IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: M.F. Chow *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012010

Study of effective laying pattern of permeable interlocking concrete paver for storm-water management

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Abstract. This study determined the skid resistance and runoff infiltration rate of different laying patterns of PICP, namely stretcher bond and herringbone patterns. The dimensions of PICP block are 10.3 cm (height) × 12.5 cm (width) × 25 cm (length) and arranged for a total coverage area of 1.8 m2. Pendulum skid resistance tester and ring method were used to determine the skid resistant and runoff infiltration rate, respectively. The herringbone pattern showed higher skid resistant value in either dry or wet condition compared to stretcher bone pattern. Herringbone pattern exhibited infiltration rate of 21450.7 mm/hr while stretcher bond pattern only has an infiltration rate of 18516 mm/hr. It is observed that herringbone pattern performed better than the stretcher pattern in term of storm-water management.

1. Introduction

Urban development is increasing around the world due to the growing human population. When the population of a city is increasing, more residential area and infrastructure is needed to cater the population, hence empty spaces are used for the construction of new buildings. Expansion of the existing structures to accommodate the growing amount of consumers can further causing the pervious surface to be reduced [1-4] for example the expanding of a single lane road into a double lane road.Over the decades, Malaysia have been struck by numerous floods with an increasing trend lately. [5, 6] proved that floods in Malaysia were mainly caused by inappropriate and insufficient drainage system and the researchers suggested that some of the precautions for flood mitigation was the use of flood preventive structures. Hence, permeable pavement plays an important role in stormwater management by infiltrating the surface runoff, especially in the urban area where lots of area are covered in impermeable surface. In addition, it act as a natural water filter by removing the suspended solids and pollutants [7, 8].

The common permeable pavements found around the world are porous asphalt (PA), permeable concrete (PC), permeable interlocking concrete pavers (PICP), plastic reinforcing grid pavers and concrete grid pavers (CGP) [9]. These permeable pavements are widely used in car park, access roads and driveway. Numerous of study have been done to compare the infiltration rate of PA, PC and PICP [9-11]. One of the studies showed that PICP reduced the most rainwater runoff with 46 % of reduction, followed by PC with 35.6 % and PA with 12.7 % of runoff reduction [10]. However, some studies revealed the initial infiltration rate of PC was the highest among others [12]. Another study showed that PC was able to allow the rainwater to infiltrate the most, while PA was the second highest and last was PICP, yet the sequence shifted after two years of monitoring, PA provide the highest rate of infiltration and PICP provide the lowest rate [11]. By comparing the studies, it turned out that PC is not the best in terms of infiltration rate, the ranking is depending on many criteria for example slope, ratio of catchment area to the permeable area and maintenance [10]. Despite the different rate of infiltration, all of them performed much better than the impervious asphalt, and all three types of pavements were performed similarly during heavy rainfall (>50 mm) [12].

Most of the research studies proved that permeable pavements were perform excellent in surface water reduction, but very few studies investigated the skid resistance performance of permeable pavement. If the permeable pavement is used to construct a parking lot or driveway, the local authorities need sufficient information during the planning stage to allow them decide whether the use of porous pavement is foreseeable. But studies related to the effects of different laying patterns on PICP are limited, hence this study will determine the skid resistance and surface water infiltration rate of different laying pattern of PICP.

2. Methodology

2.1. Layout Patterns of PICP

Different types of layout pattern were reviewed based on previous studies in order to identify the best layout pattern in the study [13,14]. It was identified that the two common laying pattern of PICP are stretcher bond and herringbone patterns. The dimensions of PICP block are 10.3 cm (height) × 12.5 cm (width) × 25 cm (length). The PICP blocks were arranged in stretcher bond and herringbone patterns and filled with the fine aggregates.

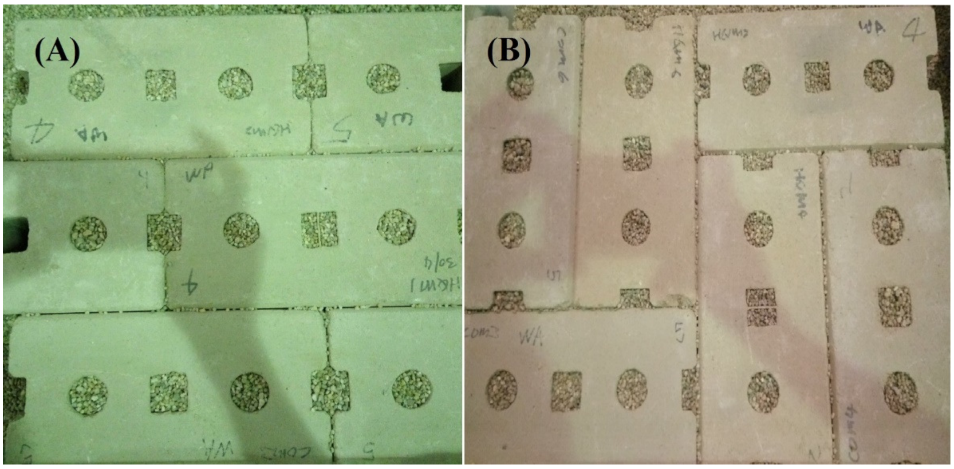

Figure 1. (A) Stretcher and (B) Herringbone bond patterns

2.2. Skid Resistance Test

Skid resistance test was conducted on the herringbone and the stretcher bond patterns as discussed in section 2.1. Both patterns were tested using the portable pendulum skid resistance tester in dry and wet conditions. The test was repeated three times to obtain the average skid resistance value of each pattern in both dry and wet conditions. Eq. 1 was used to calculate the average skid resistance value for each pattern. The average value of both herringbone and stretcher bond pattern for both dry and wet conditions were compared.

IOP Conf. Series: Materials Science and Engineering **551** (2019) 012010 doi:10.1088/1757-899X/551/1/012010

$$Average\ skid\ resistance = \frac{Total\ skid\ resistance\ value}{Number\ of\ samples} \quad (1)$$

2.3. Surface Infiltration Test

The ring method was used to study the runoff infiltration rate of the PICP. Small scale PICP pavement was constructed and tested for both herringbone and the stretcher bond patterns. The pavements were constructed together with sub base layers to simulate a small scale porous pavement. A rectangular aquarium was used to contain the sub base layer, base layer and concrete blocks during the experiment. The sub base layer was constructed using aggregates with sizes ranging from 25 mm to 4.75 mm. The aggregates were referred as #57 by the American Association of State Highway and Transportation Officials (AASHTO). Next, the base layer which was lay on top of the sub base was constructed using aggregates with sizes ranging from 9.5 mm to 2.36 mm (AASHTO categorized aggregates with this sizes as #8). Besides, the #8 aggregates were used to fill up the hole on the concrete blocks.

$$Infiltration\ rate = \frac{KM}{D^2T} \quad (2)$$

where

K = 4583666000 (constant, used to convert into mm/hr);
M = mass of water (kg);
D = inner diameter of ring (mm);
t = infiltration time (s)

$$Average\ Infiltration\ rate = \frac{Total\ infiltration\ rate}{No.of\ samples} \quad (3)$$

Eq. 2 was used to calculate the infiltration rate of each sample. An average infiltration rate was calculated using Eq 3 to represent the performance of the particular pattern and compared with each other afterward.

3. Results and Discussions

3.1. Skid Resistance

The skid resistant results for different laying pattern of PICP in both dry and wet conditions are presented in table 1. The average skid resistance values in dry and wet conditions were apparently similar. From the results showed in Table 1, the herringbone pattern showed higher average value in either dry or wet condition compared to stretcher bone pattern. Although the difference was not significant, but it showed that herringbone pattern was a better choice in term safety.

Table 1. Average skid resistance for Stretcher and Herringbone patterns in dry and wet conditions.

Pattern	Condition	
	Dry	Wet
Stretcher bond	15.7	15
Herringbone	20.2	22.2

3.2. Runoff Infiltration Rate

The results collected from the runoff infiltration test are summarized in Table 2. It is observed that the herringbone pattern performed better than stretcher-bond pattern in term of infiltration rate. Herringbone pattern exhibited infiltration rate of 21450.7 mm/hr while stretcher bond pattern only has an infiltration rate of 18516 mm/hr. This indicated that herringbone pattern was capable to infiltrate more runoff during rainfall event.

Table 2. Infiltration rate between stretcher bond and herringbone patterns.

Sample	**Infiltration rate (mm/hr)**
Stretcher bond	18516
Herringbone	21450.7

Previous study in Sweden showed that interlocking concrete paver (ICP) yield a infiltration rate of 18780 mm/hr [15]. The results reported by [15] was lower than the herringbone pattern's infiltration rate in this study. However, this might due to the different sizes of aggregates used and different thickness of bedding layer. The base course layer in the study by [15] is 50 mm thick, whereas the base course of herringbone is 30 mm thick. The sizes of aggregates used to construct the ICP are 4 mm to 8 mm for base course and 0 mm to 120 mm for sub base course, respectively. Meanwhile, the herringbone sample used 2.36 mm to 9.5 mm for base course and 4.75mm to 25 mm for sub base course.

Furthermore, a study by [16] indicated PICP provided a higher infiltration rate compared to CGP though the CGP have a higher percentage of open area. The PICP have a mean infiltration rate of 2000 cm/hr while the maintained CGP have a mean infiltration rate of 11.8 cm/hr. By comparing both findings by [16] and this study, PICP showed an infiltration rate of above 20000 mm/hr. This proved that PICP is capable of reducing peak runoff during rainfall. Belgard [17] in North America has tested the infiltration rate for PICP. According to their results, the highest infiltration rate was 2544 in/hr or 64617.6 mm/hr while the lowest infiltration rate was 785 in/hr or 19939 mm/hr. The lowest infiltration rate of 19939 mm/hr is comparable with the herringbone's infiltration rate results in this study.

4. Conclusions

The results from both experiments indicated that herringbone pattern performed better than the stretcher pattern. It provides a slightly higher skid resistance value together with a greater infiltration rate, the latter is important as heavy rainfall happened often in Malaysia, so adequate infiltration rate is one of the main consideration if the permeable pavements are to be constructed. On the other hand, the slightly higher skid resistance value of herringbone pattern might not be a significant finding if it is used for roadways construction, but it is useful for parking lots where the vehicles are travelling in low speed.

5. Acknowledgements

The authors would like to thank the YCU grant (Project No. 201801001YCU/16) provided by Yayasan Canselor UNITEN (YCU) and internal research grant (UNIIG 2017) (Project No. J510050716) provided by Universiti Tenaga Nasional.

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