Study Of Permeable Pavement Systems With Special Emphasis On Pervious Concrete

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Abstract- *One of the most effective and prevalent types of Sustainable Drainage Systems is permeable pavement systems. Permeable pavement systems allow effective management of surface water runoff and is an efficient method of improving water quality. Basic intention of Permeable pavement systems is to efficiently utilize the porous concrete in a constructive way so that it can be beneficial to society. The purpose of this review paper is to summarize the wide-range but diffuse works on permeable pavement systems (PPS) with special emphasis on one of its type i.e. pervious concrete. Additionally, our study deals with laboratory preparation & testing of pervious concrete and recommends future areas of research and development so as to provide stakeholders in storm water management with the critical information that is needed for the foster acceptance of permeable pavement systems as a viable alternative to the traditional systems.*

Keywords- Permeable pavement systems, Pervious concrete, Storm water management, Sustainable Drainage Systems

I. INTRODUCTION

Urbanization of the landscape has an appreciable negative impact on the quantity and quality of runoff water entering our lakes and streams (Davis, 2005; Wang and others, 2001; Williamson, 1993). By replacing natural land covers (like grasslands and forests) with impervious surfaces (like parking lots and streets), we lose the water retaining role of the soil and vegetation. Increased runoff from impervious surfaces causes dangerous floods, severe erosion damage to our stream channels, diminished recharge of groundwater, and degraded habitat for our fisheries. These same impervious surfaces can transport the many pollutants deposited in urban areas, such as nutrients, sediment, bacteria, pesticides, and chloride. In the worst cases, the amount of pollutants in urban runoff are high enough to prevent us from being able to swim or fish in our local waters.

Urban drainage is a major environmental challenge of modern times and solutions are an essential element for future sustainable development. Past development which did not incorporate sustainable environmental solutions has led to manifold and complex environmental problems such as flood risk and pollution. The increase in impermeable surfaces combined with the lack of effective management of surface water drainage results in increased quantities of runoff. In addition to this, these large quantities of runoff transport pollutants which can cause environmental pollution to the watercourse into which they are discharged.

Efforts to reduce the impacts of urban runoff have been happening for some time at federal, state, and local levels. Sustainable Drainage Systems (SuDS) imitate the hydrological cycle processes and offer a solution to above problems. Permeable Pavement Systems have many potential benefits such as reduction of runoff, recharging of groundwater, saving water by recycling and prevention of pollution (Brattebo & Booth, 2003). The significance of permeable pavement systems is based on the fact that they are designed to achieve water quality and quantity benefits by allowing the storm water through the pavement surface and into a base or subbase reservoir (Kumar, 2014). They are able to treat pollutants by retaining them in the pavement structure; results have shown a high removal rate of very fine and soluble pollutants (Ball & Rankin, 2010).

Permeable pavement systems provide a transportation surface and a best management practice for storm water and urban runoff. A cornerstone for low impact development (LID) and sustainable site design, permeable pavements are considered a green infrastructure practice. They offer many environmental benefits, from reduced storm water runoff and improved water quality to better site design and enhanced safety of paved surfaces. Commonly used for walkways, driveways, patios, and low-volume roadways as well as recreational areas, parking lots, and plazas, permeable pavements are appropriate for many different land uses, particularly in highly urbanized locations.

What is Permeable Pavement?

Permeable pavement is a specific type of pavement with a high porosity that allows rainwater to pass through it into the ground below. It is a porous urban surface composed of open pore pavers, concrete, or asphalt with an underlying stone reservoir. Permeable pavement catches precipitation and surface runoff, storing it in the reservoir while slowly allowing it to infiltrate into the soil below or discharge via a drain tile. The most common uses of permeable pavement are parking lots, low-traffic roads, sidewalks, and driveways.

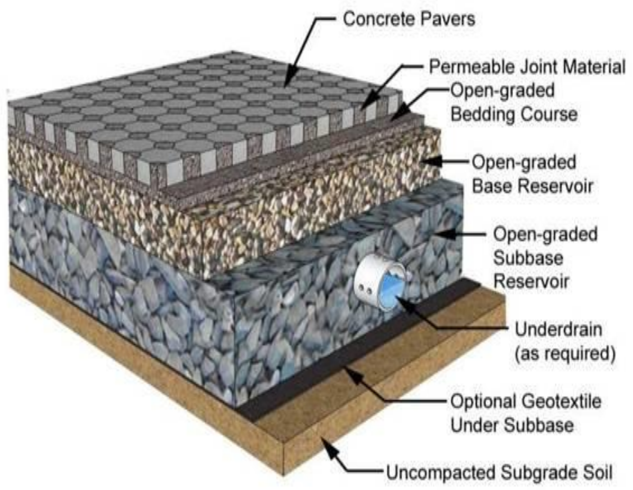


Fig. 1. Profile of typical permeable pavement. (Source: Smith, D., 2006.)

II. MATERIALS

Permeable pavements can be constructed using a variety of surface materials. These permeable surfaces are typically placed over an aggregate base/sub base reservoir, which collects the water that infiltrates through the surface. Based on surface materials, there are typically four major categories of permeable pavement:

- Pervious Concrete
- Porous Asphalt
- Permeable Interlocking Concrete Pavement(PICP)
- Others (such as Porous Turf, Grid pavement systems etc.)

The scope of this paper is limited up to pervious concrete only.

Pervious Concrete

Pervious concrete pavement is a unique and effective means to address important environmental issues and support green, sustainable growth. By capturing storm water and allowing it to seep into the ground, porous concrete is instrumental in recharging groundwater, reducing storm water runoff, and meeting U.S. Environmental Protection Agency (EPA) storm water regulations. In fact, the use of pervious concrete is among the best management practices (BMPs) recommended by the EPA—and by other agencies and geotechnical engineers across the country-for the management of storm water runoff on a regional and local basis. This pavement technology creates more efficient land use by eliminating the need for retention ponds, swales, and other storm water management devices. In doing so, pervious concrete has the ability to lower overall project costs on a first-cost basis.

Salient Features of Pervious concrete are:

- High porosity concrete, due to highly interconnected void content.
- Has little or no fine aggregate.
- Allows water to pass directly through-reduces the runoff and recharges ground water.
- Used in parking areas with light traffic, residential streets, pedestrian walkways, and greenhouses.

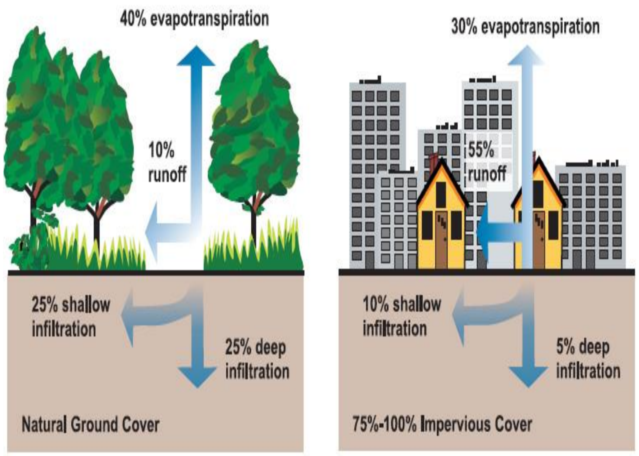
In pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are achieved in the hardened concrete, and flow rates for water through pervious concrete are typically around 480 in./hr (0.34 cm/s, which is 5 gal/ft^2/ min or 200 L/m^2/min), although they can be much higher. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for many applications is readily achieved.

While pervious concrete can be used for a surprising number of applications, its primary use is in pavement. This paper focuses on the pavement applications of the material, which also has been referred to as porous concrete, permeable concrete, no-fines concrete, gap-graded concrete, and enhanced-porosity concrete.

Constituents used in the preparation of Pervious concrete are:

- Portland cement
- Coarse aggregate
- Water
- Cementitious materials
- Admixtures

Pervious concrete is widely available, can bear frequent traffic, and is universally accessible. Pervious concrete quality depends on the installer's knowledge and experience.



Pervious Concrete Pavement   Impervious Concrete Pavement

Fig. 2. Comparison of Pervious and Impervious Concrete Pavement

III. METHODOLOGY

Design Criteria

Pervious concrete should be designed and sited to intercept, contain, filter and infiltrate storm water on site. Several design possibilities can achieve these objectives. For example, pervious concrete can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements or roofs to infiltrate runoff. Several applications use pervious concrete in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes pervious concrete installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be placed in the pervious concrete to accommodate overflows from extreme storms. The storm water volume to be captured, stored, infiltrated, or harvested determines the scale of permeable pavement. Pervious concrete comprises the surface layer of the permeable pavement structure and consists of Portland cement, open-graded coarse aggregate (typically 5/8 to 3/8 inch), and water. Admixtures can be added to the concrete mixture to enhance strength, increase setting time, or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the expected traffic loads.

Choke course - This permeable layer is typically 1 - 2 inches thick and provides a level bed for the pervious concrete. It consists of small-sized, open-graded aggregate.

Open-graded base reservoir - This aggregate layer is immediately beneath the choke layer. The base is typically 3 - 4 inches thick and consists of crushed stones typically 3/4 to 3/16 inch. Besides storing water, this high infiltration rate layer provides a transition between the bedding and sub base layers.

Open-graded sub base reservoir - The stone sizes are larger than the base, typically 2½ to ¾ inch stone. Like the base layer, water is stored in the spaces among the stones. The sub base layer thickness depends on water storage requirements and traffic loads. A sub base layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.

Under Drain (optional) - In instances where pervious concrete is installed over low-infiltration rate soils, an under drain facilitates water removal from the base and sub base. The under drain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.

Geotextile (optional) - This can be used to separate the sub base from the sub grade and prevent the migration of soil into the aggregate sub base or base.

Sub grade - The layer of soil immediately beneath the aggregate base or sub base. The infiltration capacity of the sub grade determines how much water can exhilarate from the aggregate into the surrounding soils. The sub grade soil is generally not compacted. Properly installed pervious concrete requires trained and experienced producers and construction contractors. The installation of pervious concrete differs from conventional concrete in several ways. The pervious concrete mix has low water content and will therefore harden rapidly. Pervious concrete needs to be poured within one hour of mixing. The pour time can be extended with the use of admixtures. A manual or mechanical screed set ½ inch above the finished height can be used to level the concrete. Floating and troweling are not used, as those may close the surface pores. Consolidation of the concrete, typically with a steel roller, is recommended within 15 minutes of placement. Pervious concrete also requires a longer time to cure. The concrete should be covered with plastic within 20 minutes of setting and allowed to cure for a minimum of 7 days.

Laboratory preparation of Pervious Concrete

The line of action adopted by us people for the sample preparation in the laboratory so as to perform experimental demonstration of pervious concrete is as follows:

Material Content used

- Coarse sized aggregate 1-2 cm-----------------5 Kg
- Portland cement----------------------------1.25 Kg
- Water content according to the ratio W/C ratio---0.34-0.40
- No admixtures
- Aggregate to cement ratio (A/C) is 1:0.25

Steps Involved

- Mixing of aggregate with proper water content.
- Laying of pervious concrete in artificial moulds.
- Make it dry for 1 day.
- After the sample is dried, check whether water passes through it or not.

Fig. 3. Laboratory preparation & Permeability testing of Pervious concrete

Properties

- Compressive Strength: Falls in the range of 3.5 MPa to 28 Mpa. Typical values are about 17 MPa.
- Flexural strength: Ranges between about 1 and 3.8 MPa. Influenced by degree of compaction, porosity, and the aggregate-to-cement (A/C) ratio.
- Density: depends on the properties & proportions of the materials used and Compaction procedures used in the placement. In-place densities in the order of 1600 to 2000 kg/m^3 falls in upper range of lightweight concretes.
- Durability: It depends on the saturation level of the voids in the concrete. Complete freezing can cause severe damage.
- Abrasion Resistance: Open and rough structure-abrasion and raveling of aggregate on the surface can be a problem. Hence Highways are generally not suitable for pervious concretes.

IV. DISCUSSION

Benefits of Permeable Pavement:

General hydrologic benefits

- Permeable pavements help re-establish a more natural hydrologic balance and reduce runoff volume by trapping and slowly releasing precipitation into the ground instead of allowing it to flow into storm drains and out to receiving waters as effluent. This same process also reduces the peak rates of discharge by preventing large, fast pulses of precipitation through the storm water system.
- Permeable pavement can reduce the concentration of some pollutants either physically (by trapping it in the pavement or soil), chemically (bacteria and other microbes can break down and utilize some pollutants), or biologically (plants that grow in-between some types of pavers can trap and store pollutants).
- By slowing down the process, permeable pavements can cool down the temperature of urban runoff, reducing the stress and impact on the stream or lake environment.
- By controlling the runoff at the source, such as a parking lot, permeable pavement can also reduce the need for or the required size of a regional BMP, such as a wet detention pond, which saves money and effort.

Cold-weather benefits

- Another benefit of permeable pavement is the reduced need to apply road salt for deicing in the winter time. Researchers at the University of New Hampshire have observed that permeable asphalt only needs 0 to 25% of the salt routinely applied to normal asphalt (Houle and others, 2009).
- Other researchers have found that the air trapped in the pavement can store heat and release it to the surface, promoting the melting and thawing of snow and ice (Roseen and others, 2012).

Concerns with Permeable Pavement:

Unfortunately, there are some disadvantages that come along with permeable pavements. They include:

- It is more expensive to install as compared to traditional pavements.
- The maintenance requirements of permeable pavement are quite different. It is prone to clogging if the water in the reservoir isn't drained out properly. The sand and fine particles that can block the space between the pavers must be removed using an industrial vacuum. It can even clog when you sand for ice during the winter. If you do not cater to clogging quickly, it will cause the water and pollutants to run off the surface, defeating the purpose of installing permeable pavement.
- They aren't as strong as traditional or asphalt pavements. If you put consistent pressure (like heavy vehicle braking) on it, then the pores of the pavement will collapse. Due to this, permeable pavement isn't ideal for building airport runways and highways.

V. CONCLUSION

Permeable pavement systems are changing the way human development interacts with the natural environment. Its application towards parking lots, highways and even airport runways are all improvements in terms of water quality, water quantity and safety. Today, they have become an important integral part of sustainable urban drainage systems despite the lack of corresponding high-quality research in comparison to other research areas.

This review paper looked at various aspects related to permeable pavement systems with special emphasis on pervious concrete. Design criteria, properties, benefits, concerns and challenges were discussed. Sample preparation of pervious concrete blocks for experimental study of its various properties have been performed in the laboratory.
The permeable pavements have been a subject of significant research interest over the past three decades. Previous studies have revealed a relatively significant degree of uncertainty regarding both their operational performance and maintenance requirements. Hence, in order to map out the future research needs, there is a need to explore the parameters that affect the performance of the permeable pavements such as further study needs to be done on how the surface infiltration rate can be maintained at high levels, the negative effects of compaction and clogging on the surface infiltration rate and the extent to which regular maintenance can improve SIR and durability. The development of a combined geothermal heating and cooling, water treatment and recycling pavement system is promising, and is therefore encouraged. Further work on the assessment of the self-sustainability and sustainability of PPS is also encouraged.

REFERENCES

[1] Chrysoula Pantsi et al. (2017). Permeable Pavement Systems: State of the Art, conference paper.

[2] Miklas Scholz, Piotr Grabowiecki (2006). Review of permeable pavement systems, Elsevier.

[3] Kolluru Hemanth Kumar (2014). Review paper on permeable pavement systems, conference paper.

[4] Evaluating the potential benefits of permeable pavement on the quantity and quality of stormwater runoff, www.usgs.gov.

[5] David James Sample et al. (2012). Residential Stormwater Methods for Decreasing Runoff and Increasing Stormwater Infiltration, Journal of Green Building.

[6] Miklas Scholz et al. (2014). Drainage Benefits of Porous, Permeable and Pervious Paving, Water Resources in the Built Environment, pp.302-31.

[7] Permeable Pavement: The Pros and Cons You Need to Know, www.greenblue.com.

[8] Types of Permeable Pavements and Their Benefits (chapter 2) , Guidance for Usage of Permeable Pavement at Airports, The National Academies Press www.nap.edu.

[9] Ferguson, Bruce K. (2005). Porous Pavements. Boca Raton: CRC Press. ISBN 978-0-8493-2670-7.

[10] U.S. Federal Highway Administration. Turner-Fairbank Highway Research Center. McLean, VA. Recycled Materials in the Highway Environment. Accessed 2010-07-05.