The Effects of Ground Water Level Fluctuation on Slope Stability by using SlopeW

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ABSTRACT

This study is a continuation of previous research work conducted by the author on the stability of man-made slope constructed in UPNM campus. This paper presents the effects of ground water level (GWL) fluctuation on slope stability by using numerical simulation program, SlopeW. Ground water rises were simulated from 5m below the ground until 10m above the ground. Soil samples were taken from the site and tested in laboratory and then were incorporated into the program. It was found that the stability of the slope decreased with an increase of GWL. The critical slip surface formed by each case study is categorised as toe failure with circular and non-circular shapes.

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Introduction

Road developments on hilly areas often involve excavations, earthwork and slope construction. Slopes are cut and designed accordingly to comply with specific requirements in order to satisfy safety, stability and cost factors. In a tropical country like Malaysia, slope failures are common particularly during rainy season. It was reported that 28 major slope failures occurred between 1993-2011 and the death toll was more than 100 (Rahman & Mapjabil, 2017). Although geotechnical engineer might have designed a safe slope, it still remains a challenge to ensure its stability. The complexity of materials forming the slope (Noroozi & Hajiania, 2015; Taleb & Berga, 2016; Zheng & Liu, 2016), geological conditions (Ersöz & Topal, 2018) and hydrological system (Hakim & Bahsan, 2017; Zhang et al., 2017) are among the contributing factors influencing slope stability. Despite these, ground water level (GWL) greatly affects slope stability (Alsubal & Harahap, 2018; Taib et al., 2017).
Considerable studies pertaining to GWL fluctuation in inducing slope failure have been conducted by researchers in recent years (Latief & Zainal, 2019; Pirone et al., 2015). Many empirical and analytical equations were developed to analyze the relationship of slope failure and GWL quantitatively. However, most of the empirical and analytical research were focused on specific slope regions and only considered limited parameters. With the advent of computer technology nowadays, numerical simulation program has become a powerful tool and is widely used by researchers due to its capability to solve complicated computation problem (Kainthola et al., 2013). Nonetheless numerical simulation is able to provide more accurate results in comparison to analytical methods.

This research is a continuation of previous work conducted by the author pertaining to stability of man-made slope constructed in UPNM campus (Jelani et al., 2018). There were five different slopes constructed along the road and only one was selected for investigation as shown in Figure 1. This slope was located at the highest point among others as well as the steepest. Field survey was carried out to determine the existing ground water table and seepage location.

The previous research had determined the safety factor of the slope without taking into consideration the GWL fluctuation. In this paper, further analysis was conducted to study the effects of GWL rising and to determine the shape of slip surface formation. The laboratory data presented in this paper were obtained from the local soil and then were incorporated into numerical simulation program, SlopeW.

Methodology

The methodology of this research was divided into two parts. The first part was laboratory works. Disturbed and undisturbed soil samples were taken at the top and bottom of the slope to determine the types of soil and shear strength properties. For sieve analysis, test and samples preparation were carried out as stated in BS1377:Part 2:1990. British Soil Classification System (BSCS) was used to classify the types of soil. Meanwhile, for soil shear strength determination, Automated Direct Shear Test machine was used as shown in Figure 2.

The second part of this research was to conduct numerical simulation analysis by using SlopeW program. Two analyses were carried out including the determination of the safety factor of the slope due to GWL fluctuation and identify slip surface formation. The geometry of slope model set up is shown in Figure 3, which consists of nine berms. The estimated slope height and slope inclination angle were approximately 22m and 70° respectively. All the units and scales used in the program were in meter and kilo newton. Two different types of soil layer, namely the upper and lower soil were constructed to replicate the actual site condition. The soil parameters for both layers were obtained from the laboratory test and assigned in the SlopeW program. The laboratory test data are tabulated in Table 1. The assumed GWL was initially setup at 5m below the ground (recorded as 1m) as shown in Figure 3. The GWL was then increased to 1m interval. Therefore, the variation of GWL used in this study was assumed at level 1m until 15m. The Factor of Safety (FOS) of slope for each GWL increment was computed by using the Morgenstern-Price method.

Fig. 1: Slope construction in UPNM campus (Jelani et al., 2018)
### Table 1: Soil parameters for upper and lower soil layers assigned in SlopeW

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Soil Layer</th>
<th>Soil Parameter</th>
<th>Colour Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 13</td>
<td>Upper</td>
<td>Cohesion, c (kN/m²)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angle of friction, θ°</td>
<td>21</td>
</tr>
<tr>
<td>13 - 22</td>
<td>Lower</td>
<td>Unit weight, γ (kN/m³)</td>
<td>17</td>
</tr>
</tbody>
</table>

#### Results and Discussions

The particle size distribution for both soil layers are shown in Figure 4. According to British Soil Classification System, the soil is classified as sandy slit and silty sand for upper and lower soil layer respectively.
There are nine undisturbed soil samples were tested to determine the shear strength properties for both soil layers. The average results are shown in Figure 5 and Table 1.

The influence of GWL rise upon FOS is presented in Figure 6. The GWL was simulated for each 1m height increment and it was started from 5m below the ground. The 1m to 5m heights of GWL depicted in the Figure 6 indicate water level below the ground. Meanwhile, 6m to 15m heights are water level above the ground. Meanwhile, 6m to 15m heights are water level above the ground. The highest FOS value obtained from SlopeW was 0.733 for water level height of 5m below the ground (the farthest GWL). A further increase of GWL resulted in the decrement of FOS. The decrement was noticeable for the GWL between 1m to 5m below the ground. However, no significant changes were observed when the GWL increased every 1m height above the ground. The overall FOS values were lesser than 1 regardless of any water level heights carried out in this study. This indicates instability condition for the slope and eventually, with the presence of GWL at any level could potentially cause slope failure or landslide. This finding is similar with previous studies that showed that the FOS decreased when GWL rose and the decrement declined dramatically when ground water height reached critical depth (Ashland et al., 2006).
Figure 7 shows the formation of critical slip surface for different GWL heights located below the ground. For all case studies, as the GWL increases to ground level, the shape of slip surface tends to become semi-circular and have relatively thicker soil mass. The slip surface line was observed passing through the crest of slope and extended to the toe. This type of failure is categorized as toe failure with circular shape. The toe failure may induce large scale of soil mass sliding that can cause remarkable damage. For GWL in case (a), the slip surface is much thinner as compared to other cases. This is expected due to GWL located at the farthest below the ground and FOS is the highest.

Figure 8 shows the critical slip surface for GWL rising above the ground. As the GWL increases, the slip surface tends to lie close to the slope surface and the line is not circular. This can be explained due to FOS having small changes through the cases (b) to (e). This is supported by the graph shown in Figure 6.
Conclusion

Stability analysis of man-made slope due to GWL fluctuation is studied by using SlopeW program. It was found that the stability of slope decreased with increase of GWL. The GWL increment also has an influence on critical slip surface formation. For all case studies, the slip surface formation is categorised as toe failure regardless of any increment of GWL height. This type of failure may induce large scale of soil mass sliding. The circular slip line with thick soil mass formed when GWL rose from below the ground. Meanwhile, the non-circular slip line with thin soil mass was formed for the case where ground water rose from above the ground.

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References


