Subsurface Characterization using Geophysical Seismic Refraction Survey for Slope Stabilization Design with Soil Nailing

Digital Object Identifier (DOI):
10.1088/1742-6596/995/1/012107

Published In:
Journal of Physics: Conference Series

Journal of Physics: Conference Series

Subsurface Characterization using Geophysical Seismic Refraction Survey for Slope Stabilization Design with Soil Nailing

To cite this article: Mohd Ashraf Mohamad Ismail *et al* 2018 *J. Phys.: Conf. Ser.* **995** 012107

Subsurface Characterization using Geophysical Seismic Refraction Survey for Slope Stabilization Design with Soil Nailing

Mohd Ashraf Mohamad Ismail[1], Ng Soon Min[2], Mohd Hazreek Zainal Abidin[3] and Aziman Madun[3]

[1] School of Civil Engineering, Universiti Sains Malaysia (USM), Engineering Campus, Pulau Pinang, Malaysia

[2] School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University Malaysia, Putrajaya, Malaysia

[3] Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn, Malaysia, 86400, Batu Pahat, Johor, Malaysia

E-mail: Soon_Min.Ng@hw.ac.uk

Abstract. The application of geophysical seismic refraction for slope stabilization design using soil nailing method was demonstrated in this study. The potential weak layer of the study area is first identify prior to determining the appropriate length and location of the soil nail. A total of 7 seismic refraction survey lines were conducted at the study area with standard procedures. The refraction data were then analyzed by using the Pickwin and Plotrefa computer software package to obtain the seismic velocity profiles distribution. These results were correlated with the complementary borehole data to interpret the subsurface profile of the study area. It has been identified that layer 1 to 3 is the potential weak zone susceptible to slope failure. Hence, soil nails should be installed to transfer the tensile load from the less stable layer 3 to the more stable layer 4. The soil-nail interaction will provide a reinforcing action to the soil mass thereby increasing the stability of the slope.

1. Introduction

The continuous growth of urbanization has contributed greatly to hillside development due to the scarcity of flat land. Besides that, factors such as impressive views, good ventilation and better natural lightings are also making hillside development an exclusive area [1]. This exclusiveness combined with creative architectural design has resulted more people to reside and to own this high value properties. However, hillside and sloppy terrain is vulnerable to slope failure that can lead to catastrophic disaster. For example, the Highland Tower tragedy that occurred in 1993 at Ulu Kelang, Selangor, Malaysia has resulted a total casualties of 48 lives and complete evacuation from the remaining two blocks due to safety concerns. Therefore, slope stabilization plays an important role to ensure the stability of the slope under all conditions thus preventing undesirable events to take place.

The mechanism of slope stabilization is to reduce the driving forces, increase resisting forces or both within the soil mass [2]. There are many alternatives that can be selected for slope stabilization such as drainage, surface protection, retaining wall, geosynthetic reinforcement, soil nailing and re-sloping. One of the commonly used slope stabilization method in Malaysia is soil nailing due to its technical suitability, ease of construction and relatively maintenance free [3]. According to Tan and Chow (2004), the Code of practice for Strengthened/Reinforced Soils and Other Fills (BS8006: 1995) and Manual for

Design and Construction Monitoring of Soil Nails Walls by US Department of Transportation (FHWA 1998) are commonly referred when designing soil nail [3-6].

Nail length and its location are the two critical design parameters that can ensure the optimum performance of soil nails. Hence, it is vital to determine the potential weak zone of the slope for soil nail installation prior to determining the nail length. In this study, geophysical seismic refraction was utilized to characterize the subsurface profile of a slope in Penang Island, Malaysia for slope stabilization design using soil nailing method. The objective of this study is to obtain the subsurface profile of the study area so that the weak layers can be identified. Consequently, the appropriate length of the soil nail can be determined.

2. Soil nailing

Soil nailing technique was initially applied to civil engineering project at Mexico City during the 1960s and has been widely utilized in Europe since 1970 [7]. Generally, soil nails are steel bars covered with cement grout in order to protect the steel bars from corrosion and to transfer the load efficiently to the nearest stable ground [8]. Tensile forces are developed at soil nail due to the frictional interaction between the nails and soil as illustrated in Figure 1. These tensile forces reinforced the soil mass by supporting the applied shear loadings and by increasing the normal stresses at the slip surface thus increasing the shear resistance of the slope [9].

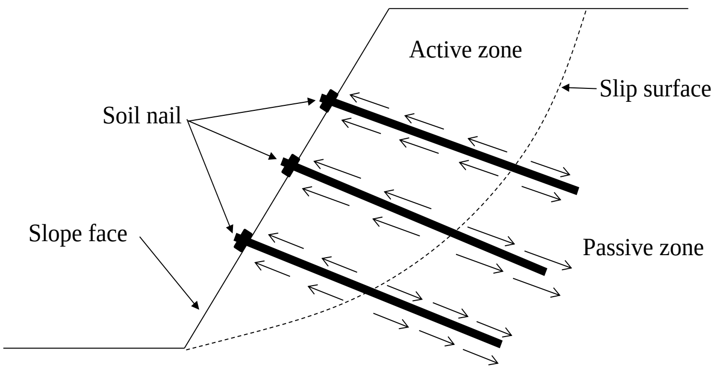

Figure 1. Mechanism of tensile forces in soil nails.

However, it should be noted that if the soil nail does not intersect with the slip surface, then no support force will be applied to the slip surface, and the support will have no effect on the stability of that slip surface as illustrated in Figure 2. This phenomenon is one of the failure mode of soil nailing which is known as pull-out failure. The part where the nail is embedded behind the slip surface will provide the resistance against pull-out failure. Therefore, it is important to locate the slip surface which represent the potential weak zone of the slope so that performance of the soil nail can be fully maximized. One of the method to investigate the potential weak zone is by applying the geophysical method.

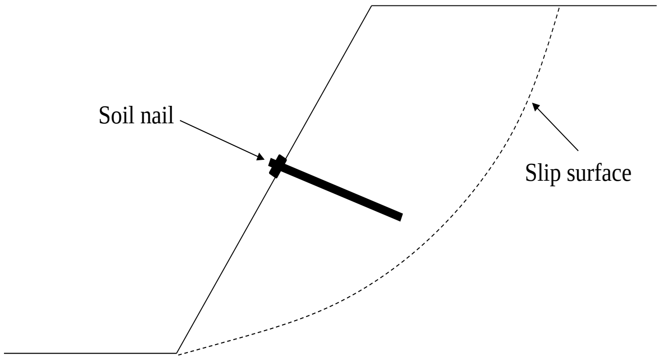

Figure 2. Soil nail that does not intersect the slip surface.

3. Geophysical Seismic Refraction

Geophysics application to determine the various physical properties of Earth materials has become a regular practice in civil engineering projects worldwide. Geophysical methods are non-destructive and are able to cover large study areas to complement on-site tests such as borehole drilling and trial pits [10]. Geophysics was initially applied in landslide investigations as an aid to back analysis [11]. Hack (2000) has reviewed the applications of geophysical methods to slope stability and has suggested that seismic refraction survey is an effective approach for slope stability studies [12].

Seismic refraction approach measures the travel time of seismic waves refracted at the interfaces between subsurface layers of different velocity as illustrated in Figure 3 [13]. Seismic energy is generated through an impact exerted on the ground such as by using a sledgehammer striking on a metallic plate. The energy will radiates out from the generated impact, either travelling directly through the upper layer, or travelling down to and then laterally along higher velocity layers before returning to the surface. This energy will be detected on the surface using a linear array of receivers known as geophones spaced at regular intervals [14]. Data are then recorded on a seismograph and later downloaded to a computer for analysis of the first-arrival times for each shot position.

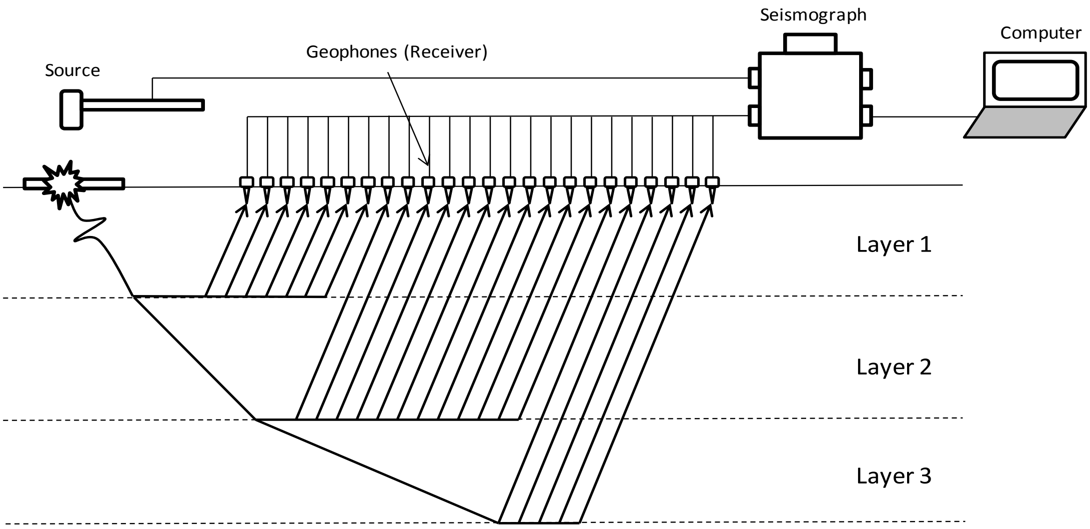

Figure 3. Seismic refraction survey method and the refracted wave [13].

4. Research Methodology

A slope located at Sungai Ara, Penang Island, Malaysia was utilized as the case study. Penang island is mainly underlain by granite bedrock with various soil overburden thickness depending on the weathering intensity, topography etc. Sungai Ara is located at the South-Eastern half of Penang Island where the terrain is composed of medium grained to coarse grained granite with microline. Based on the borehole drilling results, the average thickness of the highly to completely weathered granitic soil was found to be approximately 30 m. Meanwhile, the sampled residual soil consist of 14% gravel, 55% sand, 18% silt and 13% clay, representing coarse grained residual soil which is associated with the parents rock presence at the site namely medium to coarse grained granite. This type of residual soil should be taken into consideration for any hillside development due to its high permeability that is susceptible to rainfall induced slope failure. Figure 4 shows the seven seismic refraction survey lines that were conducted at the study area. The data acquisition for seismic refraction survey consist of Geode seismograph, 24 geophones of 14 Hz, laptop as controller, spread cable with 24 take-outs, 8kg sledgehammer and an striker plate.

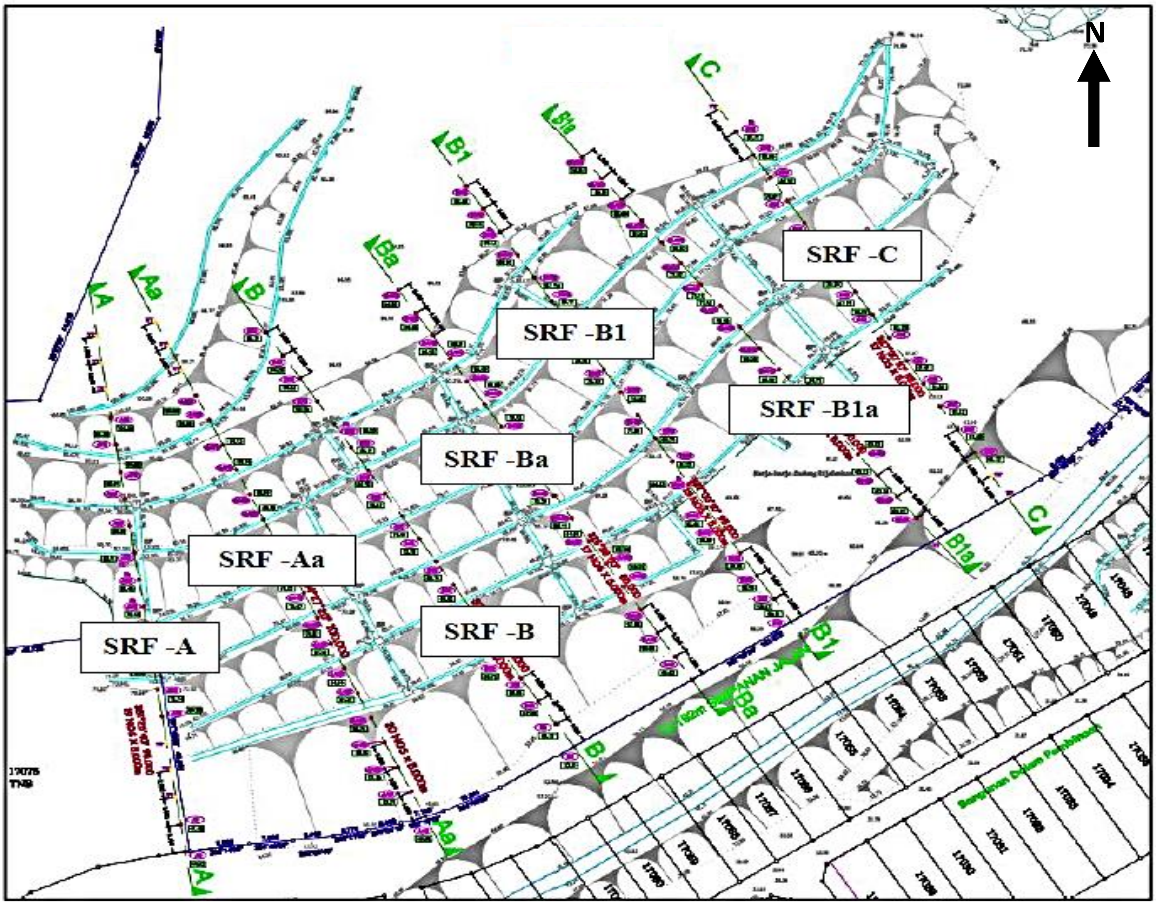

Figure 4. Location of seismic refraction survey lines.

The recorded seismic wave data were analysed using the software programs named Pickwin (ver 4.0.1.5) and Plotrefa (ver 2.9.1.6) developed by Geometrics Inc. The recorded raw data from the seismograph were first downloaded to the computer before identifying the first arrival times of seismic waves using the Pickwin software. Then, the tomographic method that consist of initial velocity model development, iteration of tracing rays through the model, comparison of the calculated travel times with the measured travel times, model modification, and repeating the process until the difference between calculated and measured times is minimum was executed by using the Plotrefa software [15]. Finally, the velocity models for each survey lines produced will be correlated and interpreted with supplementary information such as borehole data to develop the subsurface profile correspond to the seismic velocities.

5. Results and Discussion

Figure 5 to 7 show the examples of result for seismic refraction survey lines A, B and C. From the seismic velocity models, it can be observed that the subsurface can be categorized into five seismic velocity layers. The first layer has a velocity of less than 0.3 km/s and the depth of its base varies from less than 1 m to 2 m. This is followed by the second layer which has the velocity of 0.3-0.75 km/s and is then underlies by the 0.75-1.2 km/s layer. The forth layer is made up by the seismic velocity ranging from 1.2-2.0 km/s, whereas the final layer is more than 2.0 km/s. Table 1 summarized the probable weathering grades of the five layers with respect to their seismic velocities.

The thickness of the specific layer varies from place to place; depending on the degree of weathering process and existence of fractures in the granitic bedrock. It is expected that, the highly-completely weathered granitic zone (0.75-1.2 km/s) is the potential zone where slope failure may occur as it is controlled by the relict structures similar to the historical Paya Terubong slope failure that happened in 1998. Hence, serious attention should be given to the highly-completely weathered granitic zone when designing the slope or slope stabilization. Therefore, soil nails shall be installed to the depth exceeding layer 3 so that tensile forces in soil nail can be developed in the passive zone which resists the deformation of active zone as proposed in Figure 5 to 7. This tension forces result in the increment of the normal force and reduces the driving force of the shear plane.

Assessing this stabilization work is important to determine the improvement of the soil nailing work compared to the original slope condition. According to Liew (2005), such stability assessment shall be carried out at least at areas where there is an impact to human being if slope instability occurs [7]. Slope stability analysis is regularly performed to determine the factor of safety (FOS) that indicates the stability conditions of the slope. It can be performed by using either the limit equilibrium method or finite element strength reduction method as shown in Figure 8 and 9. With these approaches, the performance and effectiveness of the soil nailing design can be verified.

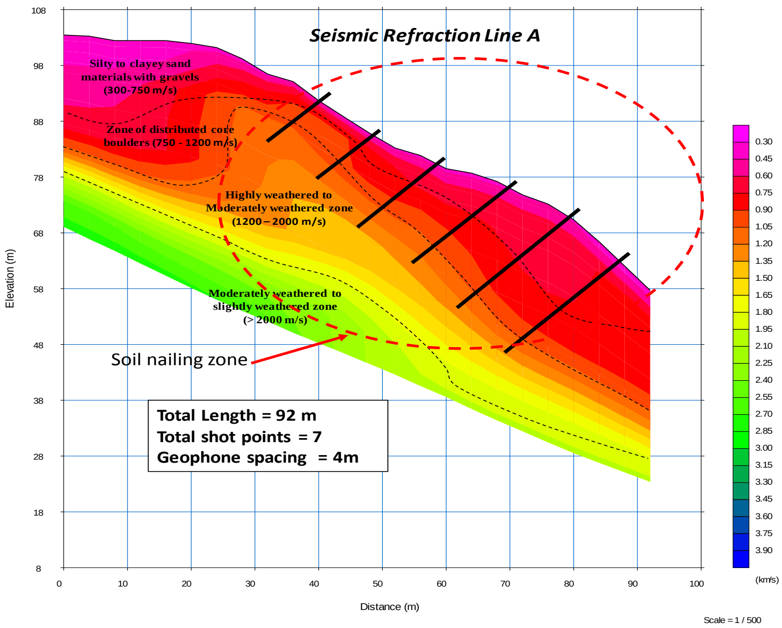

Figure 5. Seismic velocity model for survey line A.

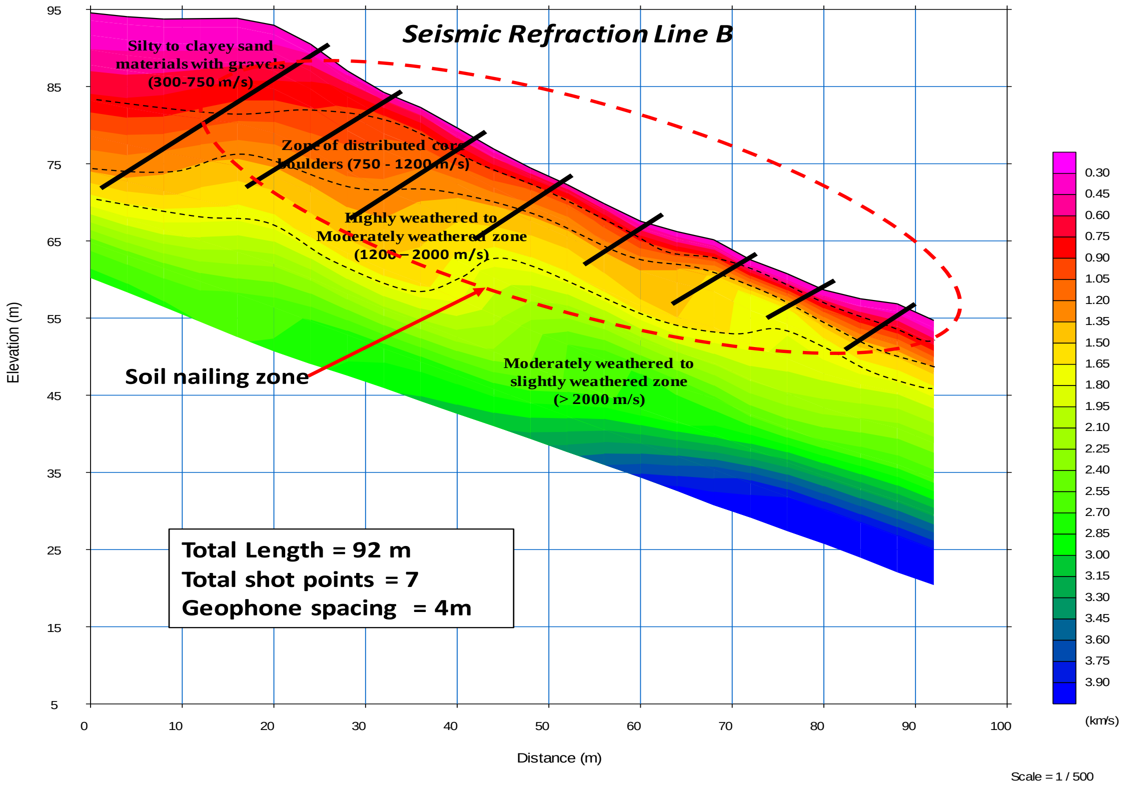

Figure 6. Seismic velocity model for survey line B.

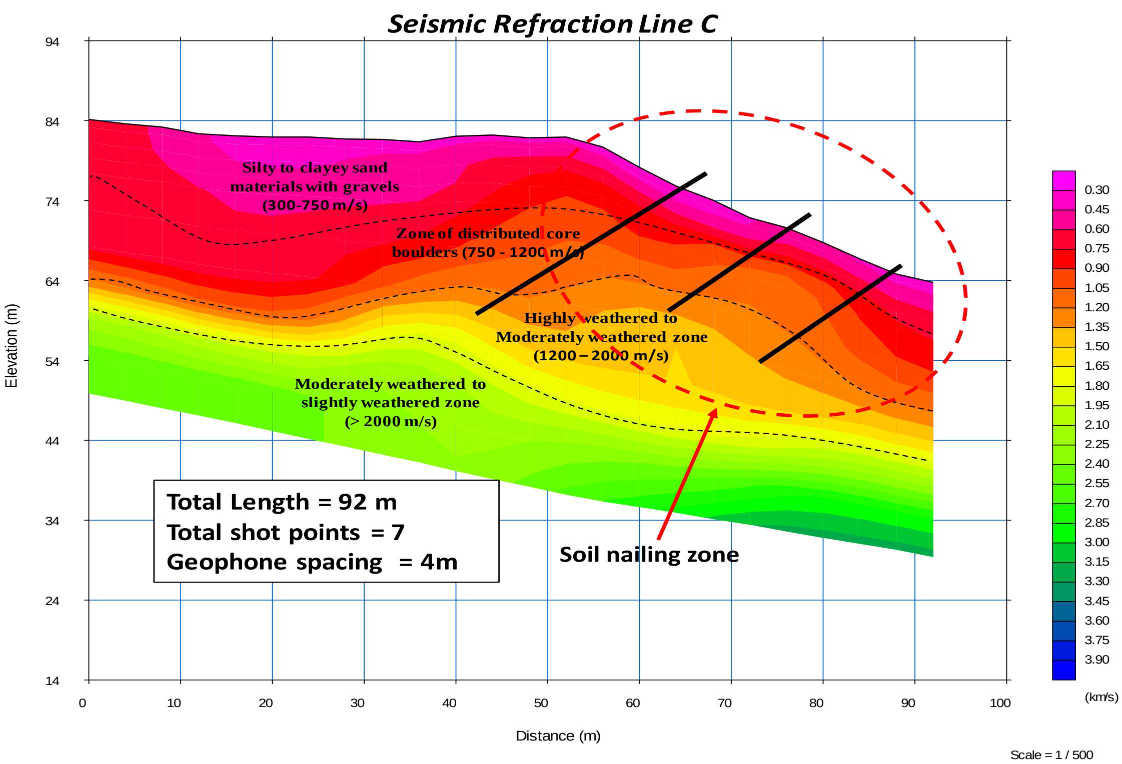

Figure 7: Seismic velocity model for survey line C.

Table 1. Summary of the five seismic velocity layers and the weathering grades.

Layer	Velocity (km/s)	Geo-materials description	Weathering grades
1	< 0.3	Subsurface soil and much loosened ground. Very dried condition	VI
2	0.3 – 0.75	Silty to clayey sand materials with gravels	VI
3	0.75 – 1.2	Completely weathered to highly weathered (zone of distributed core boulders)	V – IV
4	1.2 – 2.0	Highly weathered to moderately weathered zone	IV – III
5	> 2.0	Moderately weathered to slightly weathered zone	III – I

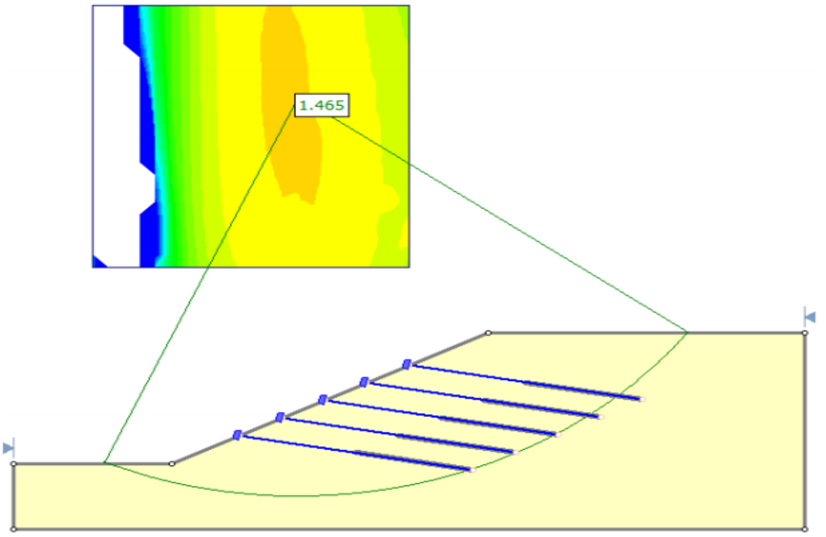

Figure 8. Example of limit equilibrium slope stability analysis [17].

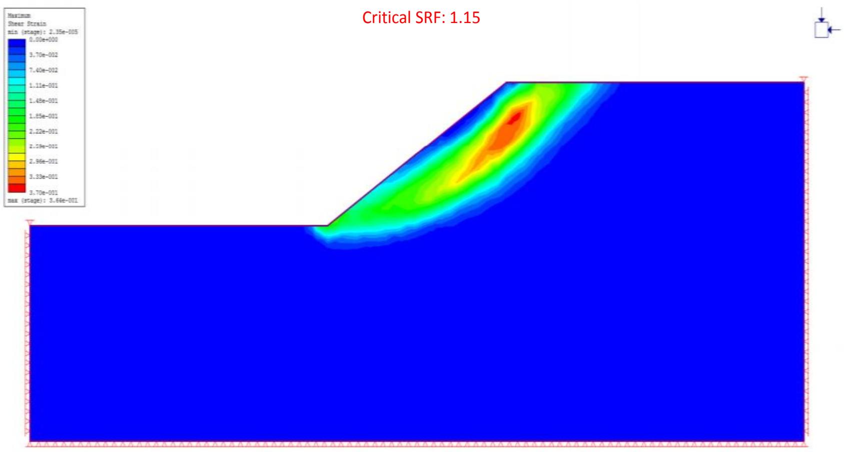

Figure 9. Example of finite element shear strength reduction analysis [18].

6. Conclusion

The seismic velocity models for the slope located in Sungai Ara, Penang Island, Malaysia have been developed by using geophysical seismic refraction survey. The subsurface profile that consist of 5 layers has been successfully derived by using the complementary borehole data and the seismic refraction results. The potential weak zone is identified to be from layer 1 to 3 which is susceptible to slope failure. Therefore, soil nails should be designed to exceed the depth of layer 3 namely the completely weathered to highly weathered zone for the development of reinforcing action. With soil nail reinforcement, the shear resistance of the soil mass will be increased while the driving forces will be reduced. Slope stability assessment should also be carried out to examine the design of the soil nail to ensure an improvement in the FOS of the slope. Through this routine the stability of the slope can be assured and disastrous events can be prevented. Nevertheless, additional tools such as geophysical electrical resistivity survey should be utilized to obtain complementary subsurface data together with the conventional geotechnical borehole drilling so that a more comprehensive subsurface information can be obtained.

Acknowledgments
The authors would like to express their appreciation to Universiti Sains Malaysia Research University (RU) Grant (1001/PAWAM/814192) for the financial support to carry out this research.

References
[1] Farisham, A.S. (2007). Landslides in the hillside development in the Hulu Klang, Klang Valley. *Post-graduate seminar*, UTM, Skudai, Malaysia, 6 Mar 2007.
[2] Abramson, L. W. (2002). Slope stability and stabilization methods. *John Wiley & Sons*.
[3] Chee-Meng, C., & Yean-Chin, T. (2006). Soil nail design: A Malaysian perspective. In *International Conference on Slopes* (pp. 379-400).
[4] Tan, Y. C., & Chow, C. M. (2004). Slope stabilization using soil nails: design assumptions and construction realities. In *Malaysia-Japan Symposium on Geohazards and Geoenvironmental Engineering, Bangi, Malaysia* (pp. 13-14).
[5] British Standard Institution, BS8006: 1995: Code of Practice for Strengthened/Reinforced Soils and Other Fills.
[6] FHWA. (1998). Manual for Design & Construction Monitoring of Soil nail Walls, Federal Highway Administration, US Department of Transportation, USA.
[7] Liew, S. S. (2005). Soil nailing for slope strengthening. Gue & Partners Sdn Bhd, Kuala Lumpur, pp 1–19.
[8] Budania, R., Arora, R. P., & CE, C. (2016). Soil Nailing for Slope Stabilization: An Overview. *International Journal of Engineering Science*, **3877**.
[9] Geotechnical Engineering Office. (2008). Guide to soil nail design and construction (Geoguide 7). Geotechnical Engineering Office, Government of Hong Kong.
[10] de Vallejo, L. I. G., & Ferrer, M. (2011). Geological engineering. *CRC Press*.
[11] McCann, D. M., & Forster, A. (1990). Reconnaissance geophysical methods in landslide investigations. *Engineering Geology*, **29(1)**, 59-78.
[12] Hack, R. (2000). Geophysics for slope stability. *Surveys in geophysics*, 21(4), 423-448.
[13] Burger, H.R. (1992). Exploration geophysics of the shallow subsurface. *Prentice Hall* P T R, Englewood Cliffs, NJ, USA, p 57.
[14] Redpath, B. B. (1973). Seismic refraction exploration for engineering site investigations. Army Engineer Waterways Experiment Station, Livermore, Calif. (USA). Explosive Excavation Research Lab.
[15] Geometrics, Inc. (2009). SeisImager/2D Seismic Refraction Data Analysis Software Manual and Examples Booklet (ver 3.3).
[16] Rocscience (2017a). SLIDE 7.0 – 2D Limit Equilibrium Analysis of Slope Stability. Rocscience Inc., Toronto.
[17] Rocscience (2017b). RS^2 9.0 – Rock and Soil 2-dimensional analysis program. Rocscience Inc., Toronto.