Inclined porous concrete surface impact on infiltration using recycled concrete aggregate

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Abstract. Predicting the infiltration rate on inclined surfaces is a pending case, especially when compared to rain intensity. The inclined surface has less ability to generate ponding, leading to higher runoff and higher erosion rates. In the rainy season, on the highway with a very steep slope, erosion usually occurs and becomes very dangerous. By using porous concrete, it is expected to receive higher infiltration and less runoff. This study aimed to determine the impact of the inclined surface of porous concrete on infiltration capacity. The research was conducted using both natural coarse aggregate and recycled coarse aggregate made from concrete waste. The infiltration and permeability test were conducted using porous concrete slabs under 0 to 30% inclined surface. It was shown that the infiltration rate is getting lower as the surface is being steeper. It was also shown that porous concrete made from recycled coarse aggregate has higher performance on permeability and infiltration rate compared to porous concrete made from the natural one.

keywords: inclined surface, infiltration rate, permeability, porous concrete, recycled aggregate

1. Introduction

The use of impermeable concrete disrupts the ecosystem’s natural equilibrium, resulting in soil erosion, flooding, and groundwater depletion. Switch to porous concrete is a straightforward option to prevent these issues [1].

Porous concrete, also known as pervious concrete, comprises coarse particles with a uniform gradation size, resulting in a bigger pore size that allows water to drain through it. Several kinds of research found that porous concrete is for concrete pavement to increase porosity and water absorption [1], [2]. However, due to its low strength, many kinds of research were made to improve porous concrete compressive strength by using additives and many other treatments for increasing its capability on carrying load [1], [3], [4], [5]. Other uses of porous concrete are focused on using it for construction material for sea walls, on being applied in wastewater treatment plants, for groundwater refilling, and for removing stormwater pollutants from the runoff [6], [7], [8].

The inclined surface has less ability to generate ponding, leading to higher runoff and higher erosion rates [9]. The nature of the soil determines the relationship between slope gradient and infiltration [10]. The soil porosity is an essential variable that affects soil infiltration rate [11]. It is also found that land slope and density are important variables in determining infiltration rate. With increasing landslope variation, the infiltration rate decreases in the same density, decreasing when soil density increases [12].
Infiltration plays a critical role in separating applied surface water into subsurface water and surface runoff [13].

In the rainy season, on the highway with a very steep slope, erosion usually occurs and becomes very dangerous. By using porous concrete, it is expected to receive higher infiltration and less runoff. The objective of this study is to examine the impact of inclined surface of porous concrete on infiltration capacity, using natural coarse aggregate and being compared to recycled coarse aggregate made from concrete waste. The utilization of porous concrete on inclined surface is expected to be adequate to reduce surface runoff.

2. Material and Methods

According to ASTM, several tests were conducted for natural and recycled aggregate, as specific gravity analysis, absorption, and weight test to meet the standard for coarse aggregate. Test for specific gravity and absorption of coarse aggregate was conducted using SNI 03-1969-1990 standard. The initial testing found that the absorption of natural coarse aggregate and recycled coarse aggregate is 1.01% and 1.42%, respectively. According to SNI 03-2834-2000, the absorption of coarse aggregate for concrete material must equal or less than 1/63%. Therefore, natural and recycled coarse aggregate used in this research has met the standard for concrete mix.

The tested concrete slab of porous concrete made with size as 5 cm depth. Furthermore, the mix design of porous concrete used in this research followed ACI 522R-10 standard [14], without fine aggregate. The ratio of material to cement: water: aggregate in this research is 1: 0.3: 4. The size of coarse aggregate used for both natural and recycled aggregate in this research was 1-2 cm. The curing process for porous concrete was conducted according to ACI 522-1-13. For each aggregate type, three concrete slab samples were made every test in this research. Each test was repeated three times for each concrete sample.

2.1. Density and void ratio test of fresh concrete

This test is based on ASTM C1688/C1688M, which discussed the Standard Test Method for Density and Void Content of Freshly Mixed Permeable Concrete. The test was made for all concrete mix with natural and recycled coarse aggregate. Density measurement and void ratio of fresh concrete were calculated using Eq. 1 and Eq. 2 [15], respectively.

\[
D = \frac{(M_c - M_m)}{V_m}
\]  

(1)

Where,

- \( M_c \) = mass of measure filled with concrete
- \( M_m \) = net mass of concrete
- \( V_m \) = volume of measure
- \( T \) = \( M_s/V_s \) (theoretical density)

\[
U = \frac{T-D}{D} \times 100\%
\]  

(2)

Where,

- \( U \) = Void Ratio
- \( D \) = Density or unit weight (kg/m³)
- \( T \) = \( M_s/V_s \)
- \( M_s \) = all mixture total weight (kg)
- \( V_s \) = all mixture total absolute volume (m³)

2.2. Infiltration test

The infiltration test was conducted following ASTM C1701 standard. The infiltration rate was calculated using Eq. 3 [16].
\[ I = \frac{K M}{D^2 t} \]  

Where,

\( I \) = infiltration rate (mm/hr)

\( M \) = weight of water (kg)

\( D \) = inner diameter (30 mm)

\( t \) = time to pass the water (sec)

\( K \) = Constant as 4.583 666 000

The infiltration test was set based on the inclined roadway using horizontal inclined as 2% and vertically inclined as 0%, 10%, 20%, and 30%. This test was set for porous concrete with natural coarse aggregate and recycled coarse aggregate for each inclined surface. This test was conducted for porous concrete slab at seven days old.

2.3. Permeability test

The permeability test was conducted for porous concrete slab at 28 days old, using cylinder concrete. Samples were made with a diameter of 100 mm and height of 200 mm in sizes, according to ACI 522R-10 standard. Permeability test was calculated using Eq. 4 [14].

\[ k = \frac{A_1 l}{A_2 t} \log \frac{h_2}{h_1} \]  

Where,

\( k \) = water permeability

\( A_1 \) = specimen cross-sectional area (150mm)

\( A_2 \) = tube cross-sectional area (150mm)

\( l \) = specimen length (150 mm)

\( t \) = time

\( h_1 \) = the initial water head (300 mm)

\( h_2 \) = the final water head (1 mm)

3. Result and Discussion

3.1. Density and void ratio of fresh porous concrete

Density and void ratio measurement was conducted according to ASTM C1688/C1688M in fresh condition after the mixing process. Density measurement and void ratio of fresh concrete were calculated using Eq. 1 and Eq. 2. The average density calculation for all samples is shown in Fig. 1., while the result of the void ratio is shown in Fig. 2.
Figure 2. Void ratio measurements for porous concrete

From Fig. 1, it can be seen that the density of fresh porous concrete with natural coarse aggregate is lower than porous concrete made of recycled aggregate. On the other hand, the void ratio of porous concrete with natural coarse aggregate gave a higher measurement.

3.2. Impact of inclined surface of porous concrete on infiltration capacity

To understand the impact of inclined porous concrete surface on its infiltration capacity, the concrete slab was inclined vertically as 0%, 10%, 20%, and 30%, respectively. The concrete was also inclined horizontally as 2% in general as a horizontal inclination for highway standard and vertical inclined as 0%, 10%, 20% and 30%. This test was set for porous concrete with natural coarse aggregate and recycled coarse aggregate, respectively, for each inclined surface.

Following the ASTM C1701 standard, the infiltration test was set for all concrete samples. By using Eq. 1, the result was calculated and shown in Table 1. In Figure 2, the impact of the inclined surface is shown clearly.

| Aggregate type       | 0%   | 10%   | 20%   | 30%   |
|----------------------|------|-------|-------|-------|
| Natural C. Aggregate | 14.14| 13.75 | 12.60 | 11.48 |
| Recycled C. Aggregate| 20.12| 20.75 | 20.31 | 18.84 |

Table 1. Infiltration rate for the inclined surface of porous concrete

Figure 3. Impact of inclined surface on porous concrete infiltration rate
From the result of the analysis, it was shown that the inclination of the surface of porous concrete impacted significantly on its infiltration rate. The 30% inclination decreased infiltration from 14.14 mm/sec to 11.48 mm/sec for porous concrete with a natural coarse aggregate or equal to -19%. On the other hand, the 30% inclination of porous concrete with recycled coarse aggregate decreased its infiltration from 20.12 mm/sec to 18.48 mm/sec or equal to -6%.

By comparing the infiltration rate of these two different aggregate sources, it was shown that porous concrete made from recycled coarse aggregate had a better ability to generate water on its surface. In general, replacing the natural coarse aggregate with recycled one will increase the infiltration rate until 7.01 mm/sec on average for every inclination, or equal to 49.6% increment of its initial infiltration rate.

3.3. Porous concrete permeability on the different inclination

The permeability analysis is used to measure the absorption of porous concrete, which is displayed with the symbol k. The experimental analysis of the permeability test was conducted using falling head apparatus. Permeability measurements are calculated based on ACI-522R using Eq. (2). The average measurements of permeability of three concrete samples for each aggregate type are shown in Figure 3.

![Figure 4: Permeability of porous concrete with natural coarse aggregate compared to recycled coarse aggregate](image)

The result in Fig. 3 shows that the porous concrete with recycled coarse aggregate significantly shows better performance in permeability measurement, as much as 50.35% compared to natural coarse aggregate.

4. Conclusions

This paper has presented the research results in determining the impact of the inclined surface of porous concrete on infiltration capacity, permeability, and runoff, using both natural and recycled coarse aggregate. The infiltration and permeability test were conducted using porous concrete slabs under 0 to 30% inclined vertical surface, all by 2% inclined horizontal surface and following ASTM C1701 standard. It was shown that the infiltration rate is getting lower as the surface is being steeper. For 30% inclined surface, the infiltration rate will decrease to 6 to 19%. It was also shown that porous concrete made from recycled coarse aggregate has higher performance on permeability and infiltration rate compared to porous concrete made from the natural one. The replacement of natural coarse aggregate with recycled one will increase its infiltration rate and permeability up to 50%. The utilization of porous concrete on inclined surface is proven to be effective in reducing surface runoff.
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