Minimize surface runoff from parking lots with permeable pavement systems

Suripin, D Ulfiana, H Budieny, PN Parmantoro, D Prastiwi
Civil Engineering Department, Engineering Faculty, Diponegoro University, Semarang, Indonesia
suripin@lecturer.undip.ac.id

Abstract. Changes in land use can lead to an increased risk of flooding in an area. One example of flood conditions due to land use change is that occurred in the Diponegoro University Campus area in Tembalang. Most parking lots in this area comprises of conventional paving block system. It is basically a permeable pavement types, but in reality, existing conventional paving block systems cannot infiltrate storm water into the soil. There are two possible causes: first, the type of paving block is not a permeable type of concrete paving block and the second is the open graded base (OGB) and subbase do not have a high permeability, or a combination of both. This condition generates stormwater runoff in this area to be high, and causes on site and/or out side inundation. In this study, permeable paving block system (P2BS) was developed to find the parking lots with zero runoff.

Keywords: land use changes, permeable paving block system, surface runoff, zero runoff.

1. Introduction
In Indonesia the use of paving blocks began to be known and used since 1977 or 1978, installation began with the construction of sidewalks on the Thamrin road and for the city bus terminal in Pulogadung, in Jakarta. At this time the paving block has spread its use in almost all cities in Indonesia, both it is used as a parking lot for malls, plazas, hotels, recreation areas, historical places, public places for terminals, as well as for footpaths and pavement of neighborhood streets in the complex - housing complex even to the use of East Flood Way (BKT) normalization in East Jakarta [1].

Paving blocks or conblocks are usually made in produced in a various shapes and colour with a wide variety in dimension. The most commonly used is rectangles that are installed in such a way that they can interlock [2]. Paving blocks are mainly composed of cement or similar hydraulic adhesives, water, coarse and fine aggregates, with or without other additives [3]. Based on its ability to absorb water, paving blocks are divided into two groups, low permeable paving block and high permeable paving block. The last is also called pervious or porous paving blocks, which has infiltration rate more then 3 mm/s can even reach about 10 mm/s [4] [5].

The P2BS is basically a permeable pavement, which has multiple environmental benefits, one of which is to reduce rainwater runoff [6] [7]. But the reality found in the field shows different results, the pavement block pavement system behaves like an impermeable pavement. When rain falls puddles...
occur, even puddles do not dry out after more than one day of rain ends (Fig. 1). This will not happen if the paving block system is properly constructed. There are several possibilities that cause water to not be easily pass through the paving block pavement: the type of paving block used is low permeable paving block; the bidding layer, and open graded base (OGB) material used are not porous, their thickness are not in accordance with the design rainfall, or a combination of some or all of these possibilities.

Figure 1. Inundation on the conventional concrete block pavement during and after rainfall

Incompatibility in the construction of a paving block system, especially in Indonesia, is due to the absence of standard paving block system design criteria. The designers have not considered the benefits to the environment. Cost and aesthetics are still the main considerations. Porous paving blocks are not widely available on the market. Many paving block systems are installed on native soil which was compacted and covered with 5-10 cm sand (Fig. 2a). The main factor that determines the success of the paving block system is the existence of open graded base (OGB) as a temporary reservoir of rainwater before exfiltration into sub-soil (Fig. 2b).

Figure 2. Typical conventional paving block system (a), and permeable paving block system (b)

The basic principle of permeable pavement is to infiltrate and percolate storm water into the soil. Storm water infiltration and percolation by means of permeable pavement is a sustainable and cost effective process. Is is suitable for urban drainage system [8] [9]. It is also has many potential benefits such as reduction of runoff, augmenting groundwater, and prevention of water pollution [10]. The permeable pavement is designed based on the water balance equation proposed by Smith [11].

\[ V_w = \Delta Q A_c + PA_p - f A_p \]  
(1)
\[ V_p = \frac{V_w}{V} = d_p A_p \]  
(2)

where: \( V_w \) is the water volume, \( m^3 \); \( \Delta Q \): addition of discharge from catchment area, \( m \); \( A_c \): area of water catchment, \( m^2 \); \( P \): rainfall depth, \( mm \); \( A_p \): surface area of permeable pavement, \( m^2 \); \( f \): infiltration
rate of native soil (soil subgrade), mm/hour; T: duration of rainfall, hours; Vr: void ratio of open graded base (OGB) and subbase; and dp: the open graded base (OGB) and subbase depth.

The combination of equations (1) and (2) yields the following relationships:

\[
d_p A_p V_r = \Delta Q A_c + P A_p - f T A_p
\]

When the contributing area out of the permeable pavement is zero \((A_c = 0)\), then eq. (3) becomes:

\[
d_p V_r = P - f T
\]

\[
d_p = \frac{P - f T}{V_r}
\]

It should be considered in permeable pavement design that the paving block used must be have a high porosity to ensure surface runoff can be infiltrate freely, as well as its base as a reservoir must have a high porosity that can hold a lot of water. They should meet storm water demands while providing a hard surface, which can be utilized in urban areas [4] [11]. The objective of this study is to develop permeable paving block system (P2BS) for parking lots with zero runoff of storm water.

2. Material and Methods

2.1. Material

Permeable paving block system comprises of four main distinct materials: paving block; bedding layer; open graded base (OGB); and soil subbase. Optionally, geotextile is needed to help prevent sand from migrating into the base of P2BS.

In this investigation, crushed stone as bidder layer and open graded base (OGB) was used i.e. passing 9.5 mm retained 4.75 mm, with the porosity of 41%, and passing 12.5 mm, with the porosity of 42%, consecutively.

2.2. Paving block

Paving block or paver is the top layer of P2BS and functions as a pavement layer. Most paving blocks on the market have low permeability, it is less then 0.05 mm/s. Meanwhile the permeability of pervious paving block higher then 0.06 mm/s even reach to 9 mm/s [4]. The model permeable paving block system (P2BS) were prepared by using porous paving block developed by Ulfiana et al. [12]. Permeable paving blocks used have an infiltration capacity of 0.10 mm/s or equivalent to a rainfall intensity of 360 mm/hr, far higher than the intensity of rain that is likely to occur.

2.3. Open-graded base

The open-graded base is designed to let water seep through the subgrade instead of settling on it for a longer period of time. Various aggregates can be incorporated into P2BS as open graded base (OGB), as long as the voids between the particles are relatively large when compacted. In this experiment, the aggregate made of crushed stone passed through 12.5 mm sieve and retained on 5 mm sieve was used as open graded base.

2.4. Geotextile

Geotextiles help to prevent sand from migrating into the open graded base and subbase of P2BS. A geotextile with a fibre area weight of 60 g/m² is usually applied [13]. Another benefit is that most geotextiles can help to retain and degrade oil, if clogging is not a problem [14].

2.5. Methods

The main work in the model was permeability test. It was carried to determine the permeability of open graded base (OGB). Falling head permeability test was used by using a permeable paving block system model (Fig.3) and the permeability was measured in term of its intensity in seconds, which indicate the time taken for a specified depth of water permeate through the system.
3. Results and Discussion

The results of running permeable paving block system (P2BS) model show that the system is able to pass water through the system with intensity higher than 300 mm/hour, higher than the intensity of design rainfall for drainage systems in general. The P2BS model has the potential to be developed into a permeable pavement system with zero runoff. Furthermore, analytically developed graphs that make it easy to design P2BS with a variety of influential factors: porosity of open graded base; sub-base infiltration rate; and duration of rain.

3.1. Open graded base (OGB) porosity

Porosity is the amount of pore space in soil, sediments, and rock. Mathematically, it can be expressed as the ratio of the volume of pore space to the total volume of the material. Porosity of unconsolidated material ranges from 25-40% for gravel, 25-50% for sand, 35-50% for silt, and 40-70% for clay [15].

Open graded base (OGB) mostly composed of gravel and sand, the porosity ranges from 20-50%. Analitically, the OGB porosity has a considerable influence on OGB thickness, as shown in Fig. 4.

![Image](image_url)
3.2. **Soil permeability**

Soil subbase is generally in the form of compacted native soil. Based on the classification of soil texture, soil could be classified into 11 classes, each of which has a different infiltration rate [11], as shown in Table 1. Based on this classification, the need for an open graded base on P2BS can be determined as set out in Fig. 5.

| Texture classes of soil | Infiltration rate (f) | mm/s | mm/hr |
|-------------------------|----------------------|------|-------|
| Sand                    | 0.06                 | 216.00 |
| Loamy Sand              | 0.02                 | 72.00 |
| Sandy Loam              | 0.007                | 25.20 |
| Loam                    | 0.004                | 14.40 |
| Silt Loam               | 0.002                | 7.20  |
| Sandy Clay Loam         | 0.001                | 3.60  |
| Clay Loam               | 0.0006               | 2.16  |
| Silty Clay Loam         | 0.0004               | 1.44  |
| Sandy Clay              | 0.0003               | 1.08  |
| Silty Clay              | 0.0002               | 0.72  |
| Clay                    | 0.0001               | 0.36  |

**Figure 5.** Depth of open graded base (OGB) for various soil classes and rainfall depth in P2BS for OGB porosity 40% and 2 hours rainfall duration.
3.3. Rainfall duration

In the planning of drainage systems, the duration of the rain is very influential on peak discharge. The shorter the duration of the rain, the higher the intensity of the rain, the peak discharge will also be higher. In P2BS, the duration of rain has no significant effect on the thickness of the OGB required, as shown in Fig. 6. This is understandable because the process of extrafiltration of stormwater into the subgrade takes a long time, longer than the storm duration itself.

![Figure 6. Depth of open graded base (OGB) for various rainfall duration and rainfall depth in P2BS for OGB porosity 40% and 2 hours rainfall duration](image)

For example, the application of this P2BS in the area of the Diponegoro University: subgrade consists of silt loam, an open graded base composed of crushed stone aggregate with a porosity of 40%, and design rainfall 150 mm. Based on Fig. 4, for OGB porosity 40% and design rainfall 150 mm, the thickness of OGB would be 38 cm, while based on Fig. 5, for silt loam subbase and rainfall design 150 mm, the thickness of OGB needed is 35 cm. It is therefore can be concluded that the thickness of OGB needed is 38 cm.

4. Conclusion

From the result of P2BS model it can be proven that permeable pavement with zero runoff can be developed. Factors that play a role include permeability of paving blocks, porosity of open graded base, permeability of subgrade, and high rainfall. The thickness of open graded layer needed is highly depended on its porosity, and subsoil permeability, while rainfall duration has insignificant influence.

5. Acknowledgments

Thank you delivered to the the Faculty of Engineering, Diponegoro University for the financial support of this research. The authors thank also to Daryono, and SA Wibowo for assistance in the field experiments.
References
[1] https://hargakonblok.blogspot.com/2019/02/sejarah-paving-block-di-indonesia.html, downloaded on 30th July 2020: 18:00 PM.
[2] Kassim K and Rohim OM 2017 J. of Adv Res in App Sci and Eng Tech 8 1-7
[3] SNI 03-0691.1996. Bata Beton (Paving Block) (Jakarta: Badan Standarisasi Nasional)
[4] Ng CY, Narong AR, Kamarul Zaman AB, Mustaffa Z, Mohammed BS, and Ean LW 2019 The Open Civil Engineering Journal 13 82-91
[5] Putri EE, Ismeddiyanto, Suryanita R 2019 Jurnal Teknik 13 1-8
[6] Fassman EA and Blackbourn SJ 2010 Hydrol. Eng. 15 475–485
[7] Bhutta M, Tsuruta K and Mirza J 2012 Construction and Building Materials 31 67-73
[8] Dierkes C, Gobel P, Benze W, Wells J 2002 In: Melbourne Water, editor. Proceedings of the 2nd national conference on water sensitive urban design, 2–4 September 2002
[9] Andersen CT, Foster IDL, Pratt CJ 1999 Hydrological Processes 13 597–609
[10] Pratt CJ, Newman AP, Bond PC 1999 Water Science and Technology 39 109–30
[11] Smith DR 2006 State of Maryland Department of the Environment Baltimore Maryland.
[12] D Ulfiana, S Suripin, H Budieny, PN Parmanator, SA Wibowo2020 IEC
[13] Omoto S, Yoshida T, Hata S 2003 Proceedings of the seventh international conference on concrete block paving (PAVE AFRICA).
[14] Newman AP, Puehmeier T, Kwok V, Lam M, Coupe SJ, Shuteleworth A, Pratt CJ 2004 Journal of Engineering Geology and Hydrogeology 37 283–91
[15] Berhanu, B, Melesse AM, Seleshi Y 2013 Catena 104 21–31