



## INTEGRAL ANALYSIS OF GEOELECTRICAL (RESISTIVITY) AND GEOTECHNICAL (SPT) DATA IN SLOPE STABILITY ASSESSMENT

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Goelectrical survey and the geotechnical SPT ( $N$  value) method were used to investigate the stability of a slope together with the influence of heterogeneous geomaterials in wet tropical region. The integration of these different field methods provides an opportunity to understand some relationship regarding the subsurface ground stiffness status through a combination of geophysical and geotechnical analysis. The analysis shows that the zone with high resistivity value generally have high  $N$  value, which stand for high stiffness and vice versa. However, some zones with low resistivity value are not accompanied by a decrease of its  $N$  value and sometimes even showing a higher  $N$  value. These contradictions show that one should be careful to directly correlate resistivity value with the actual status of the heterogeneous subsurface geomaterials. A low resistivity zone may be weak status due to a result of water conductivity or/and heterogeneous geomaterials condition. Additional physical geological mapping and laboratory test shows that the complexity of the subsurface profile in terms of geomaterials, geological structure and water seepage influence the contra zone, thus resulting for some inconsistency of resistivity value. The actual position of geoelectrical spread line and borehole drilling point conducted are also contributing a significant opposition findings. Therefore, multiple integration explorations should be planned to reduce the uncertainty in application of geophysical methods to slope instability assessment in order to compensate the resistivity finding of subsurface heterogeneous geomaterials.

**Keywords:** Goelectrical survey, Geotechnical SPT,  $N$  value, Heterogeneous geomaterials, Geological structure.

## **Goelectrical Survey and Borehole Drilling Investigation for Natural Slope**

Several researchers have shown that it is important to understand the complexity of the subsurface condition regarding the homogeneity of geomaterial, which plays a significant role in controlling the stability and safety of a slope. From the past, goelectrical survey which one of the geophysical method widely used as a tool for investigating the condition of the slope especially in landslide studies during the pre and post construction stages (Grandjean et al., 2011; Kim et al., 2010; Friedel et al., 2006; Godio and Bottino, 2001; Hack, 2000; Mauritsch, 2000). The combination of borehole and goelectrical survey provides some good correlation in subsurface profile assessment required in designing of any important civil engineering structures. A number of researchers have shown that the integration of geophysical survey and geotechnical data can provide a meaningful data and interpretation for subsurface profile characterization (Almalki et al., 2010; Sudha et al., 2008; Oh and Sun, 2007; Hack, 2000).

According to Kim et al., (2010), goelectrical survey can image a change of apparent resistivity with depth locally and is able to detect the water-saturated clay, which identified as a lower resistivity zone. The application of goelectrical survey has theoretically stated that the water content in subsurface materials has a close positive correlation with the electrical conductivity. However, this hypothesis can turn negatively in the case of natural slope that has many uncertainties. When evaluating the structure and function of the natural slope, the slope materials usually shows a variety of resistivity values ranging from low to high values. Normally, a high resistivity values indicate a low conductive zone while a low resistivity value is always assumed to be a high conductive zone which reflect to be a weak zone. In tropical climate country as Malaysia, weathering process is much progressive thus accelerating the transformation of homogeneous subsurface material into heterogeneous subsurface materials. As a result, water content can be inconsistently present due to the heterogeneous materials derived from the rapid weathering condition from a heavily rainfall phenomenon. The progressive weathering process was believed to be the main reasons that caused the slope materials to be disintegrated by physical weathering and decomposed by chemical weathering thus producing heterogeneous subsurface slope material. According to Borrelli et al. (2006), weathering of rock masses can be assumed to influence slope instability. Peninsular Malaysia has a wet and humid tropical climate throughout the year and much influenced by the the monsoons (Southwest monsoon: May - August and Northeast monsoon: November - February) that cause a heavy rainfall in form of thunderstorm especially during the inter-monsoon months (March to April and September to October) (Suhaila and Jemain, 2009). Generally, humid tropical zone as Malaysia experienced high rainfall, often seasonal with high temperatures in a longer period (Saunders and Fookes, 1970). As a result, it is common to see a heterogenous slope material in Peninsular Malaysia which sometimes comes out with unpredictably results due to its complexity of composition, layers and geological discontinuities (joint, bedding plane, fault, fold and foliation). Goelectrical method can be applied to specify subsurface variations where stiff layer underlies a soft layer and vice versa; however an error can occur due to soil resistivity that varies with moisture content and geomaterials measured indirectly (Liu and Evett, 2008). Hence, the confirmation of goelectrical survey data is important to convince each party involved with calibrations based on borehole data and geotechnical laboratory test data. Using goelectrical survey to investigate the condition of natural slope subsurface profile, the information on the variation of the resistivity anomaly pattern can be expected due to the contrast between geomaterials and water content present under the profile. Generally, resistivity value changes from low to high as the material is decreasing in water content. It is possible to think that weak

zone of subsurface geomaterials in natural slope is likely to show a low resistivity value due to the high conductive zone which commonly contained water. However, the presence of geomaterials grains variations such as gravel, sand, clay and silt are also possibly proportional to the electrical conductivity. This phenomenon may cause some confusion during interpretation of safety evaluation of natural slope since the geoelectrical survey determines its resistivity model qualitatively in form of a bulk product. According to Clayton et al., (1995), geophysical method is good for providing information on a specific target location, and assessing ground lateral variability, but their results are always more qualitative than is preferred by design engineers since most of engineering design was commonly derived from the in-situ tests conducted by borehole or self penetrating probes.

Hence, this paper attempts to make an interpretation by a combination of geoelectrical and geotechnical standard penetration test (SPT) blow counts known as  $N$  value, for a natural slope safety assessment. According to Bowles (1996), SPT test that was developed around 1927, is a foremost method for evaluating the geotechnical characteristics of overburden materials and had widely being practice all around the world. According to Oh (2007), soil stiffness can be analyzed directly and effectively based on SPT test. Thus, this study compares the SPT ( $N$  value) and the geoelectrical data to interpret the geoelectrical data trend and its relationship with the slope geomaterials condition. According to Friedel et al., (2006), soil parameters determined in grain size analysis could replicate the variety of resistivities obtained on the site very well. Geotechnical classification test such as grain size distributions, fine grained lithological units type and characteristics, water content and consistency limits should be carried out in relation to landslide behavior (Ali, 2011). Thus, this study also presents some of the geotechnical laboratory data such as particle size distribution and water content data conducted at certain selected depth of the borehole soil sample.

### **Study Area and Geologic Setting**

The study area was located at Kuala Lipis, Pahang Malaysia (site 1) and Tanjung Malim, Perak Malaysia (site 2) as given in Figure 1. Generally, both areas located at center and west coast zone of Peninsular Malaysia with surrounding area of a mixed hilly undulating topography of rubber tree and oil palm plantation. According to the Department of Mineral and Geoscience Malaysia (1985), Kuala Lipis area was located in Permian Period consists of several sedimentary rock of interbedded shale, siltstone and sandstone while Tanjong Malim study area was located in Devonian period consists of meta-sedimentary rock zone. In addition, site observation also indicates the presence of geological structure such as intense folding, faulting and even jointing has stressed both areas of sedimentary and meta-sedimentary rock. In general, the presence of geology structures, namely faults, foliations, fold: anticline, syncline, chevron structures, and joints can promote slope instability due to water problem such as a surface water seepage, groundwater carriage, and water storage in subsurface geomaterials.

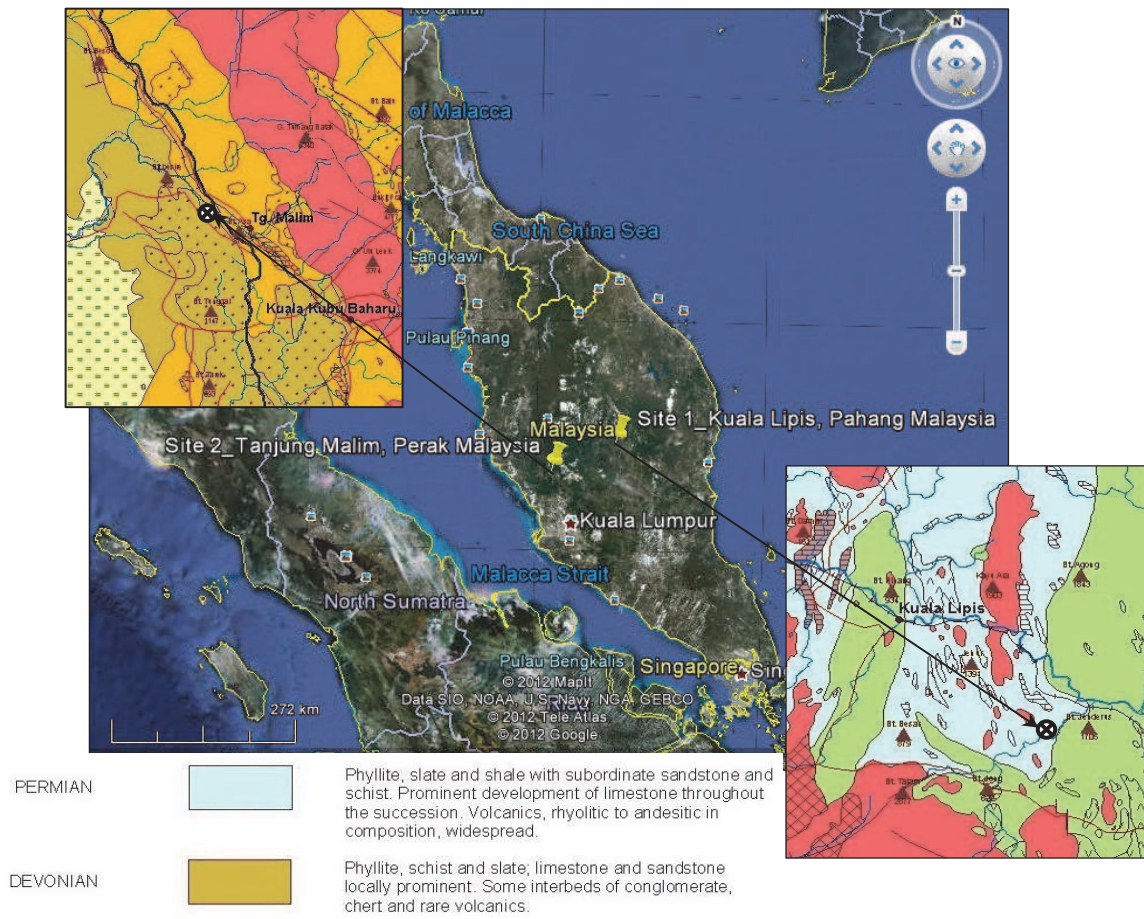


Figure 1. Site 1 and 2 based on Map (Google, 2012) and Geological Map of Peninsular Malaysia (MGDM, 1985).

### Borehole Drilling Investigation and Geotechnical Laboratory Testing

One boring was drilled at each site studied during the period at July 2010 and July 2011 (IKRAM Center of Engineering Services, Geotechnical Department, ICES). Both holes were vertical drilling done at the crest of the slope in order to determine the data from top of the slope until the hard stratum. The purpose of this geotechnical investigation was to determine the subsurface features such as depth, lithology, soil sample for testing purposes and SPT value. Standard penetration test (SPT) and laboratory measurement for soil sample were conducted from the surface and thereafter at 1.5 meter depth intervals by driving a standard split spoon sampler using repeated blow of a 63.5kg (140lb) hammer. Based on Oh (2007), vertical drilling is useful for design and performance assessment evaluation of subsurface structure and structural foundations while SPT was additionally performed to determine overburden condition and soil sample. Generally, slope materials consists of a mixture of geomaterials which dominated by cohesive soil derived from in situ bedrock. Borehole results conducted was tabulated in Table 2 and 3 respectively. Particle size distribution tests was performed to determine the descriptive term for soil type while water content test was conducted to estimate the amount of water present in soil sample at certain selected depth of borehole. Both of geotechnical laboratory tests were performed by ICES based on British Standard 1377 (BS1377).



**Table 1.** Borehole Drilling Data at Site 1 (BH1) (ICES, 2011).

Lithology	Depth	SPT (N) value
Top soil: Silty CLAY	0.00 – 0.30	NIL
Silty CLAY	1.00 – 1.45	13
	1.50 – 2.50	NIL
	3.00 – 3.45	35
	4.00 – 4.50	28
	4.50 – 5.50	NIL
Clayey SILT	6.00 – 6.43	50
	7.50 – 7.89	50
	9.00 – 9.38	50
	10.5 – 10.88	50
	12.0 – 12.31	50
	13.5 – 13.82	50
	15.0 – 15.33	50
	16.5 – 16.81	50
	18.0 – 18.31	50
	19.5 – 19.81	50
	21.0 – 21.30	50
22.5 – 22.77	50	
24.0 – 24.25	50	

**Table 2.** Borehole Drilling Data at Site 2 (BH2) (ICES, 2010).

Lithology	Depth	SPT (N) value
Top soil: SILT	0.00 – 0.30	NIL
Sandy SILT	1.50 – 1.95	21
	3.00 – 4.00	46
	4.50 – 4.95	50
Silty GRAVEL	6.00 – 6.29	50
Sandy SILT	7.50 – 7.78	50
	9.00 – 9.26	50
	10.50 – 10.70	50
	12.00 – 12.15	50

### Geoelectrical Survey

The target slope at both study areas were reported to have a localized failure at center of the slope face. The objectives of survey was to delineate the internal structure of the existing natural cut slope thus estimatating its geomaterials status calibrated with a borehole data. Generally, both spread lines are conducted on a slope crest even though spread line at site 1 was performed on a second bench of the slope despite of three benches due to the accessibility limitation. The spread line was conducted at the slope crest since it can be calibrated with an existing failure and SPT value. The geoelectrical method was conducted at Kuala Lipis, Pahang Malaysia (site 1) and Tanjong Malim, Perak Malaysia (site 2) using Schlumberger and Wenner array. From the past, both arrays experienced an established record in engineering application. Schlumberger array was performed for deeper imaging of subsurface profile with exhibits higher density data. According to Hamzah et al., (2006), Wenner array was performed for the geoelectrical traverses since it can provide dense near-surface cover of resistivity data. Also, the array provide a good vertical resolution and can give a clear image of groundwater and sand-clay boundaries as horizontal structures (Hamzah et al., 2006). Basically, the equipment consists of three main components which are source, detector and record. The source was generated by a 12V battery; steel electrode was used as detector while ABEM Terrameter SAS 4000 was used to record the resistivity data. According to Hunt (2007), geoelectrical measurements are made by injecting a

direct current flow using 12 volt battery between the two outer electrodes and the currents drop is detected by the inner electrodes and recorded on the potentiometer. Array of regular spaced electrodes are deployed in the field and connected to a central terrameter and control unit via multi-core cable. The depth of measurement is positive linearly related to the electrode spacing. Geoelectrical survey measures bulk electrical resistivity which is a function of the soil and rock matrix, percentage of saturation and type of pore fluids. The complete instrument and field arrangement of the geoelectrical method was given in Figure 2. The data obtained from the survey were interpreted using RES2DINV software. RES2DINV can provide an inverse model that approximates the actual subsurface structure (Loke, 2003). To obtain the resistivity section, the inversion algorithm, RES2DINV was used to process the data. The configuration of survey lines conducted was summarized in Table 4 while the results of the surveys were given in Figure 3 and 4 respectively.

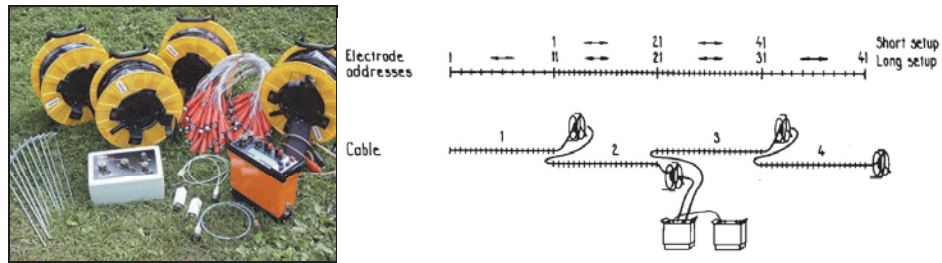


Figure 2. Equipment set and field arrangement setup of the Geoelectrical Survey (www.geoelectrical.com, 2012).

Table 4. Configuration of each resistivity profiles.

Spread Line	Array	Electrode spacing (m)	Profile length (m)
SP01	Schlumberger	2.5	135
SP02	Wenner	5	200

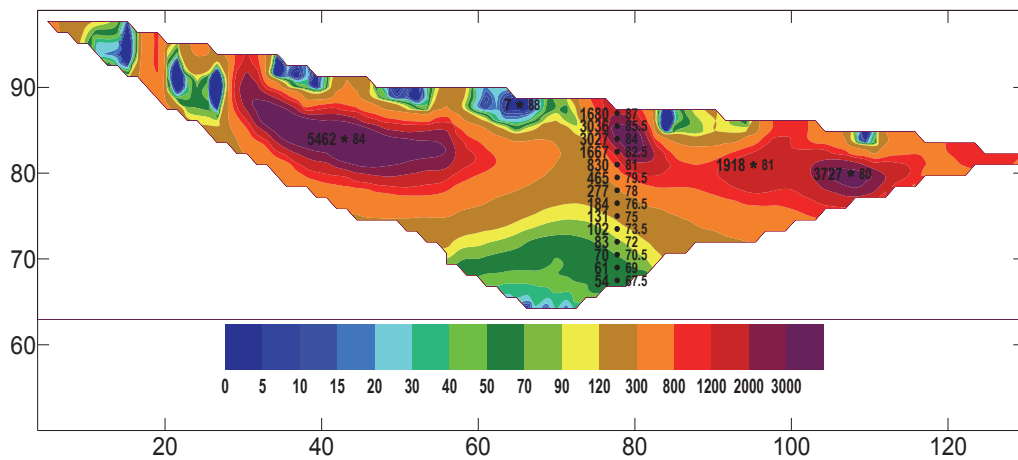


Figure 3. 2D resistivity subsurface profile image obtained from Geoelectrical Survey at Site 1.

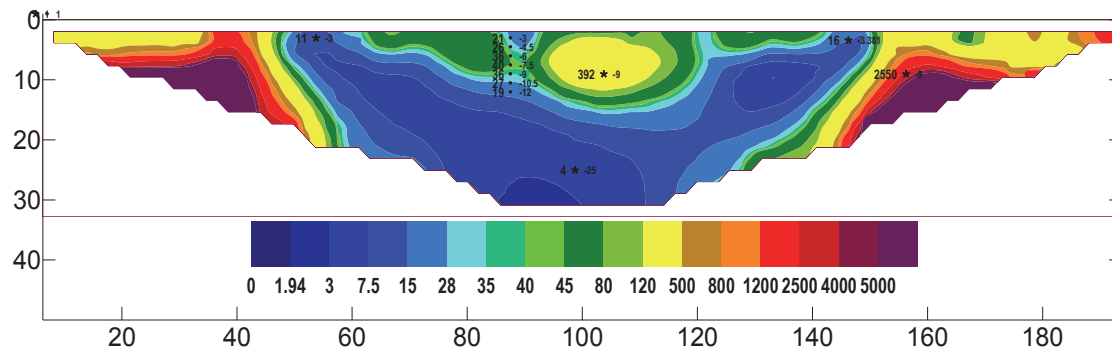


Figure 4. 2D resistivity subsurface profile image obtained from Geoelectrical Survey at Site 2.

### Integrated Interpretation of the Geoelectrical and SPT ( $N$ ) Value

The resistivity and measured  $N$  value from each borehole are compared in Figures 5 and 6 respectively to gather a relationship between those two methods. The resistivity value obtained at each depth was determined by previous inversion results processed using RES2DINV software and then presented by SURFER software. This study is always aware of the limitation that may occur due to the non uniqueness and smoothing condition of the inverted results despite the inversion results can provide a true resistivity image. All the resistivity results present in Figure 3 and 4 did not appear in an early depth since the survey was conducted at eccentrically lower stage from the borehole point due the limitation of the site accessibility (site 1) and a few resistivity data nearly to the ground level was presented as a blank data because of its limitation that affected by the surface error and electrode spacing (site 1 and 2). Therefore, the subsurface zones that have a blank resistivity data were not displayed in Figure 5 and 6. Hence, the resistivity data was only be presented at depth of BH1 starts from 4.5 m and BH 2 starts from 3.0 m at site 1 and 2. Generally, resistivity zone with a high value will also show a high  $N$  values, that represent an existing of a positive correlation between those two parameters in the region of high resistivity values.

However, some regions are showing different trend between the two parameters at certain zones of low resistivity value. These negative correlations can obviously being observed at depth of 7.5 m – 24 m for site 1. Some inconsistency of correlation between both parameters also can be observed at depth 6 m – 12 m for site 2. This phenomenon has influence this study to further some detail investigation in order to discover this unpredictable correlation. Therefore, this study has conduct an additional geotechnical laboratory test as known as particle size distribution test and water content test to discover and verify an assumption that the resistivity value was influenced by type of soils and water content intensity. The test was performed to determine a relationship between geomaterials and water content intensity which was believed has influenced the resistivity data quantitatively. All the soil sample was determine from the borehole exploration at certain selected depth and the results were given in Figure 7, 8 for site 1 and Table 3 for site 2.

At site 1, the resistivity data is showing a positive correlation with  $N$  value ( $N = 28 - 50$ ) at depth of 4.5 – 7.5 m by 1680 – 3027  $\Omega.m$  due to the high quantity of coarse soil particle (gravel and sand) based on findings as given in Figure 2. However, the resistivity and  $N$  value ( $N =$  constantly 50) are negatively correlated at depth of 7.5 m – 24 m by 3027 – 54  $\Omega.m$ . Based on particle size distributions and water content test at Figure 2 and 3, quantity of fine soil particle

(silt or clay) has increased consistently at depth 6 – 24 m by 61.5 – 96.5 %. In addition, the amount of coarse soils particle was also slowly diminished at depth of 6 – 24 m by 38.5 – 3.5 %. Meanwhile, the variation of water content shows some small variation from 10% – 14% – 11% – 5% (averaging for 10%) at depth of 6 – 24 m which can be conclude as insignificant. As a result, this finding supports the assumption of the finer soil particle such as clayey and silty soils exhibit a low resistivity value while the coarser soil particle such as gravel and sand will produce a higher resistivity value while the influence of water content is minimized.

At site 2, the resistivity data is showing a positive correlation with  $N$  value ( $N = 21 - 50$ ) at depth of 1.5 – 6 m by 19 – 36  $\Omega.m$ . However, the resistivity data and  $N$  value ( $N =$  constantly 50) has shown a various inconsistent correlation at depth of 6 m – 12 m by 36 – 19  $\Omega.m$ . Based on particle size distributions and water content test at Table 3, the quantity of coarse soil particle at depth of 6 m and 10.5 m is 72 % and 46 % while the amount of fine soil particle is 28 % and 54 %. The amount of water content at depth of 6 – 12 m has shown a small variation at 11 % and 12 % respectively. This finding also supports the previous results of the finer soil particle such as clayey and silty soils exhibit a low resistivity value while the coarser soil particle such as gravel and sand will produce a higher resistivity value.

Generally, this study has revealed that the resistivity data trend is having a relationship with the particle size distribution conducted from the tested drilled material. Sometimes, the data obtained by geoelectrical survey are negatively correlated with the SPT  $N$  values which require conducting any related testing further to support the finding used for the interpretation stages.

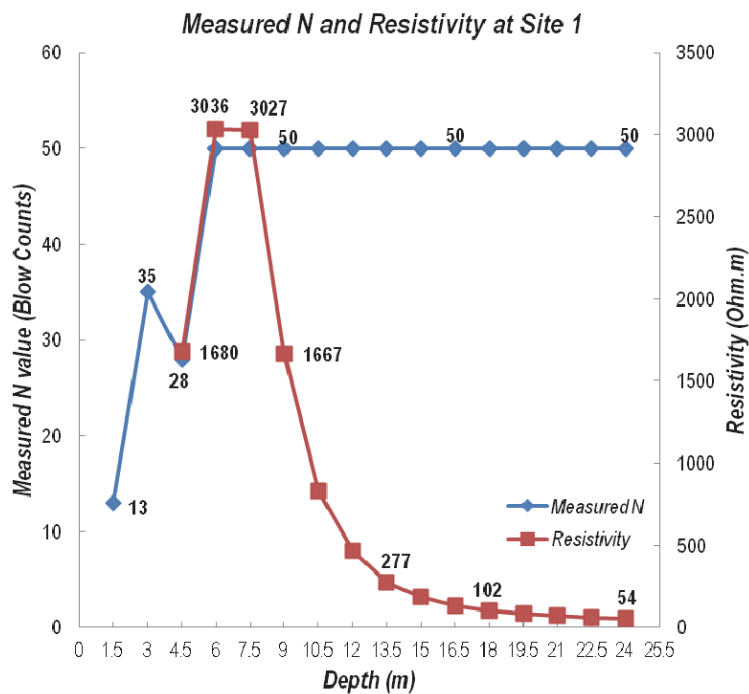


Figure 5. SPT  $N$  Value versus Resistivity (Ohm.m) for BH1 at site 1.



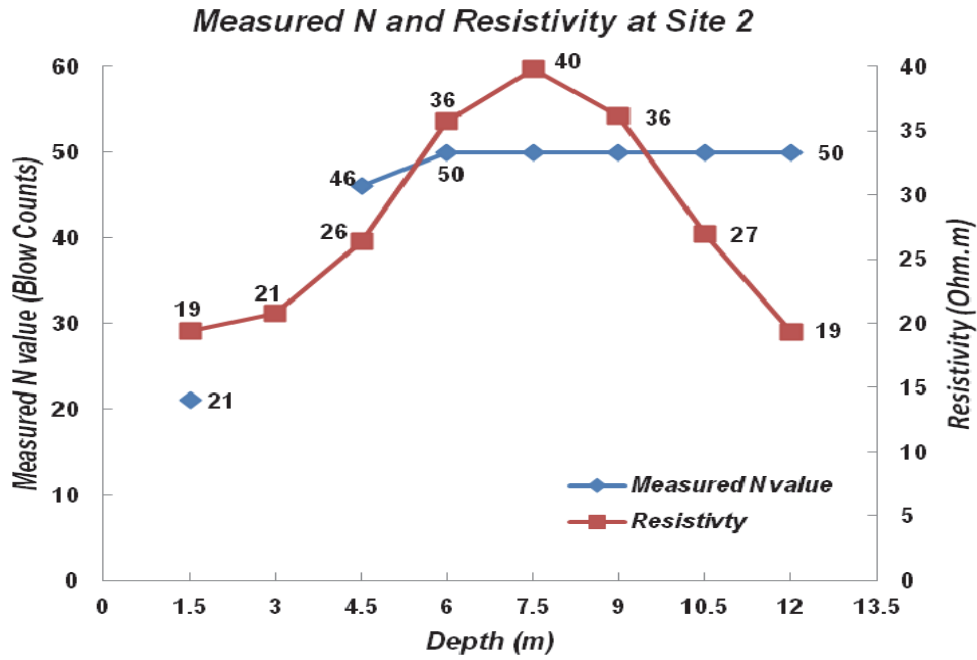


Figure 6. SPT N Value versus Resistivity (Ohm.m) for BH2 at site 2.

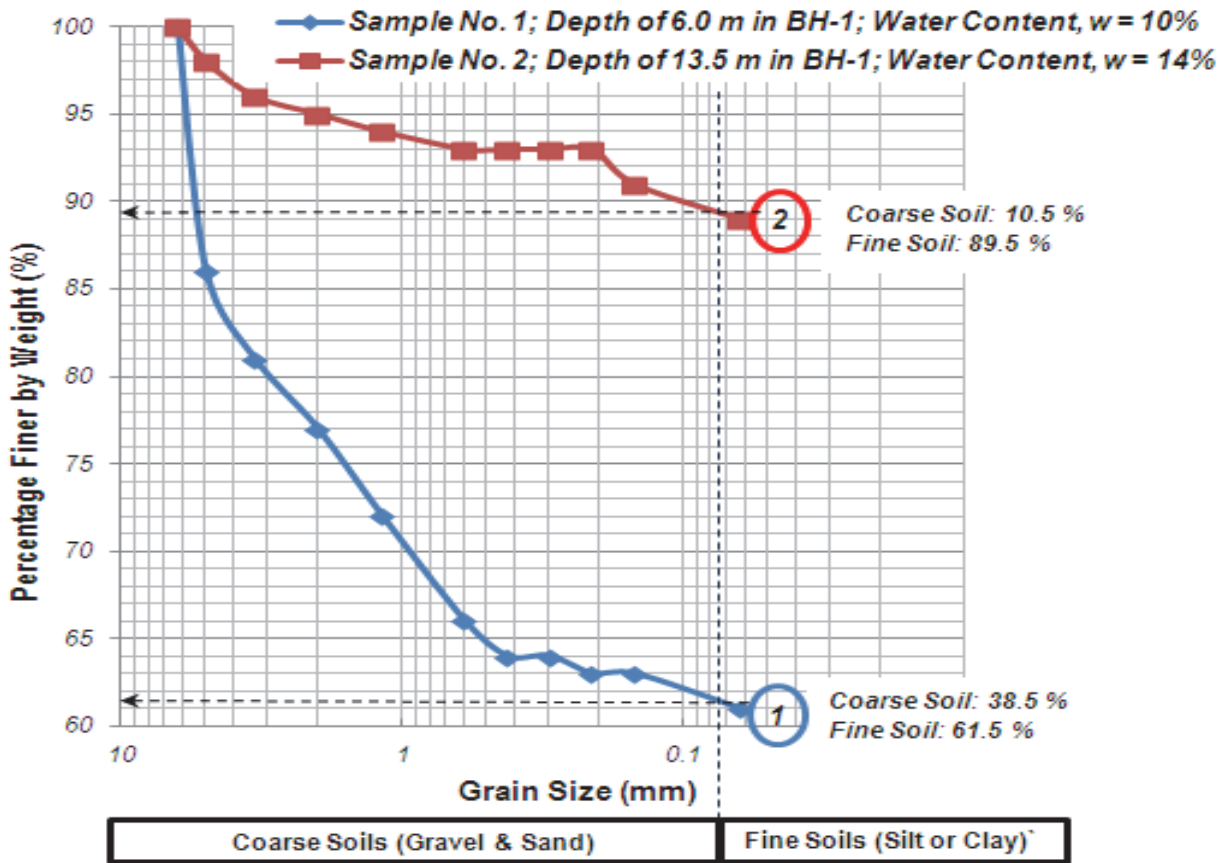


Figure 7. Particle Size Distribution and Water Content results at Site 1.

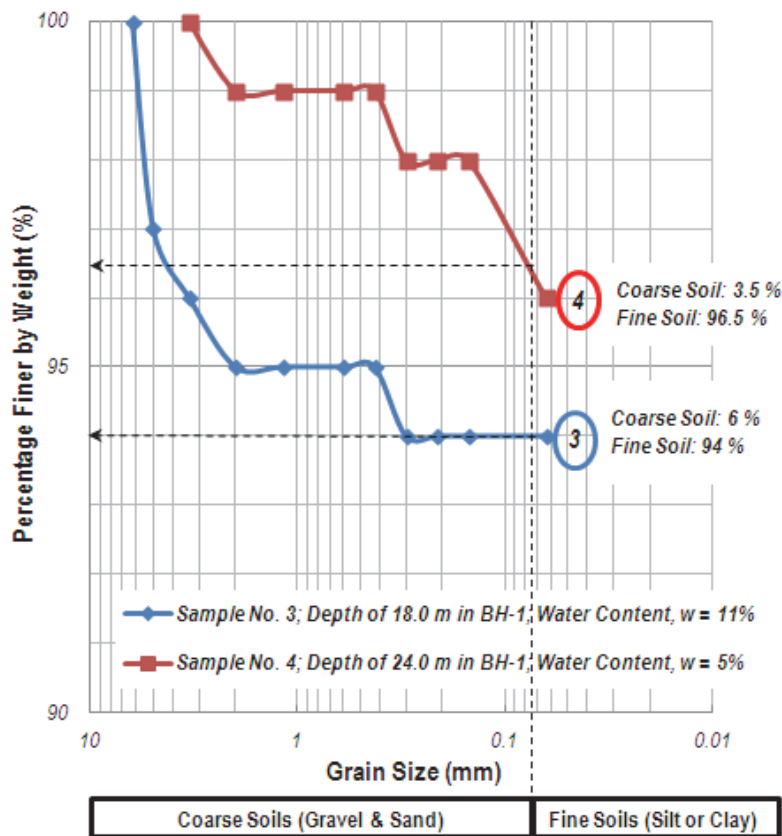


Figure 8. Particle Size Distribution and Water Content results at Site 1.

Table 3. Particle Size Distribution and Water Content results at Site 2.

Depth	Coarse Soils, % (Gravel and Sand)	Fine Soils, % (Silt or Clay)	Water Content, w (%)
6.00	72	28	11
10.50	46	54	12

### Conclusion

The results of geoelectrical survey and borehole test are interpreted together to conclude the combination analysis of geoelectrical and geotechnical SPT *N* value for slope stability assessment and to understand the relationship between two parameters involved. Based on findings, the resistivity data gathered from geoelectrical survey and SPT *N* value show some positive, negative and inconsistent correlation subjected to some reasons.

It may be erroneous to conclude that the low resistivity value always stands for unstable slope zone considering it may be influenced by particle sizes of geomaterials and water content intensity. This study have shown that some region was found to a low resistivity, but the SPT *N* value was high as given in Figure 5 and 6 respectively. This phenomenon means, in spite of the consistent *N* values, the resistivity value are still being determined subjectively due to its bulk subsurface materials acquisition and uncertainties. Hence, this study was found that the resistivity results are subjectively being influenced based on domination of geomaterials or water

content present in the subsurface. However, it was strongly believed that the zone with a low resistivity data are possible be a threat especially during a heavy raining season since the surface runoff can infiltrate and easily seep within this zone due to its highly conductive characteristic thus weaken the slope structure that may contribute to a failure.

It is hard to differentiate it with only geoelectrical survey to decide whether the slope has a normal or a critical condition, since low resistivity zone are always be a conclude as troubled zones. As a result, the study of a slope stability performed by indirect test using geoelectrical survey can produced a great appreciation and meaningful result among the geophysicist, geologist, engineers and other related parties by the integration of any suitable direct test such as geotechnical classification test in order to reduce the ambiguity of interpretation for slope stability assessment.

## References

1. ALI, Y. 2011. A geotechnical study on the landslides in the Trabzon Province, NE, Turkey. *Applied Clay Science*, 52, 11-19.
2. ALMALKI, H., EL-WERR, A.-K. & ABDEL-RAHMAN, K. 2011. Estimation of near-surface geotechnical parameters using seismic measurements at the proposed KACST expansion site, Riyadh, KSA. *Arabian Journal of Geosciences*, 4, 1131-1150.
3. BORRELLI, L., GRECO, R. & GULLÀ, G. 2007. Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures. *Geomorphology*, 87, 158-175.
4. BOWLES, J.E. 1996. *Foundation Analysis and Design*, 5<sup>th</sup> edn. Singapore, McGraw-Hill.
5. BRITISH STANDARD. 1997, *Soils for Civil Engineering Purposes – 1377 Part 2: Classification Tests*.
6. FRIEDEL, S., THIELEN, A. & SPRINGMAN, S. M. 2006. Investigation of a slope endangered by rainfall-induced landslides using 3D resistivity tomography and geotechnical testing. *Journal of Applied Geophysics*, 60, 100-114.
7. CLAYTON, C. R. I., MATTHEWS, M. C. & SIMONS, N. E. 1995. *Site Investigation*. 2<sup>nd</sup> Ed. U.K, Blackwell Science Ltd.
8. GODIO, A. & BOTTINO, G. 2001. Electrical and electromagnetic investigation for landslide characterisation. *Physics and Chemistry of the Earth, Part C: Solar, Terrestrial & Planetary Science*, 26, 705-710.
9. GOOGLE EARTH. 2012. US Department of State Geographer.
10. GRANDJEAN, G., GOURRY, J. C., SANCHEZ, O., BITRI, A. & GARAMBOIS, S. 2011. Structural study of the Ballandaz landslide (French Alps) using geophysical imagery. *Journal of Applied Geophysics*, 75, 531-542.
11. HACK, R. 2000. Geophysics for Slope Stability. *Surveys in Geophysics*, 21, 423-448.
12. HAMZAH, U., YAACUP, R., SAMSUDIN, A. R. & AYUB, M. S. 2006. Electrical Imaging of the Groundwater Aquifer at Banting, Selangor, Malaysia, *Environmental Geology* 49, Issue 8, pp. 1156–1162.
13. HUNT, R. E. 2007. *Geotechnical Investigation Methods. A field Guide for Geotechnical Engineers*. Boca Raton: CRC Press.
14. IKRAM CENTER OF ENGINEERING SERVICES, GEOTECHNICAL DEPARTMENT, ICES (2010 & 2011). *Geotechnical Investigation Report*.
15. KIM, M.-I., KIM, J.-S., KIM, N.-W. & JEONG, G.-C. 2011. Surface geophysical investigations of landslide at the Wiri area in southeastern Korea. *Environmental Earth Sciences*, 63, 999-1009.
16. LIU, C., AND EVETT, J. B. 2008. *Soils and Foundations*. 2<sup>nd</sup> Ed. New Jersey, Pearson Prentice Hall.
17. LOKE, M. H., ACWORTH, I. & DAHLIN, T. 2003. A comparison of smooth and blocky inversion methods in 2D electrical imaging surveys, *Exploration Geophysics Volume 34*, Issue 3, 2003, pp. 182-187.

18. MAURITSCH, H. J., SEIBERL, W., ARNDT, R., RÖMER, A., SCHNEIDERBAUER, K. & SENDLHOFER, G. P. 2000. Geophysical investigations of large landslides in the Carnic Region of southern Austria. *Engineering Geology*, 56, 373-388.
19. MINERAL AND GEOSCIENCE DEPARTMENT MALAYSIA, 1985. *Geological Map of Peninsular Malaysia*, 8<sup>th</sup> Ed. Ministry of Natural Resources and Environment.
20. OH, S. & SUN, C.-G. 2008. Combined analysis of electrical resistivity and geotechnical SPT blow counts for the safety assessment of fill dam. *Environmental Geology*, 54, 31-42.
21. SAUNDERS, M. K. & FOOKES, P. G. 1970. A review of the relationship of rock weathering and climate and its significance to foundation engineering. *Engineering Geology*, 4, 289-325.
22. SUDHA, K., ISRAIL, M., MITTAL, S. & RAI, J. 2009. Soil characterization using electrical resistivity tomography and geotechnical investigations. *Journal of Applied Geophysics*, 67, 74-79.
23. SUHAILA, J. & JEMAIN, A. A. 2009. Investigating the impacts of adjoining wet days on the distribution of daily rainfall amounts in Peninsular Malaysia. *Journal of Hydrology*, 368, 17-25.
24. <http://www.goelectrical.com/index.php>.2012