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SLOPE STABILITY ANALYSIS DUE TO INFRASTRUCTURE DEVELOPMENT OF RATU BOKO SITE YOGYAKARTA INDONESIA UNDER EARTHQUAKES LOADING

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The Ratu Boko site is a cultural heritage that has a high historical value and located about 30 kilometers to the east of Yogyakarta. Instability of the slope occurred due to the Yogyakarta earthquake in 2006, and it was indicated by the occurrence of cracks in the resto building that built on the top of the hill. The first reinforcement of the columns and foundations of the outside building was used a reinforced concrete that built-in 2012. The similar reinforcement on the inside building column and foundation was finished in 2017. In this research the displacement of the reinforced foundation, and slope stability generally both in safety factor and deformation were evaluated. The deformation and displacement analysis of the foundation were solved using Finite Element Analysis. On the other hand, for the safety factor of the slope, Limit Equilibrium Method was used. The simulation is divided into several stages, starting from the existing condition, after the first and second reinforcement, and also after increasing load due to development plan. Based on the numerical simulation, the horizontal displacement on the foundation of Plaza Andrawina decreases after the first and second reinforcement was installed. The horizontal displacement is significantly decreased in both foundations for 9.44 mm and 8.03 mm. Furthermore, the safety factor of the slope increases after the first and second reinforcement was installed. The slope safety factor using a maximum acceleration of 0.30g is 1.318. These obtained results are relatively safe from slope failures.

Key words: Yogyakarta, Indonesia, reinforcement, slope stability, safety factor

INTRODUCTION

Yogyakarta is an area that contains special features in terms of society, nature, and culture. One of the most prominent feature is Cultural Heritages which have a high historical value and can still be visited to this day. One of the cultural heritage in Yogyakarta is the Ratu Boko Site located in the hill, District of Prambanan, Sleman Regency, Special Region of Yogyakarta Province, Indonesia [1], [2].

In order to improve the benefit of the Ratu Boko Site, the development of infrastructure is needed. Some of the development ideas that will be carried out are the utilization of the second floor of Plaza Andrawina as a service facility (room, restaurant expansion). In addition, the lower part of the Plaza Andrawina slope will be used as visitor parking buildings.

Due to the Yogyakarta Earthquake in 2006 with 5,9 Mw, cracks were found on the beam and column joint, partial retaining walls, and open pipe connections, especially on the continuous connections with the slopes in Plaza Andrawina building as illustrated in Fig. 1 [3]. It can be considered that the crack occurred in the building as a result of slope instability. At the moment, to reduce the displacement of the slope, varying reinforcement has been installed in Plaza Andrawina. All of the reinforced foundations were installed until the breccia rock layer in the slope.

Mass movement occurred due to the unstable slope conditions. According to [4], [5], [6], [7], [8], [9] the main reason of slope failure is the shear stress due to the load acting on the slope beyond the shear strength of the soil, or in mathematically analysis, based on the criteria of Mohr-Coulomb failure illustrated as.

$$\tau_d > c + \sigma \tan\varphi$$

Where c is cohesion (kN/m^2), φ is angle of friction (°), σ is normal stress (kN/m^2), τ is shear strength (kN/m^2), and τd is shear stress (kN/m^2).

The safety factor for various rock types with various problems has been explained [10]. The safety factor of slopes can be seen in Table 1. In addition, the safety factor criterion for the slope's soil, which is shown in Table 2 was explained by Das 2002 [11].

Previous researchers [12], [13], [14] have analyzed the slope and retaining wall stability around the Ratu Boko site area. The focus points are the effect of changes in

Figure 1: Some cracks on Plaza Andrawina

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Table 1: Safety Factor of Rock Slop

Safety factor (SF)	Meaning
SF < 1	Unstable rock slope
1 ≤ SF < 1,5	Critical slope
SF ≥ 1,5	Stable slope

Table 2: Safety Factor of Soil Slope

Safety factor (SF)	Meaning
SF < 1,07	Unstable slope
1,07 ≤ SF ≤ 1,25	Critical slope
SF ≥ 1,25	Stable slope

the water content and increasing load due to the development plan in the slope. However, the displacement of the foundation and slope stability at Plaza Andarwina building after increasing load due to the development plan has never been studied. Through this paper the displacement of the foundation after reinforcement and the slope stability generally both in the safety factor and deformation was evaluated. The deformation and displacement analysis of the foundation were solved using Finite Element Analysis. On the other hand, the safety factor of the slope using the Limit Equilibrium Method.

METHODOLOGY

Slope Properties

In order to interpret the stratigraphy of slope, the core drilling and Cone Penetration Test (CPT) have been carried out. It was found that the slope layer profile consist of clay from 0-2.70 m depth in the first layer, with the average value of N-SPT is 9. In the second layer of medium tuff sandstone from 2.70 – 6.00 m depth, where in this layer the average value of N-SPT is 37. The next layers are breccia of pumice, sandstone tuff, and clay, where the value of N-SPT is more than 60 for these three layers of rock. A sample of breccia rock from the excavation in the field is shown in Fig. 2. Furthermore, the Interpretation of the slope stratigraphy, based on the core drill and excavation in the field as illustrated in Fig 3.

Figure 2: Breccia rock in 6.00 m depth

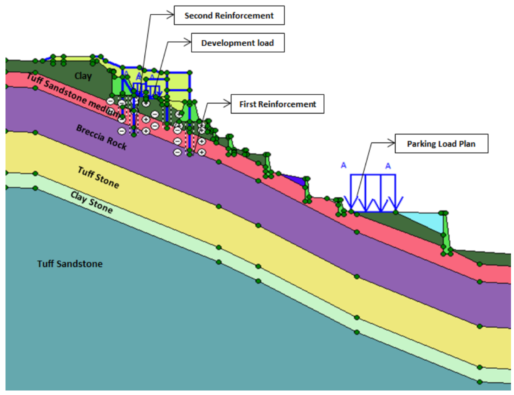

Figure 3: Cross Section of the Slope [15]

Table 3: Parameters of Soil and Rock from Laboratory Testing [15]

Materials	Models	Type	γ_b (kN/m^3)	γ_{sat} (kN/m^3)	k_x (m/day)	k_y (m/day)	v	E (kN/m^2)	c (kN/m^2)	φ (º)
Clay	Mohr-Coulomb	*Undrained*	15,5	16,4	0,0002	0,0002	0,30	40.530	56,898	17,04
Tuff Sandstone medium	Mohr-Coulomb	*Drained*	14,0	16,8	13,651	13,651	0,25	45.325	30	30
Breccia rock	Mohr-Coulomb	*Undrained*	13,2	16,2	0,001	0,001	0,2	49.988.750	44.989.875	57,9
Tuff Sandstone	Mohr-Coulomb	*Drained*	14,3	16,7	10,002	10,022	0,2	44.989.875	24.994.375	66,5
Clay stone	Mohr-Coulomb	*Undrained*	15,0	19,0	0,0002	0,0002	0,2	49.988.750	44.989.875	66,5
Tuff Sandstone	Mohr-Coulomb	*Drained*	14,5	17,0	5,011	5,011	0,2	49.988.750	44.989.875	66,5
Soil Embankment 1	Mohr-Coulomb	*Undrained*	15,899	16,385	1×10^{-6}	1×10^{-6}	0,3	25.000	16,46	25,58
Soil Embankment2	Mohr-Coulomb	*Undrained*	16,746	16,961	1×10^{-6}	1×10^{-6}	0,3	25.000	12,4	40,24
Soil Embankment3	Mohr-Coulomb	*Undrained*	17,67	17,67	1×10^{-6}	1×10^{-6}	0,3	25.000	1,53	44,62
Soil Embankment4	Mohr-Coulomb	*Undrained*	17,75	17,76	1×10^{-6}	1×10^{-6}	0,3	25.000	14,43	49,39
Soil Embankment5	Mohr-Coulomb	*Undrained*	12,0	15,0	0,0002	0,0002	0,3	2.000	15	6

Numerical Analysis Plaxis and Slope/W

In this research, deformation analysis of the foundation was solved using Finite Element Analysis with Plaxis software. This software is a two dimensional finite element program, developed for deformation, stability and groundwater flow in geotechnical engineering [16], [17], [18] The analysis was divided into several stages, starting from the existing condition, after the first and second reinforcement, also after increasing load due to the development plan.

The safety factor of the slope is analyzed using the Limit Equilibrium Method with Slope/W software (Slope/W version 2007). The analysis is similar to the Plaxis software that divided into several stages. Analyzes were performed using four different PGAs for dynamic loads (earthquakes loading) of 0.15g, 0.20g, 0.25g, and 0.30g. Groundwater table was similar to the analysis that used in the previous Plaxis software which is located on the breccia layer of pumice stone. Each of these models was analyzed by the Ordinary / Fellenius, Bishop, Janbu, Morgenstern and Price method.

Data Input

Based on the field and laboratory tests, the input parameters for soil and rock in the Plaxis and Slope/W software were obtained. Details of parameters soil and rock properties can be seen in Table 3. It can be seen that the different of soil properties from each layer.

RESULT AND DISCUSSION

Existing Condition (Initial Stage)

In this condition, Plaza Andrawina was simulated wihout reinforcement. It was found that Earthquake loads have a significant effect on horizontal deformation on the foundations at both points reviewed. The deformation values that occurred by using PGA of 0.15 g at points A and B consecutively were 58.15 and 76.52 mm. For PGA 0.25g the deformation values occurring at Points A and B were 86.32 and 108.00 mm. The results of the simulations using two different seismic loads indicate that larger PGAs result in greater deformation as well. For detail of horizontal deformation can be seen in Fig 4.

Furthermore, the analysis with slope/W performed on this existing condition is a condition where there is no reinforcement and assume that the three columns in front remain at the position (not slipping). The results of the slip surface and the safety factor of this condition can be seen in Figure 5.

The results of the analysis using dynamic loads show the safety factor of slope with PGA 0.15g in accordance Yogyakarta earthquake 2006 is 1.362. And the safety factor dramatically reduced in PGA 0.30g to the critical slope of 1.138.

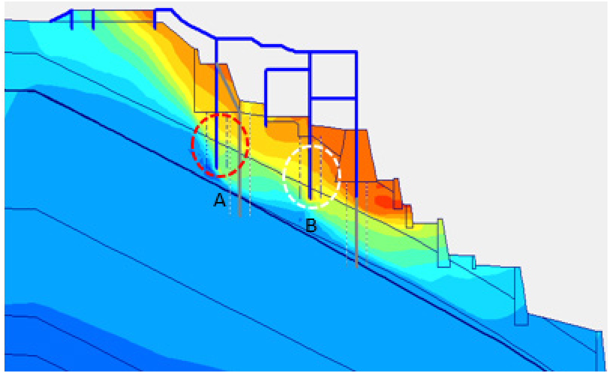

Figure 4: Deformation of Existing Condition at Point A and B (Initial Stages) [15]

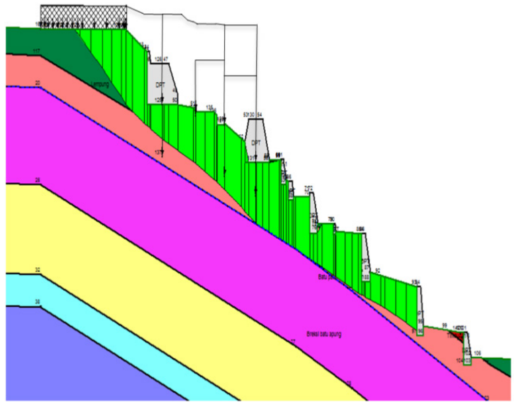

Figure 5: Slip surface of existing condition without reinforcement [15]

First Reinforcement

The first reinforcement at Plaza Andrawina is in the outer column with three supporting column. The reinforcement foundation enters up to a layer of breccia rocks at a depth of 0.5 m. The type of reinforcement made using reinforced concrete. The deformation values that occurred by using PGA of 0.15 g at points A and B were 27.17 mm and 18.41 mm, respectively. For PGA 0.25g the deformation values occurring at Points A and B are 50.10 and 42.05 mm, respectively.

The result of analysis using slope/W shows that the first reinforcement gives influence on the slope stability which is increase of the slope safety factor to 1.202.

Second Reinforcement

This second reinforcement is the same as the first reinforcement using reinforced concrete with the foundation end of reaching a layer of deep breccia rocks as deep as 0.5 m. The depth of this second reinforcing foundation differs from each column, with an average depth of 5-7 m. The simulation using the second reinforcement reduces the deformation value occurring at both the foundation point under review. The deformation values that occurred by using PGA of 0.15 g at points A and B were 9.44 and 8.03 mm, respectively. For PGA 0.25g the deformation values occurring at Points A and B are 16.08 and 14.95 mm, respectively.

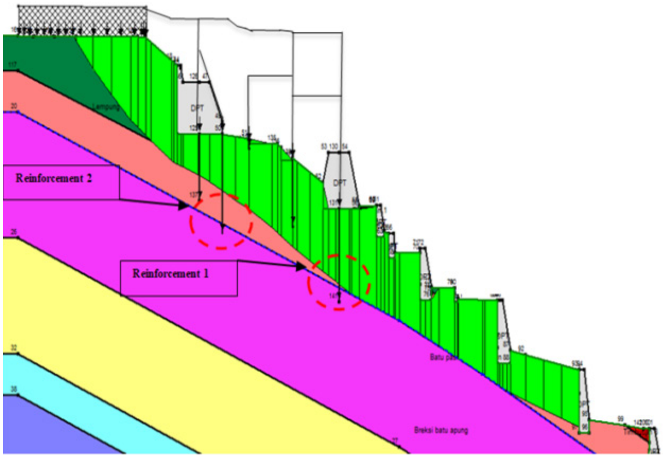

Figure 6: Slip surface after second reinforcement as illustrated with red circle [15]

This second reinforcement installed in the back column of Plaza Andrawina. The results of slip surface and safety factor analysis are presented in Fig 6.

Furthermore, the slip surface occurs only in the first and second layers of the clay layer and the tuff sandstone layer. The result of analysis shows that the second reinforcement gives a big influence on the slope stability which is increase of the slope safety factor to 1.351.

Development Load for Second Floor

With the development plan of the second floor utilization at Plaza Andrawina as a place of lodging, it will increase the load on buildings and slopes. Added loads of 12.5 kN/m^2 are regarded as standard loads.

Based on the horizontal deformation value, it can be seen that the deformation occurring at point A has not changed compared to before the addition of development load. The value of deformation that occurs the same with the previous both with PGA 0.15g and 0.25g, respectively 9.44 and 16.08 mm. Changes in deformation values occur only at point A with either PGA 0.15g or 0.25g, respectively 8.44 and 15.75 mm.

The result of the safety factor analysis shows that after the addition of development load on the second floor gives an effect on the stability of the slope that is by decreasing the slope safety factor to 1.318. The slip surface of this condition can be seen in Fig 7.

Additional Load for Parking Lot Plan

At the bottom of the Plaza Andrawina slope is planned to be developed for the construction of parking lots for vehicles. The imposition is to use standard load of three floor building and live load. Added loads of 46 kN/m2 are regarded as uniform loads. This simulation was conducted to see the effect of the plan to increase the parking load on the slope above Plaza Andrawina. Based on the horizontal deformation value, it was found that the deformation occurring at point A and point B did not change compared to before the addition of parking development load. The horizontal deformation of foundation that occurs the same as before either with PGA 0.15g or 0.25g.

Same as plaxis result, there is no change in the value of the slope safety factor. This indicates that the addition of parking load at the bottom of Plaza Andrawina has no significant effect on the upper slopes.

Result of overall horizontal displacement and safety factor analysis

Based on the analysis that has been done on various conditions, the horizontal displacement values for the two foundation points reviewed are point A and point B. The overall detail is shown in Fig 8.

When using Yogyakarta earthquake load 2006 that is with PGA 0,15g can be seen that existing condition without reinforcement has horizontal displacement at point A and point B successively 58,15 and 76,52 mm. The horizontal displacement that occurs increases significantly when using the earthquake load with PGA 0.25g, that is at point A and point B successively 86.32 and 108.00 mm.

Furthermore, after the construction of the first reinforcement on the outer column there is a decrease in horizontal displacement at both points reviewed. The decrease in displacement value that occurs is quite significant, especially at point B which is close to the reinforcement.

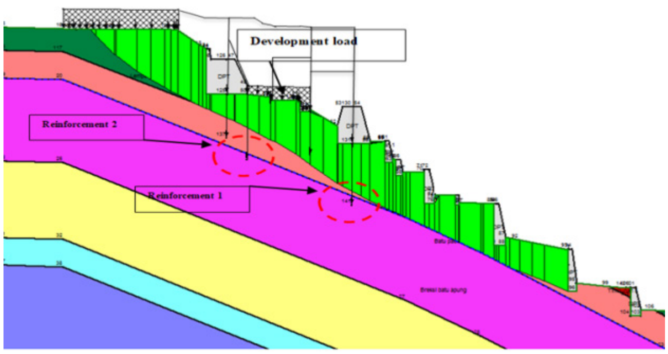

Figure 7: Slip surface after Development Load on Plaza Andrawina [15]

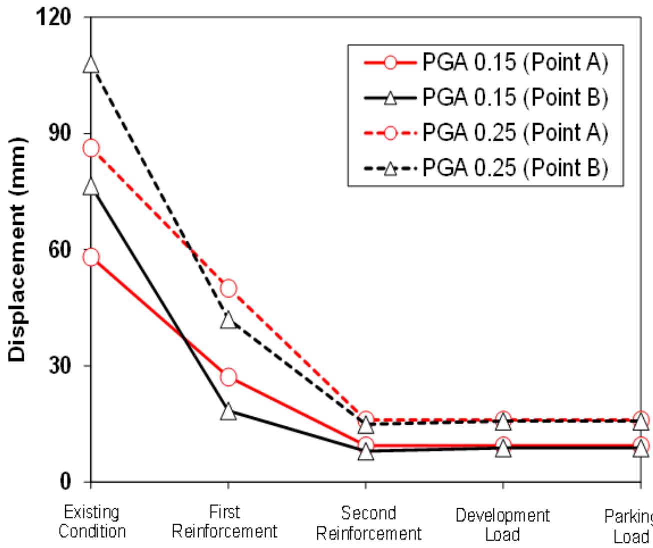

Figure 8: Reduction of Horizontal Displacement

The horizontal displacement value at the foundation of point B is reduced by almost 50% using either PGA 0.15g and 0.25g. The displacement values that occurred respectively were 18.41 mm and 42.05 mm.

On the other hand, analysis was performed after the second reinforcement on the back column results in a significant decrease in horizontal displacement as well. This is similar with first reinforcement, where the horizontal displacement value on the foundation closer to the reinforcement location is reduced by almost 50% using either PGA 0.15g and 0.25g. The value of displacement occurring at point A is successively 9.44 mm and 16.04 mm. The addition of development load on the second floor has an effect on horizontal displacement of B point foundation, there is an increase of horizontal displacement value which is not significant either using PGA 0,15g, or using PGA 0,25g. The load of second floor development does not have a significant effect on the horizontal displacement of foundation point A. Development at the bottom with the vehicle parking construction plan does not have a significant effect on the horizontal displacement of the foundations on the Plaza Andrawina slope either at point A or B.

On the other hand, the analysis using slope / W shows on existing condition without reinforcement with Yogyakarta earthquake load 2006 that is with PGA 0,15g has safety factor 1,362. When the quake load is doubled at 0.30g, the safety factor of slope approaches the critical value of 1.138. After the construction of the first and second reinforcement at Plaza Andrawina there is an increase the safety factor of slopes. Increases occurred on each PGA used that is 0.15g, 0.20g, 0.25g, and 0.30g. With the increase of safety factor, indicating the reinforcement effective to maintain slope stability. The effectiveness of reinforcement can be quantified using the index (δ). Where SF1 and SFn are the initial Safety Factor and the Safety Factor after reinforcement.

$$\delta = \left[1 - \left(\frac{SF_1}{SF_n}\right)\right] \times 100\%$$

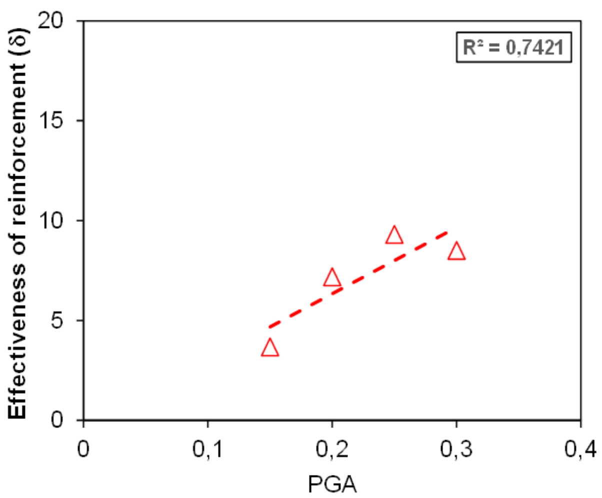

Figure 9: Effectiveness of Reinforcement

The effectiveness of first reinforcement (δ) is illustrated in Fig. 9. It can be observed that the good correlation was obtained with earthquakes load (PGA). The reinforcement significantly effective to maintain slope stability.

CONCLUSION

The analysis results using the Plaxis software show that after the first and second reinforcement, the horizontal displacement of foundation reduced almost 50% by using either PGA 0.15g and 0.25g. On the other hand, the additional load for the development plan on the second floor affects the horizontal deformation on the foundation of Plaza Andrawina.

Furthermore, based on the slope/W analysis results, it shows the location of critical slip is in the sandstone layer. The analysis of the safety factor shows the proposed reinforcement effective to maintain slope stability. After the first and second reinforcement, the safety factor of slope increases from 1.362 to 1.605 for PGA 0.15 and from 1.138 to 1.318 for PGA 0.30.

Finally a good correlation between effectiveness of reinforcement with earthquakes load (PGA)was obtained. It can be concluded that the reinforcement significantly effective to maintain slope stability.

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