Determination Of Slope Instability Using Spatially Integrated Mapping Framework

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Abstract. The determination and identification of slope instability are often rely on data obtained from in-situ soil investigation work where it involves the logistic of machineries and manpower, thus these aspects may increase the cost especially for remote locations. Therefore a method, which is able to identify possible slope instability without frequent ground walkabout survey, is needed. This paper presents the method used in prediction of slope instability using spatial integrated mapping framework which applicable for remote areas such as tropical forest and natural hilly terrain. Spatial data such as geology, topography, land use map, slope angle and elevation were used in regional analysis during desktop study. Through this framework, the occurrence of slope instability was able to be identified and was validate using a confirmatory site-specific analysis.

Keywords: Slope, Instability, Spatially, Integrated, Framework

Introduction

Slope instability monitoring and prediction in mountainous and natural terrain are normally challenging as well as dangerous. The challenge in measuring the stability of natural slopes including wild animals and accessibility, which is time consuming. Normally slope instability in natural terrains rarely notice and are encountered during periodic or routine visit into the jungle i.e. during transmission tower inspections. It is crucial to determine the stability of slope where slope failures may cause transmission tower to collapse and will affect the electricity supply to the public. Thus, in order to ensure long-term stability of the slopes, the acquisition of subsurface information such as soil profile and groundwater level is a must.

A detailed desktop study by integrating information such as geology, topography, elevation and slope angle were found useful in regional analysis to locate potential instability of slope. This paper will discuss the applicability of spatially integrated mapping framework using combination of spatial data, geological mapping data and laboratory result testing to determine slope instability and influence factor contribute to landslide in study area.

Conventional Site Investigation

According to [1], [2], [3] and [4], one of the key performance indicators in geotechnical site investigation is preparation, which includes desk study and walkover survey. This key performance indicator integrates soil information obtains from surface and sub-surface at regional as well as site-specific scale. Detailed
and thorough desk study can be done at both regional and site specific scales where at site specific scale it may help in optimizing the identification of boreholes location and numbers of borehole required. Typically in order to assess stability of slope, three to five boreholes with 10m intervals are placed in a straight line up the slope and if the area is extensive more than one line with approximately 50m intervals are required. Boreholes should penetrate up to 6m into rock before it can be terminated when a competent hard stratum is reached [2]. This requirement is merely to establish a detailed subsurface soil profile (i.e. boulders, buried dumping site, reclamation area etc.) in order to aid design. The main drawback of the conventional site investigation using borehole is that the subsurface information obtained can be classified as localized information due to anisotropy and complexity of soils. Thus, an additional step of geophysical survey, which is very useful to determine subsurface profile of a large area prior to borehole drilling, would be an advantage.

Other important aspect that is seldom overlooked in slope stability analysis is the influence of geological feature such as relicts discontinuities. A group of researchers have confirmed the importance of relict geologic discontinuities as contributing factors to many landslides in weathered rock profiles [5]. Relicts discontinuities are loci of weathering and may be partially infilled with transported clay and other sediments, commonly in association with dilation of the rock mass [6]. Relict discontinuities showed a significant and uncertain hazard whether the temporary and permanent slopes. This is because the sign of relict discontinuities is difficult to find with the aid of normal site investigation procedures and also the potential occurrences are ignored until the apparent movements by mass shear strength or failures along this planes. The combination of near vertical release surface and an extensive basal slip plane in slope failures are result of relict discontinuities [7]. Although the slope failure due to geological features is only 6%, it is suggested it should be recognised that these features play important role in residual soil especially in sedimentary formation [8]. It is also suggested that confirmatory slope mapping on exposed area should be conducted.

Spatially Integrated Slope Instability Mapping Framework

Geological mapping involves the mastery of a wide range of skills: observational and interpretive skills, a broad knowledge of rocks and geological processes, plus navigational and cartographic skills [4]. Over the past decade new ways of creating detailed and accurate digital topographic models of the Earth’s surface have been developed, and these are proving a great assistance to geological mapping [4]. Based on the enhancement of technology for geological mapping, new framework call spatially integrated slope instability mapping will be introduce. Spatially integrated slope instability mapping is a forecast model that is used to identify slope failures by analyzing triggering variables (i.e. discontinuities and relicts joint) at both regional and site-specific scales. This model is intended to make use of geological features such as relicts discontinuities for weathering grade V and VI in slope stability prediction. Analyses were done by utilize all information from large regional scale up to site-specific scale was used to identify slope instability of an area [9].

A desktop study at regional scale consists of landslide hazard assessment, terrain mapping and geological mapping study. Secondary data from geological map, land use map, topography map are transformed into spatial data using geographic information system. These spatial data were overlay and weighted to form landslide hazard map and terrain map. Geological map of study area were used to interpret the geology condition especially the occurring of fault (discontinuity) in the area using cross section. Integration of result from terrain map, landslide hazard map and geological mapping indicate the condition of the area i.e. location of potential slope stability or the area should be investigated for back analysis assessment. All these parameters (fault, erosion, stream, lineament and landslide area) were identified as disturbing factors in governing slope stability. Thus, this process is able to act as initial indicator in site visit planning. A site visit to location as identified during regional scale analysis was done to obtain information such as discontinuities and soil profile by conducting discontinuities mapping and geophysical survey. Later, this information were used to conduct analysis at site specific scale. A kinematic analysis and slope stability using SLOPE/W software was conducted to determine type of slope
failures as well the factor influence to the stability of study area. Spatially integrated slope instability mapping framework show in Figure 1.

**Figure 1.** The framework of spatially integrated slope instability mapping.

**Regional Scale Analysis**

**Study Area and Landslide Hazard Map**
The analysis starts with identification of study area in regional scale size. The topography map was used to identify the boundary of study area i.e. Batu Melintang-Jeli, Kelantan as Figure 2. The study area boundary is justified based on river basin. The data from the study area are analyzed using Geographic Information System (GIS) and spatial data such as geology map (excluding structural geology), land use and topography were overlay and weighted to develop landslide hazard map. Location of the problematic slope were integrated with the landslide hazard map as Figure 2. In Figure 2, shows that Tower T18 and the slope are located at low landslide hazard zone.

**Figure 2.** The topography and landslide hazard map of study area

However, Tower T18 was observed and identified because, previously this slope had failed and remediation works consist of guniting and soil nailing were used to stabilize the slope. Based on recent
site visits and observations, there were significant signs of new soil movements (i.e. settlement and slope failure). Therefore, integrated slope stability study was conducted to investigate the cause of slope failure.

**Geological Mapping – Geology Cross Section and Lineament Analysis**

The Geological Survey Malaysia (GSM) Solid Geology map with 1:150 000 scale, indicates the geology for Batu Melintang, Jeli, Kelantan as Figure 3. It is dominated by Stong Complex, which consists of three plutonic components (in order of decreasing age), Berangkat tonalite, Kenerong microgranite and Noring granite. The age of Stong Complex is Cretaceous – Triassic. The Stong Complex is part of East Belt granite of West Malaysia. The study area is in the area of Noring Granite.

Based on geological map and geological mapping the area consists of acid intrusive igneous rock and some trace of metamorphic rock, which is phyllite as shown in Figure 3. While, Figure 4 shows the cross section of the area and Tower T18 is located on a fault line.

The lineament analyses were conducted using data from topography map such as stream, drainage and valley near the slope failure area to produce rose diagram. The rose diagrams explained the frequency of lineament in a given orientation. From the diagrams as Figure 5 show that the highest of lineament is L1 and the orientation for lineament set as shown in Table 1. The orientation of L1 is near to north – south lineament and it shows the lineament of study area similar to major Malaysia lineament. The collection of lineaments are considered as weak zone area.
Figure 5. The rose diagram of the study area

Table 1. Lineament Orientation

| Lineament Set | Orientation (Degree) |
|---------------|----------------------|
| L1            | 320-350/140-170      |
| L2            | 50–70/230-250        |
| L3            | 280-300/100-120      |
| L4            | 80-90/260-270        |
| L5            | 0-20/180-200         |

Terrain Mapping

Initial desktop study was conducted prior to site visit to obtain geological and topography information at study area. Terrain and angle maps were generated from topography map using Geographic Information System, where the elevation and slope angle of the study area is 145 meter to 175 meter and 6° to 15° respectively as shown in Figure 6. Tower 18 is located at terrain classified as 2C3b (in terrain map as Figure 6). Terrain 2C3b indicate the area is prone to erosion, and located at landslide zone in between 10 to 50 meter near to natural stream.

Figure 6. Terrain Map of study area
Site-Specific Scale Analysis

**Geophysical Survey**
A 200 meter in length of two resistivity survey lines were conducted on site to obtain subsurface information. Based on resistivity survey, the existence of groundwater levels is at a depth of 10.0m from ground level. Generally, the subsurface is made up of sandy silt soil from weathered phyllite above the ground water level, which ranges of resistivity value from and 251-260 Ohm-m. A boulder of weathered phyllite Grade III sized 5.0m x 10.0m was found above the ground water level with resistivity value ranging from 2771 to 3390 Ohm-m as shown in Figure 7. The Standard Penetration Test (SPT-N) and Rock Quality Designation (RQD) for soil and rock types have been interpreted at 1.5m depths from the surface level based on the depth of borehole. This area consists entirely of weathered rock with RQD values of 25% to 50% and only a quarter of the area has RQD values of 50% to 75%. The sandy clay soil at this area that has SPT-N values from 7 to 29 was discovered below the ground water level. This soil can be categorised as firm to very stiff clays.

![Figure 7. Subsurface Profile from resistivity survey of study area](image)

**Slope Stability Analysis**
An in-situ discontinuities mapping and soil sampling was conducted at the failure area as shown in Figure 8. Total of 100 data of relict set are collected during discontinuity survey and kinematic analysis are performed to predict the stability of the slope at the failure area. Besides that, 36 samples of soils from grade V and grade VI were collected at the landslide area for triaxial consolidated drained test. The discontinuity data and result from triaxial consolidated drained test were analysed to predict the stability of the slope at the study area and to identify the cause of failure.
Back Analysis using Kinematic Analysis

Kinematic analysis was conducted to determine the type of potential failure plane. There are five sets of pole discontinuities exist at studied slope face. All of these poles are labeled as D1, D2, D3, D4 and D5, which D1 is the highest concentration followed by others. The orientations of these 5 poles are: D1 = N312°E/47°, D2 = N129°E/50°, D3 = N162°E/21°, D4 = N230°E/53° and D5 = N236°E/29°. By using 30° as internal friction angle from universal internal friction angle of rock, slope orientation at this site is striking to N320°E with dipping about 40°. There are four potential failures on this slope labeled as P1, P2, W1, and W2 as shown in Figure 9. Potential failures W1 and W2 were already occurred on October 2013 confirming the prediction of slope instability using kinematic analysis whereas, recent visit conducted on September 2014 shows the occurrence of toppling failures where it has been predicted in this study and labeled as P1 and P2.

Figure 8. Discontinuity mapping and sampling from landslide zone in the study area

Figure 9. Potential slope instability using kinematic analysis method
Back Analysis using Slope-W using soil sample from landslide zone
Soil samples were collected and the cohesion value for normal stress, \( c = 107.53 \text{ kN/m}^2 \) and the angle of friction value is 23.91° and the values of shear strength is 462.21 kN/m² and Figure 10 shows the slope stability analysis by SLOPE/W and the factor of safety value is 0.908 which is less than 1.

![Slope instability using slope-w](image)

Figure 10. Slope instability using slope-w

Conclusions
Back analysis using kinematic analysis and slope stability of sample from landslide zone shows that the failure of the area influences by discontinuity and the weathering process. The evidence clearly shows in resistivity result, as the area consists entirely of weathered rock with RQD values of 25% to 50% and only a quarter of the area has RQD values of 50% to 75%. The sandy clay soil at this area that has SPT-N values from 7 to 29 was discovered below the ground water level. This soil can be categorised as firm to very stiff clays. Beside that the lineament analysis and geology cross-section shows that the study area located at weak zone, which are influence by geological structure. It also can be shows clearly in terrain map, indicate as 2C3b which have prone to erosion and landslide zone in between 10 to 50 meter near to natural stream.

In conclusion, this framework is able to indicate location of potential slope instability by integrating geological features impact during analysis. By doing comprehensive regional scale analysis, slope instability can be identified without site walkabout. This framework can be an aide in determining location of slope instrumentation as well as during soil sampling. This study relates information from geology and engineering in order to get the most accurate data while doing site investigation. However, the main drawback of this framework is it relies on the availability of current spatial data.

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References

[1] Clayton C R I, Simons N E and Matthews M C 1995 Site Investigation, second ed., Halsted Press.
[2] Simons N, Menzies B and Matthews M A 2002 Short Course in Geotechnical Site Investigation, Thomas Telford, London
[3] Njue L M 2010 Presented at Short Course V on Exploration for Geothermal Resources, organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya, Oct. 29 – Nov. 19, 2010. (http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-11-04.pdf 12/9/2015).
[4] Lisle R J, Brabham P and Barnes J 2011 Basic Geological Mapping, fifth ed., John Wiley & Sons, Ltd
[5] Deere D U and Patton F D 1971 Slope stability in residual soils. In Proceedings of the 4th Pan-American Conference Soil Mechanics and Foundation Engineering, Vol. , pp. 87–170.
[6] Kirk P A, Campbell S D G, Fletcher C J N and Merriman R J 1997 The significance of primary volcanic fabrics and clay distribution in landslides in Hong Kong. Journal of the Geological Society of London , 154 , 1009 –1019
[7] Aydin A 2006 “Stability of Saprolitic Slope: Nature and Role of Field Scale Heterogeneities”, Natural Hazards and Earth System Sciences, 6 , 89-96 [Online].Available: http://www.nat-hazards-earth-syst-sci.net/6/89/2006/nhess- 6-89-2006.pdf.
[8] Gue S S and Tan Y C 2006 “Landslides: Abuses of the Prescriptive Method”, International Conference on Slope, Kuala Lumpur
[9] Abramson L W, Lee T S, Sharma S, and Boyce G M 2002 Slope Stability and Stabilization Methods, John Wiley and Sons, Inc, New York