The Effect of Rainfall Variability on Slope Stability in Canada Hill, Miri

Ming Yong Chung¹, Vera Hui Loo¹
¹Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, Miri 98009, Sarawak, Malaysia

E-mail: 7e3b2340@student.curtin.edu.my

Abstract. Canada hill is about 200 m high and located in Miri, Sarawak. Landslide is found commonly happens in Canada Hill areas and it has become a threat to the nearby villagers. This study investigates the rainfall intensity to the stability of slope failures. To achieve this objective, a slope located in Canada Hill was selected for numerical modelling. The numerical software SEEP/W was adopted for seepage analysis while SLOPE/W for stability of the slope. The parameters such as shear strength, permeability, soil water characteristic curve etc. were based on literature. The modelling of rainfall intensity was referred to historical data. The minimum, maximum and average rainfall intensity from historical data is chosen to model the infiltration of rainfall. The numerical results showed that with the continuous min. rainfall intensity of 1.509 mm/hr, the slope will not be saturated after 1 day. With the continuous rainfall intensity of 19.241 mm/hr for 24 hours, the residual soil and clay layer will be saturated at 24 hours. This is due to the infiltration of seepage flow and the increase of pore water pressure. The losing of soil suction in residual soil is significant when rainfall intensity is 36.974 mm/hr. The pore water pressure tends to weaken the soil in terms of reducing in the shear strength and matric suction of the soil. The stability of the slope will be affected. The results show that higher rainfall intensity, the lower the safety factor of the slope. This research provides a good understanding of the influence of rainfall intensity in Miri area to the stability of slope.

1. Introduction
Landslides are found commonly occurred in Canada Hill areas. There are more than 10 minor and major landslides been occurred in Canada Hill from 2009 to 2018. The landslides had become a threat to the villagers around Canada Hill area. The occurrence of landslides in Canada Hill is increasing with the time due to extreme weather condition. From the history cases, rainfall was believed to be main reason that triggered landslides in Canada Hill. Table 1 shows the information of past landslides that occurred in Canada Hill area from 2009 to 2018. All information of past landslides was taken from the e-newspaper [5-13].

The study area for this research is in Miri, the second largest city in the state of Sarawak, Malaysia [4]. Canada Hill is about 200 m high ridge that runs along Miri from North East to South West. Canada Hill is the tourist places in Miri which is famous with ‘The Grand Old Lady’, known as the first oil well drilled in the country.

Miri is categorized as narrow coastal region and the total thickness of Miri Formation is estimated to exceed 1830 m. The Lower part of Miri underground soil unit consist of interbedded shales and sandstones. Then, the Upper part of Miri soil unit is consisting of rapidly recurrent and irregular...
sandstone-shale alternations, with the sandstone beds passing gradually into clayey sandstone and sandy or silty shale [2].

This research studies the relationship of rainfall and groundwater level to the slope stability by numerical modelling. This research focuses on the understanding of the influence of rainfall intensity to the slope stability. Infiltration of rainfall changes the water level change which could induce new landslides or reactivate old landslides in tropical country, such as in Malaysia.

The methodologies of the research project include desk study, site investigation, rainfall analysis, consideration of boundary conditions and numerical analysis. The numerical software GEOSTUDIO 2018 is adopted to simulate the transient seepage by using SEEP/W. With the pore pressure distribution, SLOPE/W is used to assess the stability of slope. The soil parameters such as shear strength, permeability, soil water characteristic curve are referred to literature review.

Table 1. Historical landslides in Canada Hill between 2009 to 2018

| Date               | Location                              | Description                                           | References |
|--------------------|---------------------------------------|-------------------------------------------------------|------------|
| 16/1/2009, Friday  | Petrol Station (in front of Bintang Megamall) | Two foreign workers were buried alive due to the rock falls and earth collapsed | [12]       |
| 2/2/2009, Monday   | Kampung Lereng Bukit                   | Eight village houses were destroyed by two consecutive landslide | [8]        |
| 5/2/2009, Thursday | Access road to Miri SIB Church and Miri Gospel | Access road has collapsed and sunk due to landslip | [7]        |
| 21/1/2011, Friday  | Kampung Lereng Bukit                   | Most part of drain broke and swept away due to soil erosion | [6]        |
| 23/1/2014, Thursday| Kampung Lereng Bukit                   | Tonnes of earth and sand washed down by heavy rain    | [9]        |
| 13/11/2017, Monday | Kampung Lereng Bukit                   | Houses and vehicles were damaged, and roads cracked open due to soil erosion | [11]       |
| 15/11/2017, Wednesday | Top of Canada Hill                    | A big chunk of a deep slope collapsed and half of the road links | [10]       |
| 6/1/2018, Saturday | Kampung Lereng Bukit                   | Hillslope collapsed, mudslide to down                 | [13]       |

2. Objectives of Research
The purpose of this research is to understand the influence shear strength parameter, groundwater level and rainfall intensity to the stability of slope. The numerical software of GEOSTUDIO is adopted to analyze the seepage flow distribution corresponding to different rainfall intensity and to assess safety factor of slope in Canada Hill. The research is also used to investigate the effects of cumulative rainfall intensity to the stability of slope in Canada Hill parametrically.
3. Literature Review
This section will review components that affect the stability of slope which will be related in this research. Those factors include the physical and mechanical properties of soil, geometry of slope and rainfall thresholds.

3.1. Physical and Mechanical Properties of Soil
The physical and mechanical properties of soil such as cohesion, angle of friction, permeability, conductivity and volumetric water content will be affected by the particle size of the soil. The rate of infiltration into the soil will be lower if the grain particle size of the soil is smaller. The volumetric water content of clay is always higher than sand because it is hardly to dissipate or infiltrate the water through the clay layer due to the finest grained size of soil particles. The soil with lower coefficient of permeability will always have higher volumetric water content. Also, the soil with higher moisture content will deformed easier and weakens in term of shear strength due to higher plasticity limit.

3.2. Geometry of Slope
The slope angle can be one of the critical factors that caused the slope failures. The steeper the slope, the more unstable it will be. According to Oded Katz (2014), the size of landslide was controlled by the strength of slope materials. The landslide size will increase with the increasing in the slope gradient if the material strength has been assigned into the numerical analysis.

3.3. Rainfall Thresholds
Landslides are commonly triggered after a period of heavy rainfall. The infiltration of rain precipitation into the ground will affect the stability of slope. The infiltration process could reduce the shear strength of the soil significantly over the times. In fact, the shear strength of soil is inversely proportional to the moisture content or volumetric water content of soil. However, the rate of infiltration also depends on the particles size distribution of soil. The time taken for the rainwater to pass through the finer grain particle size of soil will be longer due to the high compactness of the soil particles.

The intense rainfall will affect the gravitational driving force and resistance forces between the soil particles. The weight of the soil after intense rainfall will be increased if the infiltration rate of surface soil is low. The gravitational driving force will increase as if the additional weight of rainwater is retained on the subsurface soil. Moreover, the resistance toward the slope movement of the soil depends on the degree of saturation in the soil. According to Daliei Peng (2018), the reduction of resistance to slope movement is caused by transient seepage in the slope. The rising of groundwater level causes the strain-softening of soil particles. The matric suction and shear strength reduce if the volumetric water content in the soil increase.

4. Methodology
The methodology includes three sections: site investigation, data and information collection and numerical analysis.

4.1. Site Investigation
Site investigation was carried out to identify the past landslides at Canada area. During the site investigation, several past landslides along the MIRI-PUJUT Main Road are identified. The soil samplings were collected on the failure slopes for laboratory tests.

4.2. Ground Condition
Soil investigation was carried out by JKR in April 2018. The borehole reveals that there are less than 5m of SILT/CLAY overlying the MUDSTONE. The SPT value is less than 10 for SILT/CLAY layer.

4.3. Topography
The geometry of selected slope is required for the numerical modelling to perform the transient seepage and slope stability analysis. The geometry of Canada Hill is based on terrain map in Google Map. Software such as SketchUp and Civil3D are adopted to create and generate the contour lines.

The study area of Canada Hill in Google Map was selected and converted into terrain model in SketchUp. Then, contour lines of Canada Hill were obtained by intersect the rectangular plane with the terrain model. After that, Civil3D was adopted to obtain the elevation of selected slope.

4.4. Soil Parameters
The physical and mechanical properties of the soil will be determined through the online literature, articles and journals parametrically. Soil parameters and groundwater levels characteristic of the Canada Hill were determined parametrically through literature review. Table 2 shows the soil parameters that used and incorporated for the numerical analysis.

| Residual Soil | Silt | Bedrock |
|----------------|------|---------|
| Hydraulic Conductivity (m/s) | 1.00E-05 | 5.00E-06 | 1.00E-9 |
| Unit Weight (kN/m$^3$) | 20.0 | 22.0 | 25.0 |
| Cohesion (kPa) | 5 | 10 | 0 |
| Friction Angle (deg) | 28 | 20 | 38 |
| Suction Frictional Angle, phi B (deg) | 18 | 15 | 23 |

4.5. Rainfall Intensities
The rainfall pattern and period of Miri is important to be identified for the research study. Fig. 1 shows the rainfall pattern of Miri from 2009 to 2018 [15]. From Fig. 1, it is observed that:

- The highest rainfall precipitation was found to be 887.37 mm/day in June 2010
- The lowest rainfall precipitation is 36.22 mm/day in February 2016
- The average rainfall precipitation is 461.795 mm/day

Three precipitations (maximum, minimum and average value) were selected for the study to understand the influences of rainfall intensity to the transient seepage and slope stability.
4.6. Numerical Analysis

A failure slope had chosen for numerical analysis to evaluate the failure slope planes. SEEP/W from GeoStudio software was adopted to simulate the seepage flow through the saturated and unsaturated soil of steady state and transient state. Fig. 2 and 3 showed the selected slope with details of boundary conditions of steady state and transient state respectively. While, SLOPE/W from GeoStudio software was adopted to determine the factor of safety for the selected slope that link with the transient seepage analysis.

**Steady State:**
- Initial Groundwater Level: 25 m below the ground surface
- Drainage Water Outflow: At ground level of downhill side
- Potential Seepage Face: On the slope surface with Water Rate: 0 m$^3$/sec
**Transient State:**

| Parameter                  | Value                                      |
|----------------------------|--------------------------------------------|
| Rainfall Flux              | Apply on the uphill slope surface          |
| Max Infiltration           | $1.02705 \times 10^{-5} \text{ m}^3/\text{sec/m}^2$ (36.974 mm/hr) |
| Average Infiltration       | $5.34485 \times 10^{-6} \text{ m}^3/\text{sec/m}^2$ (19.241 mm/hr) |
| Min Infiltration           | $4.19213 \times 10^{-7} \text{ m}^3/\text{sec/m}^2$ (1.509 mm/hr) |

![Figure 3](image.png)  
**Figure 3** Boundary condition of transient state

Then, the influence of rainfall intensity to the slope stability is modelled as follows: The selected slope with three different rainfall intensity are simulated for 24 hours to investigate the influences of cumulative rainfall on the landslide occurrence: - Case A) Minimum rainfall precipitation; Case B) Average rainfall precipitation; and Case C) Maximum rainfall precipitation.

Besides, SLOPE/W was adopted to assess the factor of safety of the slopes. A set of trial slip surfaces will be created to compute a critical factor of safety through SLOPE/W analysis.

**5. Results and Discussion**

Based on the research parameters and data information given, the following are the results and discussion on the numerical results of this research study.
Fig. 4 showed the pore water pressure condition of the slope at initial state (steady state). The highest positive pore pressure is 105 kPa while the highest negative pore pressure is -240 kPa. The blue isolines (blue dashed line) indicated the gradient line of ground water table. The soil layer below ground water table has fully saturated and experienced positive pore pressure, while the soil layers above the ground water level are not saturated and the soils are experiencing negative pore pressure. Fig. 4 showed that the layers of residual soil and silt are unsaturated along the slope at the initial state.
Case A)

1. Pore Pressure for Minimum Precipitation after 6 hours raining period

![Figure 5 Pore pressure after 6 hours raining period for minimum precipitation](image5)

2. Pore Pressure for Minimum Precipitation after 24 hours raining period

![Figure 6 Pore pressure after 24 hours raining period for minimum precipitation](image6)
Case B)

1. Pore Pressure for Average Precipitation after 6 hours raining period

![Figure 7 Pore pressure after 6 hours raining period for average precipitation](image)

2. Pore Pressure for Average Precipitation after 24 hours raining period

![Figure 8 Pore pressure after 24 hours raining period for average precipitation](image)
Case C)

1. Pore Pressure for Maximum Precipitation after 6 hours raining period

![Figure 9 Pore pressure after 6 hours raining period for maximum precipitation](image)

2. Pore Pressure for Maximum Precipitation after 24 hours raining period

![Figure 10 Pore pressure after 24 hours raining period for maximum precipitation](image)
Based on the numerical results in SEEP/W for three different flux boundaries conditions that had simulated for 24 hours period, the changes of transient seepage can be observed from Fig. 5, 6, 7, 8, 9 and 10.

Case A1 and A2 showed the pore water pressure with a minimum rainfall precipitation for 6 and 24 hours of rainwater infiltration period. The pore pressures were increased gently in the residual soil and silt soil layers. However, the residual soil and silt remain unsaturated after 24 hours of raining period.

Case B1 and B2 showed the pore water pressure with an average rainfall precipitation for 6 and 24 hours of rainwater infiltration period. The pore pressure in residual soil had increased significantly whereas the pore pressure in silt is increasing gently after 6 hours of raining period. After 24 hours of raining period, the residual soil and silt become saturated along the ground surface of the slope.

While, Case C1 and C2 showed the pore water pressure with a maximum precipitation for 6 and 24 hours of raining period. The pore pressure in both residual soil and silt layer had increased significantly, and the groundwater level has changed after 24 hours of raining period. The result in Fig. 10 showed the residual soil layer and silt layer (bottom of the slope) have fully saturated due to the rainwater infiltration process.

Figure 9 Factor of safety for minimum rainfall infiltration at 24 hours raining period
Based on the results from SLOPE/W for three different flux boundaries conditions that had simulated for 24 hours raining period, the changes for factor of safety can be observed in Figure 11, 12 and 13.

The factor of safety for maximum rainfall precipitation is 3.682 which is the smallest compared to the average rainfall precipitation (FS = 5.290) and minimum rainfall precipitation (FS = 11.186). The results showed that the factor of safety for the slopes decreased significantly if the rainfall precipitation is higher. The highest rainfall precipitation had increased the infiltration rate, where it resulted in the larger area of saturated residual soil. This had significantly affected the factor of safety.
for the slope to become lower due to positive pore water pressure and higher saturation in residual soil. The drop of factor of safety might due to the increases in pore pressure of saturated residual soil. Positive pore pressure has significantly reduced the matric suction of the soil. The soil strength reduces when the matric suction of the soil is reduced. The reduction in matric suction and shear strength for the slope with maximum rainfall precipitation has caused the soils to lose its strength to resist the shear strength. Therefore, the factor of safety for the slope with maximum rainfall precipitation will be lowest as its positive pore water pressure is minimum and average rainfall precipitation.

The results of coupled analysis demonstrate good agreement between the predicted results. These findings are useful to understand how the rainfall intensity of Miri area affect the stability of slope.

References
[1] Botts, Michael. The Effects of Slaking on the Engineering Behavior of Clay Shales. 1987.
[2] King King, Ting, Dony Adriansyah Nazaruddin, Yuniarti Ulfa, and Illiya Amalina A.R. 2016. "PETROLEUM GEOLOGY-RELATED SITES IN AND AROUND MIRI, SARAWAK, MALAYSIA." Researchgate. https://www.researchgate.net/publication/303939768_PETROLEUM_GEOLOGYRELATED_SITES_IN_AND_AROUND_MIRI_SARAWAK_MALAYSIA_POTENTIAL_GEO TOURISM_RESOURCES_Ting_KING-KINGI.
[3] Mark A. Nearing, L.J. Lane, G.R. Foster, S.C. Finkner. 1989. A Process-Based Soil Erosion Model for USDA-Water Erosion Prediction Project Technology. 10 September. Accessed 30 May, 2018. DOI: 10.13031/2013.31195.
[4] "Miri Location." Google Map. https://www.google.com/maps/place/Miri,+Sarawak/data=!4m2!3m1!1s0x321941fc74729dcf:0x2691b344fbc4816?sa=X&ved=2ahUKEwiHwK-w5-HdAhVIXiVBodoQ8gEwAHoECAAAQ.
[5] The Star Online. 2009. Continuous rain can lead to landslides at Canada Hill. 21 December. Accessed 30 May, 2018. https://www.thestar.com.my/news/community/2009/12/21/continuous-rain-can-lead-to-landslides-at-canada-hill/.
[6] The Star Online. 2011. Erosion threatens the lives of foothill residents. 21 January. Accessed 30 May, 2018. https://www.thestar.com.my/news/community/2011/01/21/erosion-threatens-the-lives-of-foothill-residents/.
[7] The Star Online. 2009. Hilltop churches stop services after landslide. 5 February. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2009/02/05/hilltop-churches-stop-services-after-landslide/.
[8] The Star Online. 2009. Landslides threaten hillslope villages. 2 February. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2009/02/02/landslides-threaten-hillslope-villages/.
[9] The Star Online. 2014. Northern region folk, especially those staying on hillslopes, fearful of more landslides. 23 January. Accessed 30 May, 2018. https://www.thestar.com.my/news/community/2014/01/23/heavy-rain-makes-residents-edgy-northern-region-folk-especially-those-staying-on-hillslopes-fearful/.
[10] The Star Online. 2017. Rain causes collapse of Canada Hill slope in Miri. 15 November. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2017/11/15/rain-causes-collapse-of-canada-hill-slope-in-miri/.
[11] The Star Online. 2017. Several houses in Miri under threat of collapsing following heavy rain. 13 November. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2017/11/13/miri-houses-damaged-landslides-flood/.
[12] The Star Online. 2009. Two Indonesian workers killed in Miri landslide. 16 January. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2009/01/16/two-indonesian-workers-killed-in-miri-landslide/.
[13] The Star Online. 2018. Two villages in Miri hit by floods and mudflows. 7 January. Accessed 30 May, 2018. https://www.thestar.com.my/news/nation/2018/01/07/two-villages-in-miri-city-hit-by-floods-and-mudflows/.
[14] Wenfeng Ding, Chihua Huang. 2017. Effects of soil surface roughness on interrill erosion processes and sediment particle size distribution. 23 August. Accessed 30 May, 2018. https://doi.org/10.1016/j.geomorph.2017.08.033.
[15] World Weather Online Developer Portal. 2018. World Weather Online. 29 May. Accessed 29 May, 2018. https://www.worldweatheronline.com/miri-weather-averages/sarawak/my.aspx.
[16] Yan, Caina, Zhijun Jin, Jianhua Zhao, Wei Du, and Quanyou Liu. “Influence of sedimentary environment on organic matter enrichment in shale: A case study of the Wufeng and Longmaxi Formations of the Sichuan Basin, China.” Marine and Petroleum Geology 92 (2018), 880-894. doi:10.1016/j.marpetgeo.2018.01.024.
Acknowledgement
The in-situ experiment work described in this paper was carried out by Jabatan Kerja Raya Sarawak. The author would like to acknowledge the JKR to provide the information of soil investigation of Canada Hill’s. Lastly, the author wishes to thank to my classmates, Mr. Kiing Teck Yiew, Mr Clement Yap and Mr Chieng Yiew Chee for their participation on site investigation of the project.