Evaluation of Porous Pavement Structure with Different Porosities and Sub layer Conditions

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Abstract:
Flash floods occur mostly due to obvious reasons such as clogged drains, huge surface run-off, the drainage capacity of the existing drainage system could easily be exceeded and lead to excess surface water could not be drained out that quickly. This project is proposed to design and assess the effectiveness of a porous pavement structure for the purpose of maximizing water infiltration. A total of eight square concrete slabs with different hole pattern with the dimension of 0.3m x 0.3m and the height of 0.5m were designated. The results indicated that holes in concrete influence the permeability of water pass through the designed concretes and thus affect the flow rate of the water. In addition, aggregate height plays a role in influencing the flow rate of water. The higher pavement height provides lower flow rates. Moreover, the bigger the size of aggregate contributed to the higher the flow rates.

Keywords: porous pavement, permeability test, concrete slab

1. INTRODUCTION

Flood, such as a deluge, is the major significant unavoidable natural disaster in Malaysia in terms of population affected, frequency, areal extent, flood duration and social economic damage. Flash flood is one of the most common and destructive weather-related phenomena that Malaysia experienced (Ngai Weng, 1995).

The increasing of flood occurrences, especially in urban area is largely due to the urbanization process could result in the conversion of pervious spaces in areas of impervious (paved) surface. In this case, the amount of infiltration of the rainfall is decreasing and can cause the water to accumulate and flash flooding occurs (Ngai Weng and Dennis, 1996).

Flooding is an inevitable and unsolvable problem for a country like Malaysia which has a high rainfall, hence reducing the flood problem is a must and only the best way to the current stage. If those impermeable surfaces could be made more permeable for surface water to infiltrate, some of the surface water could be allowed to filter down into the permeable
paving layer, and this decreases the accumulation of surface water that will not lead to flash floods.

In addition, flash floods occur mostly due to obvious reasons such as clogged drains, and huge surface run-off, the drainage capacity of the existing drainage system could easily be exceeded and lead to excess surface water could not be drained out that quickly. If those impermeable surfaces could be made more permeable for surface water to infiltrate, then caused some of the surface water could be allowed to filter down into the permeable paving layer, thus reducing the accumulation of surface water that will not lead to flash floods.

In the study of R. Gupta (2014), porous pavement is found to be an effective measure to mitigate the impact of urbanization on the environment. It has been acknowledged by many researchers that one such popular and common material that can be used to construct porous pavements and porous urban surfaces is “pervious concrete” also known as “no-fine” concrete.

According to Rehder et.al (2014), pervious concrete, also called Porous concrete or Enhanced Porosity Concrete (EPC) is a macro-porous concrete that is gaining rapid popularity in many parts of the world because of its applications unsustainable construction due to its ability to allow for water infiltration while maintaining structural performance. Water and air percolate through an interconnected network of voids in the pervious concrete structure into the subsoil beneath, resulting from the constrained use of fine aggregates, uniform gradation of coarse aggregates, and low water-to-cementitious-material ratio (w/c).

In addition, there are a lot of types of permeable pavement systems in practice as shown in the figure below.

![Figure 1. Types of permeable pavement system. (Imran, H.M.et al.,2013)](image)

Imran H.M.et al., 2013 presented in his study that concrete block as the precast grid or block-shaped concrete with open voids was used for permeable pavement to allow infiltration. Installation can be by hand or by a mechanical process. Generally, the voids of the block are filled with crushed gravel or stone, or topsoil and turf. The results indicated that the runoff volume was significantly lower compared to the asphalt driveways. Besides, plastic grids used for the systems have gained popularity in the recent years. These grids provide more void space for filling materials than concrete blocks. Concrete block pavers are mostly
impervious, whereas the plastic grids are mostly pervious. Other than that, Rushton, B. et al., 2001 stated that pervious concrete is made by omitting the fine aggregate from the concrete mixture. Parking lots installed with pervious concrete have been used successfully in many places. Although there have been some problems with the installation of the material, the pavement was successful in allowing infiltration of surface water runoff. Evaluation and comparisons were made on water storage capabilities of different types of pervious pavement in 45 places in Spain.

Generally, porous pavements consist of a porous surface for the top layer, and drainage materials are placed beneath to filter the surface runoff. Porous pavement applications are limited in some cases to fine-grained soils, due to its performance. The performance of porous pavement on clay soils was investigated by Dreelin et al., 2006 who compared the performance between an asphalt parking lot and a porous pavement parking lot of grass pavers. The results showed that the runoff of porous pavement was 93% less than the common asphalt lot. Turbidity was also significantly less and conductivity was significantly higher for the porous pavement lot compared with the asphalt pavement lot. Moreover, metal and nutrient concentrations were significantly reduced by both types of pavement.

Therefore, this project is proposed to design and assess the effectiveness of a porous pavement structure (Ordinary Portland Cement concrete slabs with holes) for the purpose of maximizing water infiltration, but also at the same time does not easily fail to function and achieve the desired design as a pavement layer.

1.1 Objectives of Study

In brief, the objectives of this project can be summarized as follows:

I. To design and assess the effectiveness of a porous pavement structure for maximizing the infiltration of surface water through the permeable layer

II. To study the performances of designed concrete slabs with various parameters

2. EXPERIMENTAL PROCEDURE

Laboratory works carried out after the selection for the design of numbers and patterns of holes in the concrete (Figure 2). First, the gradation test of aggregates was carried out to obtain certain sizes of aggregates needed for casting and used as underneath substructure in the test. A total of eight square concrete slabs with the dimension of 0.3m x 0.3m and the height of 0.5m were fabricated. Filling the different sizes of aggregates into the apparatus until the desired heights and each of the numbers and pattern of holes which having the diameter of 0.055m in the design concrete slabs was put on the aggregates. After tightening the opening, the water was poured into the apparatus at the distance of 0.25m from the surface of the concrete. At the moment when the opening is released in the water to flow out, the stopwatch was pressed simultaneously to record the entire time taken for the water to infiltrate through the concrete design. Each of the tests was carried out twice to get the average result and in order to improve the accuracy. Flexural strength tests were carried out on every designed concrete after the completion of the permeability tests. Finally, the collected data and result, such as time taken from the laboratory works were studied and analyzed. These results were used to relate with some parameters and established in the graph form using the Microsoft Office Excel. The significant relationships among the parameters were indicated by adopting the SPSS software.
3. RESULT AND ANALYSIS

The recorded times taken were related to the flow rate for every number of designs concrete for further analysis. Several relationships among the parameters were established using the graph form by fixing a constant variable such as:

i. Flow rate vs percentage of holes in concrete for each type and height of aggregates
ii. Flow rate vs the height of aggregates as the subsoil for every designed concrete and type of aggregates
iii. Flow rate vs the types of aggregates in term of sizes for each of the percentages of holes in concrete and height of aggregates

The above relationships will be further analyzed by using Microsoft Office Excel and the SPSS software. From the findings, this paper can conclude that whether there are any significant influences among all the parameters to one another. Below are the examples of graphs showing the relationship between the flow rate and the percentage of holes in concrete by fixing the variable of sizes of aggregates which are 9.5mm, 4.75mm and 2.36mm were shown below from the obtained results.

3.1 Effect of Slab Hole Percentage on the Flow

The comparisons of the permeability for water between different percentages of holes in concrete as shown in Figure 3 with three different heights of aggregates (pavement height) as substructure while fixing the size of aggregate constant were conducted as above. From all the graphs, the flow rate increases with the percentage of holes in concrete increases. However, most of the graphs show that the flow rate increases with the decreasing gradient
when the percentage of holes in concrete increases. Besides, the flow rate is hardly to be the constant or same for every percentage of holes in concrete as it is much related to the time take for the water to flow through the designed concrete that are always various even though the same test repeated. Human errors would probably occur to affect the accuracy of the result.

Furthermore, as shown in Figure 5, the percentages of holes in concrete influence the permeability of water to pass through the designed concrete and thus affect the flow rate of the water. Theoretically, the higher the percentage of holes in the concrete, the flow rate of the water will be higher. Based on the result from the graphs, the flow rate is increased proportionally to the percentage of holes in concrete for every size and height of aggregate. From this result, it stated that the permeability of the concrete increased with the number of holes in the concrete, however the significant relationship between these parameters has to be investigated through the SPSS software during the analysis work.

![Figure 3. Designated slabs with holes](image)

**3.2 Effect of Aggregate Height on the Flow**

Based on the results obtained from the test, the aggregate height plays a role in influencing the flow rates of water. In the test as shown in Figure 4, the heights of 50cm, 40cm and 30 cm were used in testing the relationship between the pavement height and the flow rate. The
photos below show the different heights of various sizes of aggregate used. The results from figures 5 indicated that, the higher the pavement height could result in lower the flow rate. However, the results do not show a significant effect.

3.3 Effect of Aggregate Size on the Flow

The flow rate can be affected by the size of aggregate used as the pavement. Different sizes of aggregates were adopted in the test to evaluate the effect of aggregate sizes on the flow rate. 9.5mm, 4.75mm and 2.36mm of aggregates as the substructure with different heights were tested to obtain the rate of the flow. From the experiment, the bigger the size of aggregate caused the higher flow rate and thus using 9.5mm aggregates to achieve the highest flow rate among other sizes of aggregates.

Figure 4. Permeability test for different pavement heights

50CM of pavement height  40CM of pavement height  30CM of pavement height
Figure 5. graphs of flow rate vs percentage of holes in concrete
### 3.4 Flexural Strength Test

The aim of the flexural strength test is to determine whether the pattern and arrangement of holes in the concrete slab affect the flexural strength of the concrete. The results from the flexural strength test of the designated concrete slabs are not consistent as shown in Table 1.

Table 1. Flexural Test results

<table>
<thead>
<tr>
<th>TYPES OF CONCRETE SLAB</th>
<th>FLEXURAL STRENGTH (KN/mm²)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>225.87</td>
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<tr>
<td></td>
<td>218.86</td>
</tr>
<tr>
<td></td>
<td>212.10</td>
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<td></td>
<td>223.95</td>
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However, it can be seen that the flexural strength of the concretes contains the same number of holes are different as the arrangement of holes are different. As the flexural strength test is using the concept of four-point bending flexural test, the two loading pins were applied on the side of the concrete slab and this easily lead to the flexural cracks initiated first at the center of the slab and finally cause the slab to fail in flexural. From the results obtained, we can see that the existence of a hole at the center of concretes possesses lower flexural strength compared to the concretes which contain no hole at the center. For an instance, by comparing the flexural strength of the concretes which contain three holes in different arrangement, for the hole placed at the center in the concrete possess much lower flexural strength compared to the other one. However, the number of holes contained in the concrete does not have many effects on the flexural strength as based on the results obtained, as can be seen in the concretes containing two holes have higher flexural strength than the concrete which only contains one hole.
4. CONCLUSION

The results indicated that, the flow rate is increased proportionally to the percentage of holes in concrete for every size and height of aggregate. In addition, aggregate height plays a role in influencing the flow rate of water. The higher pavement height provides lower flow rates. Moreover, the bigger the size of aggregate contributed to the higher the flow rates.

5. ACKNOWLEDGEMENT

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6. REFERENCES