ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

IARJSET

International Advanced Research Journal in Science, Engineering and Technology

AGNI-PANKH 16

Jawaharlal Darda Institute of Engineering and Technology, Yavatmal

Vol. 4, Special Issue 3, January 2017

Permeable Pavement a step towards Sustainable Urban Drainage System

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Abstract: This is the review paper and this paper contain the existing technology on drainage system under one roof. Permeable pavement and their types are also discussed in this paper. This paper is focused on the use of permeable pavement in sustainable urban drainage system. Recent research like geothermal heating and cooling effect is also briefly described. We have tried to give some innovative ideas regarding to this topic that how can we use permeable pavement to such an extent that it can be proved a better option to use in a drainage system. The motto of this paper is to show the application of permeable pavement in drainage system effectively.

Keywords: Permeable pavement system (PPS), sustainable drainage system (SUDS), porous pavement, storm water, sustainability, filtration, drain, geothermal heating and cooling.

I. INTRODUCTION

Permeable pavement is the range of sustainable material and technique for PPS with the base and sub base that allows water to drip through it into the soil. These are mainly used in lawns, footpaths, road shoulders, etc. Though some permeable pavement doesn't really look porous but they allow the water to pass through it. Permeable pavements are mainly used to take charge upon the storm water that saturates.

1.1 Sustainable urban drainage systems

A sustainable drainage system is design to reduce the potential impact of new and existing development with respect to surface water drainage discharge. SUDS mimic nature and typically manage rainfall close to where it falls. SUDS can be design to transport storm water slowly runoff down before it enter watercourses.

SUDS are drainage system that is considered to be environmentally beneficial causing minimum or no long term damage. They are often regarded as sequence of strategies designed to efficiently and sustainably drain the surface water minimizing the water pollution or contamination and managing the water quality of local water bodies effectively. SUDS can be used in all types of development to provide natural approach to managing the drainage. 'Urban' in SUDS may perhaps be wrong to use as drainage system can be used to make development in rural areas too.

II. PERMEABLE PAVEMENT SYSTEM

Permeable pavement systems are design to achieve water quality and quantity benefit by allowing movement of storm water through pavement surface and into a base/sub base reservoir, the passes through the voids through the gaps between pavers and provides the structural supports and conventional pavement. That's why permeable pavement can be served as an alternative to conventional road and parking lots. The purposes of using permeable pavement system over other pavement system are as follows:

- Discharge of storm water pollutant to surface water is reduced
- Reduced storm water discharge volume and rate
- Reduced temperature

2.1 Types of Permeable Pavement System

Permeable pavement designs vary greatly. For example, shows a modern permeable pavement tanked system example. The general principle of PPS is simply to collect, treat and infiltrate freely any surface runoff to support groundwater recharge. In comparison to traditional drainage systems, storm water retention and infiltration is a sustainable and cost effective process, which is suitable for urban areas. Moreover, PPS have many potential benefits such as reduction of runoff, recharging of groundwater, saving water by recycling and prevention of pollution

1) Permeable asphalt

Permeable asphalt, also known as pervious, porous, "popcorn," or open-graded asphalt, is standard hot-mix asphalt with reduced sand or fines and allows water to drain through it. It generally consists of fine and coarse aggregate stone bound by a bituminous-based binder coarse. Porous asphalt over an aggregate storage bed will reduce storm water runoff volume, rate, and pollutants. The reduced fines leave stable air pockets in the asphalt. The interconnected void space allows storm water to flow through the asphalt as shown in Figure. 2., and enter a crushed stone aggregate bedding layer and base that

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supports the asphalt while providing storage and runoff treatment.


2) Modular interlocking concrete
Modular interlocking concrete blocks with external open drainage cells are also available on the market. Open cells are formed when blocks are assembled in an interlocking manner and filled with clean gravel.

3) Permeable concrete
Permeable concrete, also known as pervious or porous concrete. Permeable concrete pavement contains aggregates and Portland cement binder. The porosity is provided by the omission of fine aggregates.

4) Concrete grid pavers
Concrete grid pavements “green parking lots” provide a cool, green surface. Solution for vehicular access lanes, emergency access areas, and overflow parking areas, and even residential driveways. Grids are proven contributors to reduced ambient urban temperatures thereby contributing to reduced heat island while taking in some rainfall and runoff. Perforated concrete units as pavement were introduced when hollow concrete building blocks were placed in the ground to support cars.

5) Block paving stones
Block paving stones made of specially designed porous concrete (i.e. polymer-modified porous concrete) exhibit better fatigue behavior than those without polymers. Yet it has been shown that these improvements decrease for low values of stress levels, and sometimes appear to be negligible in the case of traffic loads on main and highway roads.

III. DESIGN

3.1 Lifespan
The lifespan of porous asphalt, porous pavement or permeable surface, in general depends predominantly on the size of the air voids in the media. The more possibilities for oxidation, the less durability can be achieved. It can be expected that the life of a PPS is shorter than that of an impermeable pavement due to deterioration by runoff air infiltration and subsequent stripping and oxidation as well as hardening of binder. Recent work has indicated that coarsely graded superpave mixes can be excessively permeable to water at air void level of approx. 6%.

3.2 Aggregate Component
Four distinct components are used in PPS
- bedding layers and pavers
- unsaturated zone
- saturated zone
- sub-grade

Various types of aggregate can be used in PPS. Metal leaching is not observed in the practice.

3.3 Geotextiles
Geotextiles helps to prevent sand from migrating into base of PPS. In a permeable bituminous-stabilized base course, the presence of geotextile helps to reduce the rutting depth and rate of block breakage. A geotextile with fibre of weight of 60 g/m² is generally used.

3.4 Hydraulics and Hydrology
Tests have shown that evaporation, drainage and retention within the permeable structure were mainly influenced by particle size distribution of bedding material, and by the retention of water in the surface block.
Movement of water through the porous pavement installation is controlled by surface runoff, infiltration through the pavement stone, percolation through the unsaturated zone, lateral drainage at the base and the deep percolation through the sub-grade.

3.5 Maintenance
Infiltration through the permeable pavement stone and the bedding layer is usually modelled using the complex

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Green-Ampt equation, which have physically based parameter that can be predicted. Infiltration is thus related to volume of moisture infiltrate.

Green and Ampt provided an approach that is based on fundamental physics but also gives the result that match the empirical observation in the laboratory. However the corresponding set of equation is difficult to apply to the field.

Infiltration supports groundwater recharge, decreases groundwater salinity, allows smaller diameter for sewer and improves water quality of receiving water, because pollutants and high peak flow are effectively controlled. On the other hand pollutant in runoff originating from domestic and industrial emission and traffic threaten soil and groundwater, if they are not removed from runoff before it infiltrates into the ground.

IV. WATER QUALITY

4.1 Pollutants

Pollution which presents on the road and car park surfaces as a result of oil and fuel leaks, and drips, tyre wear, and dust from the atmosphere. Impervious surfaces have a high potential for introducing pollution to watercourses possible water quality variable of concern include the following

- Sediment and suspended solids
- Organic waste with high biochemical oxygen demand.
- Dissolved nutrients and pollutants
- Oil and grease
- Faecal pathogens.

Permeable pavements have a good track record at removing suspended solids and nitrogen. However, PPS which do not rely on ground infiltration and the use of an under drain system, when an under drain system, will not be successful in the removable of nitrogen. When an under drain system incorporated into the pavement design, storm water tends not to infiltrate into the soil, but into the under drain, where it can be denitrified or removed by plant uptake.

4.2 Hydrocarbon

Oil and diesel fuel contamination is frequently detected on asphalt and other non-permeable surfaces. Hydrocarbon can endanger soil and ground water, it they are not removed sufficiently during infiltration through the surface layer.

Permeable pavement can operate as efficient hydrocarbon traps and powerful in-situ bioreactor. Found out that a PPS specifically inoculated with hydrocarbon-degrading microorganisms does not successfully retain a viable population of organisms for the purpose of increased hydrocarbon degradation over many years. Naturally developed microbial communities degrade oil successfully.

For the successful biodegradation of polycyclic aromatic hydrocarbons, certain environmental condition needs to be met. Degradation takes place when prolonged aerobic, sulphate reducing and denitrifying condition occur very large hydrocarbon spills can be contained due to adsorption processes within the pavement.

4.3 Metals

Studies have shown an improvement of water quality by filtration through PPS, which work well in removing suspended solids and particularly heavy metals from runoff. For example, Legret showed that suspended solids and lead can be reduced by PPS up to 64% and 79%, respectively.

A PPS should regularly be kept clean to prevent clogging. Generally, PPS are efficient in trapping dissolved heavy metals in surface runoff. However, not all pavers and joint fillings have the ability to trap dissolved heavy metals. Pavements with large joints for infiltration must have a suitable joint filling. Otherwise, metals will pass through them, and may subsequently enter groundwater resources. Geotextiles usually separate micro pollutants such as cadmium, zinc and copper from the underlying soil, therefore preventing groundwater from becoming contaminated.

4.4 Microbiology

PPS are powerful in-situ bioreactors, which can reduce hydrocarbon contamination by 98.7%. Biodegradation in PPS is enhanced by bacteria and fungi. When inoculated with microorganisms, the protozoan population diversity within a PPS increases more rapidly than in a similar non-inoculated system. Pavements contain testate amoebae, ciliates, flagellates and gym amoebae. The understanding of microbial biodiversity helps to interpret biodegradation mechanisms. PPS have the capacity to degrade large quantities of clean motor oil.

The assessment of the microbiological water quality has been an important process in preventing waterborne diseases. The two most common alternate tests carried out are for coliforms and Escherichia coli, or faecal coliforms. Total coliforms, faecal coliforms, faecal streptococci, heterotrophs, fungi, Pseudomonas aeruginosa, Leptospira, salmonellae and viruses are often analysed in an attempt to determine the temporal distribution of bacterial pathogens and viruses in storm water runoff. However, findings usually show that it is not possible to accurately predict the time when peak microbial populations including human pathogens occur in runoff waters.

V. RECENT RESEARCH

Combined Geothermal Heating and Cooling effect

The technology has many names: ground source heat pump (GSHP), ground coupled heat pump (GCHP), geo-thermal heat pump (GHP), geo-exchange (GX), Earth energy system. Geothermal heat pumps (GHP) or geo exchange systems are commonly used in North America, China, Japan and some European countries. Most GSHP use refrigerant to move unwanted energy (i.e. heat) out of buildings during summer and into them (if required)

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during winter. (Bose JE. (2005)) they use constant temperatures of surrounding grounds, which are lower than the corresponding air temperatures during warm seasons (heat sinks) and higher during cold seasons (heat sources). For ground connections, plastic pipes are installed within the soil. Various applications such as horizontal, vertical, looped or submerged designs can be used. The main thermal carrier within coils is a mixture of water and a deicing agent. The length and width of the loops is determined by ground conductivity abilities. The most important variables are type of soil, geology and area of available land for such installations.

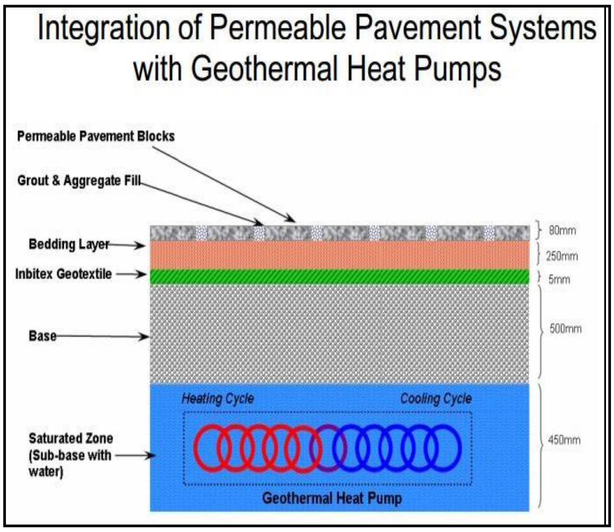

Figure 2. Cross section of PPS

Integration of PPS with Geothermal Heat Pumps

Environment not only prevents and reduces the risk of flooding and pollution of watercourses, but also reduces energy costs by the application of a green energy source (earth energy) which adds many other environmental benefits (Scholz and Graboweicki, 2008). Permeable pavement engineering is an effective and simple method of providing structural pavements whilst allowing storm water to infiltrate freely through the surfaces for temporary storage, storm attenuation, dispersal and reuse. Permeable pavement systems (PPS) are a sustainable urban drainage system (SUDS) whereby water from urban runoff can be treated by filtration and sedimentation for recycling, harvesting or reuse purposes.

Health risk associated with PPS

The main pollutant used was mineral engine oils containing hydrocarbons. Furthermore, a specific geotextile incorporating polymer beads was designed to release nutrients for better microbial community growth and more efficient hydrocarbon removal.

A different approach has been taken at 'The University of Edinburgh'. The research team had decided to use gully pot liquor mixed with tap water and animal faeces in some experimental rigs as the main pollutants. Such mixtures would mimic the most extreme conditions that may occur in practice. Gully pot liquor provides all possible pollutants available naturally. A gully pot is a biochemical reactor where pollutants are released after acidic dissolution and sediment maturation. Also various microbial degradation processes take place in the gully pot chamber.

VII. INNOVATION AND FUTURE RESEARCH

Nowadays this system is limited up to the vehicular access and pedestrian access. It should be also used in airports and also at domestic level. If the road level is raised as compare to the ground level of the residential building then PPS can be use to avoid the saturation of excess of water. There is a myriad of different applications where human's quest for development is hindered by environmental consequences. It is possible that with the use of permeable pavements these events may not be so catastrophic.

The studies and the researches conducted on the permeable pavement system have highlighted hydrological properties as it allows the water to drip into the soil it doesn't affect the drainage path. As the temperature fluctuation is induced because of the heat pump, the research can also be focused on the growth of micro-organism.

PPS can also be used in recycling the water. We can use the concept of rainwater harvesting using permeable pavements to store the rainwater. This stored water can be recycled and used. Thus the PPS is proved to be environment friendly engineering technique.

Further research on the short and long-term effects of contaminants that remain in the PPS should be undertaken. The self-sustainability of these relatively new systems in comparison to traditional pavements requires further assessment. Moreover, the long-term impact of PPS on the environment is still unclear. Before all of this can be accomplished though more research has to be put into improving the lifespan as well as decreasing the costs of permeable pavement. Hopefully if these two negative aspects of permeable pavement can be eliminated these systems can be installed in more places around the world.

VII. CONCLUSION

This review paper outlined the various studies and research conducted on Permeable Pavement System and their uses. Water quality control and maintenance are also highlighted. Recent innovation is also discussed. Advantages and disadvantages are also discussed. Permeable Pavement System have become an important integral part of sustainable urban drainage system despite the lack of corresponding high-qualities research in comparison to other research area. In contrast, porous pavement are usually associated with clogging problem and are therefore not as much applied in practice as PPS.

These permeable pavement systems are changing the way human development interacts with the natural

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environment. Its application towards parking lots, highways and even airport runways are all improvements in terms of water quality, water quantity and safety.

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