The Character of Infiltrated Water in Modeling Through a Combination Layer of Pervious Concrete and Clay Soil

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ABSTRACT
This modeling was carried out to see the characteristics of water infiltrated through two different media types by considering the characteristics of the infiltration ability of each media. The media in the first layer is pervious concrete, while the media in the second layer is clay silt. The model is made to represent the application of pervious concrete as a channel base. Pervious concrete is generally used for road pavement. In developing the effectiveness of the application of pervious concrete, water infiltration characteristic was observed using a modeling box which has an area of 80×20 cm, with a thickness of 7 cm of the pervious concrete plate and a soil layer of 20 cm thickness underneath. The discharge in the modeling is based on 10 years of rainfall. The flow of water is regulated by a flow meter within two hours of observation. The description of soil conditions, as well as contours and cross-sectional characteristics of the channel, was taken based on the condition of one of the existing drainages located at Bandung State Polytechnic. The average infiltration rate obtained from modeling is 0.026 cm/second and is used as the basis for a numerical approach using the Geostudio SEEP/W software. The results of the infiltration test which are simulated show that the higher pore water pressure in the soil underneath the groundwater table, the greater the volume of water absorbed by the soil. The addition of water pressure occurs along with the flow of water in the drainage channel. Water will seep in the porous concrete and soil, moving downhill following the direction of gravity. Once there is no flow in the drainage channel, the water will press in all directions to fill the gaps in the surrounding pores.

Keywords: *Drainage, Runoff, Porous Concrete, Infiltration, Geostudio SEEP /W.*

1. INTRODUCTION

Pervious concrete is a relatively new concept in transmitting surface runoff and is currently being used more for pavements with low loads, especially in areas with low groundwater levels. However, the application of pervious concrete must have such a system which appropriate with the conditions of the underlying soil [1]. The characteristics and conditions of the groundwater table will affect the performance of pervious concrete in its application.

Pervious concrete pavements are a unique and effective way to meet the demands of an ever-evolving environment, by capturing rainwater and letting it seep into the ground. However, these previous pavements are generally equipped with drainage made of normal concrete. The nature of normal concrete which tends to be denser has a lower infiltration ability than pervious concrete. The drainage runoff only then relies on the channel discharge capacity and flow velocity in the horizontal direction

It is known from several previous studies that the void content of pervious concrete is in the range of 18-23% [2]. The infiltration capability of pervious concrete used as a reference in this study is the result of research by Andreas Valeri, et al, 2018 and Batezini, 2015, with the highest hydraulic conductivity achieved at 10.2 mm/s or 0.102 cm/c [3,4]. The results of research by Kavern, et al., 2006 and research by Tennis et al., 2004 showed that the obtained permeability values ranged from 0.2 to 0.5 cm/s [5,6].

Research on different previous concrete applications was carried out by Aifaa et al. 2019 [7]. In their research, pervious concrete was used as a road curb. The infiltration rate test was designed under the influence of infiltration through the side surfaces of concrete pavements with various slopes. The results showed that the infiltration rate was quite high, and the infiltration rate increased as the slope of the gutter increased. Based on the infiltration rate capability obtained, the pervious concrete can be applied and be used for other similar applications. Furthermore, the test significantly revealed that the pervious concrete had a high potential in improving flow interception and was able to reduce waterlogging.

In this study, the research is conducted to simulate the application of pervious concrete as a drainage base. On the drainage base made of conventional concrete, the runoff discharge only relies on the drainage discharge capacity and flow velocity in the horizontal direction. Therefore, an increase in runoff is tried to achieve by applying pervious concrete at the bottom of the drainage, by then it is expected that the water flow in the drainage is not only in the horizontal direction but also in the vertical direction. The application of pervious concrete for the drainage base is expected to help protect the surrounding environment, integrate flood water, improve water quality, and reduce runoff discharge.

2. OBJECTIVES

To observe the characteristics of water infiltrated through porous concrete and the soil media as well.

3. MATERIALS AND METHODS

3.1. Modeling Basin

This research is based on an experiment through modeling. The dimension of the basin modeling is 80cm×20cm×50 cm. The bottom of the test box is perforated with a diameter of 5 mm, which space is 5 cm from one another. The scale of the model consists of a pervious concrete plate of 79 cm length and 19 cm of width with a slope of 2% and a soil thickness of 20 cm.

3.2. Pervious Concrete Plate

The proportion of pervious concrete materials refers to the research of Endawati, et al., 2016 [8], which consists of 70% coarse aggregate and 30% binder. This pervious concrete mixture uses 100% coarse aggregate. Meanwhile, the proportion of the binder consists of 63% Portland cement composite (PCC), 25% fly ash (FA), and 12% silica fume (SF).

3.3. Soil Used in The Modeling

The soil used in the modeling is loamy silt clay which permeability coefficient is 1.83 x10-5 cm/sec. The depth of the groundwater table is 3.93 m. Other soil characteristics used in the modeling are given in Table 1.

Table 1. Soil characteristics used in modeling

No	Parameter	Symbol	Units	Quantity
1	Water content	ω	%	34,12
2	Density	γ	t/m^3	1,67
3	Specific Gravity	Gs	-	2,455
4	Liquid limit	LL	%	67,74
5	Plastic limit	PL	%	48,40
6	Plasticity index	PI	%	18,74
7	Gravel	G	%	0
8	Sand	S	%	11,9
9	Silt	M	%	54,5
10	Clay	C	%	33,5
11	Cohesion	C	kg/cm^2	0,12
12	Shear Angle	Φ	^{0}	24

The soil in the modeling basin was given previous treatment by air drying. The soil was then moistened with water until the water content matched the lost water content. The soil was put into the modeling basin in layers and compacted. Soil density in the modeling basin was observed by testing the compacted soil density.

3.4. Discharge of Water Flow

The water flow discharge is assumed to be the water flow in existing drainage at Bandung State Polytechnic. The selected drainage as a reference for observations has an area of land cover and building layout served by 17876.42 m^2.

Ten years of rainfall data used in the hydrological analysis of 2010-2019, were taken from the Cemara rain station and the Husein Sastranegara rain station. The consistency test of the rainfall data was carried out using the double mass curve method, while the distribution characteristics were tested by the annual maximum series method. The type of frequency distribution was determined by the Gumbel, Normal, Log Normal, and Log Pearson III distributions. In ensuring the correct distribution of the rainfall data, the test was carried out using the Chi Quadrat method and the Smirnov-Kolmogorof method, which result as can be accepted hypothesis. The rainfall intensity used in this research is a 10-year return period, based on the translation or shift of the Jakarta Intensity Duration Frequency (IDF). The values of terms in the rain intensity were calculated using the Talbot, Sherman, and Ishiguro Equations.

3.5. Water Flow in Pore Media

Water flow occurs when the pores or cracks in the soil are interconnected with each other (interconnected pore space). Materials with interconnected pore spaces can flow water or fluids, which is known as permeability [9]. Vedat Batu, 1998, in his book, states that the permeability of a material is expressed by the coefficient of permeability (K). The value of the coefficient of permeability in soils generally depends on the average pore size, grain size distribution, and grain direction and displacement. He states that the permeability coefficient value which is generally used is the horizontal permeability coefficient because the value of the vertical permeability coefficient is very small.

There are two parameters of permeability: hydraulic conductivity and intrinsic permeability. Intrinsic permeability has units of cm^2 or m^2. The value of intrinsic permeability depends on the physical properties of rock or soil. The relationship between hydraulic conductivity and intrinsic permeability is determined as follows:

$$K = k\frac{\gamma_w}{\mu} \quad (1)$$

where:
K = hydraulic conductivity
k = intrinsic permeability
γ_w =density of fluid (kN/m^3)
μ = viscosity (Vedat Batu,1998)

Water in the pore media will flow when there is an energy imbalance. Water flows from a place of high energy level to a place of lower energy. In fluid mechanics theory, the total energy height of fluid is expressed by a head, such as a pressure head or velocity head, which can be calculated by Equation 2 which is commonly referred to as the Bernoulli Equation.

$$h = z + \frac{p}{\gamma_w} + \frac{v^2}{2g} \quad (2)$$

Where:
h = *total head energy* (m)
z = elevation (m)
p = pore water pressure (kN/m^2)
γ_w = density of water (kN/m^3)
v = water flow (m/s)
g = acceleration due to gravity (m/s^2)

Groundwater flow is influenced by the principles of hydraulics that have passed through the aquifer which in general as a flow medium and is calculated by using Darcy's law as follows:

$$V = Ki = \frac{K\Delta h}{L} \quad (3)$$

Discharge of the water:

$$Q = VA = KiA \quad (4)$$

Where:
V = velocity of water flow (m/dt)
K = *Hydraulic Conductivity* (cm/dt)
i = hydraulic gradient
Δh = *potential head*
L = distance of viewpoint
Q = water discharge through the aquifer (m^3/dt)
A = cross sectional area (m^2)

3.6. Infiltration Test

The infiltration test was carried out for 3 consecutive days and two hours per day. The volume of infiltration comes from measuring the decrease in the measuring tank per 10-minute intervals during the test. The condition of the test plate was made unsaturated to see the real state of the application in the field.

4. RESULTS AND DISCUSSIONS

4.1. Pervious Concrete Permeability

The concrete permeability test was carried out using the falling headwater permeability test method with measured cylindrical specimens of ∅10cm x 10cm. The average permeability value of porous concrete obtained from the test results was 0.267 cm/second.

4.2. Hydrological Parameters

Based on the calculation of the hydrological analysis for a catchment area of 39999 m^2, a surface runoff coefficient (C) =0,44, and a rain intensity (I) of 153,304 mm/hour, resulting in a designed discharge of 0,761 m^3/s.

4.3. Determination of Water Flow in Modeling

The flow discharge in the modeling is calculated based on the designed discharge. The projected run-off discharge in the model scale test can be seen in Table 2.

Table 2. Run off discharge in the modeling basin

Width of modeling box (B)	20 cm
Water level (H)	3 cm
Flow (V)	0.003313 m/s
Runoff discharge (Q)	0,8405 l/minute

4.4. The Infiltration Test

The results of the infiltrated water level obtained on the first day of testing are given in Figure 1. The infiltration rate for days 1 to 3 shows an increase in the value of the infiltration rate. However, the difference in the increase on the third day has decreased by 4.74%, compared to the difference between the second day and the first day of 22.56%. This condition occurs because the soil layer was still in unsaturated condition in the beginning.

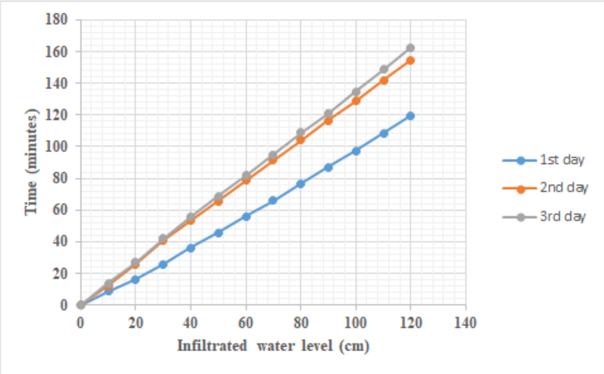

Figure 1 Infiltrated water during the test

4.5. The Numerical Simulation

The results of the numerical analysis and modeling indicate that the amount of infiltration discharge during infiltration testing is in the range of 0.000166 to 0.000244 m^3/sec. The infiltration discharge by numerical simulation is given in Figure 2. The infiltration discharge is quite large at the beginning of the test. However, the infiltration discharge that occurs during the test is not linear yet fluctuates. The actual performance of the pump also affects the flow of water, as can be seen from the fluctuations in the flow meter.

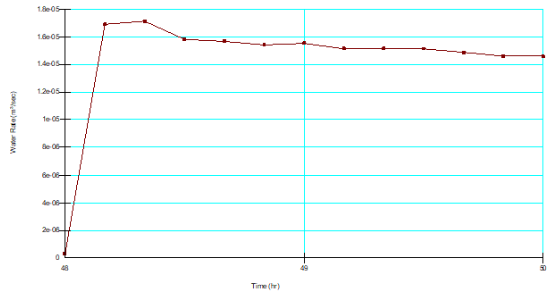

Figure 2 The relationship between water infiltration and time through the Geostudio SEEP /W simulation

The condition of the total water head shows the stress that occurs due to the water pressure resulting from water infiltration. The total head can be defined as the stress represented in units of length at a certain elevation.

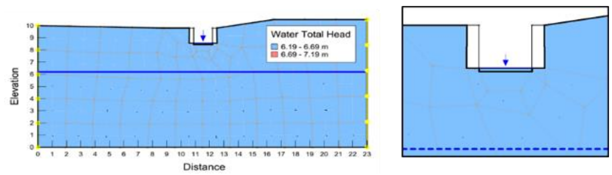

Figure 3 The existing water total head condition

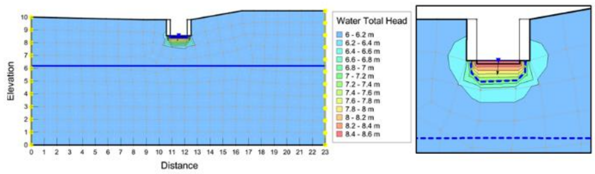

Figure 4 Water total head, 3rd day of observation

Based on the results of numerical simulations in Figures 3 and Figure 4, there is an increase in the water total head condition in the pervious concrete and the surrounding soil. This is because the water pressure at the bottom of the drainage which is installed with pervious concrete will compress and drain water from the bottom of the drainage to the part of the soil that has lower pressure.

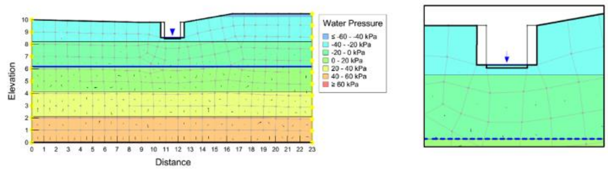

Figure 5 The existing pore-water pressure

In Figure 5, the pore-water pressure conditions in pervious concrete and soil are divided according to elevation. When the water pressure on the soil is below the groundwater table, the pressure will be longer as the the pressure becomes greater. When the land is above the groundwater table, the water pressure will be higher as the water pressure becomes lower.

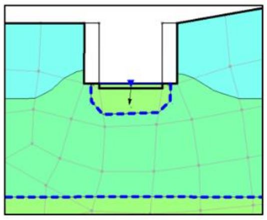

Figure 6 Pore water pressure, 3rd day of observation

Based on the numerical simulation results in In Figure 5 and Figure 6, there is an increase in pore water pressure in the porous concrete and the surrounding soil. As explained earlier, the more volume of water absorbed, the higher the pore water pressure in the soil is. The addition of water pressure occurs along with the flow of water in the drainage channel. Water will seep in the porous concrete and the soil will move downward following the direction of gravity. Once there is no flow in the drainage channel, the water will press in all directions to fill the gaps in the surrounding pores.

5. CONCLUSION

The average infiltration rate obtained from modeling is 0.267 cm/second and is used as the basis for a numerical approach using the Geostudio SEEP/W software. The results of the infiltration test which are simulated show that the higher pore water pressure in the soil underneath the groundwater table, the greater the volume of water absorbed by the soil. The addition of water pressure occurs along with the flow of water in the drainage channel. Water will seep in the porous concrete and soil, moving downhill following the direction of gravity. Once there is no flow in the drainage channel, the water will press in all directions to fill the gaps in the surrounding pores.

AUTHORS' CONTRIBUTIONS

Each author is fully contributed to the planning, implementation, and analysis of the research.

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