology Emphasis in Construction Education

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Abstract

This paper focuses on using of pervious concrete for runoff drainage as an alternative to traditional methods of drainage involving storm-water drainage pipes, ditches, swales, retention and detention basins. The advantages of using pervious concrete for this purpose is elaborated on and the need to include this technology in the related courses in a construction management curriculum is emphasized.

Introduction: The Problem

The flow of water on the ground as a result of snow or rainfall is known as “surface runoff.” It is a known fact that the amount of this runoff increases as a result of development (i.e. building) of an area. The reason for this is that the impervious surfaces, such as roofs, driveways, sidewalks, roads, highways, parking lots, runways, etc., that are created as a consequence of development do not allow surface runoff to penetrate into the soil or be absorbed by the soil.

As shown in Figure 1, before development of an area the surface runoff is less than 1% of the water that ends on ground as a result of rainfall or snow. After development though, as shown in Figure 2, this percentage increases to about 20~30%. Thus, in connection with any development, there is a need to handle this resulting runoff that flows on different surfaces and address the problems it leads to.

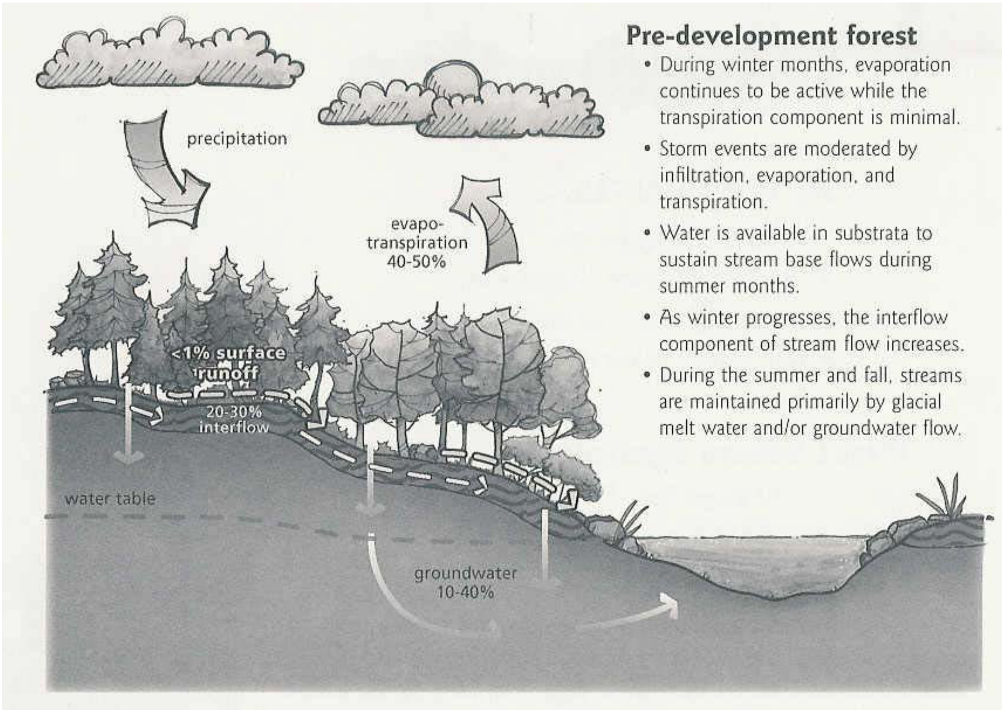

Figure 1. Pre-development hydrology moderates rainfall.
(Source: www.concretethinker.com/Papers.aspx?DocID=21) Photo courtesy of AHBL consulting eng. www.ahbl.com)

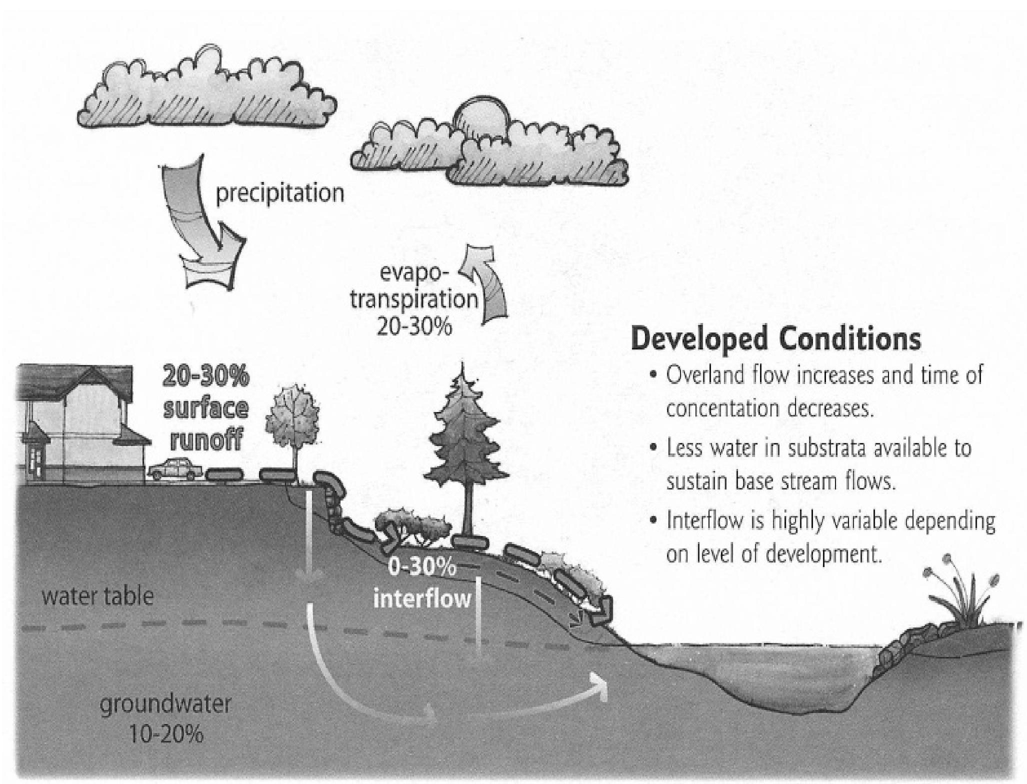

Figure 2. Post-development hydrology produces erosion and pollution.
(Source: www.concretethinker.com/Papers.aspx?DocID=21) Photo courtesy of AHBL consulting eng. www.ahbl.com)

The above described problem is naturally more significant for types of construction that the EPA includes under “permanent structures” such as “flatwork”, a term encompassing all horizontal construction such as parking lots, roads, driveways, sidewalks and similar [9]. All this construction, irrespective of whether they are of asphalt or normal concrete, lead to large impervious surfaces that create increased water runoff.

Solutions

A number of traditional approaches are known in the construction industry and have been employed over the years for drainage of runoff from developed areas. With minor variations almost all of these classical methods entail providing slopes on these flatwork surfaces so that the runoff can be conveyed by means of a storm-water drainage pipe, swale, ditch, canal, or similar means to large bodies of water such as a lake, river, the sea or retention and detention ponds/basins [5]. All of these traditional drainage techniques associated with conventional concrete and asphalt flatwork construction, suffer from the same inherent disadvantages, namely:

- Earthwork construction activities of significant volume to produce the needed slopes,
- Additional construction requirements in terms of additional structures such as pipes, swales, ditches, detention and retention ponds,
- Retention and detention ponds that may be requires and serve the purpose of holding the surface runoff permanently or temporarily respectively, reduce the area available for development (i.e. area for buildings, parking lots, sidewalks, etc.)
- Periodic maintenance requirements for pipes, ditches, ponds, etc.,
- Possible erosion resulting from flow of runoff over diverse surfaces before reaching its destination,
- If the flatwork is out of asphalt, asphalt can leach over time. All kinds of surfaces are contaminated over time by the kind of traffic that they address and the oil and grease this traffic generates. Runoff water inevitably flows over these impervious surfaces to reach its intended destination and in doing so, carry all the surface pollutants to the destination leading to pollution problems for bodies of water they end up in. Runoff can also carry fertilizers and pesticides. It is stated that runoff water can be more toxic than sanitary sewer water [8].
- Asphalt and conventional concrete pavements absorb the sun’s rays and heat up and thus increase the temperature of the runoff water as it flows over these surfaces. This warm water can stress or kill marine life, water plants, and some helpful bacteria.
- Since none of the classical drainage methods entail any sort of natural cleaning or filtering of the runoff en route to the destination, there may be a need for treatment or cleaning at the destination point leading to additional construction and investment requirements.
- None of the classical drainage methods are “green” in the sense that they contribute to pollution due to carrying of pollutants during flow over the flatwork surfaces and additional energy and investment requirements to alleviate the resulting problems.

In line with ever increasing emphasis on green and sustainable construction, using porous (pervious) concrete has emerged as a methodology that can bring forward economically and environmentally viable alternatives to rainfall and snow drainage [12]. This technique has significant advantages over traditional drainage methods employed in relation to flatwork construction especially concrete parking lots.

Methodology/Material

Porous or pervious concrete, known and used for about 50 years in Europe and less in the U.S., is a type of concrete that contains little or no fines (i.e. sand) but is composed mostly of aggregate and cement paste. Consequently, it has a significant void content in the range of 15 % ~ 25 %. Porous concrete has highly permeable, interconnected voids that drain very quickly. It also can serve as a mass that can store substantial amounts of runoff water. Porous concrete can store a volume of water equal to 15 % ~ 25 % of its own volume. For example, a 6 inch thick porous concrete pavement with 20 % voids can hold over 6.5 gallons of water per square yard, and/or ensure a flow rate of 3~5 gallons/inch/sq.ft through it. These features can be emphasized singly or in combination depending on the design and construction objectives in mind [4,7,8,10,11,14].

Table. 1 shows mix proportioning for pervious concrete [3]. Contrary to possible intuitive thinking that this kind of mix may lead to weak concrete, it has been shown that pervious concrete exhibits flexural strength in the 150~550 psi range and compressive strength in the 500~4000 psi range. [3]

Table 1. Typical* Ranges of Materials Proportions in Pervious Concrete**

Cementitious materials	270 to 415 kg/m³ (450 to 700 lb/yd³)
Aggregate	1190 to 1480 kg/m³ (2000 to 2500 lb/yd³)
Water-cement ratio (by mass)	0.27 to 0.30***
Aggregate-cement ratio (by mass)	4 to 4.5:1***
Fine-coarse aggregate ratio (by mass)	0 to 1:1****

* These proportions are given for information only.

** Chemical admixtures, particularly retarders and hydration stabilizers, are also commonly used. Use of supplementary cementitious materials, such as fly ash and slag, is common as well.

*** Higher ratios have been used, but reductions in strength and durability may result.

****Addition of fine aggregate will decrease the void content and increase strength.

(Source: www.cement.org/bookstore/download.asp?mediatypeid=1&id=6249&itemid=CT043)

Figures 3, 4, 5, 6 and 7 below show typical cross-section, texture, and flow characteristics for pervious concrete.

Figure 3. A cross-section view of pervious concrete and water flowing through it.
(Source: www.cement.org/bookstore/download.asp?mediatypeid=1&id=6249&itemid=CT043)

Figure 4: Samples of pervious concrete with different water contents, low to high.
(Source: www.cement.org/bookstore/download.asp?mediatypeid=1&id=6249&itemid=CT043)

Figure 5. Cross-section view of typical pervious concrete.
(Source: chatterbox.typepad.com/photos/abstract_portland/seid_mar_20_walk_16.html)

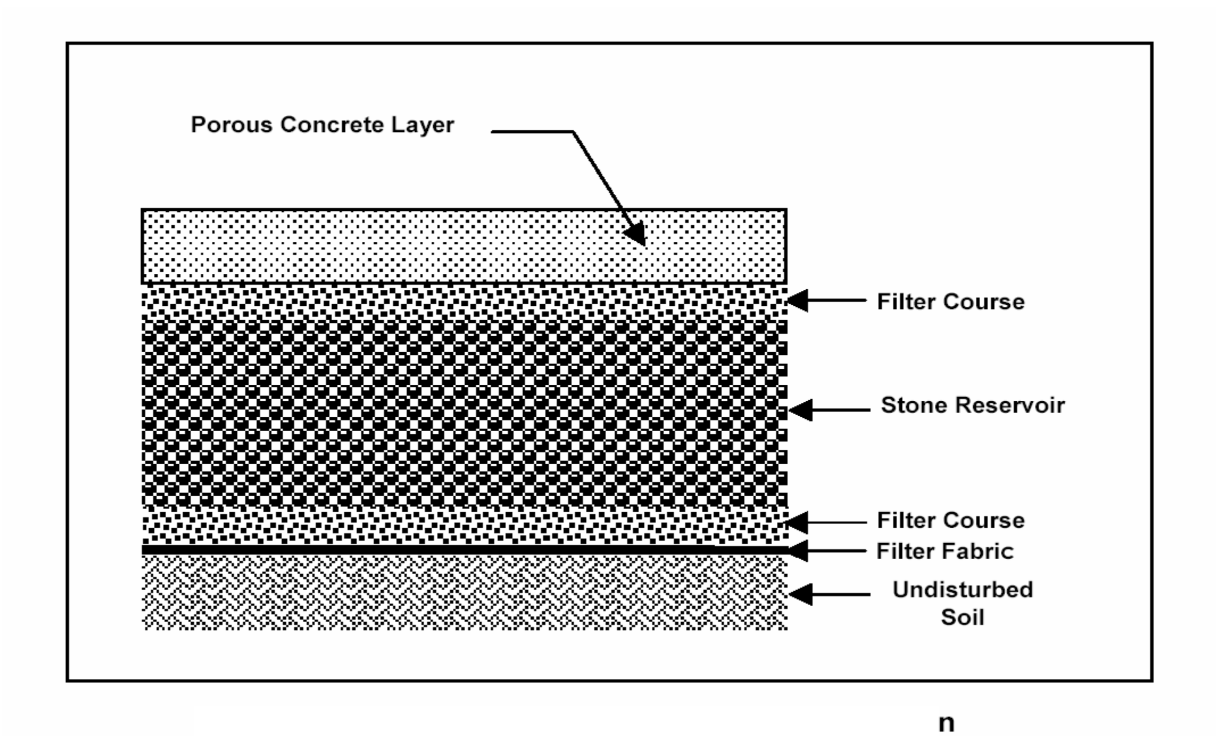

Figure 6. Porous concrete pavement system section.
(Source: www.georgiastormwater.com/vol2/3-3-7.pdf)

Figure 7. Cross-section of pervious concrete (left) and runoff water draining onto porous concrete from an impervious surface (right).
(Source: http://www.epa.gov/ednnrmrl/events/04-06-2006presentation3.pdf)

There are a number of advantages to using pervious concrete as an alternative to conventional drainage techniques [[2,4,10]]:

- The pervious concrete mass itself serves as the storage medium for the runoff water till it is absorbed by the soil and thus acts as a dry retention pond,
- Pollutants inherently present in the runoff are captured , water is retained and purified as a result of going through the filter beds if present or through the soil if not, and the water aquifer is charged with water that goes under the soils rather than being wasted and thus there is significant water conservation,
- Usage of pervious concrete can minimize or totally eliminate using under ground storm sewer drains depending on the method for putting in pervious concrete used and this concrete could also handle the runoff from the roofs that are directed onto it,
- Pervious concrete is a very durable material as conventional concrete and it gets even stronger over with water going through it when it is functioning as intended for drainage purposes,
- Low freeze-thaw susceptibility and damage due to high percent of voids inherently present in the pervious concrete and water going through it and not staying in it long term.
- Established performance history over the past 50 years of use in Europe and about 20 years in the U.S. and getting increasingly popular [[11]],
- Pervious concrete not susceptible to oil leaching as would be the case with asphalt pavements,
- Pervious concrete is a recyclable materials thus promoting green construction and sustainability,
- Pervious concrete has a high thermal mass and coupled with its higher reflectivity compared to asphalt, it lowers the urban heat island effect and regulates temperature variations,
- Pervious concrete uses local materials, which is a prominent criteria for sustainable construction, it can be cast in different colors, is inherently more reflective compared to asphalt and thus will not retain heat and warm up the runoff water which can be a problem as stated earlier,

- Fly-ash can be used in the range of 20~25% for replacing cement in the pervious concrete and thus helping with the storage problem associated with ever increasing amounts of fly ash due to electricity generation from coal,
- Runoff water going through pervious concrete is better for plant roots since water carries oxygen.
- Insurance premiums for businesses that use pervious concrete for their parking lots may be lower since most of the accidents due to slips and falls on icy lots are minimized or eliminated due to runoff water being dissipated into the pervious concrete in a fast manner. The pictures in Figures 8 and 9 illustrate the difference between an asphalt pavement and a pervious concrete pavement in terms of speed of drainage and the runoff not lingering on the surface and freezing etc…

Figure 8. Asphalt pavement with water runoff lingering on it.
(Source: www.perviouspavement.org/asphalt%20vs.**concrete**.htm)

Figure 9. Porous concrete pavement with runoff water quickly gone through the pervious concrete. (Source: www.perviouspavement.org/asphalt%20vs.**concrete**.htm)

The above stated characteristics of porous concrete has allowed it to function as a very logical and cost-competitive alternative to traditional drainage methods that utilize retention and detention basins and their associated structures, piping, and ponds. Porous concrete, with proper design and construction, ensures all the sheet runoff from a rainfall to be absorbed and/or drained through thus serving as a dry retention pond. As a result, the area requirements for traditional retention and detention ponds are eliminated or minimized. This allows more of the available land area to be developed for building construction purposes. Examples of application of pervious concrete for drainage purposes are illustrated in Figures 10,11, an 12.

Figure 10. Typical porous concrete system applications.
(Source: www.georgiastormwater.com/vol2/3-3-7.pdf

Figure 11. Porous concrete: driveway application.
(Source: Indiana Ready Mixed Concrete Association. www.irmca.org)

Figure 12. Porous concrete: parking lot application.
(Source: Indiana Ready Mixed Concrete Association. www.irmca.org)

Figure 13. Porous concrete for sidewalk.
(Source: Indiana Ready Mixed Concrete Association. www.irmca.org)

Dry retention ponds out of porous concrete have been accepted as fulfilling EPA, Phase II, NPDES requirements for storm-water mitigation and drainage practices [[9]]. They are also considered under Best Management Practices (BMP) for storm-water pollution prevention since runoff-borne pollutants are not carried to rivers or sewers but removed from the water in the process of having it go through the porous concrete and its underlying strata such as sand and gravel beds. Several states have included use of pervious concrete in drainage undertakings in their drainage manuals [[7,13]]. The LEEDS system of the U.S. Green Building Council (USGBC) and the NAHB recognize and give credit to use of porous concrete in flatwork construction in their proprietary certification processes [[15]].

Construction Details

Based on information available from research and applications [[2,7,16,17]]], pervious concrete constructed on a bed of pervious material such as a sand bed or a crushed rock or stone bed may be the best practice. This practice also makes more sense for climates with severe winters since pervious concrete constructed directly on soil may lead to increased water presence and storage in the mass of pervious concrete depending on the absorption capabilities of the underlying soil and thus pose a problem in terms of freezing. Such construction is illustrated below in Figure 14 [[7]].

Figure 14. Porous concrete system installation.
(Source: www.georgiastormwater.com/vol2/3-3-7.pdf)

This advisable type of construction on a pervious bed may be done with or without an under-drain as shown in the details in Figures 15 and 16 below [[14]].

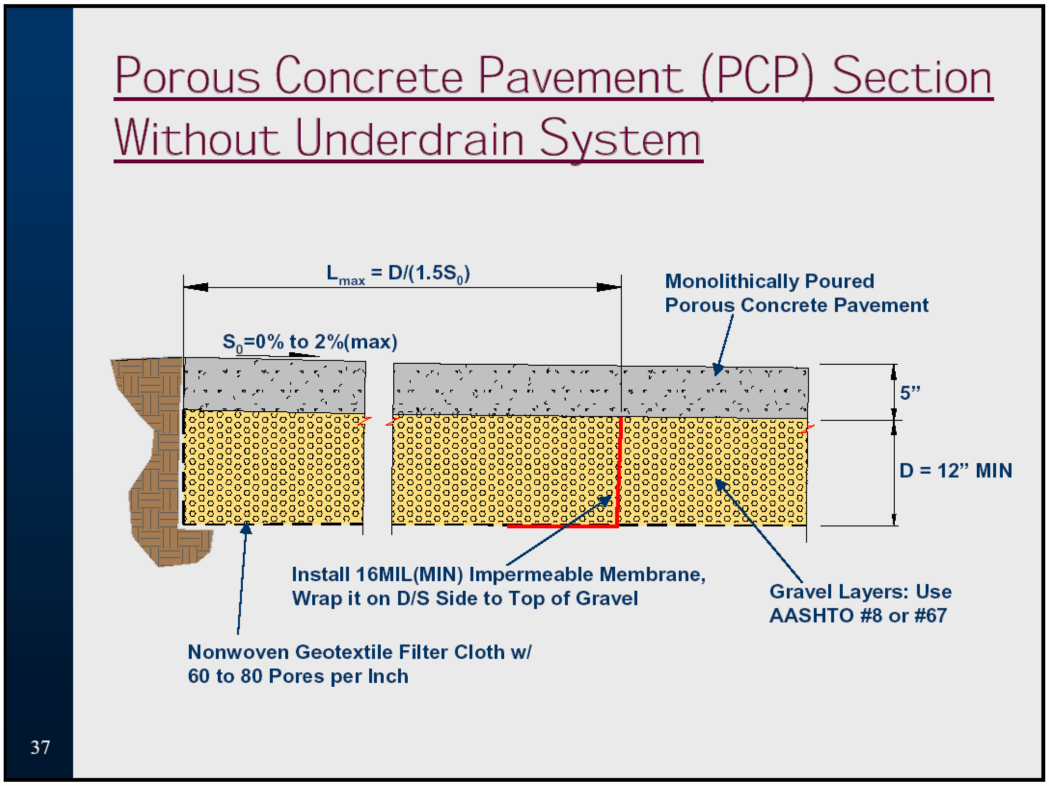

Figure 15. Porous concrete pavement section without underdrain system.
(Source: www.udfcd.org/conferences/pdf/conf2005/3-Urbonas2005.pdf)

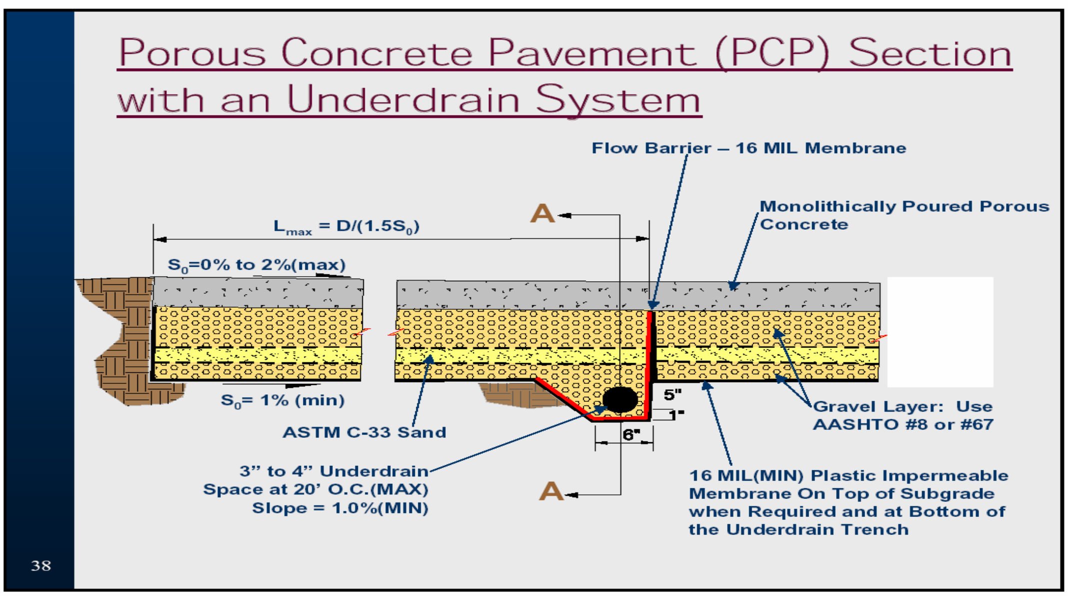

Figure 16. Porous concrete pavement section with an underdrain system.
(Source: www.udfcd.org/conferences/pdf/conf2005/3-Urbonas2005.pdf)

Since most rain events are one inch or less in depth, EPA requires that the first ¾" of each rain (i.e. first flush) be kept on site until dealt with. Most of this water contains a large concentration of contaminants and pollutants which are diverted to retention/detention ponds by means of storm water lines or other means [9]. A 5 inch thick pervious concrete pavement on the other hand, has the capability to absorb and hold an inch of rainfall before any runoff occurs.

Concerns about Pervious Concrete Use

Having noted most of the advantages of pervious concrete for drainage undertakings, it also has to be pointed out that there some issues that have been alluded to as being concerns about its use. These are listed below with some explanations as to why do not necessarily matter;

- Pervious concrete costs more than conventional concrete as a finished product. The cost increase is in the range of 10~40%. In general this is not a problem when this situation is evaluated in terms of a life cycle cost approach. Pervious concrete totally eliminates or minimizes the need for drainage lines, drainage basins, and other construction associated with conventional drainage techniques. It also increases the area that can be used for construction since area needed for basins etc is minimized or eliminated. Consequently in terms of a holistic look at the costs, increased cost of the product is not much of an issue.
- Pervious concrete necessitates compaction of soil under it during construction. This is a requirement for any type of pavement in general and not necessarily an issue for pervious concrete.
- Although the pervious concrete pavements can become clogged with the surface debris and junk brought by the runoff water over time, periodic maintenance has been shown to revert the permeability of this type of pavement back to its original levels.

Conclusions

Most of the conventional drainage related construction undertakings encompassing storm-water pipes, ditches, swales, retention and detention ponds/basins are covered in construction education curricula. Such coverage not only entails construction aspects and details related to such construction but also hydrology, fluid mechanics, and permitting issues related to runoff creation, flow, and drainage.

Even though I do not know per se to what degree usage of pervious concrete in drainage construction undertakings is being taught in diverse construction education programs in the U.S., which could be a good survey research topic in itself, considering the underlying advantages this technique brings to the forefront, I think it should be a permanent part of such coverage if it already is not. I, for my part, have ensured that this is the case and will continue to do so.

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Biography

Erdogan M. Sener., Professor and past Chair at the Department of Construction Technology of Purdue School of Engineering & Technology at Indiana University – Purdue University Indianapolis (IUPUI). B.S. Civil Eng., Middle East Technical University; M.S. Civil Eng. Michigan State University. He has over 13 years of international industrial experience in design and construction and has been in engineering and technology education for more than 24 years. Member of ASCE, ASEE, ACI, and past President of the Construction Eng. Division of ASEE. Registered Prof. Eng. in Indiana. Prof. Sener was awarded numerous teaching awards including the Indiana University President's Award for Distinguished Teaching in 1993 and the IUPUI Chancellor's Award for Excellence in Teaching in 1994 and several TERA awards.