

Engineering Geological Investigation of Slow Moving Landslide in Jahiyang Village, Salawu, Tasikmalaya Regency

Investigasi Geologi Teknik pada Gerakan Tanah Lambat di Desa Jahiyang, Salawu, Kabupaten Tasikmalaya

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Abstract

An understanding of landslide mechanism is imperative to determine the appropriate mitigation method. The slow moving landslide (creeping) which occurred in Kampung Salawangi, Jahiyang Village, Salawu Subregency, Tasikmalaya had caused economical and environmental losses due to the frequent active movement particularly following rainfall events. Engineering geological investigation and slope stability analysis were carried out in the studied area in order to elucidate the mechanism of the landslide. The engineering geological investigation consists of local topographical mapping, geotechnical drillings, hand borings, cone penetration, and laboratory tests. The slope stability assessment of the recent landslide was conducted by a finite element method. The results of engineering geological data analysis show that the studied area is composed of residual soils of soft to firm sandy silt and loose to compact silty sand and base rock of fresh to weathered volcanic breccias with groundwater level varying between 3 - 16 m. The engineering properties of the residual soils indicate that the sandy silt is of high plasticity and the shear strength properties of the sandy silt and silty sand show low value with effective cohesion of 6.0 - 21.74 kPa and effective friction angle of 12.0° - 25.98°. The assessment of slope stability shows that the stability of the studied area is largely influenced by the rise of groundwater level marked by the decrease of safety factor and increase of slope displacement.

Keywords: slow moving landslide, residual soil, rise of groundwater level, finite element method

Sari

Pengetahuan tentang mekanisme gerakan tanah diperlukan untuk menentukan metode mitigasi yang tepat. Gerakan tanah dengan kecepatan lambat (rayapan) yang terjadi di Kampung Salawangi, Desa Jahiyang, Kecamatan Salawu, Kabupaten Tasikmalaya telah menyebabkan kerugian ekonomi dan lingkungan akibat pergerakannya yang aktif, terutama setelah turun hujan. Penyelidikan geologi teknik dan analisis kestabilan lereng dilakukan di daerah studi untuk mengetahui mekanisme terjadinya gerakan tanah. Penyelidikan geologi teknik yang dilakukan terdiri atas pemetaan topografi lokal, pemboran geoteknik, pemboran tangan, pengujian penetrasi konus, dan pengujian laboratorium. Analisis kestabilan lereng gerakan tanah terkini dilakukan dengan metode elemen terbatas. Analisis data geologi teknik menunjukkan bahwa daerah studi tersusun oleh tanah-tanah residu yang terdiri atas lanau pasiran dengan konsistensi lunak sampai teguh dan pasir lanauan dengan kepadatan lepas hingga kompak serta batuan dasar breksi vulkanik lapuk hingga segar. Permukaan air tanah di daerah studi bervariasi antara 3 - 16 m. Sifat keteknikan lanau pasiran dan pasir lanauan memiliki kuat geser yang cukup rendah dengan kohesi efektif 6,0 - 21,74 kPa dan sudut geser dalam efektif 12,0° - 25,98°. Analisis kestabilan lereng menunjukkan bahwa kestabilan daerah studi sangat dipengaruhi oleh peningkatan permukaan air tanah yang ditandai dengan penurunan faktor keamanan dan peningkatan pergerakan lereng.

Kata kunci: gerakan tanah lambat, tanah residu, kenaikan permukaan air tanah, metode elemen terbatas

Introduction

Java Island is an area with the highest landslide susceptibility in Indonesia with almost 50% of the total number of events (Cepeda *et al.*, 2010). The high susceptibility is mainly due to topographical factors (hilly morphology with slopes inclination over 25°), intense weathering of volcanic soils, uncontrollable land use, and high intensity of rainfall (up to 100mm/day) during wet months (Tohari *et al.*, 2006). The recurring events of landslides every year in the provincial area have claimed a number of human lives and caused great economic losses as well as environmental consequences. According to the landslide forecast map of Java Island, January 2006 (PVMBG, 2006), the Salawu Subregency, Tasikmalaya Regency, belongs to the medium to high susceptibility class. During the year 2006-2007, five consecutive landslide events took place in this region. They were happening on 18 November 2006 in Salawu Village, on 18 February 2007 in Kutawaringin Junction, on 4 March 2007 in Salawangi, Jahiyang Village, and on 9 June 2007 in Nyalindung, Tenjowaringin Village. The landslides occurred in Jahiyang and Tenjowaringin Villages are of slow moving type which is commonly described as creeping. The landslide in Tenjowaringin Village in June had induced cracks to form 150 m length and 3 m depth, causing two houses to collapse and seven others in danger, while the landslide in Jahiyang Village during March 2007 had caused 12 houses to collapse and destroyed a rice field area of eight hectares (Pikiran Rakyat, 5 March 2007) (Figure 1).



Figure 1. Slow moving landslide in Jahiyang Village causing destruction of rice field and displaced housing.

The active mass movement of creeping type has caused substantial damages and economic loss. Each landslide event has a specific characteristic site such as local geology, topography, hydrology, climate, and land use. Therefore, it is imperative to understand the engineering geological characteristics of the active landslide of this area, in order to elucidate the mechanism of the landslide activation. Engineering geological investigation had been conducted in the landslide area, in Kampung Salawangi, Jahiyang Village, consisting of geotechnical borings, Cone Penetration Test (CPT), topographical survey, and series of geotechnical laboratory tests. Analysis of engineering geological data and slope stability modelling were carried out to clarify the landslide mechanism.

Engineering Geological Investigation

Methods

The field investigation began with local geological and topographical mappings, followed by three mechanical drillings up to a maximum depth of 22.5 m, thirteen mechanical cone penetration tests, and five shallow hand borings up to a maximum depth of 6.0 m. Figure 2 shows the topographical map of the studied site and the locations of the field investigation. Mechanical drilling aims to reveal the soil stratification. For this purpose, one borehole was located at the upper and middle slopes, and the last one at the lower slope. The drilling programme also included both the N-SPT tests at an interval of 1.50 m and undisturbed sampling. The depth of groundwater table was measured following the completion of

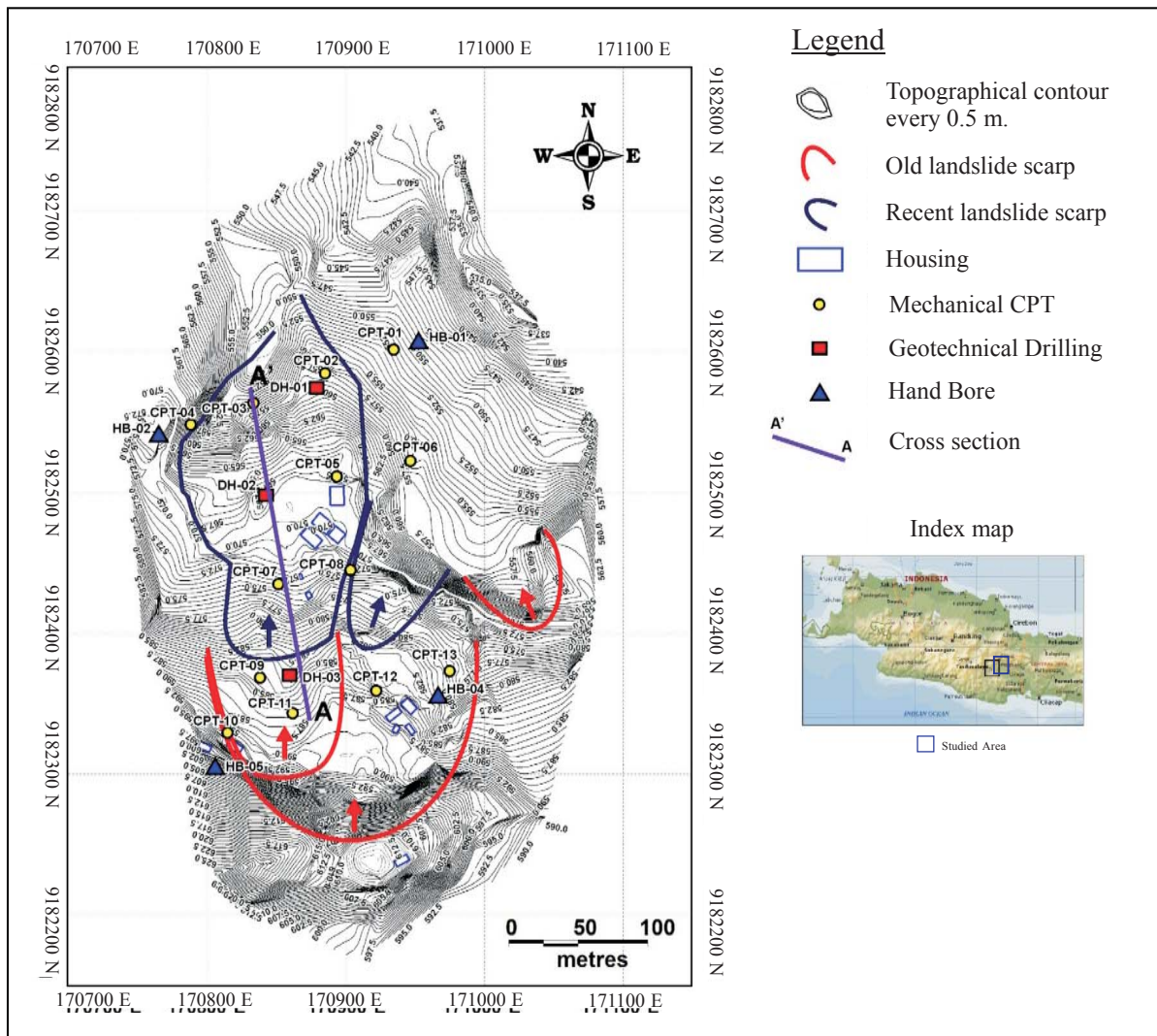


Figure 2. The topographical map of studied location showing points of investigation.

the drilling programme. Disturbed and undisturbed samples recovered from the mechanical and hand borings were subjected to series of laboratory tests to determine the index and shear strength properties. These properties were then used in the slope stability analysis. The analysis was carried out using the finite element package Plaxis 8.0 under the change of groundwater level condition.

Results

Landslide Profile

The landslide area in Jahiyang Village is 10 hectares covering rice field and housings. The landslide

had forced twenty housings to be relocated due to the unsuitable condition. The topographical map (Figure 2) shows the undulating slope morphology at the upper part and planar slope at the lower part. The map also indicates the development of recent landslide scarp due to the slope movement in 2007 and the existence of old landslide scarps at the upper part of the recent scarp. The development of several scarps indicates that the area is experiencing slow movement (*e.g.* creeping). Tension cracks, depressions, and displaced materials of 20 - 50 cm wide were found during the field investigation along the recent landslide body (Figure 3).

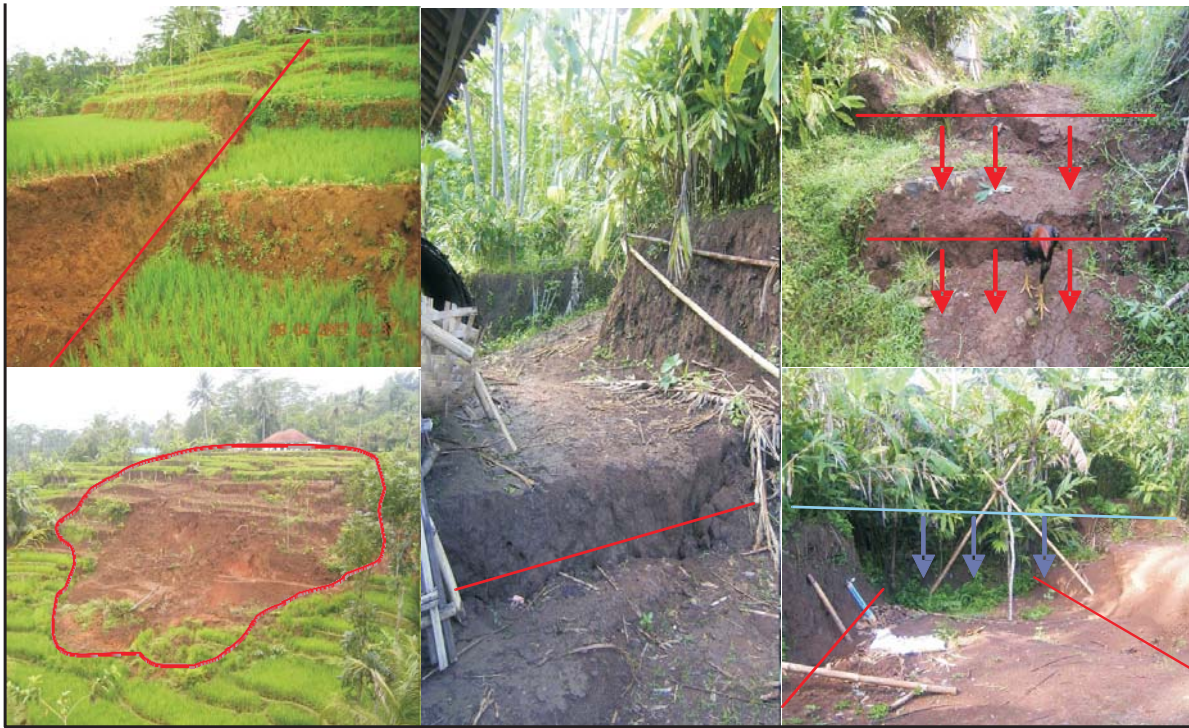


Figure 3. Tension cracks, depressions, and displaced materials observed at the studied location.

Local Geology

According to the geological map of Tasikmalaya Quadrangle (Budhitrisna, 1986), the studied area belongs to the Old Volcanic Unit of volcanic breccias, flow breccias, tuff, and andesitic to basaltic lava of Gunung Kukul. This unit is of Quaternary age spreading from Nagreg to Garut. Local geological mapping combined with the borehole logs and CPT logs reveals that the studied area is composed of compact breccias, weathered breccias, and residual soil. Figure 4 shows the distribution of springs along the toe of the slope. The cone resistance value (q_c) and N-SPT correlation logs indicate the existence of weak zone (transition of low to higher value of N-SPT and q_c) which is also the area of groundwater fluctuation (Figure 5).

Soil Stratification

The results of the field geotechnical investigation show that the slope is composed of two layers of soils originated from volcanic breccias approximately 10 - 15 m thick. The stratification of the slope is divided into three different layers (Figure 6) as follows:

1. Brown clayey silt of 7.0 - 10.0 m thick with N-SPT value of less than 15 and cone resistant value, q_c of 10-20 kg/cm².
2. Brown loose fine silty sand layer of 5 m thick, N-SPT value of 15-14 and cone resistant values, q_c of 32-73 kg/cm². Breccia fragments of gravel to pebble sizes were found in this layer.
3. Grey volcanic breccia, fresh to weakly weathered (grade I-II), N-SPT value >50 and q_c >250 kg/cm².

The occurrence of groundwater table measured varied between 3 -16 m and getting shallower towards the slope toe.

Results of geotechnical drilling and N-SPT value (Table 1) reveal that the existence of loose to compact sand layer (low N-SPT value 7-22) is of 3.5 - 6.5 m thick. The occurrence of this relatively loose layer acts as the controlling factor to the stability of the slope, particularly during groundwater level fluctuation.

Soil Geotechnical Properties

Results of laboratory tests on undisturbed sandy silt samples show that the soil has the porosity of

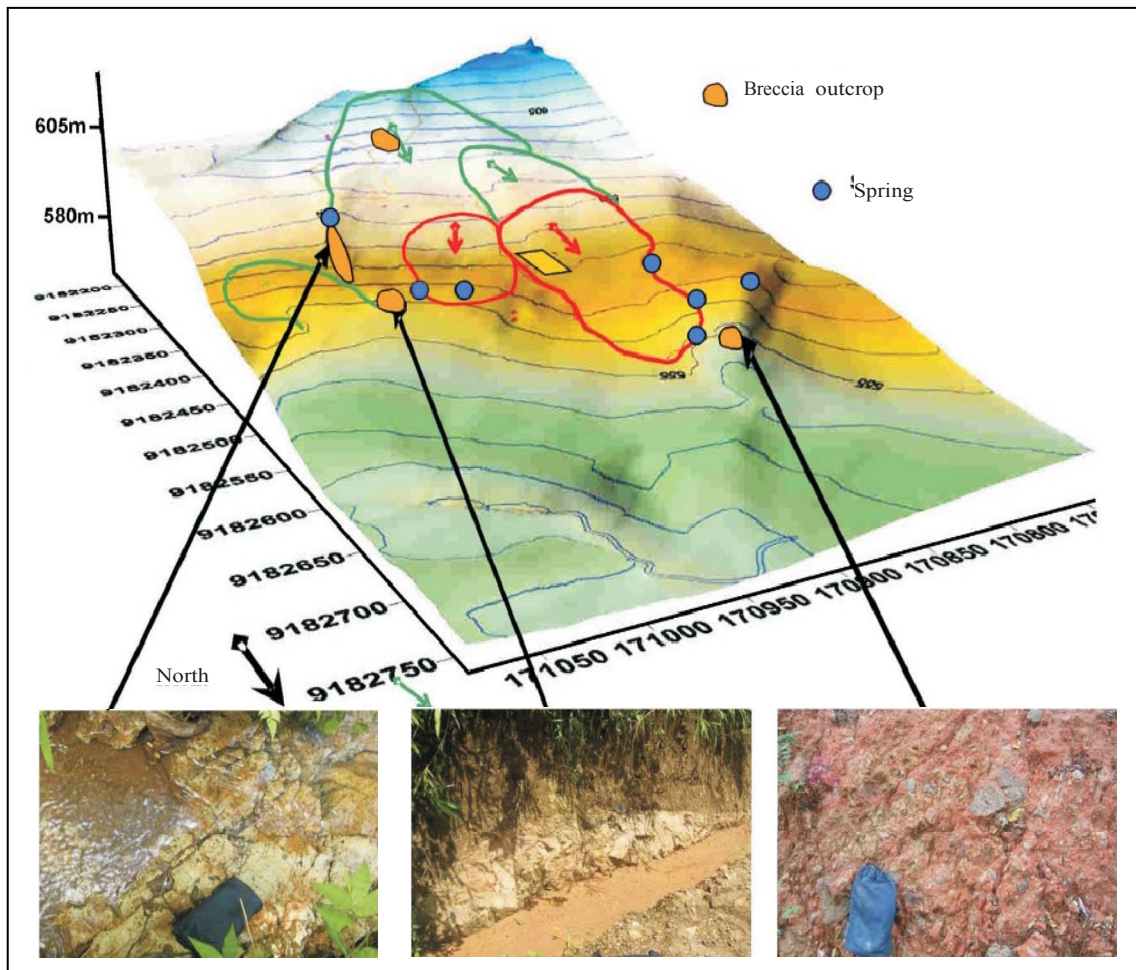


Figure 4. Block diagram of studied location showing the locations of breccias outcrops and springs.

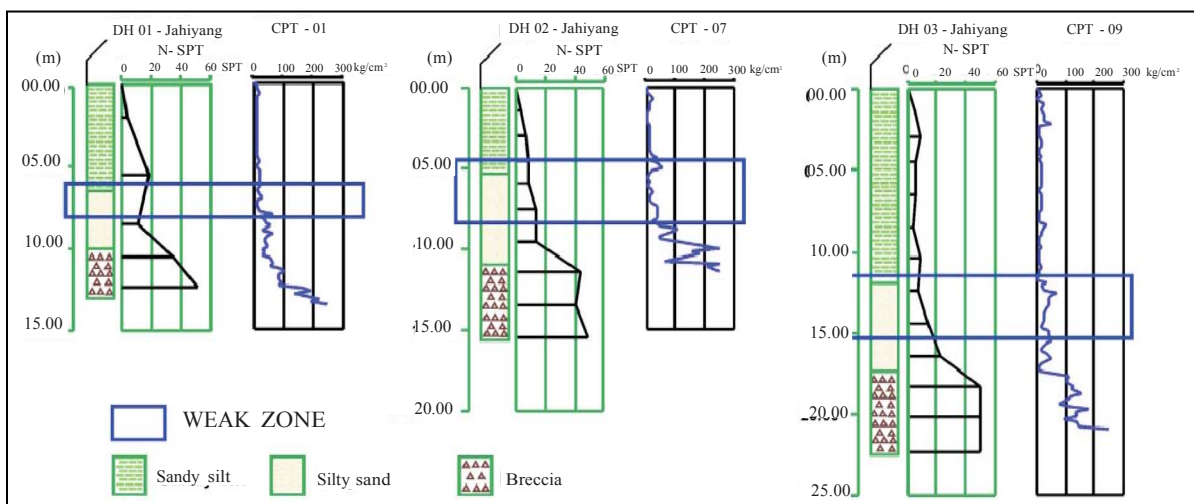


Figure 5. Correlation of cone resistant value and N-SPT showing the occurrence of weak zone.

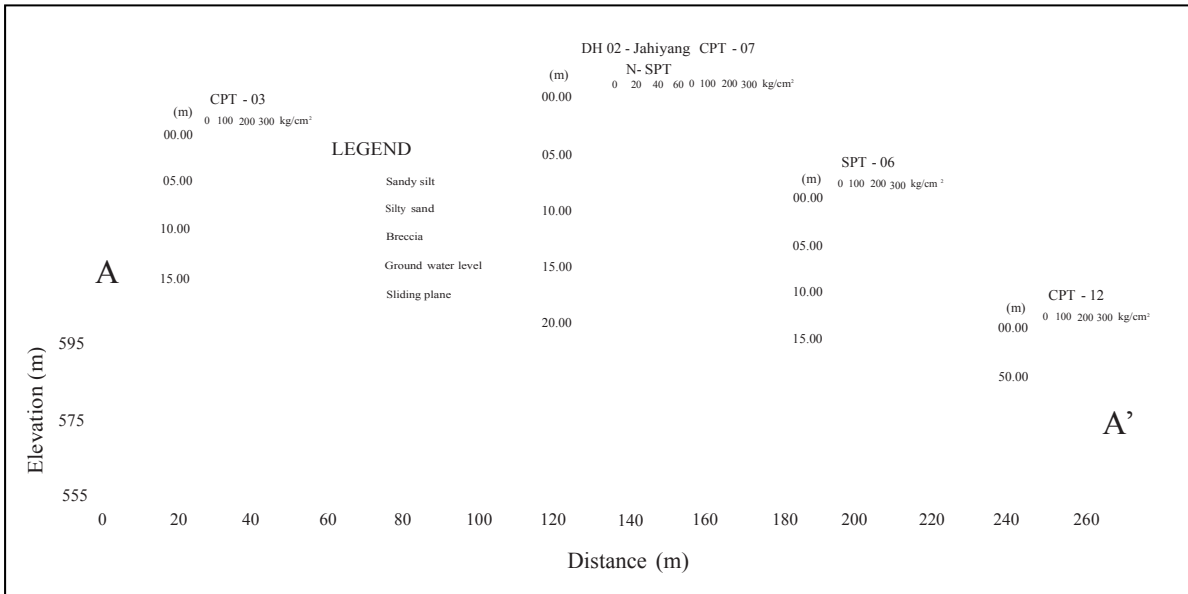


Figure 6. Cross section of Jahiyang Village landslide along line 6 illustrating soil stratification.

Table 1. N-SPT Value and Relative Density of Sand

Borehole	Depth (m)	N-SPT value	Relative density of sand (Meyerhoff, 1956)
DH-01	5.5-5.95	18	Compact
	8.5-8.95	10	Loose
	10.55-11.00	35	Dense
DH-02	6-6.45	9	Loose
	7.5-7.95	13	Compact
	9.5-9.95	14	Compact
DH-03	10.5-10.95	9	Loose
	12.5-12.95	7	Loose
	14.5-14.95	15	Compact
	16.50-16.95	22	Compact

45 - 73% with the degree of saturation of 33 - 106%, indicating that almost all soil pores were occupied by water. The geotechnical properties of all soil layers are summarized in Table 2.

Atterberg limits of the sandy silt show that the soil is classified as high plasticity silt (BS 5930, 1999). The percentage of clay fraction < 0.002 mm is low and the activity of clay is considered normal (Skempton, 1953). The permeability of the silty sand is one order of magnitude higher than the sandy silt. The effective shear strength of the soils shows the relatively low value of effective cohesion (c') and effective friction angle (ϕ').

Assessment of Slope Stability

The slope stability and safety factor were analyzed in selected section 6 (Figure 6) along the recent landslide by using Plaxis software. Plaxis is one of the most widespread code works with finite element method which is capable to model complex slope morphology and also to calculate the weakest point of the slope (Gorog and Torok, 2007). The effective stress parameter and saturated permeability for the finite element modelling were taken from the geotechnical laboratory test (Table 2) and the modulus of elasticity was estimated from empirical formulas

Table 2. Summary of Geotechnical Laboratory Test

Soil Properties	Sandy silt	Silty sand	Breccia
Plastic limit (PL) (%)	67.20 - 116.54		
Liquid limit (LL) (%)	33.97 - 72.37		
Plasticity index (IP) (%)	11.42 - 63.29		
Clay fraction < 0.002 mm (%)	13 - 16		
Activity (IP/ % clay)	0.87 - 1.10		
Unit weight (kN/m ³)	18.0	16.4	19.0
Saturated permeability (m/s)	3.5 x 10 ⁻⁷	3.73 x 10 ⁻⁶	
Porosity	0.45 - 0.73		
Degree of saturation (S _r)	0.33 - 1.06		
Effective cohesion, c' (kPa)	6.0 - 21.74	6.0 - 12.50	150.0
Effective friction angle, φ' (°)	12.0 - 21.30	13.0 - 25.98	35.0

as the following:

- The elasticity modulus (E) for sandy silt was estimated from N-SPT value (Bowles, 1996):
E = 0.6 (N-SPT+5) (MPa) (1)
- The elasticity modulus for silty sand was estimated from N-SPT value (Bowles, 1996):
E = 0.5 (N-SPT+15) (MPa)(2)

The summary of geotechnical properties utilized for slope stability modeling is presented in Table 3.

Mohr Coloumb material model is used in the slope stability assessment. In this finite element code the safety factor is calculated by phi- C reduction method where the input shear strength parameters are successively reduced until failure occurs (Plaxis, 1998). Boundary conditions of the modelling include application of plane strain 2D stress condition, standard fixities along the outer slope boundary, and assigning 15 nodes triangular mesh (Figure 7)

Assessment of slope stability was carried out for two conditions of measured groundwater level and

one condition of low groundwater level. For condition 1, the groundwater level is at the boundary of sandy silt and silty sand layer, whereas for condition 2 the groundwater level is 3 m elevated from the first condition (phreatic level at sandy silt layer), and furthermore for condition 3 the groundwater level is 7 m lowered (phreatic level at silty sand layer) (Figure 8).

Results of Slope Stability Assessment

The results of condition 1 model show that the overall factor of safety is 1.43 and maximum displacement of 20 cm was found at the top and the mid of the slope (Figure 9).

The largest displacement found at the crest and mid of the slope corresponds to the movement of the landslide body where large cracks and depression were found at the landslide scarp and within the landslide body. The result of condition 2 shows similar pattern with lower safety factor of 1.21 and higher displacement of 24 cm at the crest of the slope and 20 cm at mid of the slope (Figure 10).

Table 3. Geotechnical Properties for Slope Stability Modelling

Layer	Parameter						
	γ_{unsat} (kN/m ³)	γ_{sat} (kN/m ³)	Permeability k (m/day)	Cohesion c' (kN/m ²)	Friction angle φ'	Modulus elasticity (MPa)	Poisson ratio ν
Sandy silt	15.0	18.0	0.03	6	12	9	0.3
Silty sand	10.8	16.4	0.32	6	25	12.5	0.3
Breccia	18	19	0.0026	150	35	2000	0.3

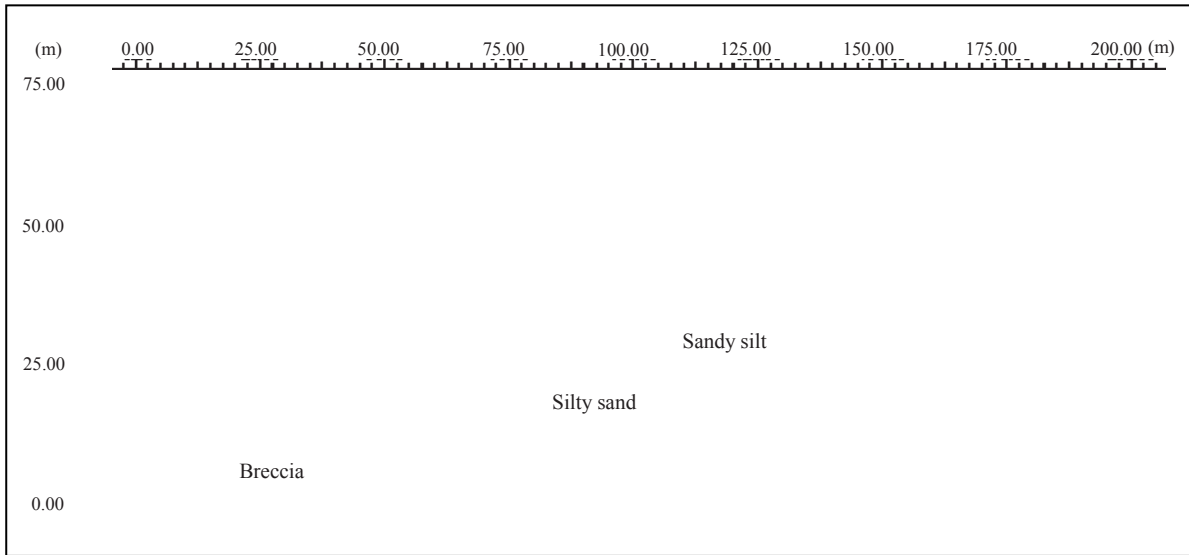


Figure 7. Boundary condition of slope stability modelling.

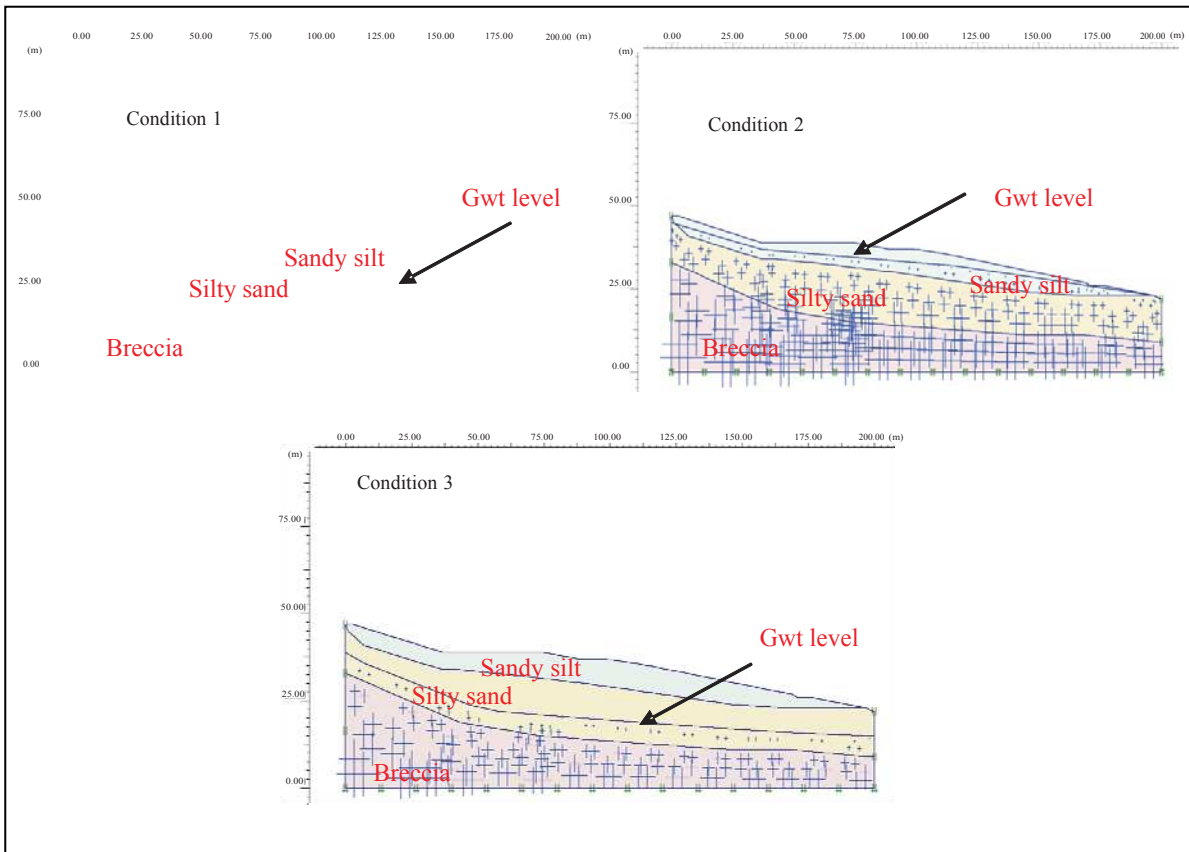


Figure 8. Groundwater level for first, second, and third conditions.

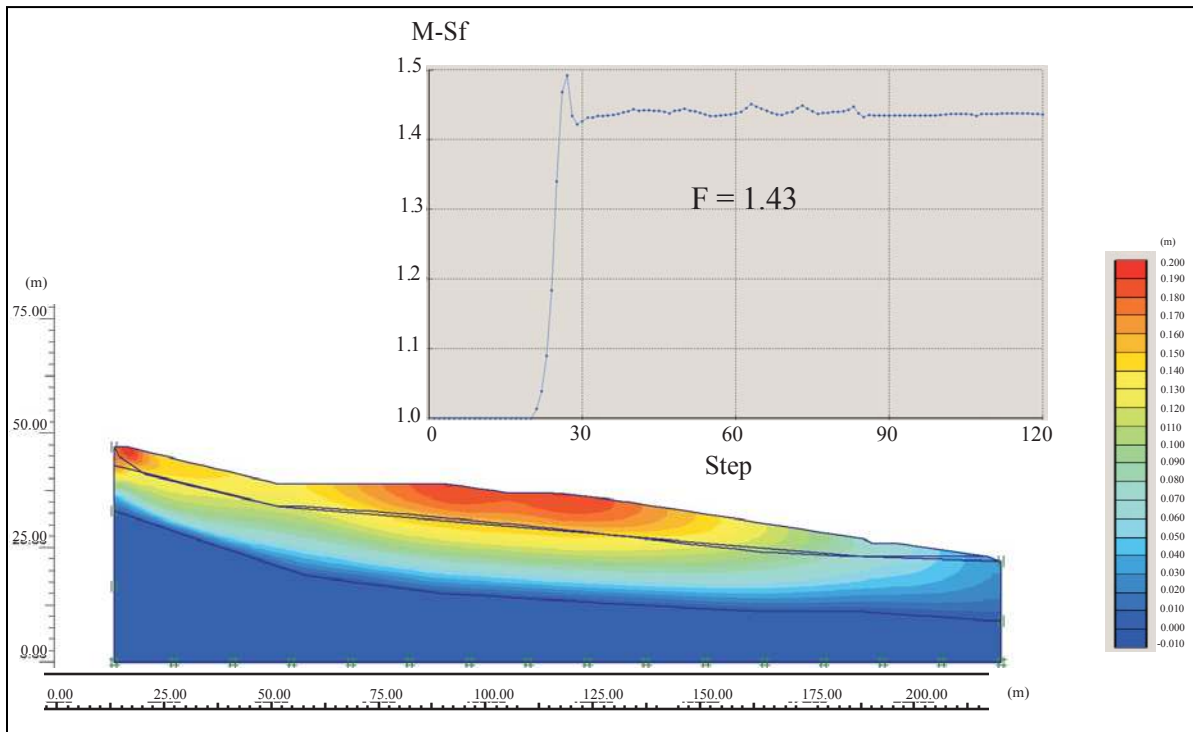


Figure 9. Factor of safety (M-Sf) and slope displacement contour for condition 1.

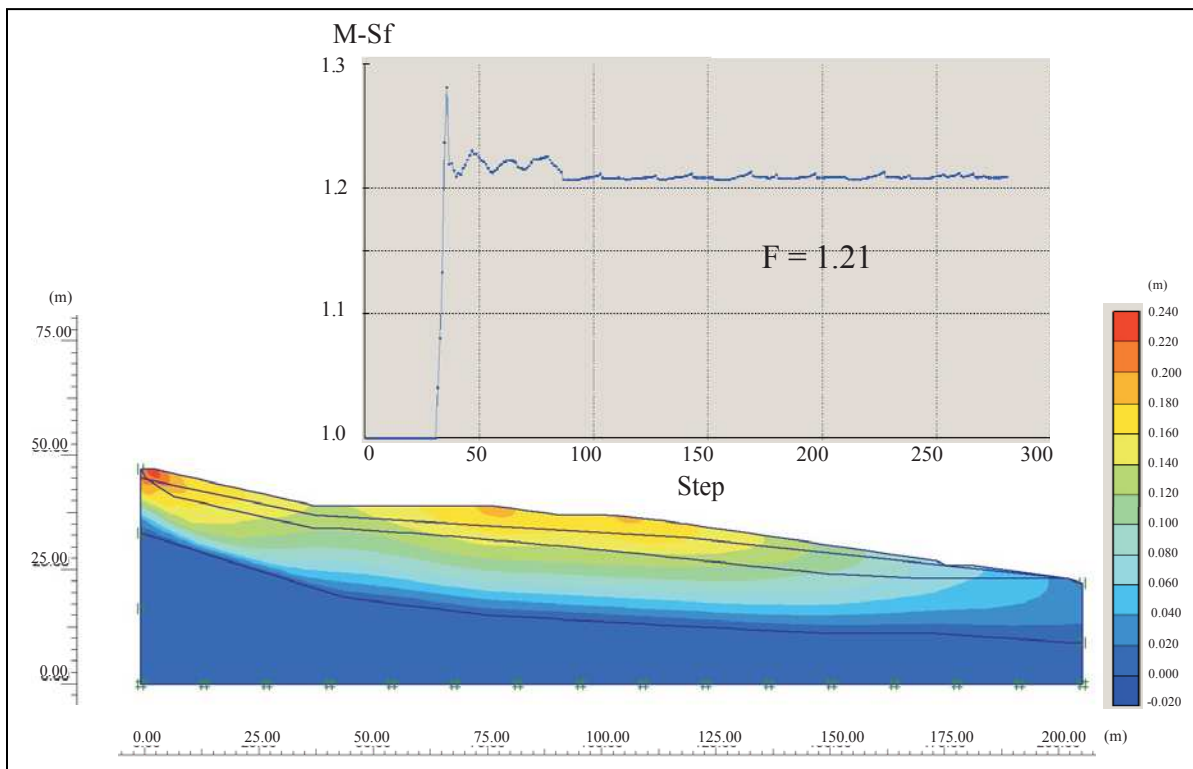


Figure 10. Safety Factor (M-Sf) and slope displacement contour for condition 2.

When the groundwater level is lowered to be within the silty sand layer, the safety factor slightly increases to 1.44 and the largest displacement of 22 cm takes place at the mid of the slope and the displacement at the crest decreases to 14 cm (Figure 11).

The summary of the slope stability modelling results for each condition can be seen in Table 4. From the summary of slope stability modelling (Table 4) using measured groundwater level (condition 1 and 3) and low groundwater level (condition 2), it can be seen that the slope is in critical to stable condition. To further verify the slope

stability condition, simulation of slope stability was made at the most critical condition of lowest shear strength and high water content. Lowest shear strength parameters of sandy silt ($c' = 6$ kPa and $\phi' = 12^\circ$) and silty sand ($c' = 6$ kPa and $\phi' = 13^\circ$) were applied and the highest water content is represented by the saturated unit weight at highest groundwater condition (condition 2).

The result of slope stability at the most critical condition (Figure 12) shows that the slope condition still belongs to critical category ($F = 1.12$). Increased displacement is seen at the crest of the slope (56 cm) and mid of the slope (40 cm).

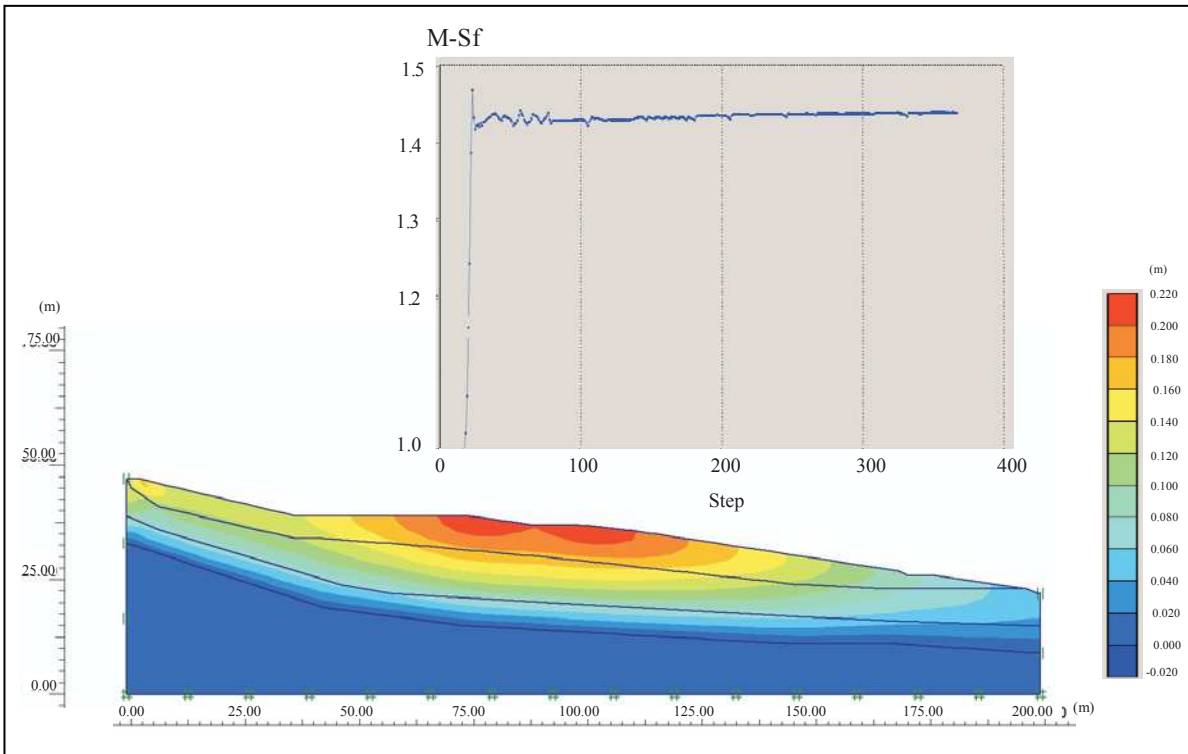


Figure 11. Safety Factor (M-Sf) and slope displacement contour for condition 3.

Table. 4 Summary of Slope Stability Modelling

Condition	Groundwater Level (m)	Safety Factor (F)	Criteria of safety factor (F) (Bowles, 1989)
1	- 6.0	1.43	$F > 1.25$, Stable
2	- 3.0	1.21	$1.07 < F < 1.25$, Critical
3	- 13.0	1.44	$F > 1.25$, Stable

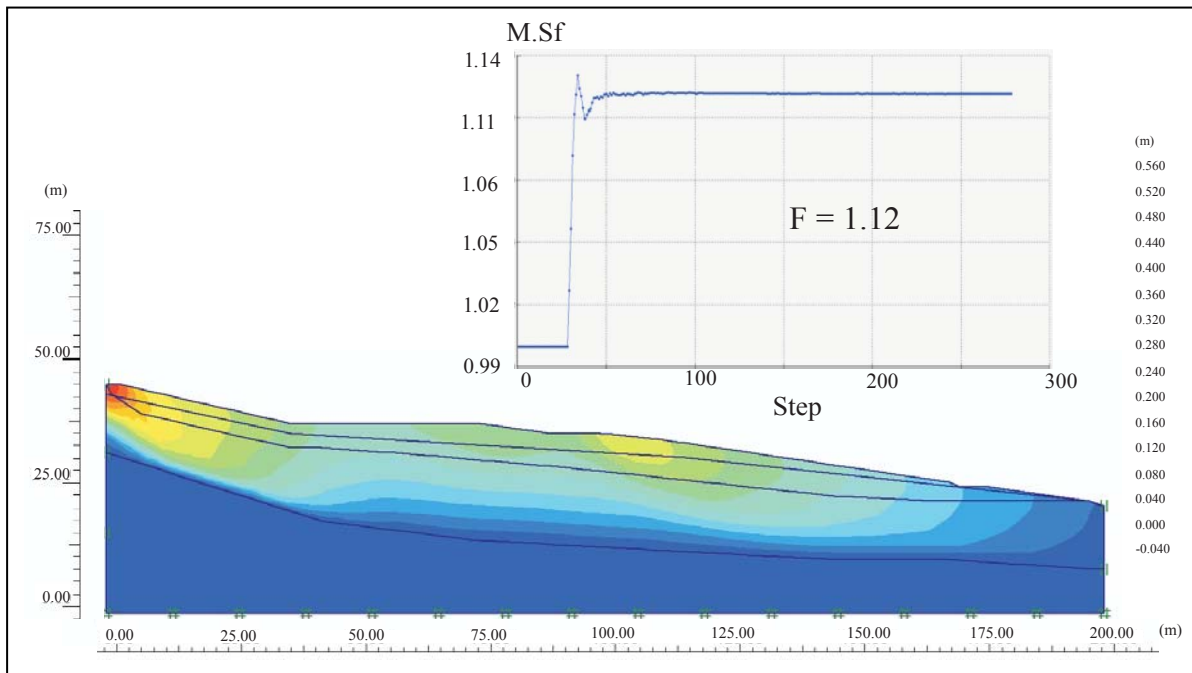


Figure 12. Safety Factor (M-Sf) and slope displacement contour for condition 3.

Discussion

Engineering geological investigation results reveal that the landslide area consists of residual soil of sandy silt, silty sand, and fresh to weathered breccias. The sandy silt conditions are plastic, generally porous (porosity 45 - 73%), existing in partly saturated to saturated state (degree of saturation 33-106%). Meanwhile, the silty sand exists in loose to compact density. The studied area is normally wet where several seepages and springs were found at the old and recent landslide areas. Correlation of N-SPT and cone resistant q_c values indicates the existence of weak zone which is also the zone of groundwater fluctuation. The weak zone extends from the loose to compact silty sand to the soft to firm sandy silt layer.

Slope stability modelling results show that the fluctuation of groundwater level at this zone causes the decrease of safety factor. When the groundwater level is low (condition 3), the safety factor (F) is 1.44 and the rise of groundwater level to the boundary of sand to firm sandy silt only slightly decreases the F to 1.43. Further rise of groundwater level to the soft to firm sandy silt largely reduces the F to

1.21. Analysis of slope stability at critical condition (lowest shear strength, high water content, and high groundwater level) resulted in slight decrease of safety factor (F) to 1.12. Based on the safety factor criteria (Bowles, 1989), the slope generally exists in the stable to critical condition, depending on the fluctuation of groundwater level. The results of slope stability modelling also indicate that relatively large displacements (14 to 22 cm) would still take place at the lower groundwater level condition (condition 1 and 3). Those results suggest that the occurrence of groundwater potential in the landslide area greatly influences the movements of the slope which signify the area as an active landslide area. Local inhabitants interviewed during a field investigation confirmed that large slope movements frequently took place following rainfall events which indicated that the rise of groundwater level trigger the incident of slope displacement.

Modelling results confirmed that large displacements took place at the crest and mid of the slope which corresponded to the slope movement recognized in the field. Evaluation of safety factor (F) shows that the stability of the slope tends to be disrupted when the groundwater level is at the

soft to firm sandy silt layer (condition 2). However, the fact that a displacement would still occur even at lower groundwater level condition implies that evaluation of safety factor only is not sufficient to explain the instability of the landslide area. The result of slope stability modelling proves that the combined evaluation of the safety factor and slope displacement through the finite element modelling provides a better explanation to elucidate the mechanism of the slow moving landslide in the studied area.

Conclusions

Engineering geological investigation carried out in the studied area reveals that the landslide occurred is of slow moving type involving materials of residual soil of soft to firm sandy silt, loose to compact silty sand, and base rock of fresh to weathered breccias. The landslide area is generally wet and the groundwater potential condition largely affects the stability of the studied area. Slope stability modelling shows that the decrease of safety factor and increase of slope displacement are influenced by the rise of groundwater level. Taking into account that the studied area is an active landslide area, it is proposed that the area is suitable for noneconomic purposes.

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