International Journal of GEOMATE, Oct., 2021, Vol.21, Issue 86, pp.32-39
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.86.j2249
Geotechnique, Construction Materials and Environment

PROPERTIES OF POROUS PAVER CONCRETE BLOCKS AND THEIR OVERALL INFILTRATION RATE IN PAVEMENT FORMATION

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*Corresponding Author, Received: 24 June 2021, Revised: 02 Sept. 2021, Accepted: 23 Sept. 2021

ABSTRACT: Porous paver concrete block is a mixture of Portland cement, coarse aggregate or gravel, and water. It is porous because finer material, like fine sand from the concrete mixture, is removed. The focus of this research is to study the properties and the consistency of readymade porous paver concrete blocks produced by a local factory for possible use in future application as components in interlocking/non-interlocking paver systems with water storage capability. The water infiltration rates of the paver block samples were studied through characteristics such as density, water absorption and porosity. The weight, density, and void content of porous paver concrete blocks that were presented in this study are based on 38 samples and analyzed using descriptive analysis. Then, samples were arranged in paver formation. Two variations of jointing surfaces were identified to study the infiltration rates. From the statistical analysis results, 84.2% of the block samples were consistent in terms of weight, density, and void content, and the remaining 15.8% of the block samples were excluded from the infiltration test. Results from the infiltration test showed that there were differences in infiltration rates between the two jointing variations, as infiltration rates for jointing Design B were higher compared to jointing Design A. The overall infiltration capacity of 33559.75 mm/hour (0.93 cm/s) complies with the requirement of standard paver blocks systems.

Keywords: Porous pavers, Infiltration rate, Coefficient of variations, Water storage, Pavement formation

1. INTRODUCTION

Urbanization is the process of becoming less rural, developed, and more urban for a certain area [1]. An urban area consists of a large population in every country, and this will continue to be the most widely used artificial landscape. The rapid development of urban areas has caused changes in land use on earth surfaces, reduction of green areas, an increase of impermeable surfaces, and changes in surface albedo and geometry especially in rural areas [2-3]. As a result of urbanization, natural earth surfaces like grassland, forest land, and agricultural land have been replaced by impermeable surfaces and other artificial landscapes [4], and this has led to the decrease of areas that could absorb stormwater and rainwater to be discharged naturally [5].

An impermeable surface is defined as the soil cover with impermeable materials, like asphalt pavements, concrete pavements, metal, plastic, glass, and metal [1], which prohibit water from infiltrating the underlying soil [5]. While a permeable surface (also called porous surface) allows stormwater and rainwater to infiltrate it and into a gravel reservoir before being discharged naturally into drainage [6]. Usually, permeable surfaces are rough and could reduce the flow of stormwater runoff and prevent flooding or water pooling [7]. Permeable surfaces are commonly used for parking, footpath, driveways, walkways, and low traffic load [6-7]. Removing fine materials like sand from the concrete mixture could make the concrete porous and permeable [8], and the porosity of the concrete is usually in the range of 15 percent to 35 percent [9]. Permeable pavements are considered a substitute for conventional impermeable pavements where the interconnected void in the pavement allows water to infiltrate through the pavement particularly in rainy seasons. Generally, it is regarded to be one of the highly efficient rainwater management techniques [10].

Apart from its usage as the stormwater management system [11], permeable pavement also offers a variety of benefits such as improve water quality, noise reduction, slip resistance, and help to mitigate urban temperature [12]. Permeable pavements have a higher water holding capacity compared to impermeable pavements and this could lead to higher evaporation rates which could give cooling effects to the pavements [13]. Fig.1 shows the typical general structure of most types of permeable pavements.

The focus of this research is to study the properties and the consistency of readymade porous paver concrete blocks produced by a local factory for possible use in future application as components in interlocking/non-interlocking paver systems with water storage capability. The infiltration rate of the porous paver concrete blocks was measured to ensure the infiltration rate was within acceptable rate as mentioned in the Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems (ASTM C1781). This is important as the results obtained can be used for possible applications of the paver blocks as a component of a pavement water storage system in the next subsequent study.

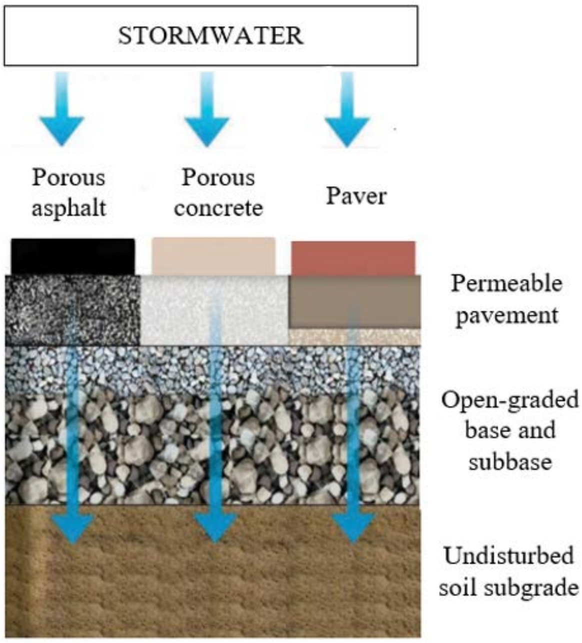


Fig.1 A general cross-section of the permeable pavement [14]

2. RESEARCH SIGNIFICANCE

The significance of this part of the study is in the use of paver blocks characteristics namely density, water absorption and porosity to verify their suitability for use as porous pavement components that allows satisfactory infiltration capacity. Factory-made porous concrete blocks were evaluated for consistency before being used for infiltration studies. The infiltration studies take into consideration the common variation of the paver arrangements that influence the rate of infiltration. The result of this work will provide the basis for the future design of water storage systems to be embedded in the interlocking/non-interlocking porous pavement system.

3. MATERIALS AND METHODS

This research studied the properties of readymade porous paver concrete blocks, where the weight, density, and porosity were measured and analyzed to ensure the consistency of their characteristics. The infiltration rate measurement was taken to measure the effects of infiltration rate on different jointing variations of porous concrete pavers. Fig.2 shows the experimental test and analysis employed in this study.

Data from the experimental test of density, water absorption and porosity were analyzed using descriptive analysis, where the values of minimum, maximum, mean, standard deviation, and deviation of variation were measured. The consistency of the production of readymade paver blocks was measured using standard deviation and deviation of variation measurement. The nearer the standard deviation spread to the mean value and fewer variation values showed better consistency of paver block production.

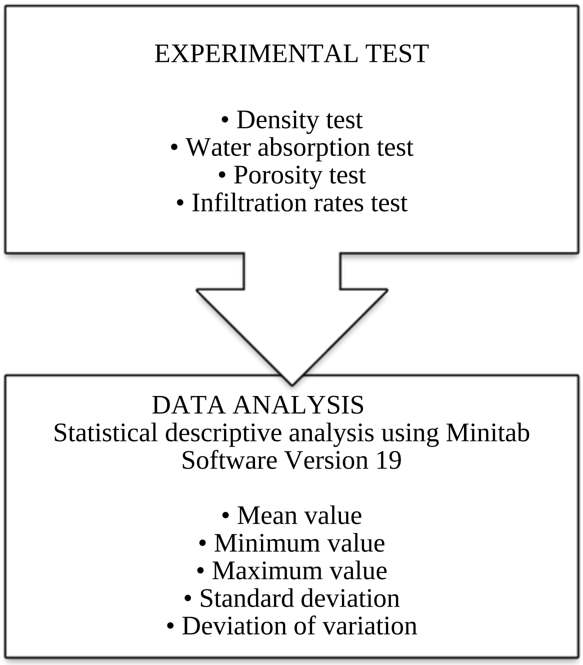


Fig.2 Flowchart of experimental test and data analysis

3.1 Materials

The paver blocks were acquired from a local manufacturer in Nibong Tebal, Penang, Malaysia. They were produced within a controlled environment and production. Table 1 shows the specifications of the paver blocks given by the manufacturer. Table 2 shows various shapes of paver blocks which are divided into three types: Type A, Type B, and Type C. For the construction of block pavements, there are about 40 commonly used shapes of blocks. A hexagon-shaped Type C paver block with a thickness of 80 mm was used in this study is shown in Fig. 3.

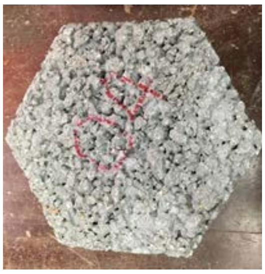
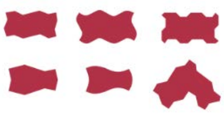
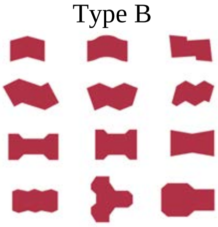


Fig.3 Porous paver concrete block in a hexagon shape

Table 1 Material specifications of readymade porous paver concrete blocks from a manufacturer

VARIABLES	DESCRIPTIONS
Compressive strength	30 MPa
Porosity	15% to 17%
Density	2100 kg/m3
Aggregate size	Fines = < 2mm, Coarse = < 10mm
Thickness	80mm
Color	Grey
Block surface	Rough surface
Binder	Ordinary Portland Cement

Table 2 Shapes of paver blocks [15]

Types of blocks	Descriptions
Type A 	Dentated units that key into each other and by their plan geometry, interlock and resist the relative movement of joints parallel to both longitudinal and transverse axes of the units.
Type B 	Dentated units that key into each other and by their plan geometry, interlock and resist the relative movement of joints parallel to one axis.
Type C 	Units that do not interlock with each other.

3.2 Methods

Several experimental tests were conducted to find out the characteristics of the porous paver concrete block samples. Tests on density, water absorption, and void content were carried out using ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete [16]. The values of maximum, minimum, mean, standard deviation and coefficient of variation were measured and analyzed, then, the results were compared with findings from previous studies. In addition, the consistencies of weight, density, and porosity of the samples were also measured and analyzed to ensure all parameters were measured accurately.

Infiltration rate test was also carried out by using ASTM C1781 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems [17]. This test method included the measurement of the permeable unit pavement systems such as interlocking block, grid paving, or clay pavers by using a single infiltration ring. Fig.4 shows the dimension of a single infiltration ring used in this test.

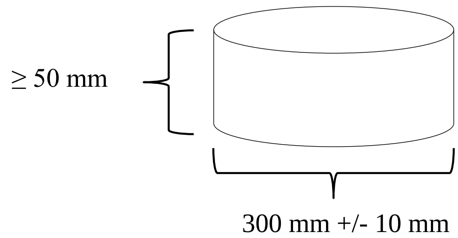


Fig. 4 Dimension of a single infiltration ring

Figure 5 (a) and Figure 5 (b) show the paver jointing designs in AutoCAD software and the locations of the infiltration ring used for the infiltration test. Both lengths of joint are drawn in AutoCAD software version 2017 based on actual paver measurement, and the overall length of jointing was determined.

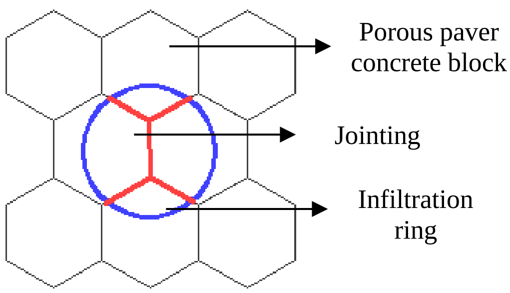


Fig.5 (a) Jointing Design A

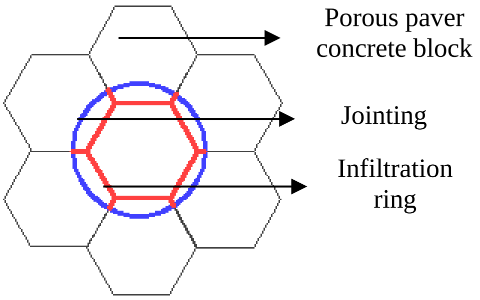


Fig. 5 (b) Jointing Design B

4. RESULTS AND DISCUSSIONS

4.1 Weight, Density, and Porosity

The characteristics of the block samples studied were analyzed using descriptive statistical analysis where the mean (under central tendency measurement) and standard deviation and coefficient of variation (under dispersion measurement) were measured to select the consistent block samples [18].

The weight of a paver block depends on the size, shape, thickness, and materials used in the mixture. A few manufacturers have produced similar shapes of blocks with similar thickness and dimensions weighed 5.8kg, 6.0kg, and 6.1kg. However, from Table 3, the weights of paver block samples range between 5.3kg and 5.6kg, and this may be due to the omission of finer materials in the mixture of porous paver concrete block samples.

The density of a permeable concrete block depends on the properties and proportion of the materials used, and the compaction procedures used in placement [19]. Based on ASTM C1754, the density of permeable pavements ranges between 1.7 Mg m-3 and 1.9 Mg m-3 [20]. Tennis et al. [19] mentioned that the in-place density of permeable pavements between 1.6 Mg m-3 and 2.1 Mg m-3 is common. Shanmuganathan et al. [21] described the density of de-icing concrete pavement, which is somewhat permeable, as between 1.3 Mg m-3 to 1.8 Mg m-3. Table 3 shows the statistical descriptive results of the porous paver concrete block samples. It can be seen that the weight of each porous paver concrete block is between 5.3kg and 5.6kg, and the mean weight of a paver block is 5.5kg. The density of paver block samples is between 2.0 Mg m-3 and 2.1 Mg m-3, with an average of 2.0 Mg m-3. Based on the value of density shown in this study, the density of all paver block samples is acceptable because it is within the range mentioned in the method and manual for permeable pavements.

Typically, in porous concrete pavers, about 15.0% to 25.0% of porosity is achieved in hardened concrete, while the range of void percentage is usually within 15.0% to 30.0% [19]. Studies by other researchers have shown porosity ranges between 12.0% and 25.0% [22], between 15.4% and 14.9% [23], between 15.0% and 35.0% [24], and between 14.0% and 31.0% [25]. The ASTM C1754 states that the void content of the specimens is in range from 22.6% to 37.0% [20]. To summarize, it can be seen that the lowest void percentage is 12% [22], while the highest void percentage is 37% [20].

The result in this study shows the lowest percentage of porosity is 12.5%, while the highest porosity percentage is 18.4%. The average percentage of porosity is 15.9%. It can be seen that the mean porosity of paver block samples in this study achieved the lowest percentage but did not achieve the lowest porosity percentage range in ASTM C175. This may be due to the sizes of aggregates used in the paver block samples, as the manufacturer uses a mixture of less than 2mm of fine aggregates and less than 10mm of coarse aggregates.

Table 3 Statistic descriptive results of porous paver concrete blocks

Variables	N	Mean	Min	Max
Weight (kg)	38	5.481	5.3	5.6
Density (Mg m-3)	38	2.047	2.0	2.1
Porosity (%)	38	15.926	12.5	18.4

Higher porosity in a paver block was the result of the usage of larger aggregates in paver block production. However, the ultimate aim of this work is to consider the overall porosity and infiltration rate of the whole interlocking paver systems.

4.2 Consistency of Weight, Density, and Porosity of Porous Concrete Pavers

The consistency of porous concrete pavers was measured to ensure that the properties (weight, density, and porosity) of the samples did not vary much between each other. The values of standard deviation and coefficient of variation were used to study the consistency of the paver samples. Standard deviations were used to measure the dispersion or spread of the block samples from the mean value [18]. While the coefficient of variations expresses the standard deviation in the form of percentage [26]. Table 4 shows the mean, standard deviation, and coefficient of variation of the hardened porous paver block samples.

As can be seen in Table 4, the standard deviation and coefficient of variation of weight show the lowest values followed by density, and porosity shows the highest values of standard deviation and coefficient of variation. This could be due to the weights of the samples that diverge closer to the average value of the data samples. A low standard deviation means the data value is closer to the average data value, while a high standard deviation means the data values are spread farther away from the average.

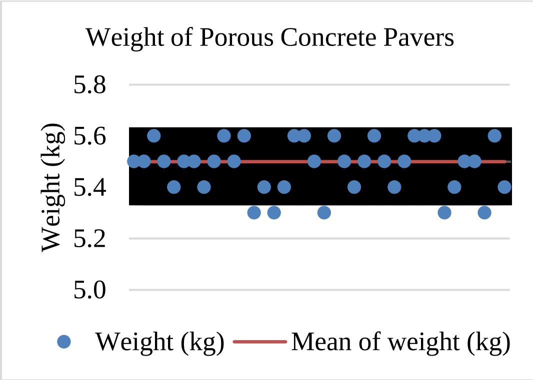
Table 4 Mean, standard deviation, and coefficient of variation of porous concrete pavers

Variables	Mean	Standard Deviation	Coefficient of Variation
Weight (kg)	5.481	0.101	1.84
Density (Mg m-3)	2.047	0.051	2.47
Porosity (%)	15.926	1.222	7.67

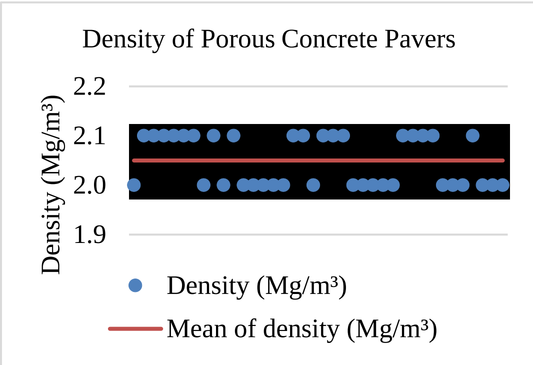
Fig.6 (a), (b) and (c) shows the graphs of dispersion of the standard deviations and mean values of three characteristics of block samples studied. This can be seen in Fig.6 (a), the standard deviation of each block sample is mostly closer to the value of the mean of 5.481 kg. A total of 5 blocks of samples were seen dispersed far from the standard deviation error bar. These 5 block samples were considered to be rejected for future study. While from Fig.6 (b), the standard deviation values of each block sample are within the standard deviation error bar range. All the density of block samples is nearer to the mean value of the density of 2.047 Mg m-3. Hence, there are no samples were rejected for the density test.

For the porosity test in Fig.6 (c), it can be seen there are 6 block samples are dispersed from the mean of 15.926% and standard deviation error. However, the block samples can be considered to be rejected or accepted because the dispersion was quite close except for the 1 block sample shown in Fig.6 (c).

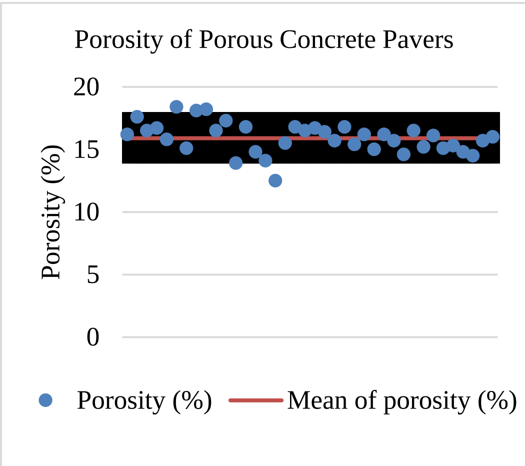
Overall, the sample can either be discarded or retained in the experiment because there will only be a slight difference in the standard deviation. As a whole, it can be seen that all samples in this assessment are consistent in terms of weight, density, and porosity.



(a)



(b)



(c)

Fig.6 Mean and standard deviation graphs of porous paver samples; (a) Weight of porous concrete pavers, (b) Density of porous concrete pavers, (c) Porosity of porous concrete pavers

4.3 Effects of Jointing Variation on Infiltration Rates

The infiltration rate of a specific pavement surface at a given moment in time depends on the quality of materials and construction, and the history of compaction and sedimentation. The infiltration rate assigned to the design of a surface should be a typical value applied for the life of the pavement [27].

Table 5 shows the results of infiltration rate and length of jointing. Also shown in Table 5, the infiltration rate for Design B is higher compared to the infiltration rate for Design A. It can be seen that the infiltration rate is higher when there is a longer jointing design. Longer joints infiltrate more water compared to shorter joints. This situation is advantageous as porous pavements are designed to infiltrate rainfall that falls directly onto the surface [28]. A pavement's surface infiltration rate is measured with water ponded on the pavement [27]. The standards of infiltration tests for two types of permeable pavement systems: ASTM C1701 and C1781, were developed for porous concrete and interlocking concrete pavers, respectively [29]. It is also noted that, the surface infiltration rates of some porous pavements change over time, due to processes such as compaction, sedimentation, migration of pavement binder, and aggregation of soil particles by growing vegetation [27].

Lee et al. [30] in their study mentioned that the range of infiltration rates for permeable concrete pavements is between 57 000 mm/h (1.6 cm/s) to 100 800 mm/h (2.8 cm/s). Other studies on infiltration rates of block pavers are 91 400 mm/h (2.54 cm/s) [31], 5 508 mm/h (0.153 cm/s) to 13 104 mm/h (0.364 cm/s) [32] and 9 000 mm/h and 36 000 mm/h [33]. It can be seen the range of infiltration rates of permeable paver blocks from previous studies is between 5 508 mm/h to 100 800 mm/h.

However, based on ASTM C1781 [17], the average infiltration rate ranges from 762.0mm/h to 4 064 762.0 mm/h (0.21 cm/s to 1.13 cm/s), and the average result difference between two location averages is 19.1 percent with a median value of 12.2. The overall average infiltration rate from the two variations of jointing is 33 559.75 mm/h (0.93 cm/s). This is well within the higher performance range of standard practice of porous paver system applications.

Table 5 Infiltration rates and jointing lengths.

Designs	Infiltration rates (mm/h)	Jointing lengths (cm)
A-1	30 454.6	±5.44
A-2	29 845.0	±5.44
B-1	37 998.4	±8.67
B-2	35 941.0	±8.73

5. CONCLUSIONS

In this study, the outcomes of the consistency test for density and porosity are used to select porous concrete paver blocks for infiltration tests. The density of the readymade porous concrete pavers selected is within the range of the standard density of concrete paver blocks. The recommended range of porosity is between 12% and 37%, and this could be concluded that the porosity of the samples in this study is also acceptable where the porosity of block samples is between 12.5% and 18.4%. The subsequent infiltration tests reveal that the infiltration rate of a paver system formed using these blocks indicated an overall infiltration capacity of 33559.75 mm/hour. ASTM 1781 specifies the standard range of infiltration rates should be between 762.0 mm per hour and 4064762.0 mm per hour. Area with longer total joining length helps promote more infiltrations.

This study is limited to laboratory investigations. However, it is expected that a full scale field study would have produced the same outcome because the dimensions of paver blocks arrangement would still be the same.

6. ACKNOWLEDGEMENT

This study is supported by the Ministry of Higher Education Malaysia's Fundamental Research Grant Scheme with Project Code: FRGS/1/2017/TK08/USM/02/2.

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