Reduction of Excessive Use of Water in Buildings: Use of Permeable Concrete to Develop Permeable Pavement System for Water Harvesting

Stefano Andriolo and Emir Barrera.

,Universidad Tecnológica Nacional, Facultad Regional Paraná, Civil Engineering School
1033 Almafuerte Av., Paraná, (3100), Argentina

Abstract
The following article presents how permeable pavements can be used to develop a non-potable water collection system for water reuse in homes and buildings. As well as this, the parts of the system, its operation and how to maintain it will be specified. The system to be developed has multiple advantages and few disadvantages, which make it an optimal system to avoid the waste of drinking water in the household.

***Index Terms*—Permeable pavement systems, permeable concrete, harvesting water in buildings, water harvest systems, second water provision for building.**

I. Introduction

IN the last years people have searched for new methods for water harvesting so as to reduce the use of drinking water for home maintenance purposes. Therefore, the development of water harvesting systems has been a central issue in the last decades. The United Nations' 2030 Agenda has as its 6th goal “Clean Water and Sanitation”, which among many other targets encourages new approaches to solving this problem. The population is growing, and the water resources are limited; therefore, limiting the demand for mains water and finding new methods for water harvesting are needed. If drinking water is not used for cleaning or irrigation, the demand of mains water will go down.

A solution to the water overuse problem is to find a system for buildings which has a second water provision of non-drinking water. The most affordable water resource in the buildings is rain since it does not need investment for its obtention; it just presents the problem of its storage.

Permeable concrete (PC) is a type of concrete used in pavement to reduce the overall volume of runoff, capturing as much rainwater as possible. This property makes this concrete suitable for the development of Permeable Pavement Systems (PPS), which are systems aimed to harvest water under lanes, roads, driveways, homes, building, and the like. Coupe, Nnadi and Charlesworth state that:

> The reservoir structure beneath an impermeably lined PPS, is an area that is ideal providing void storage to attenuate flow from a development, but also to trap the water for rainwater harvesting. As a general rule, a total pavement depth of 500 mm can provide 1000 liters of water within 10 m2 of paving. [1, p.2]

Stefano Andriolo is an Civil Engineering student at UTN FRP: stefanoandriolo@frp.utn.edu.ar. Emir Barrera is a Civil Engineering student at UTN FRP: emirbarrera@frp.utn.edu.ar.

The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering’s Grand Challenges or the United Nations’ Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students’ developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar

The aim of this paper is to explain each part of a PPS to trap water for rainwater harvesting. To achieve this objective, this article is developed as follows. Firstly, the discussion begins with a description of the function of each part of the system and their different possible composition materials with its advantages and disadvantages. Secondly, the paper is going to analyze the performance of the system, taking into account rain amount and frequency. Finally, this system is compared with other systems for water harvesting.

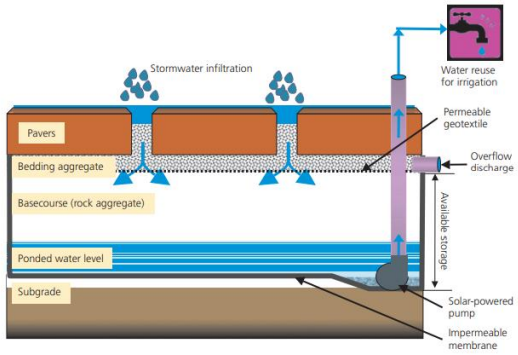

Figure 1. Permeable pavement system with water reuse capability (adapted from Myers *et al.* (2009a))

This is a conceptual diagram of a PPS. [2, p,2]

II. Parts Of the System And Its Operation

The PPS are systems of harvesting and storing stormwater. The most common uses of permeable concretes are parking lots, low-traffic roads, sidewalks, and driveways. For PPS to work properly, they need to have five parts, a permeable pavement, a basecourse, an impermeable membrane, a subgrade and water pipelines.

A. Permeable Pavement of Permeable Concrete

Permeable pavement is a porous urban surface composed of open pore pavers, concrete, or asphalt with an underlying stone reservoir. This catches precipitation and surface runoff, storing it in the reservoir while slowly allowing it to infiltrate into the soil below or discharge the water via a drain tile. The PC is a type of concrete with open network of pores to allow infiltration of stormwater as its main feature. Xie, Akin and Shi note:

> Typical Pervious Concrete Pavements can feature a wide range of properties, effective air voids from about 15 to 30 percent, permeability from 20 to 500 m/day, and compressive strength from 5.5 to 20.5 MPa [3,p 2-3].

The production and utilization of PC is standardized by the American Concrete Institute (ACI) committee 522 (ACI 522-R10) and the American Society of Civil Engineers (ASCE) permeable pavement task committee. Some of their considerations are a water/cement ratio between 0.27 to 0.43 and coarse aggregate size between 4.76mm to 25.4 mm [3, p.21]. This concrete has little or no amount of fine aggregate.

Apart from collecting precipitations, PC greatly withstands the damage caused by permanent use and weather action. Also, the PC can adopt the shape needed.

The permeable pavement is the system's surface and complies with both aesthetic and functional tasks. It is the first water filter and one of the most important structural parts.

B. Basecourse Aggregate

The basecourse aggregate fulfills a structural and hydraulic function. It is placed under the pavement and transmits the pavement's charges to the soil. Also, in this system, the basecourse is in charge of storing the water in its matrix. Ghisi, Belotto and Thives state that:

> In permeable pavements, stormwater infiltrates from the surface to other drainage layers, which have a high interconnected voids volume,and in turn, allows the water to flow through them to be filtered. Each layer has specific functions depending on the structure and purpose and is optional, depending on the pavement purpose. [4, p.2].

This basecourse, which is constituted by one layer, has a voids volume greater than 40% because it is a reservoir layer. It uses coarse aggregate with continuous gradation. Depending on the structural and hydraulic design, the nominal sizes range from 50.0 mm to 75.0 mm [4, p.3].

C. Impermeable Membrane

The impermeable membrane is an impermeable geotextile. It is in charge of generating the water reservoir with the basecourse aggregate.

It surrounds the base course, separating the subgrade from the soil. The impermeable membrane needs a structural and hydraulic design to use the geotextile more appropriately.

D. Water Pipeline

The water pipeline is in charge of taking water from the reservoir. It takes water from the lower part of the basecourse and carries it to the water tap.

The system needs a pump since the water is stored underground. Also, this has an overflow discharge in the higher part of basecourse to discharge the surplus.

III. The System's Performance.

A. Water Catchment

The PPS vary their harvesting by the capacity of their layers to infiltrate water. Also, the amount of water depends on climatic factors like intensity, frequency, among others.

The PC have different infiltrating rates depending on their composition. Although the basecourse is more efficient infiltrating water with a lower number of layers, the water chemical quality decreases.

According to [4], the infiltration (measured in 4 PPS different) was from 70.1% to 88.1%, showing a higher infiltration in the PPS without filter layer in their basecourse [4, p. 7]. This gives an idea of the water quantity harvesting

per rain depending on the number of layers.

The capacity of stored water depends on the basecourse dimensions and the voids volume of the coarse aggregate. For example, with a voids volume of 40% and a basecourse thickness of 40cm, the capacity will be of 160lt per m2. With this, in a house parking driveway of 25m2 the basecourse creates a tank of 4000lt.

B. Water Demand in The Building

The water demand per capita/day varies from 50lt to 209lt [5, 3.3.1]. The capacity of covering the water demand will depend on surface size, amount of precipitation and the water use into the building. Souza and Ghisi note:

> When the catchment surface area is small (100 m2), the potential for potable water savings of most cities ranges from 10% to 40%. However, by increasing the catchment area to 400 m2, a higher potential for potable savings can be achieved, since a greater amount of rainwater can be collected. [5, 4.2]

Although the amount of water is not enough to cover the totality demanded in a building, the system greatly relieves the drinking water provision. It is important in areas with an elevated cost of drinking water because it can bring a lot of money savings. According to [1, p.2] a PPS in UK supplies between 25% to 33% of interior demand and a 100% of external demand.

C. Inspection And Maintenance

Keeping an optimal hydraulic performance is needed for the PPS to work within acceptable ranges. The clogging is the process by which the permeable pavement's voids are blocked by water pollution. It is the most important problem that the PPS have because it stops the water infiltration and its harvesting. This processes just affects the PPV's surface. Therefore, cleaning the upper surface is enough to return the original infiltration [6, p.6].

When a permeable material has a variable cross-sections and random interconnectivity, this has a high tortuosity. The PC's voids are highly complex and heterogeneous. Therefore, generally the PC has a high tortuosity. A higher tortuosity increments the possibility of generating clogging [6, p.7].

With the objective to lower the clogging, the PC's pore structure must be uniform. Also, according to [6, p,7], with questionable effectiveness, vacuum sweeping and pressure washing are methods that can return PC's infiltration.

IV. Comparison With Other Systems

The PPS has the advantage of storing water without another reservoir than itself. Also, since this is the surfaces of road, sidewalk, driveways, among others; it does not modify the aesthetics of the place. Moreover, it can cover biggest extensions than other systems.

The PPS tank can be connected with other systems to harvest water or other water reservoirs. With the first, the amount of water infiltrated into system in a rainfall will be higher. If other tank is added to a PPS, the storage capacity will increase.

On the other hand, the PPS can have other functions than just harvesting water. Systems of heating buildings can be created with a PPS. It is accomplished with pipes into the basecourse that are heated by sunlight. According to [1, p.8], in an office development in the UK, this system had a reduction of 70% of carbon emissions and a reduction of 50% in utility bills.

inside of the PPS combinations there are a lot of types of permeable surfaces, basecourses and water reservoirs. Each combination has a different infiltration, water capacity and water quality. The best PPS for an area will depend on local materials, amount of rainfall, local technology, among others.

V. Conclusion

Permeable pavement systems are an excellent option to harvest water in buildings. This paper has presented an option to create one with permeable concrete as a surface option and a water reservoir made with the basecourse aggregate covered with impermeable membrane.

Generating a second water provision of non-drinking water can be the solution to areas with water shortage. The PPS harvests rainwater efficiently. Therefore, in areas with high rain amount it is an excellent option to solve its shortage. Also, the PPS can be connected with other systems and maximizing rainwater harvesting. The PPS presented in this paper uses accessible technology and does not need highly skilled workforce to be installed.

To conclude, the PPS presented in this paper can be made in any actual context or inspire a new PPS. The use of PC implicates higher infiltration but there are a lot of options to create a permeable pavement. Also, there are a lot of forms to create a water reservoir. The ideal combination of these components will depend on both the area where the PPS will be working and the builders' tastes and preferences.

References

[1] S.J. Coupe, E. O. Nnadi and S. Charlesworth "Multiple Benefits Derived from the Installation of Permeable Pavement Systems" http://documents.irevues.inist.fr/bitstream/handle/2042/35793/23603-349COU.pdf?sequence=1

[2] B. Myers, J. A. Van Leeuwen, S. Beecham "Water quality with storage in permeable pavement basecourse" https://scihub.se/https://www.icevirtuallibrary.com/doi/10.1680/wama.2011.164.7.361

[3] N. Xie, M.e Akin, X. Shi "Permeable concrete pavements: A review of environmental benefits and durability" https://scihub.se/https://www.sciencedirect.com/science/article/abs/pii/S0959652618335376

[4] E. Ghisi, T. Belotto, L. P. Thives "The Use of Permeable Interlocking Concrete Pavement to Filter Stormwater for Non-Potable Uses in Buildings" https://www.researchgate.net/publication/343134731_The_Use_of_Permeable_Interlocking_Concrete_Pavement_to_Filter_Stormwater_for_Non-Potable_Uses_in_Buildings#pfc

[5] E. L. Souza and E. Ghisi “Potable Water Savings by Using Rainwater for Non-Potable Uses in Houses” https://www.mdpi.com/2073-4441/4/3/607/htm

[6] M. Razzaghmanesh “A Review of Permeable Pavement Clogging Investigations and Recommended Maintenance Regimes” https://www.researchgate.net/publication/323749654_A_Review_of_Permeable_Pavement_Clogging_Investigations_and_Recommended_Maintenance_Regimes