Slope protection using geosynthetic materials - a case study on the graveyard complex of mataram royal king

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Abstract. This paper presents the study case of landslide occurred at the Imogiri Cemetery, Mataram Royal Kings Graveyard Complex. On March 17, 2019, a landslide occurred, it was expected to have been triggered by heavy rainfall of 148 mm/day intensity. The study was carried out by slope stability modelling using PLAXIS software. Based on the results of field observations and numerical analysis, the type of slope failure that has occurred is a translational landslide. The failure line is between hard soil layer that tends to be horizontal and weak surface soil. In anticipating the occurrence of subsequent landslides, a reinforcement solution is needed with a combination of Geosynthetic and bored pile at the bottom of the slope which functions as a counterweight. The output of this analysis safety factor value is around 1.55 for the static load. This design also considered the earthquake pseudo-static load, where the result of the safety factor was 1.15 and fulfilled the criteria stated in Indonesian National Standard for Geotechnic Design Requirement (the slope safety factor must be above 1.10). The combination of Geosynthetic and Bored Pile application work effectively as a retaining wall because it is a more economical solution, faster and more environmentally friendly.

1 Introduction

The slope failure or landslide is a phenomenon when a slope collapses due to the weakened self-retain ability of the earth to the influence of rainfall or an earthquake [1]. In Indonesia, rainfall is the most common cause of landslides. On March 17, 2019, a landslide occurred, it was expected to have been triggered by heavy rainfall of 148 mm/day intensity [2, 3]. At other hands, some news state that landslide happened on Imogiri Cemetery not only triggered by heavy rainfall but also triggered by small earthquakes happened frequently [2]. Based on field observations, a larger slope collapse is also feared because the position of the slope crown is very close to the tomb building, there are quite large cracks in the building

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foundations next to the landslide area and cracks that have occurred in the tomb structure above the slope (Figures 1 & 2).

Fig. 1. Conditions at top elevation

To reduce the hazards of landslides or stabilize the potentially unstable slope, an effective mitigation technique is needed to handle this landslide problem. The slope reinforcement applied is in the form of a retaining wall at the top and a combination of geosynthetics and bored piles at the bottom of the slope which function as a counterweight. Below is the conditions of the existing slope before slope reinforcement was carried out.

Fig. 2. Existing conditions after landslide

2 Design Methodology

2.1 Study area

Imogiri is located in area with a medium level of landslide vulnerability, but has the potential to be hit by a strong earthquake [4]. Based on lithology, the location of the landslide is composed of volcanic breccias which sustain weathering and form a thick layer of soil [5]. Based on the morphology, the landslide location has a slope range between 20^{o} and 40^{o}. The area is dominated by gardens, hills, and residential area [6] –(Figure 3).

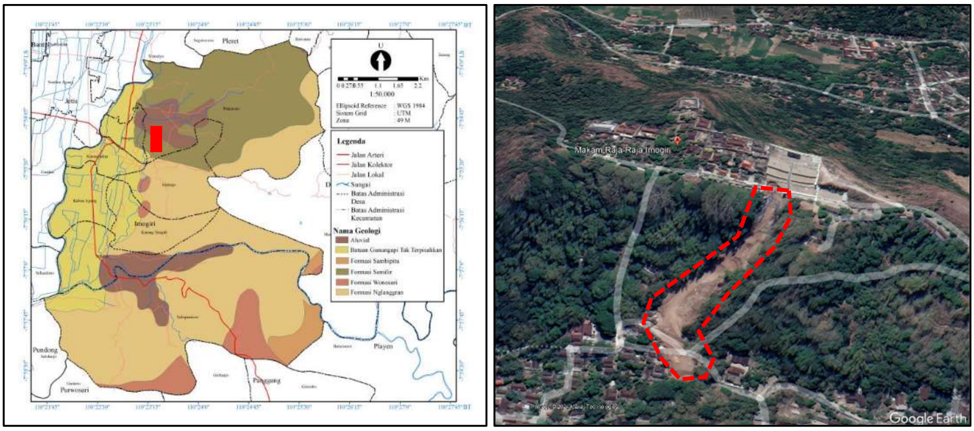

Fig. 3. Study area

2.2 Geotechnical investigation

2.2.1 Soil data

Soil samples were tested in the Soil Mechanics Laboratory, Civil and Environmental Engineering, Gadjah Mada University. The existing slope modelling (Figure 4) was taken at the highest elevation point at each station to obtain a more critical safety factor value. In this analysis using drills point BH02, the soil property index as shown in Table 1.

Table 1. Soil index properties

Parameter	Layer 1	Layer 2	Layer 3
Depth (h) (m)	1.5 - 2	2.5 - 3	6 – 6.5
Ø ()	34.5	36.8	34.0
Cohesion (c) (kN/m^2)	13.0	9.0	13.0
Coefficient of permeability (m/s)	1.70E-07	8.50E-09	1.10E-06

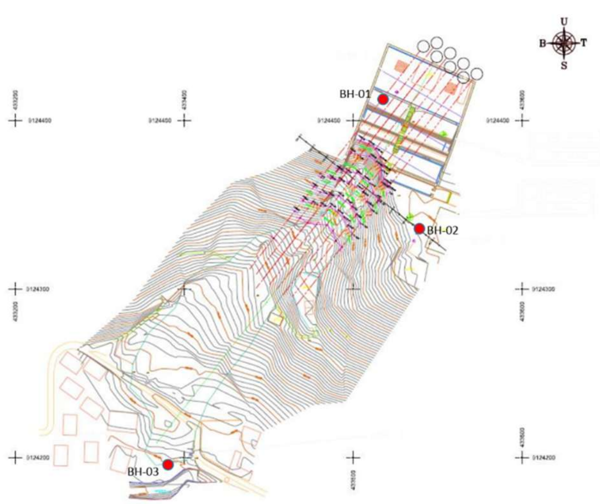

Fig. 4. Borehole layout

2.2.2 Seismic data

Based on geotechnical design requirements in national standardization agency documents number 8460:2017, for excavation or embankment slopes using an earthquake with the possibility of exceeding the magnitude during the design life of 50 years is 2% or equivalent to a 500-year return period with reference to the earthquake map contained in the SE Minister of Public Works No. 12/SE/M/2010. Based on the earthquake map, the location has a peak ground acceleration (PGA) value: 0.695g [7].
The magnitude of the peak acceleration at ground level is determined by multiplying the acceleration amplification factor (FPGA) by the magnitude of the acceleration in the bedrock. The size of the FPGA depends on the site classification based on the following table [8].

Table 2. PGA amplification factor for T=0.2s (AASHTO, 2012)

Site Class	$PGA \leq 0.1$ $Ss \leq 0.25$	$PGA \leq 0.2$ $Ss \leq 0.5$	$PGA \leq 0.3$ $Ss \leq 0.75$	$PGA \leq 0.4$ $Ss \leq 1.0$	$PGA \leq 0.5$ $Ss \leq 1.25$
Hard Rock (SA)	0.8	0.8	0.8	0.8	0.8
Rock (SB)	1.0	1.0	1.0	1.0	1.0
Hard (SC)	1.2	1.2	1.1	1.0	1.0
Medium (SD)	1.6	1.4	1.2	1.1	1.0
Soft (SE)	2.5	1.7	1.2	0.9	0.9
Typical (SF)	SS	SS	SS	SS	SS

Description:
- PGA is the peak acceleration of bedrock (SB) referring to the earthquake map with a design return period according to the requirements of the infrastructure used.
- Ss is the spectral acceleration of the horizontal response in bedrock (SB) at a period of 0.2 seconds with a design return period according to the requirements of the infrastructure used.
- SF is the location that requires geotechnical investigation and site-specific response analysis.

Seismic calculation is done in pseudo-static, with the acceleration coefficient as follow
Kh = 0.5 x PGA x FPGA
Kh = 0.5 x 0.695g x 1.00 = 0.348g

2.3 Design recommendations

One of the mitigation methods in this case is used with geosynthetic materials. The combination material is Geogrid as reinforcement, non-woven geotextile as a filter, and facing using galvanized iron. In the calculation, the long-term tensile strength of geogrid is considering the reduction factor for several conditions as follow.

Table 3. Durability (aging) reduction factors for PET (FHWA NHI-10-024 page 3-36)

Product[a]	**Durability Reduction Factor, RF_D**	
	$5 \leq pH \leq 8$	$3^b < pH \leq 5$ $8 < pH < 9$
Geotextiles Mn < 20,000,40 < CEG < 50	1.6	2.0
Coated geogrids, Geotextiles Mn > 25,000, CEG < 30	1.15	1.3

Description :
Mn = number average molecular weight
CEG = carboxyl end group
Notes :
a. Use of materials outside the indicated molecular property range requires specific product testing. Use of products outside of $3 < pH < 9$ range is not recommended (Tables 3,4 &5).
b. Lower limit of pH for permanent applications is 4,5 and lower limit for temporary applications is 3, per Article 11.10.6.5.2b (AASHTO, 2007)

Table 4. Installation damage reduction factors (FHWA NHI-10-024 page 3-32)

Reduction Factor, RF_{ID}		
Geosynthetic	**Type 1 Backfill Max. Size 4 in (100mm) D_{50} about 11/4 - in. (30 mm)**	**Type 2 Backfill Max. Size ¾- in (20mm) D_{50} about #30 (0.7 mm)**
HDPE uniaxial geogrid	1.20 - 1.45	1.10 - 1.20
PP biaxial geogrid	1.20 - 1.45	1.10 - 1.20
PVC coated PET geogrid	1.30 - 1.85	1.10 - 1.30
Acrylic coated PET geogrid	1.30 - 2.05	1.20 - 1.40
Woven geotextiles (PP&PET)[a]	1.40 - 2.20	1.10 - 1.40
Non-woven Geotextiles (PP&PET)[a]	1.40 - 2.50	1.10 - 1.40
Slit film woven PP geotextile	1.60 - 3.00	1.10 - 2.00
a. Minimum weight 8.0 oz/yd^2 (270 g/m^2)		

Table 5. Creep reduction factors (FHWA NHI-10-024 page 3-33)

POLYMER TYPE	CREEP REDUCTION FACTORS
POLYESTER (PET)	2.5 to 1.6
POLYPROPYLENE (PP)	5 to 4.0
HIGH DENSITY POLYETHYLENE (HDPE)	5 to 2.6

High tensile strength polyester geogrid coated with bitumen or other polymers with a special design that produces a high friction coefficient, hence the reduction factors follow the polyester material reduction factors range. Based on Table 3, the reduction factor for durability (aging) is taken 1.30. This value follows the soil-environment pH level which is in the range of $3 < pH \leq 5$ or $8 < pH < 9$. Based on Table 4, for the installation damage reduction factor the value was taken 1.10 as the backfill soil were similar to Type 3 backfill. Based on Table 5, for the creep reduction factor the value was taken 1.60. The allowable tensile strengths are calculated with the following formula [6]:

$$T_{allow} = T_{ult}\ [1/(RF_D \times RF_{ID} \times RF_{CR})] \quad (1)$$

3 Result and discussion

3.1 Design analysis

Slope stability analysis is carried out to determine the safety factor of the slope to be made (Figure 5). To carry out this analysis, the following parameters are used based on the interpretation and assumptions of the soil data because the available data are incomplete. The analysis was carried out using the finite element method with the Plaxis 3D program. The existing contour of the slope after landslide as follows.

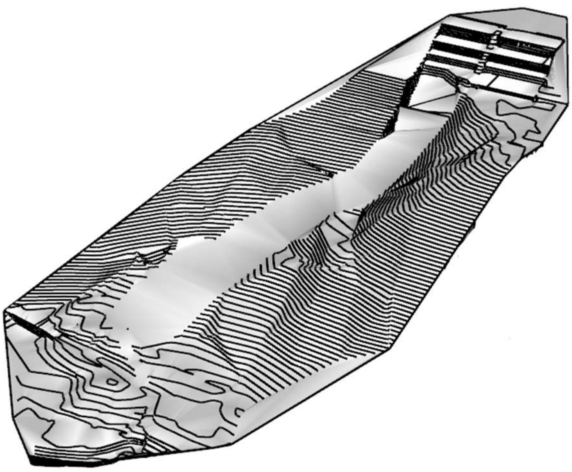

Fig. 5. Existing contour conditions after landslide

The construction load applied to the PLAXIS model is 10 kN/m^2 according to applicable standards (SNI 1727-2013 on Minimum Loads for Designing Buildings and Other Structures). All topsoil are replaced with gravel sand fill. Below the design of slope protection using several type of retaining wall (Figure 6).

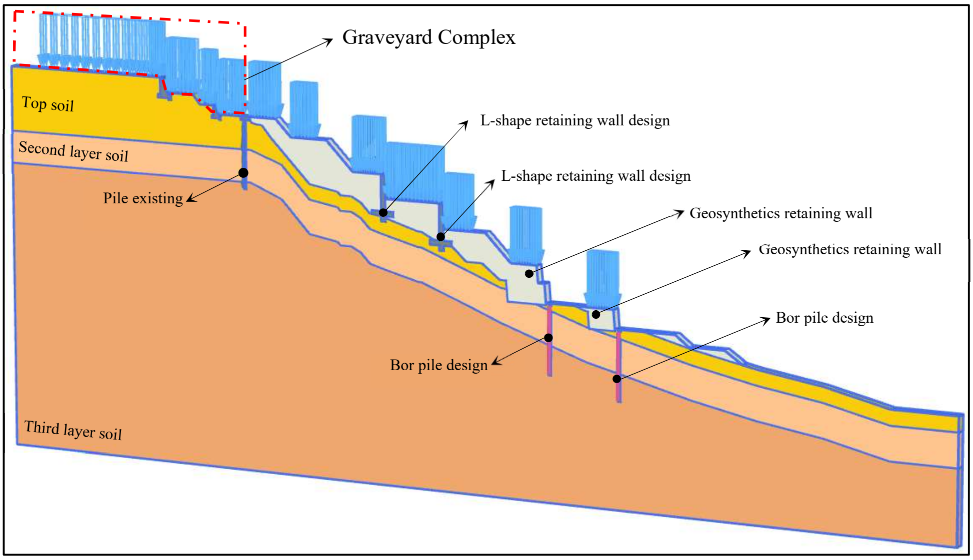

Fig. 6. Design slope protection

The stability analysis was carried in several stages of construction. The first stage of analysis is carried out on the existing slope conditions after landslide. The value of the safety factor at the initial condition after landslide is 1.39 (Figure7).

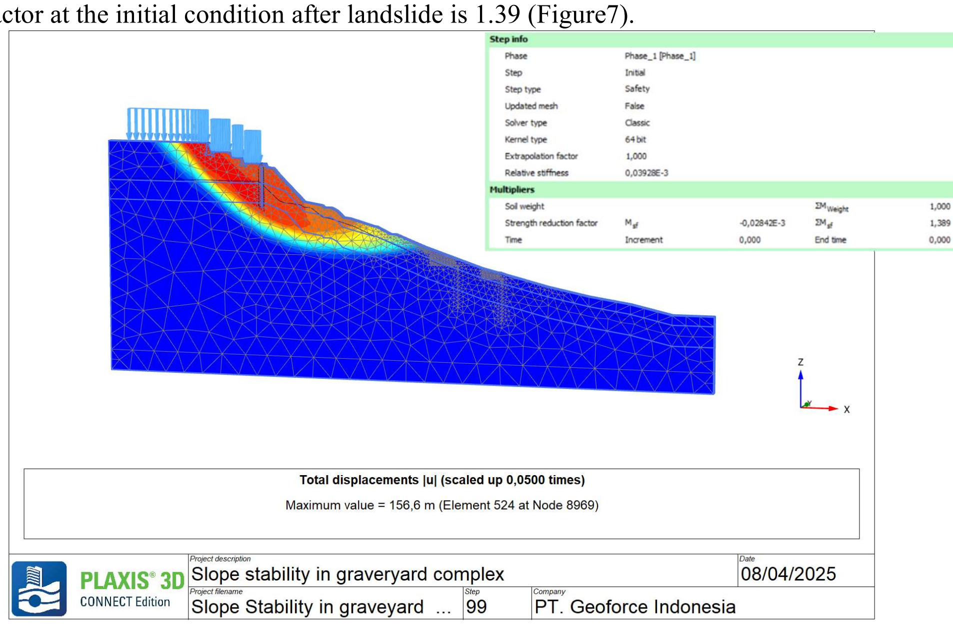

Fig. 7. Analysis of Initial Conditions after landslide

Based on the existing conditions after the landslide analysis results with static loads (before design applied), it can be seen that the slip plane is located at the top of the slope. To keep the slope safe, a retaining wall structure is needed from the top to the bottom. The condition below after the design applied (Figure 8).

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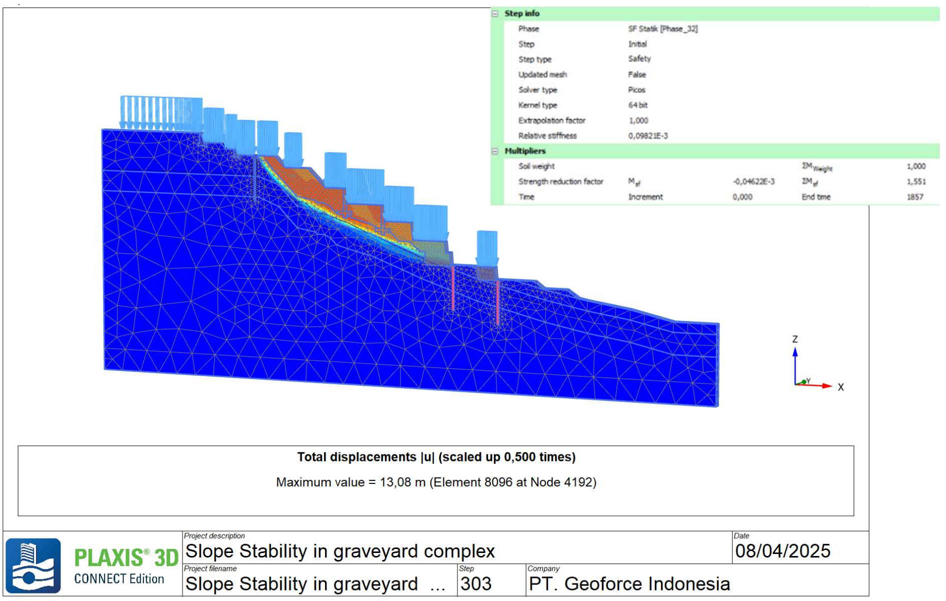

Fig. 8. Value of safety factor with design load and retaining wall design applied

The safety factor value after the design applied is 1.55. Based on the analysis results, it can be seen that the slip plane shifts towards the slope surface, so that the design combination has been able to improve the slope conditions. The minimum value for embankment's static condition factor of safety based on Indonesian National Standards: Geotechnical Design Requirements 8460: 2017 is 1.50. Below are the results of the safety for pseudo-static analysis (Figure 9).

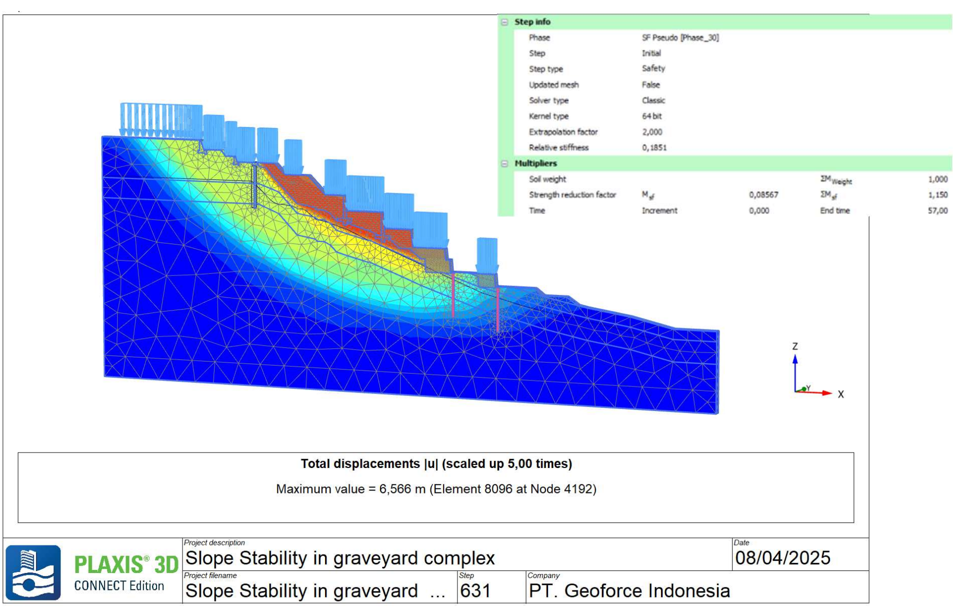

Fig. 9. Analysis results with earthquake load conditions

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Pseudo-static analysis was carried out to see the safety factor in earthquake conditions with the PGA value calculated based on the earthquake map and the amplification factor obtained by the kh is 0.348g.
Identical to the previous results, the risk of collapse is still possible but has shifted to the ground surface so that the potential for the soil mass to collapse has decreased.

Based on the results of the analysis, the value of the safety factor is 1.15. The value of this safety factor is still above the SF limit value > 1.10 in accordance to Indonesian National Standard for Geotechnic Design Requirements (8460:2017).

3.2 Geosynthetics as green construction

The implementation of green buildings is in line with the Sustainable Development Goals (SDGs) program because both have similar goals in supporting environmental and social sustainability, contributing significantly to achieving the SDGs. Geosynthetics act in realizing the Sustainable Development Goals (SDGs) as follow (Figure 10) :

- Industry, innovation and infrastructure : Creating new things in infrastructure to increased industrialization, support innovation and become a driver of economic growth and development.
- Sustainable Cities and Communities : Green buildings support the development of greener and more sustainable cities by promoting resource efficiency, reducing environmental impacts, and creating healthier and safer living spaces.
- Responsible Consumption and Production : The use of environmentally friendly and sustainable building materials, as well as effective management of construction waste, supports more responsible consumption and production.

Slope reinforcement with geosynthetics has several components, one of which is found in the facing which can be a means for the growth of vines, so that the CO_2 released from the material manufacturing and installation process can be neutralized by the plants with the CO_2 absorbed and the O_2 released. This process is expected to be carbon neutral (every CO_2 released into the atmosphere from construction activities is balanced by an equivalent amount absorbed). Below is a comparison of slope conditions after reinforcement.

Fig. 10. Slope reinforcement several months after construction and current slope conditions

By integrating sustainability principles in design, construction, and operation, green buildings play a vital role in supporting various SDGs goals, both in terms of environmental, social, and economic aspects. Thus, green buildings are not only part of a sustainable development program, but also one of the key elements in achieving the overall sustainable development goals.

4 Conclusions

The results of the slope stability analysis obtained the value of the safety factor in accordance to Indonesian National Standard for Geotechnic Design Requirements (8460:2017). The increase of safety factors occurs in conditions after the design is applied. The slip plane shifts towards the slope surface so that the combination design of retaining walls, geosynthetics, and bored piles has been able to improve slope conditions. .The application of retaining walls with geosynthetics is more environmentally friendly because the conditions of this slope are already overgrown with vegetation.

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