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DRAINAGE SYSTEM OF PRAMBANAN TEMPLE YARD USING NO-FINE CONCRETE OF VOLCANIC ASH AND BANTAK MERAPI

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ABSTRACT: This paper focuses on the potential utilization of volcanic ash and coarse volcanic slag for no-fine concrete for drainage structure of Prambanan temple yard. This material produced from volcanic eruption also becomes environmental important issues as waste material if it is not effectively reduced or reused. Coarse volcanic slag is commonly known by local people as *Bantak.* The experimental study was conducted to determine engineering properties of no-fines concrete materials and discharge capacity of drainage system was calculated to identify the optimal dimensions of the drainage channel. In addition, a numerical analysis was carried out using SAP2000 and Plaxis to control structure stability. Based on numerical and experimental study, the utilization of no-fine concrete from volcanic ash and *bantak* by using certain mix design can be used as a porous drainage structure. By utilizing the eco-friendly material as structural material, the originality of the building will not be disturbed.

Keywords: Volcanic Ash, Coarse Volcanic Slag, No-Fines Concrete, Drainage System, Prambanan Temple Yard

1. INTRODUCTION

As one of UNESCO World Heritage, Prambanan Temple is the largest Hindu temple in Indonesia that needs to be preserved, maintained, and conserved. Due to heavy equipment activities during renovation period after Yogyakarta earthquake in May 2006, soil in the temple yard has become dense, and ponding often occurred during rainfall as ilustrated in Figure 1. This condition shows that existing drainage system is not sufficient and needs more effort to organize and improve the drainage systems in the First Yard of Prambanan Temple.

The water flow in the soils has a significant influence in any civil engineering project, especially related to drainage system. Reference [1] shows the pore space in the soil or rock is a very influential factor in hydrogeological problems, because the water or its movement occured in the pore space. Water flow appearing in the soil is normally occured because of the interconnection of pore spaces or cracks and this is the potential ability of soil/ rock to drain water.

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. Ditch or channel is an effort to collect and control water run off in the saturated soils condition. The functions of porous media are both as a drainage medium and a filter to separate suspension particles from water, so the particles won't be carried away with the water flow.

Reference [2] shows that the use of clay and concrete as impermeable media is a misconception because the water still flows through the exposed surface of the material, but the water does not seep significantly due to the low permeability of materials. No-fine concrete is one of concrete type that use a little or even zero fine aggregate material, so it has more pores than normal concrete. No-fine concrete aggregate increase permeability and reduce the proportion of cement, but the compressive strength value obtained is lower than normal concrete.

Fig. 1 Ponding area in Prambanan Temple Yard

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One of the alternatives to reduce post rain-puddle in Prambanan temple yard is by application of no-fine concrete as drainage structure regarding to the ability to drain of water, so the application of the concrete will not lead reduction of the soil shear strength due to long time inundation of land surface. The aggregate developed in this study was the Merapi eruption material. Merapi eruption material is used because of the easiness to find these materials in large quantities along the river and the ineffectiveness of utilization of this material. This material is low quality of porous gravel (*bantak*) and volcanic ash.

Coarse volcanic slag is commonly known by the local people around Merapi volcano, Yogyakarta, Indonesia as *bantak*. *Bantak* are the materials product from the eruption of a volcano together with sand, which represent lightweight gravel. *Bantak* is a gravel sized as a waste material of sand mining. Based on the research conducted at the Department of Civil and Environmental Engineering UGM, structurally, *bantak* has low structural strength, so it is not too familiar for building materials.

Indonesia is one of the most countries that has a number of active volcanoes. Eruption often occurs with high intensity. Spilled lava and volcanic material out from core of the earth makes the area around the volcano has a thick layer of volcanic ash. A lot of volcanic material will become important environmental issues as a waste if it is not effectively reduced or reused. Literatures related with characterization and utilization of volcanic ash and coarse volcanic slag in geotechnical field are limited. It becomes a new approach in a view of environmental aspect.

This study focuses on replacement of cement and coarse aggregate with volcanic ash and *bantak* to produce more economical and eco-friendly concrete product. The results of this research are expected to be able to contribute on engineering practice as well as give advantages in geo-environment view. Study and analysis on no-fine concrete as a drainage structure are described and discussed.

2. MATERIAL AND RESEARCH METHOD

This research is located in the first yard of Prambanan Temple, which is the highest point of the series of Prambanan Temple Yard as shown in Figure 2. The land area is about 110 meters by 110 meters and a spacious courtyard of the temple of 3747 m^2. According to [3] the stratification of the soil in Prambanan temple yard is silty sand. Some improvements have conducted in the first yard by addition of a puddle layer on top of the original soils and drainage system improvements. The drainage system applied in the temple courtyard was horizontal and vertical recharge.

Research materials were disposed volcanic ash and bantak from Mount Merapi. Volcanic ash resulted from Merapi eruption in 2010, was taken from Cangkringan, Yogyakarta, Indonesia as shown in Figure 3.

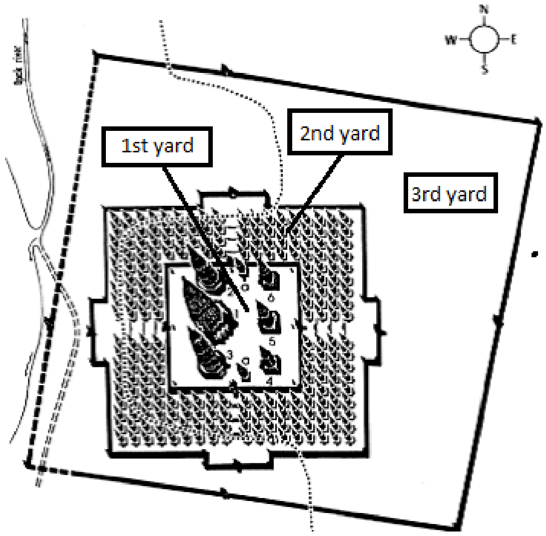


Fig. 2 Site plan of Prambanan Temple Yard (1st, 2nd, and 3rd yard)

The used material size of volcanic ash is the material which passed by sieve number 270. 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 KEP 02/MENKLH/I/1988 (Indonesian health ministry regulations) 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

Fig. 3 Volcanic ash material

Fig. 4 Coarse volcanic slag (*bantak*)

Table 2 Physical properties of coarse volcanic slag *(bantak)*

Parameters	Value	Unit
Loose unit weight	1360.22	kg/m^3
Compacted Unit weight	1507.61	kg/m^3
Specific gravity	2.49	-
Specific gravity in SSD	2.56	-
Water absorption	4.61	%
Water content	4.40	%
Abrasion	54.75	%

Coarse volcanic slag is used as an aggregate in this experimental research. Figure 4 shows the coarse volcanic slag that was supplied from the quarry in Boyong River, Yogyakarta, Indonesia. The aggregates obtained from the quarry were screened into 10-20 mm size fractions. Table 2 shows the physical properties of coarse volcanic slag. In this study percentages of volcanic ash which added into the concrete mix design were 0% and 30%. 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.

Rainfall analysis data was determined by using HAVARA program. The analysis obtained the characteristics of rainfall that occurs at the location including the duration and the intensity of rainfall for a certain period. The hourly rainfall data from four rain gauges around the study area for a time period from 1998 to 2012 were used. 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).

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

$$f_i(t) = k\left(\frac{\psi\Delta\theta}{F_i(t)} + 1\right) \tag{3}$$

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 θD is difference between porosity with initial soil moisture.

Then, the result of rainfall analysis is used as input to calculatee the drainage capacity. At this stage the analysis of the suitability of the rain discharge (Q_l) and discharge channel (Q_f) was done. If obtained $Q_l \geq Q_f$, then the redesign of trench or channel should be done. However, if $Q_l \leq Q_f$, it only needs to take some improvement, one of the improvement methods with proposed drainage channel from *bantak* and volcanic ash.

Reference [4] Dimension of the channel was determined by trial and error using Eq. (4).

$$B' = \frac{-fkT}{nb\left\{ln\left(1-\frac{fkH}{Q}\right)\right\}} \quad (4)$$

f is geometric factor which calculated by Eq. (5).

$$f = \frac{4H + 4\sqrt{bB}ln2}{ln\left\{\frac{H+4\sqrt{bB}}{6\sqrt{bB}} + \sqrt{\left(\frac{H}{6\sqrt{bB}}\right)^2 + 1}\right\}} \quad (5)$$

Where B is length of the channel, k is permeability coefficient, T is rainfall duration time, n is porosity of material, b is channel width, H is depth of the channel, and Q is discharge capacity. According to [5] the seep discharge into the channel (Q_f) calculated by using Eq. (6).

$$Q_f = A.V_x \quad (6)$$

If the concrete channel wall were added by no-fine concrete, with $Q_1 = Q_f$, can be obtained by the minimum hydraulic conductivity value of no-fine concrete material that must be provided to the walls of the channel can be calculated using Eq. (7).

$$k_f = \frac{Q_f}{\sin\alpha\, .\, t_f} \quad (7)$$

Analysis result obtained the optimum distance between adjacent channels, water discharge that was able to enter into the channel and the minimum thickness of the channel. Based on [5] the optimum distance between two channels calculated by using Eq. (8). The representation of the subsurface flow can be seen in Figure 5.

$$S = \left[\frac{4kh_{max}}{i}\left(h_{max}{}^2 - h_w{}^2 + 2dh_{max} - 2dh_w\right)\right]^{\frac{1}{2}} \quad (8)$$

The numerical analysis were carried out using SAP2000 and Plaxis assuming the drainage structure as a plain strain model in Plaxis and frame model in SAP2000. Calculation analysis about the strength of the structure channel is based on the result of the simulation using Plaxis and SAP2000 programs.

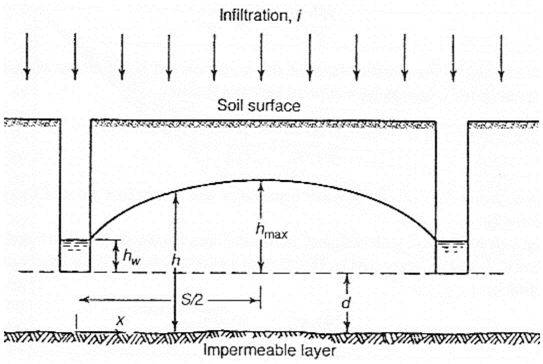


Fig. 5 The representation of the subsurface flow into the channel

3. RESULT AND DISCUSSION

Table 3 shows the drainage system applied to the first yard of Prambanan temple has not been effective enough to accommodate the flood discharge that occurs on this area. There is residual discharge resulted the ponding area in Prambanan Temple yard. Therefore an improvement of drainage system, either in the form of new canals or drainage management arrangement on the drainage system, is needed to solve this problem. Based on field observations, horizontal recharges system is not functioning properly. The number of puddle distribution locations above the horizontal recharges system indicates this. The total amount of discharge (Q) used in a cross-sectional dimension of planning control in the channel is 4.63×10^{-3} m^3/sec. This value represents the difference discharge of rain that fell in the area of the temple courtyard to natural infiltration capacity land and total discharge vertical infiltration.

The value of total run off represents the difference between the natural discharge of rain that fell in the temple courtyard and the total discharge of vertical recharge. Based on these considerations, the length of channel is determined to be planned in accordance to the existing total length of recharge channels. By trial and error using Eq. (4), the acquired new channel dimension is 0.40 meters by 0.40 meters.

Table 3 Recapitulation of drainage capacity analysis

Parameter	Value	Unit
Vertical infiltration	7.67×10^{-4}	m^3/s
Horizontal infiltration	2.70×10^{-3}	m^3/s
Total runoff	3.47×10^{-3}	m^3/s
Peak rainfall discharge	4.70×10^{-2}	m^3/s
Natural infiltration capacity	4.16×10^{-2}	m^3/s
Residual discharge	1.93×10^{-3}	m^3/s
Total amount of discharge	4.63×10^{-3}	m^3/s

Table 4 Engineering properties test result of no-fine concrete

Parameter	Value	Unit
Volcanic ash percentage	30	%
Porosity	10.03	%
Compressive strength (28 days)	9.61	MPa
Elastic modulus	2480	MPa
Density	2065	kg/m^3
Permeability	1.33×10^{-3}	m/s

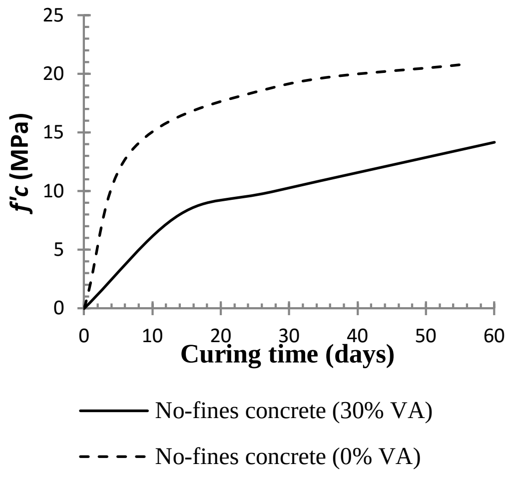


Fig. 6 Correlation of curing time with compressive strength

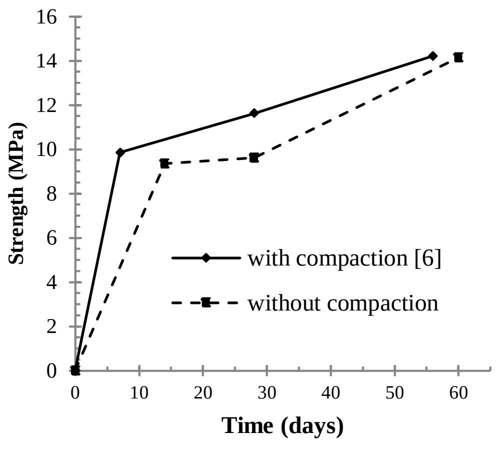


Fig. 7 Influence of the concrete compaction to increased strength

Effect of Merapi eruption material to concrete parameters such as porosity, compressive strength, and modulus of elasticity of no-fine concrete can be seen in Table 4. Based on laboratory tests, the unit weight of no-fine concrete (*Bj*) obtained at 2065 kg/m^3, or in other words, no-fine concrete has successfully produced according to SNI 03-2847-2002, the obtained value from the test can be categorized as lightweight concrete, because of the value of Bj < 2200 kg/m^3.

The relationship of concrete curing period for concrete compressive strength is shown in Figure 6. It shows that with the same mixture, the trend of increasing no-fine concrete strength will continue to increase with increasing curing time, as well as to the relationship of no-fine concrete strength against compaction energy applied. Based on Figure 7, the compaction energy derived from the comminution process greatly affects the strength of the concrete. However with longer curing time, no-fine concrete strength is relatively the same. The permeability coefficient of no-fine concrete generated in this study amounted to 1.33×10^{-3} m/sec.

From the Eq. (6), the seep discharge into the channel is Q_f = 1.49×10^{-5} m^3/sec. If the channel wall of concrete walls were added with no-fine concrete, the analogy, with Q_1 = $Q_{f,}$ can be obtained by the minimum hydraulic conductivity value of no-fine concrete material that must be provided to the walls of the channel at 1.49×10^{-4} m/s. The permeability coefficient value of no-fine concrete applied to channel wall is 1.33×10^{-3} m/s then the media will fulfill the qualification as a drainage layer. However, this condition does not make this qualified as a filtration function, so it is still necessary to carried soil particles into the channel.

Further evaluation of reviews, these calculations were added to determine the channel spacing of subsurface drain. The optimum distance between adjacent channels is 7.50 m. To anticipate the drainage system damage due to structural failure, it would require some evaluation of loading models. Numerical analysis were performed to determine the effectiveness of Merapi eruption material for drainage channel. The proposed typical channel model proposed can be seen in Figure 8. Representation of working load location on the ground surface illustrated in Figure 9. In this analysis, simulations were assumed on the location of the ground level water table (the most critical condition).

Figure 10 shows a comparison of the bending moments value occured in the channel structure due to the influence of forklift movement and groundwater pressure from SAP2000 and Plaxis simulation. The calculation results for the thickness of channel structure are shown in Table 5. It presents that the maximum channel structure moments when loading of Condition 2 was applied (see Figure 9), then it was used as a parameter value to determine the minimum thickness of channel structure. The minimum thickness required of the channel is 0.05 m. Results of numerical analysis can be seen in Table 5.

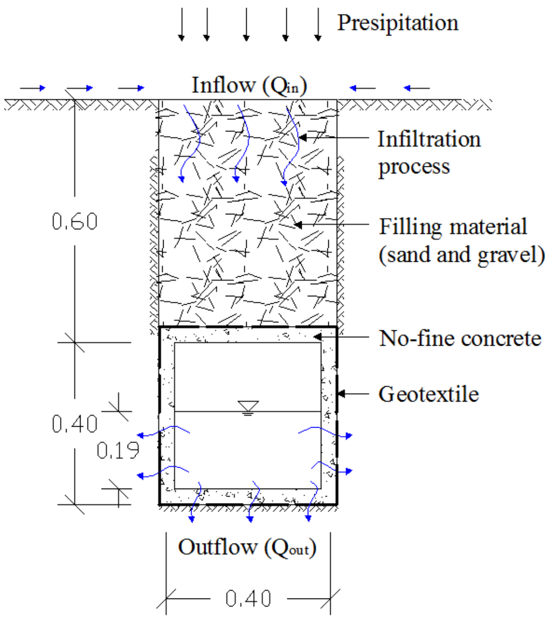


Fig. 8 The proposed drainage system

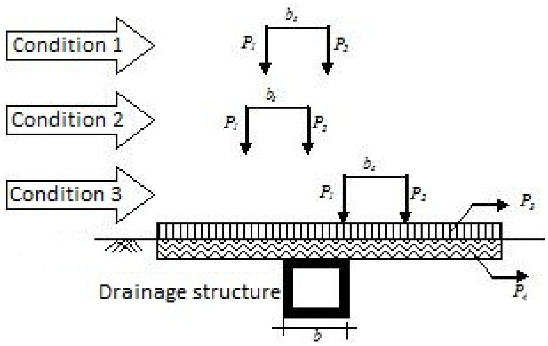
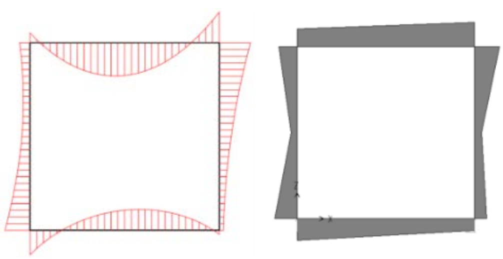


Fig. 9 Scheme of loading models on the ground surface



(a) (b)

Fig. 10 Moment of channel structure simulate in (a) Plaxis and (b) SAP2000

Table 5 Results of numerical analysis

Load	Displacement (m)	M_{max} (kN.m)		Min. thickness (m)
		SAP2000	Plaxis	
1	1.63×10^{-3}	0.28	0.30	0.03
2	6.79×10^{-4}	0.56	0.56	0.05
3	6.63×10^{-3}	0.54	0.44	0.04

From the hydrological analysis and evaluation of the channel structure calculations, the typical channel model that can be applied to the first yard of Prambanan Temple is subsurface channels with the addition of filter media in the form of non-woven geotextile to avoid clogging by fine soil particles. Theoritically, the silty sand soil in Prambanan Temple yard has a low-capability of draining water (small permeability value). To avoid the impairment of soil hydraulic conductivity (k) caused by the visitor activities and the heavy equipment movements, layers formed of gravel and sand should be added on the top of slab channel to make the water completely seep into the channel.

4. CONCLUSION

Drainage system of Prambanan Temple yard using no-fine concrete as a porus media with volcanic ash and coarse volcanic slag are presented. The utilization of volcanic material is purposed to reduce cement need on drainage construction, which leads to global environmental problem. The experimental study was conducted to determine the optimum mix design and the engineering properties of the material. The discharge capacity of drainage system also was calculated to identify the optimal distance of two ditches. In addition, numerical analysis was carried out using SAP2000 and Plaxis to control structure stability.

The value of natural soil infiltration capacity at first yard of Prambanan Temple is of 4.16×10^{-2} m^3/sec, whereas maximum rainfalls discharge of 4.7×10^{-2} m^3/sec. This condition shows that existing drainage system was not sufficient and still need improvement using porous media of no-fine concrete. The optimum distance between adjacent channels is 7.50 m with channel dimensions of 0.4 m by 0.4 m at depth of 1.00 m as typical proposed channel model. The value of no-fine concrete permeability using volcanic ash and *bantak* is 1.33×10^{-3} cm/sec. Meanwhile, the seep discharge into the channel has smaller value than permeability of concrete that is 1.49×10^{-4} cm/sec. According to this statement, the proposed drainage system of volcanic ash and *bantak* shows that no-fines concrete material has fulfilled the qualification as a material for drainage layer.

Based on numerical analysis and experimental study, the utilization of no-fine concrete from volcanic ash and *bantak* by using certain mix design can be used as a porous drainage structure. This can be seen from the strength of no-fine concrete based on numerical modelling and the ability to drain the water. The proposed drainage structure is very eco-friendly because the use of waste material is surely compatible to be used as structural improvement for historical site such as Prambanan Temple. By utilizing the eco-friendly material as structural material, the originality of the building will not be disturbed.

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