

PHYSICAL MODELING OF PROPOSED POROUS DRAINAGE SYSTEM TO SOLVE INUNDATION PROBLEM

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ABSTRACT: Post rain inundations that occurred in Prambanan Temple yard interfere the visitor's mobility and heavy equipment that operated for restoration activities in the temple. A typical porous drainage system was proposed using waste material from Merapi eruption to reduce the inundations. Research on the characteristics of the waste material becomes important due to the availability of so many supplies from these materials and it has not been utilized optimally. A full scale of physical modeling experimental test, with a modified equipment to determine the performance of the porous drainage system, was proposed in this study. Physical modeling of the porous drainage system is expected to represent the actual conditions in the field. The groundwater level was designed in two conditions, deep groundwater level based on the natural field condition and shallow groundwater level that is an extreme condition that may occur in the field. In this test, rainfall simulator was built to flow the discharge constantly into this physical modeling. The effectiveness of this system amounted to 20% of the drainage capacity in natural field condition during the rainfall duration of 2.183 hours. In the extreme condition, the effectiveness of the system amounted to 75% of the drainage capacity during the rainfall duration of 2.383 hours. It shows that the porous drainage system is quite effective when applied at Prambanan Temple yard that has an average rainfall duration of 2.375 hours. The proposed porous drainage system is expected to solve the inundation problem in Prambanan Temple yard.

Keywords: Post Rain Inundations, Physical Modeling, Porous Drainage System

1. INTRODUCTION

Prambanan Temple yard is divided into three stages, with the main stage of Prambanan temple complex is located on the first yard. The first yard of Prambanan Temple is the main destination for tourists to enjoy the beautiful view. But in these last few years, the convenience of the tourism activity in the first yard of Prambanan Temple was quite disturbed due to the water inundations that always occur during the rainy season. Inundation that appears after rainfall in certain parts in the first yard of Prambanan Temple, as shown in Fig. 1, is one of the issues that must be solved. Cultural Heritage Institution of Prambanan Temple attempted to reduce the inundation problem by adding a special soil above the original soil layer, so that the ground is not expected to quickly become saturated, free of dust, and it is not a growing medium of grass. Moreover, some drainage channels have added on Prambanan Temple yard to reduce the potential inundations of water occurrences, but this treatment is still not effective. To preserve this cultural site and keep the convenience of visitor's mobility, it needed some solution to organize and improve the drainage systems to reduce the inundated area.

According to the soil stratification data, as shown in Fig. 2, the soil layer in Prambanan temple yard is dominated by sandy soil. The water level condition is on 12 meters under the soil surface. One of solution that can be conducted is by creating a drainage system that able to reduce runoff by infiltration through porous media of a porous material [1].



Fig. 1 Inundation that occurs in the yard of Prambanan Temple.

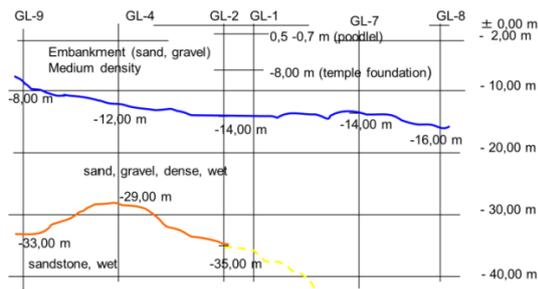


Fig. 2 Stratification of soil layer [2].

In addition, to obtain the high permeability material, a porous medium in the drainage system also serves to reduce the water pressure, prevent erosion, and prevent soil particles transported by the water flow. An alternative porous medium application is the utilization of porous drainage channels and porous paving block as an access road for visitors which considered to solve the inundations. Both of these alternatives are used in this study to optimize the drainage system and to solve the inundations problem. In this study, physical modeling of drainage system based on field condition parameter was conducted. This study focused on the effectiveness of the proposed drainage system with a physical model that has adapted to the conditions in Prambanan Temple yard.

Reference [3] has conducted research on utilization of low strength aggregate or Bantak and volcanic ash for drainage porous. Bantak and volcanic ash are used in no fine concrete as the main substituting material. The materials are used as a basic calculation of the total requirement of drainage material for producing of porous concrete samples. A numerical analysis model of the drainage channel was conducted and the distance between the nearest channels is 7.48 m. In addition to the distance between the channels, a typical channel model was proposed and shown in Fig. 3.

In addition to the porous drainage channels, to reduce inundation that caused by lack of water infiltration into the soil, porous paving blocks can be an alternative construction for pavement, especially for sidewalks, open parking area, etc. Reference [4] has conducted research on utilizing Bantak and volcanic ash to porous paving block in the handling of drainage at Prambanan temple page. The test results of the characteristics of porous paving blocks can be seen in Table 1. In [4], the model testing was conducted in an acrylic box with an area of 50 cm by 50 cm to get the value of the original soil permeability coefficient and porous paving block. This modeling was also performed on the normal paving block as a comparison. The calculation result of infiltration based on the data modeling results can be seen in Table 2.

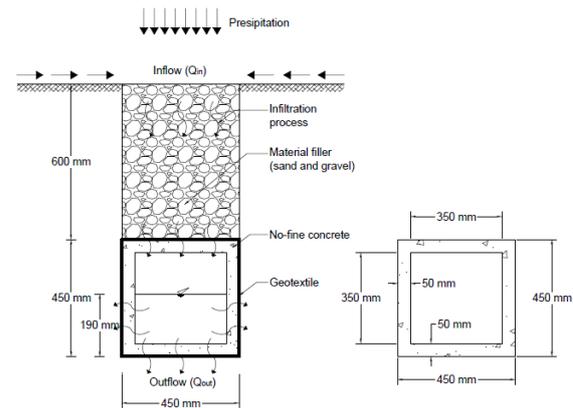


Fig. 3 Proposed drainage system by [3].

Table 1 Characteristics of the porous paving block using volcanic ash [4].

Characteristic	Value
Specific gravity (kN/m ³)	16.80
Compressive strength (MPa)	5.72
Porosity (%)	28.40
Permeability (m/s)	1,93 x 10 ⁻²

Table 2 Hydraulic properties of the soil and paving block [4]

Parameter	Soil	Normal paving block	Porous paving block
Permeability (m/s)	5.8 x 10 ⁻⁶	1.3 x 10 ⁻⁵	1.1 x 10 ⁻⁴
Infiltration capacity (m)	4.2 x 10 ⁻²	1.1 x 10 ⁻¹	-
Infiltration velocity (m/s)	7.5 x 10 ⁻⁶	1.4 x 10 ⁻⁵	-
Runoff (m)	8,8 x 10 ⁻²	1,6 x 10 ⁻²	-
Inundations time (hour)	3,2	0,3	-

2. RESEARCH MATERIALS AND METHODS

Three-dimensional physical modeling was conducted in this study to validate theoretical results that have obtained through a mathematical calculation. In the physical modeling, detailed planning with analytical calculations is needed in order to build a physical modeling that represents the actual conditions in the field. Physical modeling can use the full scale or can be scaled from the actual conditions taking into account the scale factor. Detailed figure of a porous drainage system was proposed by [3]. Typical porous drainage channels that have been made by previous researchers then modified into a physical model in a scale of 1:1, that shown in Fig. 4.

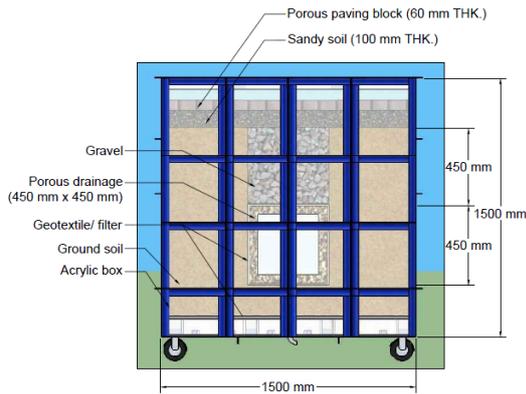


Fig. 4 Physical model of the proposed porous drainage system.



Fig. 5 Experimental test apparatus.

Physical modeling testing of the porous drainage process begins with regulating the flow of rain simulation equipment, water discharge arranged until approaching rainfall conditions in the first yard of Prambanan Temple as shown in Fig. 5. Water discharge released from the rain simulation equipment is 14 ml/sec assuming the typical heavy rain. This water discharge represents the rain intensity about 70 mm/hour where it is 5 times higher than normal intensity obtained from the field data that equal to 14 mm/hour. Water discharge flow through a pipe that has been hollowed and the slope of the pipe needs to be taken to ensure that water can flow as expected. There are two conditions in this test, shallow groundwater table for the critical condition and deep groundwater table that represents actual field conditions.

Conditions of the shallow groundwater table can be modeled using an impermeable layer on the bottom of the porous drainage. It is made by letting an empty space at the bottom of the modeling box filled with water. The condition is considered to

represent a layer of impermeable because the water does not flow out and the water that seeps through the physical modeling test stuck in the bottom layer. Meanwhile, to simulate actual field conditions, the water valve at the bottom of the box was opened and the flow rate is set in accordance with the soil conditions in the field. Permeable layer conditions on the bottom of the porous drainage are made by making a puddle in advance at the box support as high as the bottom limit of the soil layer, then open the valve outlet of 8.7 ml/sec with assumption that the value of the discharge that comes out of the valve outlet is the same discharge in the modeling test. At the same time simulation of rain still running.

The observations focused on the direction of water flow and time to achieve the highest inundation level at 75% of the drainage capacity in saturated soil conditions. Changes of water content to determine the saturated condition was maintained by using soil moisture sensor devices. Groundwater flow direction can be visually seen when conducting this physical modeling. When the rain simulation equipment conducted, the time monitoring start. Furthermore, every inundation of 2 cm in porous drainage, the elapsed time is recorded until the altitude target. The simulation equipment was stopped when rain inundation on a porous drainage has reached 75% of the porous drainage height, then the elapsed time is recorded.

3. RESULTS AND DISCUSSIONS

In the shallow groundwater level conditions, when rainwater simulation equipment was conducted and the surface of the soil in physical modeling start to wet, at that time the rain time calculation begins. The valve is opened by setting a constant flow of 14 ml/sec. This value is obtained from the calculation using 5 times of the rain intensity on the field that is equal to 70 mm/hour (> 60 mm/hour) and classified as the category of very heavy rain [5]. It used 5 times of the normal intensity because the intensity of rainfall simulation equipment was limited, so it used the higher rain intensity that can be seen visually and the represent the rain in the field. The process of physical modeling test is executed when the soil reaches the saturated condition and based layers as deep as 20 cm below the drainage porous considered impermeable. This impermeable layer is an interpretation of extreme field conditions where the soil is saturated with a high water level.

The results of the physical modeling test are time and water level contained in porous drainage. Observation of the water level in porous drainage every 2 cm to 26 cm, obtained from the 75% of the drainage capacity. The observations are then made in the form of a graph as shown in Fig. 6.

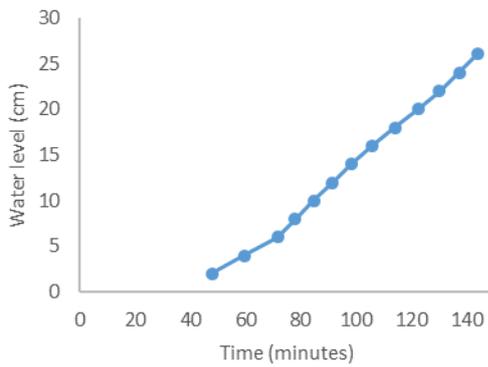


Fig. 6 Recapitulation of physical modeling observations with impermeable layer

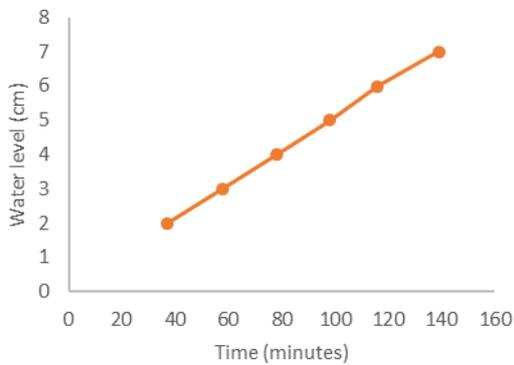


Fig. 7 Recapitulation of physical modeling observations with a permeable layer

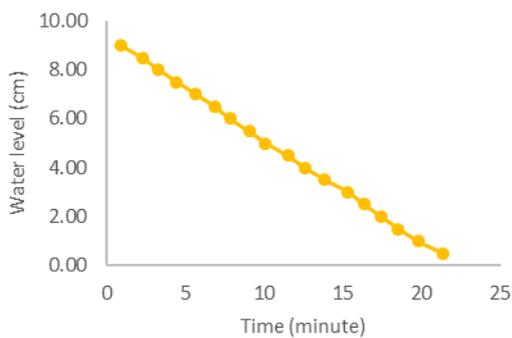


Fig. 8 Testing results of the decreasing water level in porous drainage with a permeable layer

From Fig. 6, it can be seen that the time required for the water level every 2 cm is not constant. It appears there was a decrease in significant time when the water level of 6 cm to 8 cm and shows the water flowing into the drainage porous faster. After the water level height above 8 cm time required every 2 cm relatively constant, although there are up and some going down but not too significantly. The

test data obtained from the time required for porous drainage inundation heights of 26 cm for 2 hours 23 minutes or 2.383 hours with rainfall intensity 5 times the normal intensity that is equal to 70.55 mm/hour. Data on the average duration of rainfall that occurred in the first yard of Prambanan Temple based on previous research that is over 2,375 hours. Thus the porous drainage system can be said to be effective for the treatment of inundation occurred in the first yard of Prambanan Temple despite heavy rain conditions (intensity of > 60 mm/hour).

On the deep groundwater level condition, after the rainwater discharge valve is opened to discharge of 14 ml/sec with the intensity of 72 mm/hour interval of ± 10 minutes the water had penetrated the upper surface of porous drainage. With the soil conditions in the experimental test equipment were saturated and the water level at the bottom has been setting the limit as high as the bottom layer of soil, the results showed after waiting 1.5 hours, groundwater level touches the bottom of the porous drainage. After the water reached the base of the porous drainage, then did a calculation of increasing inundation over time as shown in Fig. 7.

Based on Fig. 7, it can be seen every change of time elevation of inundation rose by 2 cm, and then averaged summed it takes about 20 minutes per increment inundation of 2 cm on porous drainage. So the speed of inundation in porous drainage was 0.1 cm/min. Of the total duration of the rain occurs about 2 hours 11 minutes gained inundation height on drainage pore of 7.5 cm from the inner surface drainage. So, in a case of rain with an intensity of 72 mm/hour for 2 hours 11 minutes, the condition is still very efficient drainage as a reservoir and seepage of rain. It is shown at an inundation height still 20% of the total of the level.

Decreasing water level is only performed on a permeable layer, which assumed that the water could flow down. The test results can be seen in the graph shown in Fig. 8 below concluded that the rate of decreasing water level per 0.5 cm takes 1.203 minutes. From the results of this study concluded drainage catchment speed is 0.416 cm/min.

In decrease testing inundation in the porous drainage, rain simulation was stopped but the discharge outlet remains open in accordance groundwater flow that is 8 ml/sec and the position of the state remain saturated soil conditions. The test results can be seen in the graph below, inundation concluded that the decrease rate every 0.5 cm takes 1.203 minutes. It can be concluded from the speed of the drainage catchment is 0.416 cm/min.

Fig. 9 shows in the direction of flow that occurs in the physical modeling of the porous drainage system. Running physical modeling to determine groundwater flow direction was made during a field dry conditions up to saturated soil conditions. Based on visual observations, the direction of flow on

physical and mathematical modeling there is no significant difference, with it can be assumed that the input and output physical modeling and numerical modeling is correct. Conditions on groundwater flow above using rain discharge of 20 ml/sec to the direction of flow as shown above. In the picture, shown in number 1-6 as the change in shape of the flow of time. The initial condition is shown in number 1 and number 6 shows the final condition. In numerical modeling using Finite Element Method is modeled with the same soil conditions such as conditions on the modeling of physical test equipment. Results of running the software SEEP/W is shown in Fig. 10. It was concluded from a comparison of both models show the direction of flow which is not much different shape.



Fig. 9 Pictures direction of flow in modeling tools experimental test

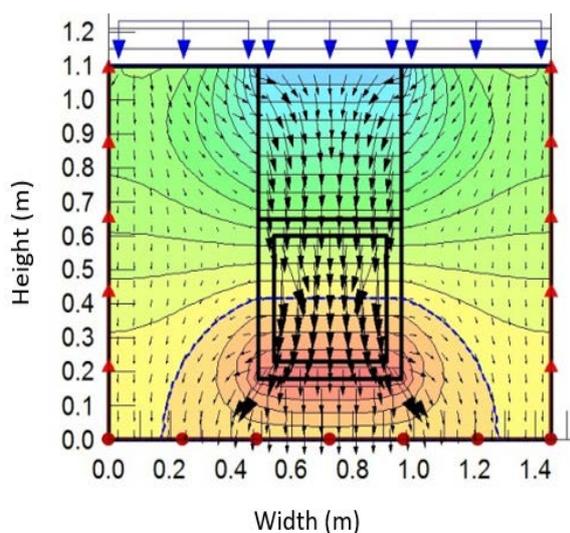


Fig. 10 Vector direction of water seepage on numerical modeling

4. CONCLUSIONS

After testing on modeling of porous drainage system with the condition of the groundwater level in accordance with the conditions of the field, the results obtained by 7 cm water level from lower surface drainage within 139 minutes. This shows that the porous drainage system used is quite efficient for streaming and storage of rainwater runoff intensity 5 times the average rainfall intensity in the field. The time required for each increase of the water level in the drainage porous 1 cm nearly constant. This is possible because of the influence horizontal water flow coming into the porous drainage changed and influenced also by the already saturated ground conditions. The duration of the decrease in drainage porous inundation with a height of 0.5 cm takes 1.203 minutes. This is possible because the permeability of the non-sand concrete drainage density is very high and the soil density that is not so dense.

On the condition of the shallow groundwater table below the drainage system obtained results height of inundation by 26 cm within 2.383 hours of this suggests that the drainage system is porous enough used effectively in reservoir drainage and water runoff. The time required for each increase of the water level in the drainage of 2 cm is not constant and even tends to decrease. This is possible because of the influence of the horizontal flow of water coming into the porous drainage increased. Comparison of flow direction on physical modeling with Finite Element Method is not too significant.

5. ACKNOWLEDGMENTS

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