The infiltration capacity of eco-concrete paving on different block shapes

J Rangkang¹, L Samang¹, S Adisasmita¹, and M Hustim¹

¹Civil Engineering Department, Hasanuddin University, Makassar, Indonesia
E-mail: jeanelyr@yahoo.com

Abstract. The study evaluates the infiltration capacity of the three eco-concrete paving block types, they are the three-diamond, the S, and the straight pavers. The objective of the study is to evaluate the infiltration capacity of those paving block types in different scenarios of slopes in high rainfall intensity. This research is carried out in the laboratory with some boundaries, namely: paving blocks used are 80 mm thick, gaps between pavers is 5 mm wide, the bedding layer thickness is 100 mm, the slopes of the test field are 0%, 2%, and 4%, rainfall intensities is 275 mm/hour. A box model for the infiltration capacity test was developed with a size of 1m², which is equipped with a modified rainfall simulator. The main conclusions of this study are:
(a) Each paving shapes shows different infiltration capacity characteristics; (b) The infiltration rate of pavement is strongly influenced by paving shapes; (c) The slope gradient increases, the volume of infiltrated water decrease; (d) The trihex type gives a better infiltration characteristic than that of the uni page and the rectangular types.

1. Introduction
Concrete paving blocks (PCB) that are used as pavement surface layer on the permeable pavement is designed to be used specifically to infiltrate stormwater through the gaps between pavers in order to reduce runoff volume and to treat the quality of infiltration water. This kind of pavement is generally applied as a water management strategy as an example Sustainable Urban Drainage Systems (SUDS) in Europe, Water Sensitive Urban Design (WSUD) in Australia, or Low Impact Development (LID) in the USA [1]. However, the paving block implementation as a permeable pavement surface layer in Indonesia is not familiar. Currently, it only considers the aesthetic side, while the hydraulic benefits are ignored. Actually, the hydrological benefits of this pavement material can be a powerful water management strategy for solving problems associated with stormwater runoff which potentially reduces the risk of downstream flooding [1, 2].

Eco-concrete paving blocks are material that is commonly applied as a pavement surface layer on the permeable pavement. In its utilization concern most on environmental issues, such as to minimize the ability of stormwater runoff to transport pollutant substances from the catchment surface that can hazard the downstream area, and/or improve water quality in water bodies that are known as the sensitive ecological zone [3, 4]. The urban areas typically have a much wider proportion of paved area than that of the unpaved area. Therefore, the stormwater runoff brings a significant problem in urban areas [4]. US EPA publishes rainwater that is falling on the natural ground cover, approximately 10%, will become runoff, while on the impervious cover is about 55% become runoff [5]. It pictures clearly
that the urbanized area produces more than 5 times more runoff volume than that of the wooded area. Moreover, land-use changes in the catchment area, as a result of the development of housing, industrial, and other urban facilities, have disrupted the hydrological cycle chain, causing a decrease in rainwater infiltration into the soil, and increasing surface runoff [6]. Therefore, a strategy is needed to control peak discharge by reducing rainwater runoff volume through the implementation of the eco-concrete paving block as a permeable pavement surface layer.

A number of previous permeable pavement infiltration studies had been conducted on block shape influence on infiltration capacity [7, 8]. The finding is the pavement infiltration rate is influenced by the length of the circumference of a block. In order to assess the infiltration capacity of several paving block shapes which are commonly used in Indonesia, this study evaluates the infiltration capacity of the three eco-concrete paving block types, they are the three-diamond, the S, and the straight pavers in different scenarios of slopes and one selected rainfall intensity.

2. Research methodology
In Indonesia, there are several types of pavement surface layer typically used. In the Indonesian term, they are known as the straight, the three-diamond, the S, the hexagon, and the grass block pavers. However, the commonly used as road pavement are the only three types of pavers that are mentioned first. Figure 1 shows the pictures of the pavers types from (a) to (e) respectively as mentioned above.

![Figure 1. The common pavers types in Indonesia.](image)

2.1. The developed infiltration test device
A number of previous studies on permeable pavement infiltration have been conducted by some researchers using the Cantabrian Fixed Infiltrometer (CFI) which was developed in the Universidad de Cantabria (UC) [7, 9-12]. The CFI is a laboratory device that was created to measure the infiltration capacity of permeable surfaces, which allows testing pervious pavement with any kind of surface layer. The test piece area of the CFI is 0.25 m², the rainfall intensities range is 10-150 mm/h, and the surface slope test is between 0% to 10% [10]. Other researchers constructed a steel box test model with infiltration holes set up on the bottom plate [13]. The two laboratory devices that were developed in UC and that was constructed [9]. The study had become the basis of the development of the steel box infiltration test model used in this study [13]. The device that is developed in this study, was designed to test the infiltration capacity of paving area 1 m². Moreover, it only allows measuring the direct infiltration capacity for vertical rain falling, where the rain intensities could be independently adjusted to the target intensity. The apparatus was not facilitated with runoff generators such as the Cantabrian Fixed Infiltrometer from the Universidad de Cantabria. The developed device consists of three main parts, i.e.: test frame, grid, and modified rainfall simulator. The device sketch as shown in Figure 2 are marked with letters and numbers that will explain each section, they are:

- tests frame;
- grid;
- the sprinklers that produce raindrops;
- pavers;
- bedding layer;
• geotextile filter cloth;
• long threaded screws to adjust the grid’s slope;
• a roof sheeting to collect runoff water ($Q_R$);
• the subsuperficial flow water funnel for collecting infiltrated water ($Q_I$), and;

($Q$) selected inflow rate, which can be calculated from the following formula:

$$Q = Q_I + Q_R$$  \hspace{1cm} (1)

where $Q_I$ is runoff outflow rate, and $Q_R$ is infiltrated outflow rate. Figure 2 shows the sketch of the developed device.

![Figure 2. The sketch of the developed apparatus.](image)

2.1.1. Modified rainfall simulator
A rainfall simulator is an important part of the developed apparatus. It is placed at a separate upper frame, right above the pavement. The raindrops are produced through simple pipelines with sprinklers from a modified rainfall simulator that is positioned directly over the pavement area. In order to get a specific intensity, the rainfall simulator is connected to a valve to adjust the flow rate. The 275 mm/h is the selected intensities for this study.

2.1.2. Test frame and grid
The frame has four legs for supporting the grid and the modified rainfall simulator. The frame and grid are both made of steel. The pavements are placed inside the grid. To get the specific test slopes, it is adjusted via two long threaded screws that are placed on one side of the frame. It is possible to adjust the grid’s slope for varying slopes test. The selected slopes of this study are 0%, 2%, and 4%.

Moreover, to collect the infiltrated water and the runoff water, the grid is equipped with a sub superficial flow water funnel for infiltrated water, and a roof sheeting 50 mm wide for runoff water. Both the sub superficial flow water funnel and the roof sheeting are placed on the opposite side of the slope adjusted screws position. Assumed that infiltrated water will infiltrate through the bedding layer to the bottom of it, and then flow to the sub superficial flow water funnel that is placed right below the roof sheeting.

2.2. The developed infiltration test device
Three types of concrete block pavers, a bedding layer, and a geotextile filter cloth are the permeable pavement materials which will be described below. Each material is marked with number 6, 5 dan 4 in Figure 2.

2.2.1. Concrete blocks
Three concrete block types were tested in this study to determine infiltration rates. They are the paver type (a) to (c) as shown in Figure 1.
The three-diamond, the S and the straight, are the Indonesian term of those shapes. While the commercial term of these pavers are the trihex, the uni paper, and the rectangular paver, in which these types of pavers are commonly used in Indonesia. The blocks tested were made of Portland Composite Cement (PCC) that is widely used in Indonesia, in which PCC has a high compressive strength [14]. The blocks tested were produced by Super Star Enterprise in North Sulawesi Indonesia. Table 1 shows the dimensions of each tested paver.

| Paver type       | Trihex | Uni papier | Rectangular |
|------------------|--------|------------|-------------|
| Length (mm)      | -      | 220        | 210         |
| Width (mm)       | -      | 105        | 105         |
| Height (mm)      | 80     | 80         | 80          |
| Upper surface area | 28,059 | 23,100     | 22,050      |
| Circumference surface area | 57,600 | 52,000     | 50,400      |

The pavers were placed on top of the bedding layer, whose gaps between pavers are 5 mm. The gaps filled with graded sand used as the bedding layer material. This treatment is based on a laboratory study on pavement using fine and coarse joint sand that was conducted by other researchers. The study concluded that is coarser the gradation of jointing sand, the performance of the pavement will be better. However, the maximum size of the jointing sand should be less than the joint width [15]. The specification of the jointing sand will be discussed in the description of the bedding layer material.

Furthermore, the permeability of the concrete block is not considered in this study, even though the other factor that should be concerned about paver tested is its permeability. The reason for this treatment is based on findings from several researchers that the permeability of the concrete block is very low. Moreover, the degree of concrete block permeability is determined by the capillary porosity of the concrete. The study reveals that the permeability of concrete was taken as a constant value of 1 x 10^-4 m/sec. Finally, the study concluded that permeability of the concrete block has no considerable effect on pavement surface permeability [8].

2.2.2. Bedding layer and geotextile

![Figure 3. Bedding material grading curve.](image-url)
The gradation of the bedding material was chosen based on ASTM C 33 [16]. This material was taken from a quarry located in North Sulawesi Indonesia. Figure 3 shows the bedding layer gradation according to ASTM C 33. The blue line with square red dots, as shown in Figure 3, presented the gradation curve of the selected material for this study. While the two black lines with black round dots are both gradation envelope of ASTM C 33 specification. The material properties of the bedding layer are listed in Table 2, in which the bedding material properties are gained through laboratory testing.

| Properties of material bedding | Value |
|-------------------------------|-------|
| Max. Dry density, $\gamma_d$ (gr/cm$^3$) | 1.47  |
| Specific gravity, $G_s$        | 2.655 |
| The density of water, $\gamma_w$ (gr/cm$^3$) | 1.00  |
| Void ratio, $e$               | 0.806 |
| Porosity, $n$ (%)             | 44.6  |
| Hydraulic conductivity, $k$ (mm/s) | $4.325 \times 10^{-1}$ |

In this study, the thickness of the bedding layer was 100 mm, and it was compacted and leveled manually. The bedding material was placed on the top of geotextile, inside the grid. In order to create an interlocking between paving blocks and to help seal the pavement, in the segmental concrete pavement, the gap between the paving block must be filled with the jointing sand, which has the same gradation as the bedding material gradation [16]. Geotextile has an important role in the pavement structure. There is six principles application of geosynthetics in civil engineering, as follows: erosion protection; filtration/sediment trapping; separation layer; deflection resistance; void forming; and pollutant trapping/supporting bio-remediation [17]. The selected geotextile in this study was polypropylene filter cloth whose technical specifications are the weight of 350 g/m$^2$ and permeability of 117.9 L/m$^2$s. Unfortunately, the presence of geotextile in this study is not taken into the calculation. It was used only as a filter to protect the bedding material not to be carried by water. The geotextile was placed at the base of the grid.

3. Result and discussion
A series of laboratory tests have been conducted on three types of concrete pavers, three slopes gradients, and in high rainfall intensity of 275 mm/h. In order to evaluate the infiltration capacity of selected concrete paver shapes, there is 9 times infiltration testing, with the following test boundaries:

- Newly built pavement surface, so no clogging scenario applied.
- The water infiltrates through the gaps between pavers, not through the pavers,
- Direct rainfall storms of uniform intensity were simulated
- No runoff simulator.
- Five minutes is the time selected interval to collect water flow until the flow rate was almost constant.

Figures 4, 5, and 6 depict the output rates subjected to pavement surface slopes at rainfall intensities of 275 mm/h of trihex, uni paper, and rectangular types, respectively.
Figure 4. Experimental output rate subjected to slopes of trihex type.

In the trihex type, an extraordinary infiltration capacity is indicated by this paving type, in which its infiltration capacity is higher than that of the other types. However, the volume of infiltration water decreases along with the increase in slopes gradients, as shown in Figure 4 above.

Figure 5. Experimental output rate subjected to slopes of uni paper type.

As can be seen in Figure 5, the unipaver type has a better infiltration rate than the infiltration rate of the rectangular type, even though its infiltration rate is still under the trihex type. Unfortunately, the tendency of decreasing in the infiltrated water volume is indicated by the increase in the slope gradient.

Figure 6. Experimental output rate subjected to slopes of rectangular type.
Figure 6 shows the relationship between the output rate and time of rectangular pavers. As can be seen, the volume of infiltrated water of this type is the lowest of all tested paver types. In general, it can be said that the increase in pavement slope, the volume of infiltrated water decreases. In addition, one of the most influencing factors of the infiltration rate is the length of the circumference of a block. Figure 7 depicts the infiltration rate of each paver tested.

![Figure 7. Circumference surface area of pavers subjected to time.](image)

The trihex shape gives a better performance in the infiltration rate, followed by the unipaver and the rectangular shape respectively. It can be seen in Table 1 that the circumference area of the trihex type is greater than that of the other two types.

4. Conclusion
Based on the evaluation of the three types of paving tested, some valuable findings can be conveyed, as follows:

- The slope gradient increase, the volume of infiltrated water decreases.
- The infiltration rate of pavement is strongly influenced by paving shapes.
- The trihex type gives a better infiltration characteristic than the unipaver and the rectangular types.

In order to validate the results obtained through the laboratory investigation, an analytical calculation should be developed on the next level. Also, further evaluation should be done on all selected paver shapes by applying other rainfall intensity, and by applying the same laboratory methodology. The study should be conducted to characterize the permeable pavement infiltration behavior, in order to obtain the influence of the paving block shapes on the infiltration rate.

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