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CHARACTERIZATION OF SOIL PERMEABILITY IN PRAMBANAN TEMPLE YARD BASED ON DEVELOPMENT OF IN SITU TEST

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ABSTRACT: Prambanan Temple is a cultural site which has been declared as world cultural heritage that is required to be conserved. Due to heavy equipment activities during maintenance period after Yogyakarta earthquake in May, 2006, soil in temple yard become dense, and ponding occurred after rainfall. A poodle layer and a drainage system has ever built to avoid such a problem, but the pond still didn't stop appearing after rain. Permeability parameter needs to be characterized to find exact method of solution. This experiment used Constant Discharge method which suitable for permeability test of sandy soil. The procedure were carried out from unsaturated until saturated soil condition. Volumetric water content were being monitored by using soil moisture probe. The results were value of permeability coefficient from unsaturated until saturated condition. The value of permeability coefficient and soil type characterization was mapping based on geographic reference using software Arcview GIS 3.3. Developed instruments were quite efficient and easy to be implemented on determining field soil permeability coefficient of sandy soil. Using constant discharge model, the value of unsaturated soil permeability can be obtained without establishing the matrix suction. The result of soil permeability characterization mapping can be used to determine the alternative solution of the ponding problem.

Keywords: Puddle, Instrument Model, Coefficient of permeability

1. INTRODUCTION

Prambanan Temple which located in Yogyakarta, Indonesia is a cultural site which has been declared as world cultural heritage that is required to be preserved, maintained, and coserved. One of the facilities around the Prambanan Temple is drainage system in the yard. Due to heavy equipment activities during renovation/ maintenance period after Yogyakarta earthquake in May, 2006, soil in temple yard become dense, and ponding occurred during rainfall. This condition shows that existing drainage system is not sufficient. For this purpose, further analysis must be investigated.

Post-rain puddles which occurred at certain parts of Prambanan Temple yard is one of issues that need to be solved. This problem caused inconvenience to the visitor's mobility while relishing the beauty of Prambanan Temple. Cultural Heritage Conservation Office of Prambanan Temple (BPCB) had overcome the puddle issue by adding poodle soil layer and drainage channel to decrease the post-rain puddles potential. However, those actions were found to be less effective nowadays.

Indonesia is a tropical country that has two seasons that are rainy season and dry season. The season changes have significant influence on natural phenomena. The influence of natural events such as evaporation and precipitation that result in ground water level fluctuations. Rising groundwater levels due to rainfall influence the nature and behavior of the soil in response to the pressure/ load occurs [1]. Rainwater infiltration process above the ground surface can also be the cause of puddling. Infiltration is influenced by the characteristics of porous material or soil porosity. It initiates the alteration of soil condition from unsaturated to saturated which causes the change of soil permeability coefficient.

The determination of permeability coefficient value was initiated from unsaturated soil condition to saturated soil condition where the results were later used to solve the puddling issue at first yard of Prambanan Temple. Based on [2], seepage control on geotechnical structures is needed to lower the ground water level base surface that is aimed to be protected or strengthened regarding to prevent ponding water on the ground surface. The functions of porous media are both as a drainage medium and a filter to separate suspension particles from water, so the particles will not be carried away with the water flow.

This research aims at generating testing instrument model using a simple, efficient, and easy-to-implement permeability field testing procedure to figure out the characteristic of coefficient of permeability at Prambanan Temple yard, which are permeability coefficient at saturated and unsaturated condition as well as its correlation to volumetric water content for sandy soil. The data were later used for mapping the spacial data which represent certain area with geographic reference using software ArcView GIS 3.3. GIS has the capability to manage, store, and referencing geotechnical data to its geographic locations. It has been used to integrate existing data such as soil investigations aided by geographic coordinates with specific project data to identify potential geotechnical challenges [3].

Reference [4] proposed an experiment to measure unsaturated permeability for sandy soil. Firstly to determine the value of permeability coefficient in saturated conditions using Guelph Pressure infiltrometer (GPI). Secondly the unsaturated permeability were measured by Instantaneous Profile Method during drainage test. The value of volumetric water content were measured using a type PR1 Profile Probe (Delta-T Devices Ltd.) as an indicator of when the soil is saturated condition.

Permeability coefficient in unsaturated conditions obtained from numerical models as [5]. The field permeability test was conducted for top soil cover in Piyungan waste disposal site in Yogyakarta, Indonesia. The field experimental method can be a good practical in-situ permeability test because of its quite simple procedure.

However, this method is only limited to the soil in disposal site with homogeneus and uniform type of soil. In addition, the tools used are also deemed to be too complex and difficult to obtain in Indonesia. Saturation indicator is only determined at the moisture sensor devices are used. So we need a tool that is simple, inexpensive, precise, and able to test the soil with a higher density.

Reference [6] shows the core drilling data in Prambanan temple yard. According to the core drilling data as shown in Figure 1, the stratification of the soil in Prambanan temple yard is sandy soil. Based on the soil type characteristic, this experiment used proposed constant discharge model to measure the permeability parameter from unsaturated until saturated condition.

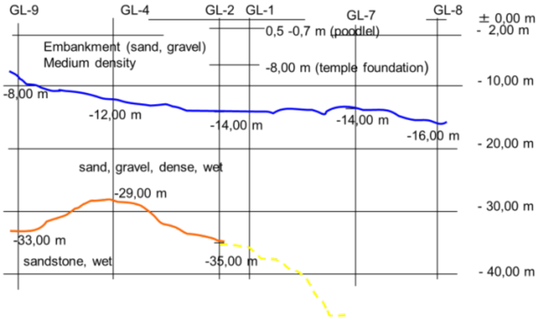

Fig. 1 Stratification of soil layer

2. MATERIAL AND RESEARCH METHOD

2.1. Constant Head Permeameter Test

The obtained observation data from the test were being substituted into Darcy equation:

$$k = \frac{QL}{hAt} \tag{1}$$

where A is sample section and Q is water volume in measuring glass, h is the height difference of energy, t is flow time, and L is sample length or current length.

2.2. Soil Permeability Testing at Unsaturated Condition

This test was performed by creating a sample of Prambanan Temple soil in a container with certain density. Laboratory soil permeability testing at unsaturated condition was conducted using constant water reservoir and container and soil moisture probe instrument as the indicator of soil degree of saturation in wetting and drying process through the changes of volumetric water content values. Laboratory testing was performed through two process including wetting and drying.

2.3. Permeability Test and Volumetric Water Content Measurement

This test aims to obtain the mapping of field permeability coefficient at ground surface using permeability test instrument model at the first yard of Prambanan Temple. The measurement of volumetric water content was also conducted by using soil moistrue probe instrument during the field permeability test procedure. The measuring process was initiated from unsaturated soil condition until the soil became saturated. In addition to the instrument model as [7], development and simplification of field permeability test instrument for sandy soil was also conducted. Referring to this and laboratory constant-head permeability testing concept, instrument model was created.

Based on bore drilling test results at Prambanan Temple yard by [6], the type of soil in Prambanan Temple yard was sandy soil so used Constant Discharge Model to characterized the permeability coefficient. In testing procedure using Constant Discharge model as illustrated in Figure 2, casing borehole was installed by staking casing pipe to ground depth with sampling depth of 1D from ground surface where D is casing diameter, then followed by the installation of permeameter pipe.

Sample height was taken 1D as [7]. Soil moisture probe was staked below casing. After both pipes and Soil moisture sensor instrument properly installed, Data Logger was installed at the base of soil moisture sensor. Data interpretation was conducted using data logger instrument which was connected to computer to read and save volumetric water content data.

The test is performed by making an unsaturated soil conditions to become saturated, to obtain the water discharge out of sample casing to be equal to water entering through permeameter pipe (Q = constant). Water was being flowed using constant water reservoir and container which was continuously flowed by water with constant discharge through permeameter pipe. In this test, it was assumed that groundwater level was at the edge of sample casing. Initial volumetric water content (θ_1) was being recorded. At certain time after the test took place, with constant flow discharge Q, water level at permeameter pipe became constant (H = constant),volumetric water content θ_2 was then obtained. This test was being conducted by conditioning the soil from unsaturated state to saturated state. To obtain permeability coefficient calculated by (2).

$$k = \frac{Q}{FH} \tag{2}$$

with,

k = coefficient of permeability of soil (cm / sec)
Q = water discharge (cm^3 / sec)
F = geometric factor (cm)
H = height of water level in the well (cm)

According to [8], equation (2) is used to calculate the permeability coefficient *(k)* at steady flow condition. Discharge used in the calculation is using the discharge flow into the casing permeameter. It is assumed that the water table is located at the end of *the casing* samples. Then for borehole conditions, the value of F (geometry factor) according to [8] and [9].

$$F = \frac{\pi D}{1 + \frac{11D}{L}} \tag{3}$$

with,

R = radius of the well (cm)
L = thickness of existing soil in the well (cm)

The value of unsaturated permeability coefficient (k_{unsat}) for any depth of soil can be proposed by [10]:

$$k_{unsat} = \frac{\int_0^{z_1} \frac{\partial \theta}{\partial t} dz}{\left(\frac{\partial h}{\partial z} + 1\right)} \tag{4}$$

where h is pressure head, t is time, z is depth, and θ is volumetric water content. Measurement of volumetric water content value is done by soil moisture probe until the water level is constant or no significant changes. Value of hydraulic gradient is assumed to 1.0 so it is not necessary to know the parameters tensiometer Soil Water Characteristic Curve which is quite expensive. Testing instrument is shown in Figure 2.

Values of permeability coefficient in unsaturated conditions obtained from numerical models as [10] using the equation:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[\frac{1}{1 + (ah)^n}\right]^m \tag{5}$$

$$K(S_e) = K_s S_e^{0,5}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2 \tag{6}$$

where m = 1-1/n, S_e is effective degree of saturation, θ_s is saturated volumetric water content, θ_r is residual volumetric water content, K_s is saturated permeability coefficient, α and n are empirical parameter. This equation usually named as *VG model*. Some unknown parameters are measured from Hydruss-2D data base for sandy soil.

Fig.2 Permeability test instrument (*Constant Discharge model*)

3. RESULT AND DISCUSSION

3.1. Comparison between k_{CD} and k_{lab}. Value

The value of soil permeability coefficient in saturated condition obtained from field testing result was found to be a satisfactory. The comparison between field and laboratory testing resulted in a relatively similar comparison value at several points. However, there are quite a view data has difference from the laboratory testing result.

The comparisons between constant discharge permeability coefficient (k_{CD}) and laboratory permeability coefficient (k_{lab}) obtained from the testing points were mainly similar. Hence, it indicated that there are differences between field and laboratory testing. Thus correction factor can be determined to field testing. Figure 3 shows the relationship between k_{CD} and k_{lab}.

The overall result showed that the value of k_{lab} less than the value of k_{CD}, so the value of permeability coefficient using instrument model and constant discharge testing procedure are relatively close to laboratory testing result.

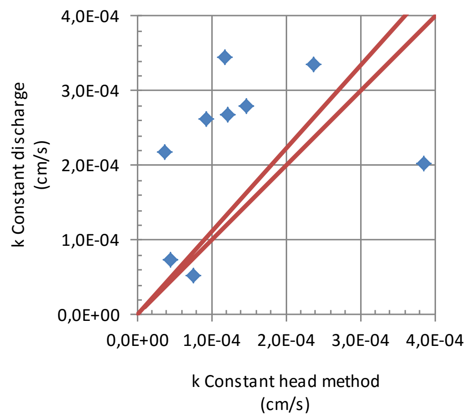

Fig.3 Testing results in saturated condition

3.2. Permeability test in unsaturated condition

Permeability test in unsaturated condition was being performed at SM soil (silty sand) layer with density of 18.0 kN/m^3 and 20.4 kN/m^3. The test of SM soil resulted in graph of volumetric water content (θ) changes from wetting to drying process due to time function (t) as displayed in Figure 4. Residual volumetric water content value represent by θ_r and its value will be performed trials in several conditions. The θ_r value become 7.5% when the soil is oven dried and become 5.5% when using Hydruss data. Based on the equation (4) and (6) the relationship between k and θ can be drawn in a graph as displayed in Figure 5.

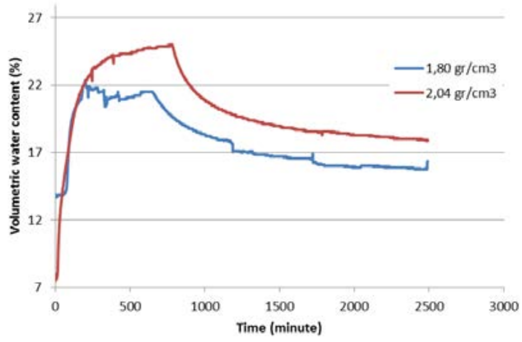

Fig.4 Various volumetric water content value during permeability test

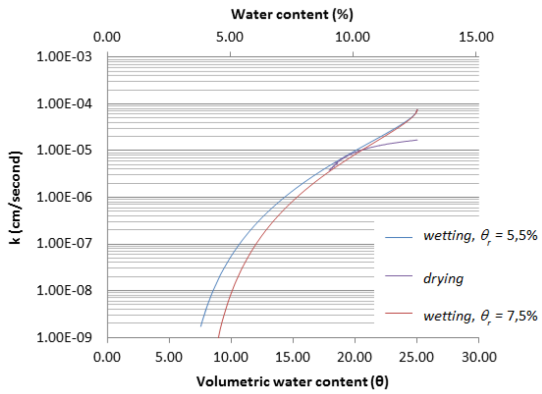

Fig.5 Unsaturated coefficient of permeability for sandy soil using constant discharge method

3.3. Soil permeability coefficient in unsaturated condition

The difference in saturated volumetric water content value and residual volumetric water content value in soil with different densities is less significant. From field testing result in unsaturated condition, the data showed that soil permeablity coefficient value in unsaturated condition is increasing along with the increment of volumetric water content due to less soil ability to flow water during initial wetting.

The amount of water which penetrated the soil during initial wetting filled soil pore cavities which were priorly filled with air before, so water could not pass through the soil. The determination of permeability coefficient value using VG model required some parameters which can be obtained through testing and modeling. The used parameters are θ_s, θ_r, dan n. In this research, comparison was made between the graph of k vs θ and variation of θ_r value as shown in Figure 5. The graph shows that the increasing value of θ_r resulted in more vertical curve and the decreasing value of θ_r resulted below the curve. The three curves are curve on wetting process which will be compared with curve of drying process as shown in Figure 5. It shows that curve of wetting procedure which has value of θ_r = 7,5% is fit well with curve of drying. The SM soil with θ_r = 7,5% is in very dry soil condition as [5].

The laboratory testing result in unsaturated condition was later compared to direct field testing result as shown in Figure 5. There are gaps between the value of field and laboratory permeability coefficient in unsaturated condition, resulting from field factors such as temperature and environment which are difficult to be kept under control. The soil around the testing point also influenced the field testing result.

3.4. Soil permeability mapping using ArcView GIS 3.3

The results obtained from overall testing were later procesed and analysed so spatial data such as soil types, permeability coefficient, and density were obtained to be used for mapping with geographic reference. For geospatial data which is field permeability coefficient were taken from testing and measurement result using instrument model and constant discharge procedure. Mapping result is displayed in Figure 6 and Figure 7.

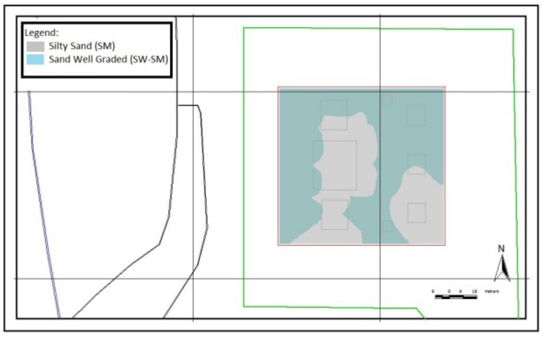

Fig.6 The result of soil types mapping at Prambanan Temple yard

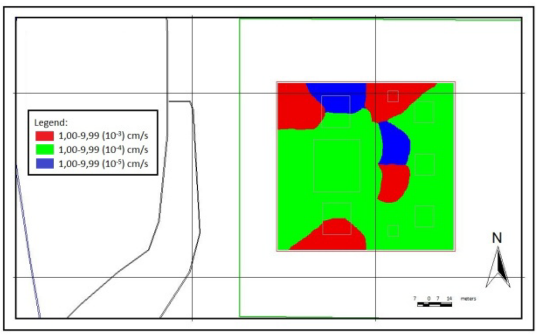

Fig.7 The result of simplified soil permeability coefficient mapping at Prambanan Temple yard

4. CONCLUSION

A simpler and more efficient field permeability test instrument model and testing procedure can be used to characterize soil permeability. The coefficient of permeability instrument model design and testing procedure developed in this research are quite effective, efficient, simple, and easy to implement in determining field soil permeability coefficient value for sandy soil. Using constant discharge instrument model design and testing procedure, soil permeability coefficient value in unsaturated condition (k_{unsat}) can be obtained without establishing Soil Water Characteristic Curve which requires preceding expensive matrix suction measurement.

Soil permeability characteristic of Prambanan Temple yard 1 which are permeability coefficient in saturated and unsaturated condition can be figured out through measurement result using both instrument model design and testing prosedure which are relatively fine and accurate. The correlation between permeability coefficient and volumetric water content (θ) from unsaturated to saturated condition for sandy soil can be discovered. Soil permeability coefficient value display in mapping using software ArcView GIS 3.3 which demonstrates the soil permeability condition and characteristic at Prambanan Temple yard.

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