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GEOTECHNICAL INVESTIGATION OF A LANDSLIDE INCIDENT IN HULU KELANG, MALAYSIA

Jestin Jelani[1], Muhammad Shafiq Soffian Abdul Rahman[1], Suriyadi Sojipto[1], Wan Mohamed Syafuan Wan Mohamed Sabri[1], Lee Min Lee[2] and Nordila Ahmad[1]

[1]Civil Engineering Department, National Defence University of Malaysia, Malaysia
[2]Civil Engineering Department, University of Nottingham Malaysia, Malaysia

ABSTRACT

Malaysia has a tropical climate and receives high rainfall intensity, especially during the monsoon season, and is often associated with landslide disasters. This study conducts a geotechnical investigation and numerical simulation to examine the causative factors and failure mechanism of a landslide incident occurred on 18 September 2021 in a residential area in Hulu Kelang, Selangor, Malaysia. The landslide moved and shifted 2536 m^2 of land. This study conducts a desk study, site visits, field tests, soil sample collection and laboratory tests at the disaster area. The preliminary investigation showed that the bedrock in Kemensah Heights is between granite, phyllite and schist rocks. The 23mm/hr, 18mm/hr and 19.2 mm/hr rainfall intensity for the three days before the landslide raised the groundwater table to 3 to 4 m below the ground level. The laboratory tests revealed that the soil is silty SAND comprising primarily 42% sand and 28% silt. The cohesion, internal friction angle, unit weight, particle density and permeability were 11.3 kN/m^2, 29°, 16.5kN/m^3, 2.63 Mg/m^3 and 5.96 x 10^{-3} mm/s, respectively. The researchers performed a TLS survey to measure the slope dimension at the Kemensah Heights landslide; the 35m high, 80m wide and 60m long slope forms a 35° slope angle. The JKR probe test revealed two distinct soft and hard layers at a shallow depth which could have influenced the slope stability. The slope stability was evaluated using Plaxis 3D and Slope/W to determine the Factor of Safety (FOS) value. Both simulations showed that the FOS value was ranging between 1 and 1.095, indicating the slope is approaching the critical state. The critical potential failure plane obtained from the simulations showed good agreement with that observed from site. The failure plane was classified as a toe failure. This study concluded that there are four key triggering factors in the Kemensah Heights landslide, 1) antecedent rainfall, 2) excessive surcharge load, 3) soil type, and 4) the existence of two distinct soft and hard soil layers.

Keywords: Landslide, Plaxis 3D, Slope/W,

INTRODUCTION

Landslides are natural geological hazards where gravitational action causes soil or rock movement down a slope [1]. Landslides seldom occur due to a single factor; instead, a combination of several factors, such as rainfall [2], earthquake and volcanic activities [3], changes in groundwater table [4], excessive surcharge load [5], steep slope profile [6], and anthropogenic factor, including poor slope design and maintenance [7], contribute to a landslide. Nonetheless, rainfall is the primary factor causing landslides in Malaysia. According to the United States National Aeronautic Space Administration (NASA), Malaysia ranks among the top ten countries globally most susceptible to landslides [8]. The vulnerability is particularly evident during the monsoon season when Malaysia receives frequent and prolonged rainfalls. Between 1993 and 2011, there were 28 significant landslides, which resulted in 100 casualties and economic losses exceeding US $1 billion [9]. Twenty-one of them were triggered by rainfall.

Hulu Kelang is a residential area located 10 km from Kuala Lumpur. It is a well-known area for landslides due to its hilly and undulating terrain and location close to the toe of the Titiwangsa mountain range. Since 1993, the Hulu Kelang area has consistently experienced devastating landslides. Most of the landslides occurred in developed hillside areas which disturb the natural slope. The situation exacerbates because the Hulu Kelang receives a high rainfall annually, with an average rainfall of 2400mm [10]. The combination of these factors contributes significantly to the occurrences of landslides.

Many studies have been conducted in the Hulu Kelang area to determine the main causes of landslides. The study by [11] identified inadequate design of retaining structures and slopes as the primary cause of landslides in Hulu Kelang. The study by [12] supported these findings; they found that improper design and construction methods were the primary causes of the landslides, such as an inadequate support of lateral load caused by land movement underground. These poorly designed and constructed slopes failed during or after heavy rainfall events. Another potential contributing factor to the landslides was inadequate maintenance of the internal drainage systems of the slopes and retaining structures. Another study conducted by [13] identified 152 landslide scars on both soil and rock slopes, indicating that these slopes are potential slope failure sites. Furthermore, [14] conducted a detailed investigation into one of the major landslides, the 2008 Bukit Antarabangsa landslide, and concluded that the prolonged rainfall during the monsoon season was one of the primary triggering factors of the landslide.

This paper investigates a landslide incident in September 2021 in a residential area in Hulu Kelang to understand the main factors initiating it and its extent. The researchers conducted laboratory testing to characterize the soil and gather information on the topographical, stratigraphical, geological, hydrological and failure surface and used the PLAXIS 3D and Slope/W to evaluate the slope stability and compare the results with site observation.

RESEARCH SIGNIFICANCE

It is vital to identify and understand the factors causing the landslide and the interactions between them to develop effective measures to stabilise the slope and minimise the impacts of future landslides.

STUDY AREA

Fig. 1 shows the photograph taken at the studied landslide. The landslide translated approximately 2536m^2 of earth, blocking a river downstream of the slope (Fig. 2). It affected three bungalows and 19 double-story houses at the top and toe of the slope and necessitated the evacuation of 28 families. However, there was no fatality. The landslide disaster occurred after three days of rainfall. The daily rainfall data at the Bukit Antarabangsa station in Fig. 3 showed the antecedent rainfall from 15, 17 and 18 September 2021 was 23mm/hr, 18mm/hr and 19.2 mm/hr, and 14 mm/hr and 9mm/hr on 19 and 20 September 2021. According to the local experts, the rainfall raised the groundwater table to 3 to 4m from the ground level.

The geological map provided by Mineral and Geoscience Malaysia shows that the bedrock of the site is between granite, phyllite and schist rocks. The soil deposits are residual soil with highly varying engineering properties depending on the degree of weathering. The hydraulic properties of residual soil may vary up to two orders of magnitude and correspond with the soil infiltration rate [15].

Fig.1 Location of the landslide

Fig.2 A photo of the affected area taken two days after the landslide.

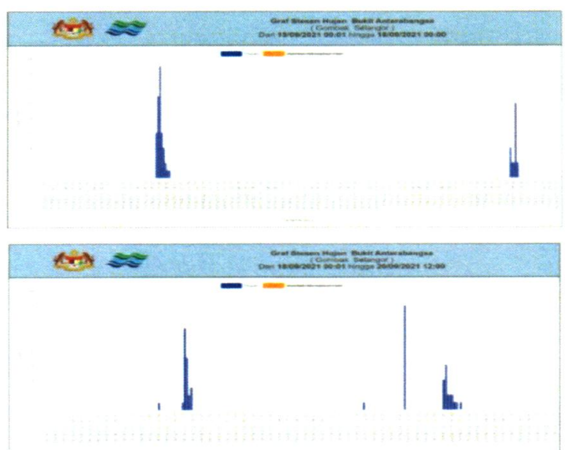

Fig.3 The antecedent rainfall at the Bukit Antarabangsa station.

METHODOLOGY

The study method comprises three stages. The first stage is desk study, field observation and investigation, soil sampling and laboratory test. The second stage is stability analysis using Plaxis 3D and verifying the result with Slope/W and field survey, and the final stage determines the factors causing the landslide.

Desk study, Field Observation and Investigation, Soil Sampling and Laboratory Test

The desk study gathered information of the landslide from the open-source data available in the news, the Internet, Google map and other free platform. The field data collection included Terrestrial Laser Scanner (TLS) survey, JKR probe test and soil sampling. The TLS equipment used in this study is the Leica 360 ScanStation with an accuracy of ±0.006 m at a range of 100 m to obtain spatial data of the landslide area, namely the height, width and length of the slope. The TLS was placed in front and on the side of the landslide, as shown in Figure 4. The JKR probe test was conducted at three points at the top, the middle and the toe of the slope, as shown in Figure 5. The disturbed and undisturbed soil samples were collected using a shovel and split spoon sampler with a diameter of 50 mm for the tri-axial test and a 110 mm diameter core cutter for the permeability test. All samples were stored in sealed plastic bags to preserve the moisture content. Table 1 lists the sample types, laboratory tests and standards used in the laboratory testing.

Table 1 The tests, sample types, number of samples and standard tests

No	Test	Type and number of soil sample	Standard
1	Triaxial test	Undisturbed (3)	BS 1377: 1990, Part 8
2	Permeability	Undisturbed (3)	BS 1377: 1990, Part 6
3	Sieve analysis	Disturbed (1)	BS1377:1990, Part 2, Clause 9.5
4	Soil density	Disturbed (1)	BS1377: 1990, Part 2, Clause 8.3
5	Moisture content	Disturbed (1)	BS 1377: 1990, Part 4
6	Compaction	Disturbed (3)	BS 1377-4: 1990, Part 4.
7	Atterberg limit	Disturbed (3)	BS1377: 1990, Part 2, Clause 4

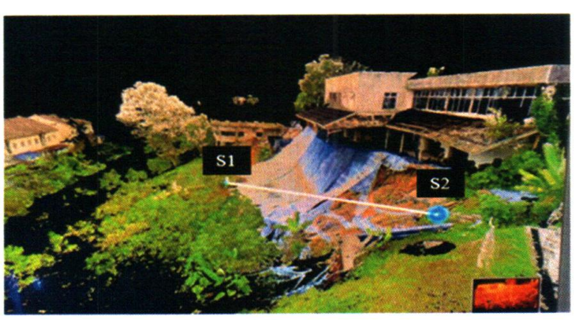

Fig.4 The positions of the TLS at the site. S1 is at the front, and S2 is at the side of the landslide.

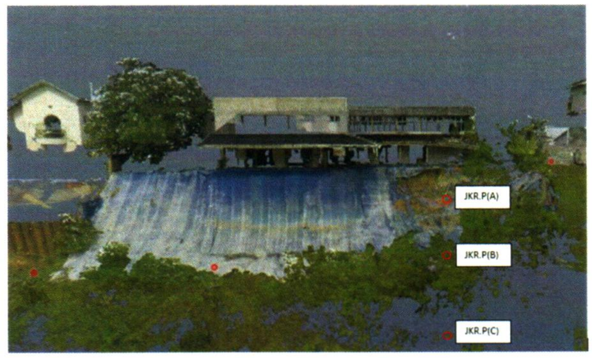

Fig.5 Locations of the JKR Probe Test conducted on the slope

Slope Stability Analysis Using Plaxis 3D

This research used a finite element analysis method (FEM), the Plaxis-3D software, to evaluate slope stability and analyse the mode of failure. Figure 6a shows the two levels of the groundwater table for the flow condition stage, where the lower level is a borehole water table located at a depth of 25m from the ground surface, and the upper level is the user-defined water table located approximately 4m based on the site investigation conducted by local experts. Figure 6b shows the 3D model of the slope in Plaxis 3D with a height, width and length of 35, 60m, and 80m, forming a 35°slope angle. A 50kN/m^2 surcharge load was imposed at the top of the slope to represent the structural load from existing buildings.

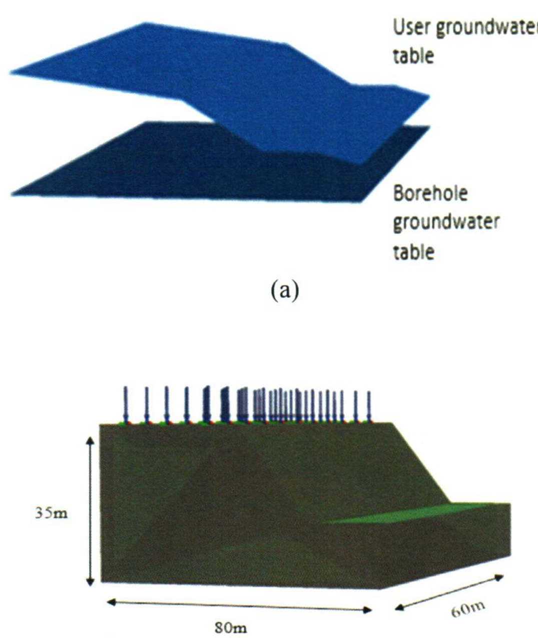

Fig.6 The slope model in Plaxis 3D. (a) Groundwater table input. (b) Slope dimension.

RESULT AND DISCUSSIONS

Field Data Result

Figure 7 presents the results of the JKR probe test at the top, the middle and the toe of the slope. It shows that the schematic cross-section of the slope can be interpreted with probable hard layer located at depth of 3.5 m to 6 m from the failure plane, as shown in Figure 8. There are distinct soft and hard layers on the slope profile. The hard layer could be a hard rock or dense layer since the JKR probe test penetrated 0.3 m with 400 blows. The soft layer is at a shallow depth 3 to 5 m from the failure surface.

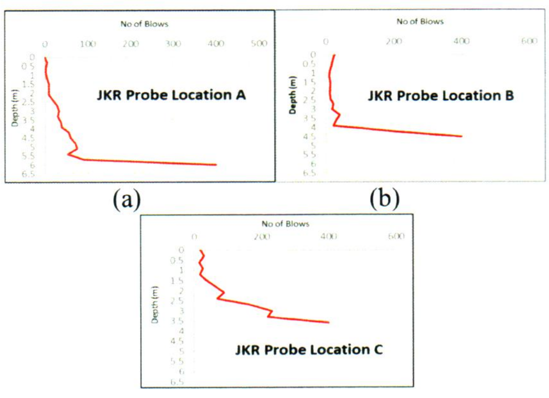

Fig.7 The result of the JKR probe test for the (a) top, (b) middle, and (c) toe of the slope.

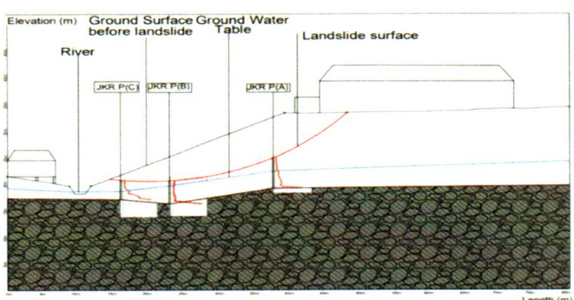

Fig.8 Schematic drawing of the Kemensah Heights slope.

Laboratory Test Result

Sieve Analysis and Atterberg Limit

Figure 9 shows the result of the sieve analysis. The soil consists of 16% clay, 28% silt, 42% sand and 14% gravel and, thus, classified as silty SAND based on British Standard soil classification. The Liquid Limit and Plastic Limit for the soil is 40 % and 26 %, thus classifying the soil as low plasticity.

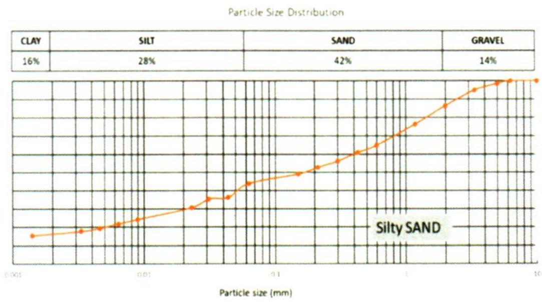

Fig.9 Particle size distribution

Permeability and Particle Density

The average permeability of the soil is 5.96 x 10^{-3} mm/s, which gives it a medium permeability. The soil has a particle density of 2.63 Mg/m³.

Soil Compaction

Figure 10 shows the result of the soil compaction test, where the maximum dry density of the soil is 16.51 kg/m³ at an optimum moisture content of 7.3%.

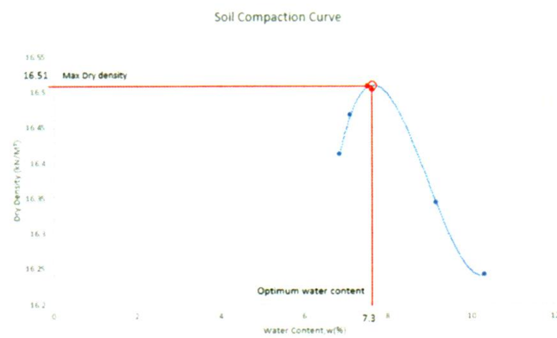

Fig.10 Soil compaction.

Consolidated-Undrained Triaxial test (CU)

The CU triaxial compression tests were conducted at three confining pressures of 50kPa, 100kPa and 200kPa for specimens A, B and C. Figure 11 shows the test result for the shear strength of the soil, where the cohesion, c, and angle of internal friction, ϕ, were 11.3 kN/m² and 29°.

The soil stiffness parameter, E50, was determined from the slope gradient of the stress-strain curve of each sample (see Figure 12). The average of the slope gradients was $E50^{ref}$. The $Eode^{ref}$ and Eur^{ref} were calculated using Eq. 1 and Eq. 2. Table 2 summarises the input strength parameters for the Hardening Soil Model (HSM) obtained from CU triaxial compression results.

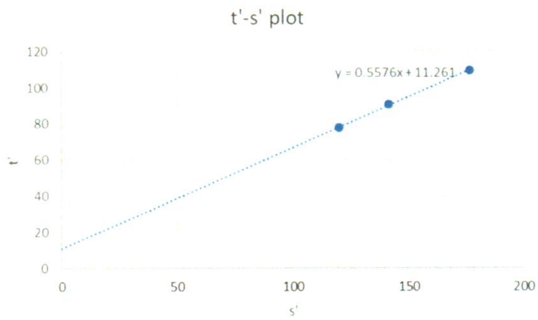

Fig.11 The shear strength parameters derived from t'-s' plot.

$$Eode^{ref} = \frac{E50^{ref}}{1.25} \quad (1)$$

$$Eur^{ref} = 3 \, x \, E50^{ref} \quad (2)$$

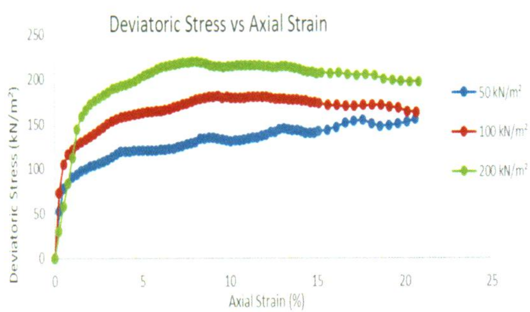

Fig.12 Stress-strain curve

Table 2 The E50, $E50^{ref}$, $Eoed^{ref}$ and Eur^{ref}

Effective major principal stress, σ'_1 (kPa	Effective minor principal stress, σ'_3 (kPa)	E50	E_{50}^{ref} kN/m^2	E_{oed}^{ref} kN/m^2	E_{ur}^{ref} kN/m^2
198	42	15493	15835	12688	47504
232	51	20835			
286	67	11176			

The Plaxis 3D and Slope/W results

Figure 13 shows the Plaxis 3D results which gave a FOS of 1, indicating that the slope is unstable. The critical slip plane occurred at the crest and intersected at the toe of the slope. The failure line is categorized as a toe failure. The result was validated using SLOPE/W to verify the FOS value. Fig. 14 shows that the FOS given by Slope/W was 1.095, indicating an unstable slope.

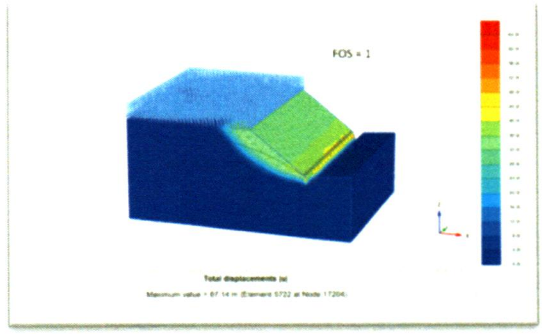

Fig.13 The Plaxis 3D result

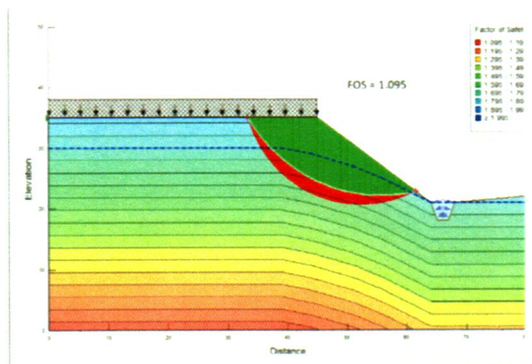

Fig.14 The Slope/W result

CONCLUSIONS

The conclusions drawn from this study are as follows:

The information from the local authorities, namely the Mineral and Geoscience Department Malaysia and the Department of Irrigation and Drainage, and the local residents were pivotal in this landslide case study. The preliminary data was useful in determining the geological and hydrological condition of the site, which allowed the researchers to perform the correct analysis. The site observation using TLS was very beneficial in obtaining the spatial data for the landslide site.

The in-situ test (the JKR probe test) to determine the soil strength showed that the slope consists of distinct soft and hard layers. The soft soil layer was located at a shallow depth of 3.5 to 6 m from the failure plane. The soft layer of the soil could have triggered the landslide since the failure plane did not intersect the hard layer. The laboratory test result showed that the soil at the site was silty SAND (with low plasticity), which consists primarily of 42 % sand and 28% silt. It has a low shear strength with an 11.3 kN/m^2 cohesion value and a 29°angle of friction, and its unit weight and particle density were 16.51 kg/m^3 and 2.63 Mg/m^3, and the average permeability was 5.96x10^{-3} mm/s. The soil friction angle was lower than the slope angle. The characteristics of residual soil indicated that it was prone to landslides due to the highly varying engineering properties influenced by the degree of weathering.

In summary, the key factors triggering the landslide in this case study were the antecedent rainfall, excessive surcharge load constructed at the edge of the slope, the soil type, and the presence of the hard and soft layers.

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