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UTILIZATION OF BANTAK AND MERAPI VOLCANIC ASH FOR POROUS PAVING BLOCK AS DRAINAGE CONTROL IN THE PRAMBANAN TEMPLE YARD

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ABSTRACT: Ponding area occurred in the main yard of Prambanan Temple during rainfall is very bothering visitor activities. Some improvements have ever conducted but no longer effective. This paper shows the application of porous paving blocks to reduce the puddle. This porous paving block was made using waste materials from Mount Merapi eruption, such as bantak and volcanic ash. Volcanic ash was substituted for cement and bantak would replace the aggregate. Aggregate ratio used on this research is 1:5 and 0,4 for water-cement ratio. Characterization testing of porous paving block consists of density, compressive strength, porosity, and coefficient of permeability. The result shows that the optimum mixture of porous paving block is the mixture with 30% volcanic ash, strength capacity 6.05 MPa, porosity 28.4%, and coefficient of permeability 1.93 cm/s or 8 times faster than normal paving block and 18 times faster than the soil of Prambanan Temple yard. The infiltration analysis indicated that runoff level in the main yard of Prambanan Temple is 8.8 cm and ponding time is 3.2 hours. When using normal paving blocks, ponding can be reduced up to 81.6%, however when porous paving blocks was used, the ponding was not occurred because coefficient of permeability of porous paving blocks is faster than intensity rainfall at Prambanan Temple area (1.5×10^{-3} cm/s). From the evaluation of porous paving blocks strength against forklift load shows that total forklift load allowed to work on porous paving blocks is 9 tons' load.

Keywords: Bantak, Permeability, Porous Paving Block, Volcanic Ash

1. INTRODUCTION

Prambanan temple is the largest Hindu temple in Indonesia which is often visited by tourists, located on the boundary between Yogyakarta Special Region and Central Java. These last few years, the convenience in the main yard of Prambanan Temple is disturbed by ponding area that occurred in temple yard during rainfall. In general, Prambanan Temple yard consists of silty sand layer. Some improvement had been done with addition of a puddle layer above ground surface and drainage system improvements. The drainage system that is applied to the temple courtyard is horizontal and vertical recharge. At this time, the puddle layer is no longer effective due to soil compaction by accumulation of load visitors and heavy equipment activity during rehabilitation process after earthquake at 2006 that caused the ground contour of the First Yard cannot absorb the rain water well. The existing drainage and recharge system was not optimally functioned to reduce the puddle. Based on field observations in the main yard, the puddle still found after rainfall as shown in Figure 1.

One of the alternatives to reduce puddle in the main yard of Prambanan Temple is by application of porous media that can drain the water into the soil surface, which is porous paving blocks. This porous paving block is made by using waste materials from Mount Merapi eruption, such as coarse volcanic slag (bantak) and volcanic ash which until now not utilized optimally. Volcanic ash can be used as cement substitution to reduce the use of cement. Bantak would replace sand material that commonly used with diameter 10-20 mm. By using this porous paving block, it is expected to reduce the waste material and use it optimally. The result of this study are expected to be used as an alternative economic and environmental friendly construction material and also can absorb the water and reduce the puddle, especially for open parking area, local roads, sidewalks, and residential park area.


(a) (b)

Fig. 1 (a) Comparison of the conditions during the rainy season and (b) during the dry season

A study of the properties of the no-fines concrete using bantak as the aggregate was concted by [1]. The study used bantak aggregate size Ø 10-20 mm and Ø 20-40 mm. The ratio of cement and bantak were 1: 4 and 1: 6. The results of these studies indicate that the higher ratio of cement and bantak will be followed by the decreasing of the specific gravity and the compressive strength of concrete but porosity of the concrete was increased. Aggregate size also affects the result of porosity value, the larger the size of aggregate will be followed by the increasing of the porosity value. The test result using bantak with diameter size of 10-20 mm obtained the higher strength of no-fines concrete than bantak with diameter size of20-40 mm.

Based on [2], the research on the utilization of bantak Merapi and volcanic ash as a geo-structural material on the slope protection was conducted. Volcanic ash was used as much as 0%, 25%, 30%, 35%, and 40% by the weight of cement. The results showed that the addition of the volcanic ash in the concrete mix effect to the decreasing of the compressive strength and occurs the slow reaction of cement hydration. This reaction can happen due to the volcanic ash contains silica and alumina which does not have the typical properties of cement, but if the volcanic ash mixed with water it will react chemically with the calcium hydroxide to produce a compound of calcium silicate hydrate that has the same properties as cement and will be have a hardening process but this process takes longer than cement.

In normal concrete, the hydration reaction of cement reached the optimum at the age of 28 days and decreased at the age of 56 days. It can be seen from the compressive strength of concrete that reaches optimum at the age of 28 days, while at the age of 56 days, the increasing of compressive strength is not too significant. Unlike the pozzolan, i.e. volcanic ash, the reaction tends to be slow at 28 days, but it will increase significantly at the age of 56 days, so the optimum compressive strength of concrete with a mixture of volcanic ash reached at the age of 56 days. The optimum grain size volcanic ash that can be used as a substitute for cement is through sieve No. 270, because of the size of fine volcanic ash pozzolanic properties is getting stronger [3]

Based on [4] volcanic ash is a natural pozzolan which is required in chemical reaction in concrete mixture. The mineral compositions of volcanic ash that used in this research are given in Table 1. Volcanic ash from Merapi has dissolved heavy metal content below the threshold by Indonesian Ministri of Health in KEP 02/MENKLH/I/1988 for a list of criteria for water quality class D (safe water for agricultural purposes and can be used for urban businesses, industry and hydropower). Therefore, the volcanic ash was safely applied.

Table 1 Physical properties of volcanic ash

Mineral composition	Value (%)
Silica (SiO_2)	57.59
Alumina (Al_2O_3)	21.36
Calcium Oxide (CaO)	4.24
Magnesium Oxide (MgO)	2.26
Iron Oxide (Fe_2O_3)	5.89
Potash (K_2O)	3.32
Natrium Oxide (Na_2O)	4.10
LOI (Loss of Ignition)	0.96

2. METHODOLOGY

This research is located in the main yard of Prambanan Temple which has a square shape with a land area is about 12100 m^2 and a spacious courtyard of the temple of 3747 m^2. Research materials were disposed volcanic ash and bantak from Mount Merapi. Volcanic ash resulted from Merapi eruption in 2010, was taken from Glagaharjo, Cangkringan, Yogyakarta, Indonesia as shown in Figure 2. The volcanic ash was filtered and used as cement substitution that through sieve no. 270. There is still a lot of volcanic ash material in this Merapi area due to the eruption that frequently occur in this decade. Coarse volcanic slag or bantak is used as an aggregate in this experimental research. Figure 3 shows the coarse volcanic slag that was supplied from the sabodam quarry in Boyong River in Yogyakarta, Indonesia.

This material can be easily find near the sabodam quarry because the local people usually take the good aggregate material and leave the bantak material that have poor quality for building material. The aggregates obtained from the quarry were screened into 10-20 mm size fractions. Bantak was being washed, so that it does not contain sand or other organic substances that can reduce the quality of concrete, as well as in the dry saturated condition of the face (Saturated Surface Dry-SSD).

Fig. 2 Coarse volcanic slag (Bantak) quarry

Fig. 3 Volcanic ash

Concrete parameters would be used as a reference standard for concrete such as unit weight, porosity, permeability coefficient of no-fines concrete, and the uniaxial compressive strength. Initial testing that includes some laboratory testing such as soil properties testing to determine the coefficient of permeability of the soil, and also bantak and volcanic ash properties testing. Rainfall analysis data are analyzed using HAVARA program, the analysis will obtain the characteristics of rainfall that occurs at that location includes the duration and the intensity of rainfall for a certain period. The peak discharge of rainfall calculated by using Eq. (1).

$$Q_{peak} = 0{,}278CIA \tag{1}$$

Where Q is peak rainfall discharge, C is rational method coefficient, I is rainfall intensity and A is drainage area. Meanwhile the natural infiltration capacity calculated using Eq. (2) and Eq. (3).

$$Q_i = fA \tag{2}$$

$$f_i(t) = k\left(\frac{\psi\Delta\theta}{F_i(t)}\right) \tag{3}$$

Where Q_i is infiltration capacity, f is infiltration velocity, A is area, k is hydraulic conductivity, F_i is cumulative amount of infiltrated water, ψ is suction, and $\theta\Delta$ is difference between porosity with initial soil moisture.

Then, the result of rainfall analysis is used as input to calculation of infiltration and runoff. Calculation of porous paving blocks mix design, volcanic ash is substituted of cement as much as 25%, 30%, and 35% of the weight of cement, bantak is used with diameter 10-20 mm, and water-cement ratio was used of 0.4. One method to determine infiltration capacity on flat ground surface is Green-Ampt Method. Reference [5] developed a physical theory approach which can be solved with exact analytic equations (Exact Analytical Solution) to determine the infiltration. Infiltration by Green-Ampt is a function of the soil hydraulic parameters, i.e. permeability, suction head, and soil moisture. These parameters closely linked to the physical characteristics of the soil. The relationship between the two characteristics of the soil can be formulated through empirical research.

In the approach, the Green-Ampt express terms of wetting front, which is a clear boundary between soils with certain humidity in the basement with saturated soil on it. Wetting front is contained at a depth L is reached at time t as [6] shown in Figure 4.

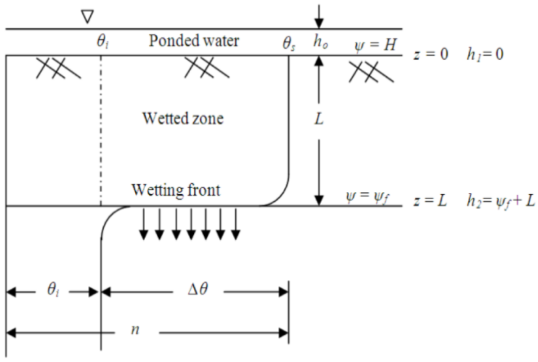

Fig. 4 Green-Ampt infiltration method [6]

In this approach, the volume control of soil column used as the unit of analysis which is limited by the surface area and depth L. Water that entering into the soil will increase the soil moisture. Added water as the result of infiltration to a unit volume can be seen in equation (4) and (5) which is referred to as the cumulative infiltration (F_t) and infiltration velocity, *f(t)*.

$$F_t = kt + \psi\Delta\theta \ln\left(1 + \frac{F_t}{\psi\Delta\theta}\right) \tag{4}$$

$$f(t) = k\left(\frac{\psi\Delta\theta}{F_t} + 1\right) \tag{5}$$

Where F_t is cumulative infiltration (mm), f (t) is infiltration velocity (mm/hour), $\boldsymbol{\psi}$ is suction head, $\boldsymbol{\Delta\theta}$ is difference between porosity (η) and initial water content (q) and k is soil permeability (cm/s).

The test that conducted in this research such as compressive strength test, permeability test and porosity test of no-fines concrete sample. The amount of sample that use in each test is 9 samples for every variation of volcanic ash. The total sample for each test is 81 samples.

Fig. 5 Acrylic box for modeling of permeability test

The next step is manufacture test specimen, and curing time of test specimens are immersed in water for a certain age. Modeling of permeability testing to original soil in the main yard of Prambanan Temple, porous paving blocks, and normal paving blocks in an acrylic box measuring 50×50 cm^2 (Figure 5) based on constant-head concept. The results of this modeling are used to determine how the effects of the utilization porous paving blocks on original soil in the main yard of Prambanan Temple in an effort to reduce runoff.

3. RESULTS

Rainfall duration are obtained from the 4 nearest rain gauge station from 1998 through 2012 amounted to 2.375 hours, and from the frequency analysis, design of rainfal rate is selected by annual return period 2 years which is 54702 mm. Based on the analysis of soil grain size, the obtained coefficient of permeability in the main yard of Prambanan Temple is $5.8×10^{-4}$ cm/sec. Based on the infiltration capacity (*F*) on the area is 4.195 cm, while the amount of infiltration rate is 2.712 cm/hour. Runoff that occurred in the area was obtained equal to 8.798 cm, and the required time by runoff to absorb into the soil until the ground surface become to dry is obtained equal to 3.244 hours. Therefore, it is needed a porous media that is able to drain rain water more quickly so that runoff will not occur.

The specific gravity of bantak aggregate is smaller than the normal aggregate but it can absorb water higher. Specific gravity of bantak aggregate based on the test result is 2.449, so it can be classified as light aggregate [7]. The result of the technical parameter of bantak Merapi shown in Table 2.

Based on the technical parameters testing of bantak Merapi, bantak material has pore cavity of 41%. This porous paving blocks uses bantak Merapi with diameter 10-20 mm and uniform gradation to make an interconnected pore so that the result will have the characteristic of porous concrete, which has a good porosity and permeability. It can be seen the difference with normal paving blocks as shown in Figure 6 where porous paving blocks has pore cavity larger than normal paving blocks, so that the water can rapidly passed through the cavities.

This study uses the same volcanic ash material with [2]. Based on the results compared with [7] about specification of pozzolan, volcanic ash included in pozzolan type N, with a specific gravity value of 2.606 g/cm^3, this value is lower than the average specific gravity of cement that is 3.15 g/cm^3, so it will greatly affect the strength of the structure. The effect of utilization of volcanic ash as a cement substitute for the porosity and permeability of porous paving blocks can be seen in Table 3.

Table 2 Technical parameter of bantak Merapi

Parameter	Nilai
Loose unit weight, kN/m3	13.60
Dense unit weight, kN/m3	15.07
Specific gravity	2.449
Specific gravity SSD*	2.562
Water absorption, %	4.605
Water content, %	4.402

**SSD = Saturated Surface Dry*

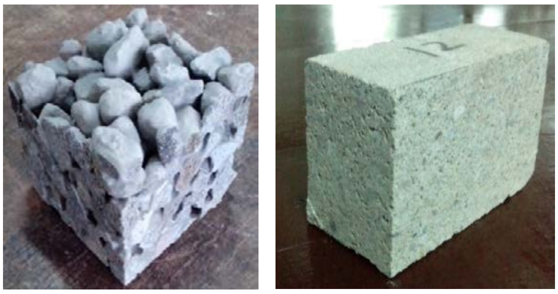

Fig. 6 Porous paving block (left) and normal paving block (right)

Table 3 Porosity and permeability of porous paving blocks and normal paving blocks

Variation of Volcanic Ash (%)	Average porosity of Porous Paving Block (%)	Average porosity of Normal Paving Block (%)	Permeability of Porous Paving Block (cm/sec)	Permeability of Normal Paving Block (cm/sec)
25	26.88		1.76	
30	28.40	2.05	1.93	$7.6×10^{-3}$
35	28.11		1.96	

Based on the Table 3, it can be seen that the addition of volcanic ash variation and utilization of bantak Merapi are able to increase the percentage of the porosity and the permeability of paving blocks. Based on [8], porous paving blocks in this study have fulfilled the requirements of porous concrete with a porosity of 15-35%. The porosity of porous paving block is equal to 14 times greater than porosity of normal paving block. Table 3 shows that the increasing value of the coefficient of permeability (*k*) for each variation of volcanic ash is not very significant, but the increasing value of *k* is very large compared to normal paving blocks. The increasing of porosity will decrease the compressive strength of paving blocks. The compressive strength and density of porous paving blocks in this study and their comparison with normal paving blocks are presented in Figure 7.

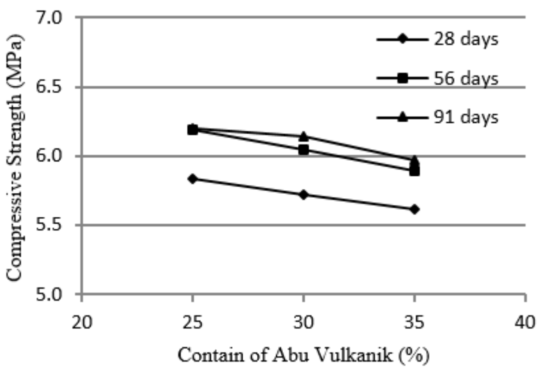

Fig. 7 The effect of volcanic ash addition to compressive strength of porous paving block

Based on Figure 7 it can be seen that the variation of 25%, 30% and 35%, the compressive strength of porous paving blocks decreases with the addition of volcanic ash, and the optimum mix design is a variation of volcanic ash with 30% of the cement weight, even if the technical properties are not much different from the variation 25%, more volcanic ash content will give more economically and environmentally benefits. Compressive strength of normal paving blocks in this study is 25.51 MPa and the compressive strength of porous paving blocks is 6.05 MPa, so the value of compressive strength decreased amounted to 76.28%, it is not qualified to use as a normal road pavement with a minimum compressive strength of 8.5 MPa as specified in [9].

According to [8], this porous paving block has been categorized as porous concrete because the compressive strength generated are in vulnerable 2.8 to 28 MPa, so that to use as a residential parks and sidewalks can be applied. The addition of volcanic ash and utilization of bantak are able to reduce the density of porous paving blocks up to 25.1% than normal paving blocks (0% volcanic ash), this happens due to the density of volcanic ash material is lower than cement.

4. DISCUSSION

The results of the modeling to determine the coefficient of permeability and hydraulic properties of the original soil material from the main yard of Prambanan Temple, porous paving blocks, and normal paving blocks can be seen in Table 4. Based on the modeling results that shown in Table 4, coefficient of permeability of porous paving blocks is 8 times faster than normal paving blocks and 18 times faster than the soil of Prambanan Temple yard.

Infiltration analysis indicates that runoff level on Prambanan Temple yard was 8.8 cm and ponding time was 3.2 hours. If using normal paving blocks, runoff can be reduced until 81.6% with a shorter time, but if using porous paving blocks, runoff would not happen because coefficient of permeability of porous paving blocks was faster than intensity rainfall at Prambanan Temple area (1.5×10^{-3} cm/s). Soil with porous paving blocks on it has coefficient of permeability faster than soil without porous paving blocks, therefore the rain water is able to drain by porous paving blocks without runoff so it is not interfering the visitor activities around temple.

Table 4 Comparison of the hydraulic properties of the soil material, porous paving blocks, and normal paving blocks

Parameters	Soil material	Normal paving blocks on groups	Porous paving blocks on groups
Coefficient of permeability, *k* (cm/sec.)	5.8×10^{-4}	1.3×10^{-3}	1.1×10^{-2}
Infiltration capacity, *F* (cm)	4.2	11.4	-
Infiltration rate, f_t (cm/hour)	2.7	5.1	-
Runoff, R_{off} (cm)	8.8	1.6	-
Ponding time, t_g (hour)	3.2	0.3	-

In this study, evaluation of the porous paving blocks strength against the forklift load was also done. The input calculated load is the weight of forklift with its maximum capacity. This evaluation was conducted to determine the maximum load of forklift that is allowed to work on the porous paving blocks which have compressive strength of 6.05 MPa. The calculation shows that the forklift is allowed to work on porous paving blocks is a forklift with a maximum total load of 9 tons with the needs of the compressive strength of porous paving blocks at 5.63 MPa, for forklift with a total load greater than 9 tons are not allowed to work on this porous paving blocks because it requires compressive strength of porous paving blocks more than 6.05 MPa.

A similar study about the utilization of bantak and Merapi volcanic ash with the same ratio was also done by [4] to create a non-sand concrete as porous drainage. The study result was non-sand concrete with compressive strength of 9.6 MPa, that value is higher than the porous paving blocks. Based on the value then the non-sand concrete with a mixture of bantak and volcanic ash is able to withstand the total load of forklift up to 15 tons with compressive strength of 9.38 MPa is needed. The difference of the compressive strength values from the two studies are due to the cutting samples of porous paving blocks before compressive strength testing, so that the bond between the bantak material of paving blocks is reduced, and this is also due to the negation of sand as a filler material between the gap of bantak so the yield is lower compressive strength.

5. CONCLUSION

Based on the modeling results, the soil of Prambanan Temple Yard with the use of porous paving block on it has a coefficient of permeability value faster than the soil without the use of porous paving block so it can effectively accelerate the absorption of rainwater. Thus the rainwater able to be drained into the ground surface without any runoff that interferes the activity of the visitors. The porous paving blocks strength can be able to against forklift's load showed that total load of forklift that have maximum 9 tons. The porous paving block is already included in the category of porous concrete and its use as a residential parks and sidewalks. This no-fine concrete also safe to be applied because the composition of the material is still on the safety limit, so it can be applied as paving block in Prambanan Temple yard. Utilization of bantak and volcanic ash for no-fine concrete can effectively reduce the amount of waste material in riverside.

6. ACKNOWLEDGEMENTS

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