The development of a permeable pavement from concrete bricks

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Abstract. Global climate change is causing an increase in the intensity of rainfall in Indonesia. This causes an increased risk of flooding because it is not supported by changes in infrastructure planning and water resource management. Infrastructure construction, especially roads, sidewalks, and parking lots, still uses waterproof construction such as asphalt and concrete. This waterproof construction causes rainwater to not infiltrate to soil layers and consequently rainwater runoff increases. The increasing intensity of rainfall that is not compensated by an increase in infiltration areas causes an increase in the risk of flooding. Therefore, the design of a mixture of concrete bricks that has a high level of permeability needs to be developed to reduce the risk of flooding. This research was conducted by making test samples of four mixture design. The design approach is carried out by varying the proportions between coarse and fine aggregates, and the water-cement ratio. The infiltration testing method was also conducted to accommodate research needs. Based on the analysis, for paving block with an aggregate-cement ratio of 4 by volume, the optimum water-cement ratio was 0.40 with a permeability level of 630 mm/hour and compressive strength of 21.29 MPa.

1. Introduction
Global climate change causes Indonesia to experience changes in rain characteristics. In general, the duration of the rainy season is getting shorter, on the contrary, the duration of the dry season is getting longer. The number of rainy days tends to decrease, while the rainfall intensity tends to increase [1]. This change in rain characteristic is not supported by changes in infrastructure planning and water resources management.

The southern part of Semarang City is an area that is growing rapidly due to the existence of Diponegoro University and several private universities. This development led to changes in land use, where many residential were established. Nowadays, residential roads, public parking lots, even residential playgrounds use asphalt and concrete as construction materials. Both of these materials are impermeable materials. The use of impermeable materials to cover the surface of the land causes an increase in the surface runoff because water cannot infiltrate into the soil layer [2]. The uses of asphalt and concrete in many infrastructure planning have contributed greatly to the increases in flood vulnerability [3].

One of the floods caused by changes in land use is the flood that occurred in the Diponegoro University area in March 2019. Water inundated the streets and also parking lots. The worst flooding occurred on the parking lot of the Faculty of Economics and Business campus. Most of the roads and parking lots in the Diponegoro University area use paving blocks as the pavement.
Paving blocks are one of the permeable pavements, but in reality, the existing paving blocks cannot infiltrate water. This condition could occur because the paving blocks used have a low level of permeability. Permeable pavement is a pavement layer structure that allows water to flow easily through the pores of the structure so that it could reduce surface runoff [4], [5]. The main purpose of using permeable pavement is to infiltrate stormwater, recharge groundwater, and preserve stream base flow [6], [7].

Based on the problems mentioned above, it is necessary to develop paving blocks, especially for parking lots, that could infiltrate water easily through the pavement structure. In this study, the development of permeable pavement from concrete bricks was carried out in the form of permeable concrete paving blocks (PCPB). The difference between PCPB and conventional paving blocks is the use of coarse aggregates [8]. Conventional paving blocks usually use only fine aggregate in the mixture design. Coarse aggregates added to PCPB could increase the number of voids so that water could infiltrate easily through the paving block structure [9]. Some researchers have design PCPB without adding any fine aggregate in the mixture [10], [11]. This causes a significant decrease in the strength of the paving block.

In this study, variations were made by adding coarse aggregates with several kinds of composition ratios. The analysis is focused on varying the ratio of coarse aggregates and fine aggregates as well as the water-cement ratio. The infiltration testing method was also conducted to accommodate research needs. The results of this study are expected to provide a mixture design that has an infiltration rate that could infiltrate the stormwater in the area of Diponegoro University

2. Research Method
The research on the development of permeable pavement from concrete brick was carried out in the Hydraulic Laboratory of the Department of Civil Engineering, Diponegoro University, Semarang Indonesia. This research was conducted by making paving block test samples that have size 20 cm in length, 20 cm in width, and 9 cm in thickness. The test sample is made in a variety of mixture designs for further to be tested for the infiltration rate to determine the concrete brick design that has the highest level of permeability. Generally, this research method could be divided into three steps, namely preparing materials and equipment, determining the design of mixtures and making the test samples, and testing the rate of infiltration.

2.1. Materials and equipment
Materials used in the development of permeable concrete paving blocks are cement, coarse aggregates, fine aggregates, and water. The cement used in this study was Semen Gresik. The fine aggregate used was Muntilan Sand while the coarse aggregate used was crushed stone. First, an analysis of the specific gravity of the material was carried out for later use in determining the mixture design. The specifications of the material used can be seen in Table 1.

| Materials   | Type of materials | Diameters (mm) | Specific Gravity (kg/dm³) |
|-------------|-------------------|----------------|---------------------------|
| Cement      | Semen Gresik      |                | 1.260                     |
| Fine aggregate | Muntilan sand     | <4.75          | 1.417                     |
| Coarse aggregate | Crushed stone    | 9.5 - 12.5     | 1.373                     |

The main equipment used in this study was a paving block making machine and infiltration test equipment. A paving block making machine was used to make the test samples. The machine used could be seen in Figure 1. The machine could be used to make a maximum of two test samples, with a length of 20 cm, a width of 20 cm, and a thickness of 9 cm. The machine uses a hydraulic vibrator to help flatten the mixture of the paving block. The choice of using a hydraulic machine is to ensure that all test samples undergo the same treatment compared to making the paving block manually.
Infiltration test equipment was used to measure the infiltration rate of the test sample. This infiltration test equipment was made using acrylic with a length of 20.5 cm, a width of 20.5 cm, and a height of 30 cm as shown in Figure 2.

![Image of infiltration test equipment](image)

**Figure 1.** The paving block making machines  
**Figure 2.** The infiltration test equipment

### 2.2. Mixture design and test samples

The porous concrete paving block design approach was carried out by varying the proportions between coarse aggregates and fine aggregates, and the water-cement ratio (w/c). Based on the results of the analysis that has been carried out, it was determined to make four types of mixture designs. The aggregate-cement ratio for all mixture designs is 4 by volume with w/c ranging between 0.35-0.40. The details of the composition of material for each mixture design could be seen in Table 2.

The permeable concrete paving block is different from conventional paving blocks because it uses coarse aggregate in its structure. This causes the shape of the top layer of paving blocks to look less good and uneven. Therefore, in this study, the top layer of the paving block was coated with a layer of a mixture of fine aggregate and cement in a ratio of 4 by volume and with w/c of 0.35.

| Mixture design no | Mixture design ratio | Thickness (cm) | w/c | Cement percentage | Coarse aggregate percentage |
|-------------------|----------------------|----------------|-----|-------------------|-----------------------------|
| 1                 | Bottom layer 1 : 3 : 1 8 0.35 | 17.20% | 18.74% |
|                   | Upper layer 1 : 4 | 1 0.35 |
| 2                 | Bottom layer 1 : 2.5 : 1.5 8 0.35 | 17.26% | 28.20% |
|                   | Upper layer 1 : 4 | 1 0.35 |
| 3                 | Bottom layer 1 : 2 : 2 8 0.38 | 17.22% | 37.52% |
|                   | Upper layer 1 : 4 | 1 0.35 |
| 4                 | Bottom layer 1 : 1.5 : 2.5 8 0.40 | 17.21% | 46.88% |
|                   | Upper layer 1 : 4 | 1 0.35 |

Each mixture design was then made as many as six test samples. The samples were made using the paving block making machine. The paving blocks were made by inserting the bottom layer mixture
into the mold as high as 8 cm. Then, the machine was vibrated for 10 seconds to flatten the mixture. After that, the upper layer mixture was inserted into the mold as high as 1 cm. Then the paving block was pound to condensed the mixture. All mixture designs are made with the same treatment. Each test sample was then given a date of manufacture and was stored for 28 days before the infiltration test was carried out. The paving blocks for each mixture design could be seen in Figure 3 until Figure 6.

2.3. Infiltration test and compressive strength test
The infiltration test was conducted to determine the ability of the paving block to infiltrate water by calculating the infiltration rate of each mixture design. This infiltration test was carried out by installing a paving block on the infiltration test equipment then the edges are sealed using rubber as shown in Figure 7.
Figure 7. Paving block settings in the infiltration test equipment

This was done to ensure that water only flows through the paving blocks pores. The water was filled up to as high as 14 cm and then the time of decreases in water depth was recorded every 1 cm. Each mixture design was tested as many as three samples. Each sample was tested three times. The results of the infiltration test are then analyzed to obtain the value of the infiltration rate.

The compressive strength test was conducted in the Material and Construction Laboratory of the Department of Civil Engineering, Diponegoro University. Each mixture design was tested as many as four samples.

3. Results and Discussion

The development of permeable pavement from concrete bricks aims to be able to infiltrate stormwater into the subsoil to reduce surface runoff in parking lots at Diponegoro University. Based on the analysis of the infiltration test results, the graph of the relationship between water depth and infiltration rate could be seen in Figure 8. It is found that the higher the water that inundates above the paving block, the infiltration rate will also be even greater. The results of the infiltration test analysis also showed that the four mixture designs of PCPB development had a higher infiltration rate than conventional paving blocks. Mixture design no.1 which has a ratio of 1 part of cement : 3 parts of fine aggregates : 1 part of coarse aggregate and mixture design no. 2 which has a ratio of 1 part of cement: 2.5 parts of fine aggregate: 1.5 parts of coarse aggregate has similar infiltration rate with an average infiltration rate of 27 cm/hour. Mixture design no.3 which has a ratio of 1 part of cement : 2 parts of fine aggregates : 2 parts of coarse aggregate and mixture design no. 4 which has a ratio of 1 part of cement: 1.5 parts of fine aggregate: 2.5 parts of coarse aggregate has similar infiltration rate with an average infiltration rate of 62 cm/hour. Whereas the conventional paving blocks have an average infiltration rate of 11 cm/hour.
This research focuses on substituting fine aggregate with coarse aggregate with a certain ratio. Based on analysis results, it was obtained a graph of the relationship between the percentage of coarse aggregate and infiltration rate as shown in Figure 9. It could be concluded that the greater the percentage of coarse aggregate in the mixture, the greater the level of PCPB permeability. The relationship between the percentage of coarse aggregate to PCPB permeability could be expressed using equation 1 below.

\[ y = 120.01x^2 + 67.517x + 8.6935 \]  

Based on the PCPB compressive strength test results, it is necessary to analyze the optimum mixture design based on compressive strength and permeability. In the graph of the relationship between the w/c ratio with infiltration rate and PCPB compressive strength as shown in Figure 10, it could be seen the w/c ratio which has the optimum infiltration rate and compressive strength is 0.40.
The optimum PCPB has a permeability level of 63 cm/hour or equivalent to rain which has an intensity of 630 mm/hour. It is still greater than the one-hour duration of five years rain that occurred in the Diponegoro University area which is 52.43 mm/hour. The PCPB has an optimum compressive strength of 21.29 Mpa. Based on SNI 03-0691-1996, the PCPB is included in the category B quality, which is suitable for parking lots.

4. Conclusion
Based on the result analysis, it could be concluded that the higher the water that inundates above the paving block, the infiltration rate will also be even greater. The addition of coarse aggregate to the PCPB mixture design also increases the permeability level. It could be also concluded that the optimum PCPB has a permeability level of 630 mm/hour and compressive strength of 21.29 MPa. The optimum PCPB is included in the category B quality, which is suitable for parking lots.

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