Jurnal
Teknologi

Full Paper

GEOTECHNICAL PARAMETERS STUDY USING SEISMIC REFRACTION TOMOGRAPHY

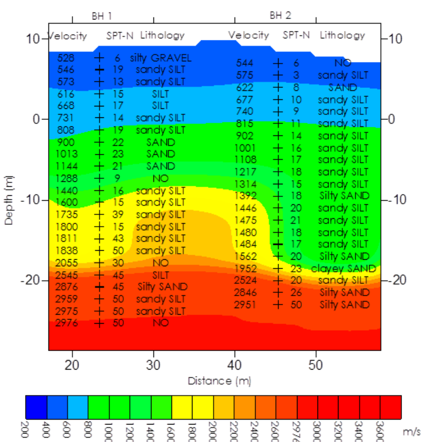
Rose Nadia[a], Rosli Saad[a]*, Nordiana Muztaza[a], Nur Azwin Ismail[a], Mohd Mokhtar Saidin[b]

[a]School of Physics, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia
[b]Center for Archeological Research Malaysia, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia

Article history
Received
18 January 2016
Received in revised form
8 March 2016
Accepted
18 March 2016

*Corresponding author
rosli@usm.my

Graphical abstract



Abstract

In this study, correlation is made between seismic P-wave velocities (V_p) with standard penetration test (SPT-N) values to produce soil parameter estimation for engineering site applications. A seismic refraction tomography (SRT) line of 69 m length was spread across two boreholes with 3 m geophones spacing. The acquired data were processed using Firstpix, SeisOpt2D and surfer8 software. The V_p at particular depths were pinpointed and correlated with geotechnical parameters (SPT-N values) from the borehole records. The correlation between V_p and SPT-N values has been established. For cohesive soils, it is grouped into three categories according to consistencies; stiff, very stiff and hard, having velocity ranges of 575-314 m/s, 808-1483 m/s and 1735-2974 m/s, respectively. For non-cohesive soils, it is also divided into three categories based on the denseness as loose, medium dense and dense with V_p ranges of 528-622 m/s, 900-2846 m/s and 2876-2951 m/s, respectively.

Keywords: Correlation; soil strength; P-wave velocity

Abstrak

Dalam kajian ini, halaju gelombang seismik P, (V_p) dan nilai ujian penusukan piawai (SPT-N) dilakukan untuk menghasilkan penganggaran parameter tanah bagi aplikasi tapak kejuruteraan. Satu garis tinjaun seismik pembiasan tomografi yang panjangnya 69 m direntangkan merentasi dua lubang jara dengan sela antara geofon ialah 3 m. Data yang diperolehi diproses menggunakan perisian Firstpix, SeisOpt2D dan surfer8. V_p pada kedalaman tertentu dikeluarkan dan dikorelasikan dengan parameter geoteknikal (SPT-N) daripada rekod lubang jara. Korelasi antara V_p dan nilai SPT-N telah dihasilkan berdasarkan kekuatan tanah. Untuk tanah jeleket, ia telah dikumpulkan kepada tiga kategori berdasarkan kepada kekonsistenan; kaku, sangat kaku dan keras, masing-masing dengan halaju 575-314 m/s, 808-1483 m/s and 1735-2974 m/s. Untuk tanah tidak jeleket, ia juga dibahagikan kepada tiga kategori berdasarkan kepada kepadatan; longgar, sederhana padat dan padat, masing-masing dengan nilai halaju 528-622 m/s, 900-2846 m/s and 2876-2951 m/s.

Kata kunci: Korelasi; kekuatan tanah; halaju gelombang-P

1.0 INTRODUCTION

Geophysical methods have been widely utilized in engineering fields for subsurface study. In particular, seismic refraction (SR) method had been widely used to encounter civil engineering problems in Malaysia such as in pavement, geotechnical and environmental engineering [1]. Seismic refraction tomography (SRT) is an advanced of SR method used in interpreting seismic refraction data, which apply gridding and technique of inversion to determine velocity in 2-dimension blocks (pixels) for velocities modelling. As a result, SRT could provide better resolution and more accurately model the complex subsurface velocity of structure. The combination of geophysical and geotechnical approach was proved as a very cost effective methods [2].

Detailed information about mineral content of the soil or rock, and also the rock fabric are usually obtained through drilling. The drilling method relies on the aim of the study, information required and the soil or rock types being drilled. From the past decades, the interest for drilling through geologic structures of the uppermost continental crust has been increased [3]. Several studies have been done to acquire a relation between seismic wave velocities and soil mechanics parameters [4-11]. Also, many studies have been carried out to obtain a relation between the seismic wave velocities and various lithological properties of rocks for the exploration geophysics purpose [12-18]. Unfortunately, there is no theoretical relationship which can be used to correlate between destructive methods (e.g., SPT-N) and non-destructive methods (e.g., seismic refraction methods) [19]. The purpose of this study is to develop a correlation between seismic P- wave velocities (V_p) obtained from SRT with respect to SPT-N values.

2.0 METHODOLOGY

Universiti Sains Malaysia (USM) is an investigation area, situated at east of Penang Island, Malaysia. Geologically, igneous rock underlain major portion of the Penang Island (Figure 1). The igneous rock is granites in terms of Streckeisen classification and classified on the basis of proportions of alkali feldspar to total feldspars. Granites of Penang Island are further divided into two main groups: North Penang Pluton and South Penang Pluton. In the northern part of the island, the alkali feldspars, that generally do not exhibit distinct cross-hatched twining, are orthoclase to intermediate microcline in composition. In the southern region, they generally exhibit well-developed cross-hatched twining and are believed to be microcline. The North Penang Pluton has been divided into Feringgi Granite, Tanjung Bungah Granite and Muka Head micro granite. The South Penang Pluton has been divided into Batu Maung Granite and Sungai Ara Granite [20].

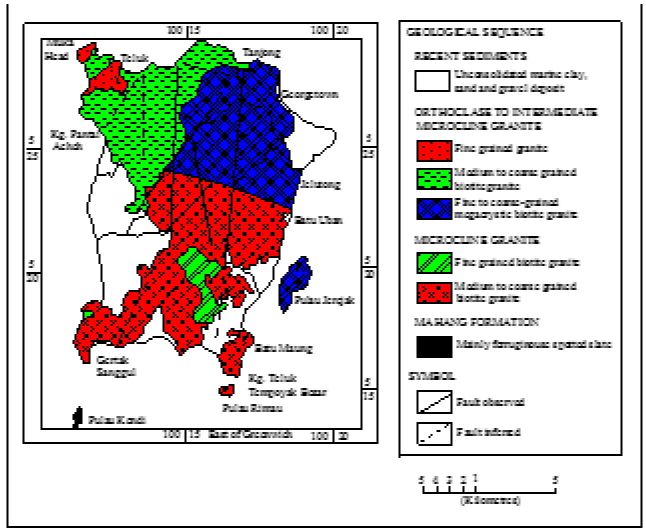


Figure 1 Geological map of Penang Island [20]

Seismic data were acquired on a seismic line using a 24 channels ABEM Terraloc MK8 seismograph with a, 24 geophones (14 Hz), 2 seismic cables, 20 kg weight-drop and a roll of trigger cable. In this study, geophones have been set at 3 m interval with 5 inline shot-points and 8 offset shot- points (Figure 2). The data were processed using FIRSTPIX v4.21, OPTIM (SeisOpt2D) and SURFER 8 software. Two boreholes (BH1 and BH2) are located along the seismic line at the distance of 23.3 m and 45.0 m, respectively. The correlations between V_p and SPT-N values were established for two soil categories; cohesive and non-cohesive.

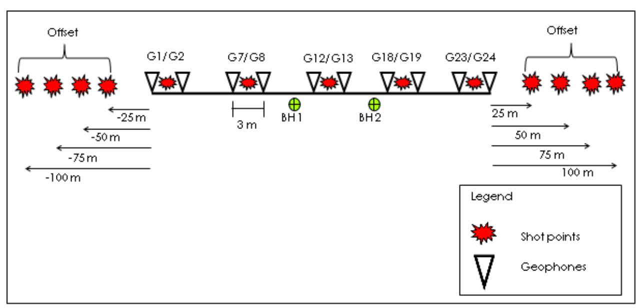


Figure 2 Schematic diagrams of shot points for seismic survey

3.0 RESULTS AND DISCUSSION

SRT is utilised to produce a seismic cross section which is displayed using Surfer 8 software after being processed using FirstPix and SeisOp@t2D software. Seismic results show that the V_p of the subsurface varies from 400-3600 m/s to the depth of 38 m (Figure 3). Table 1 shows borehole record of BH1 and BH2 including SPT-N value and soil description of the sample at interval of 1.50 m.

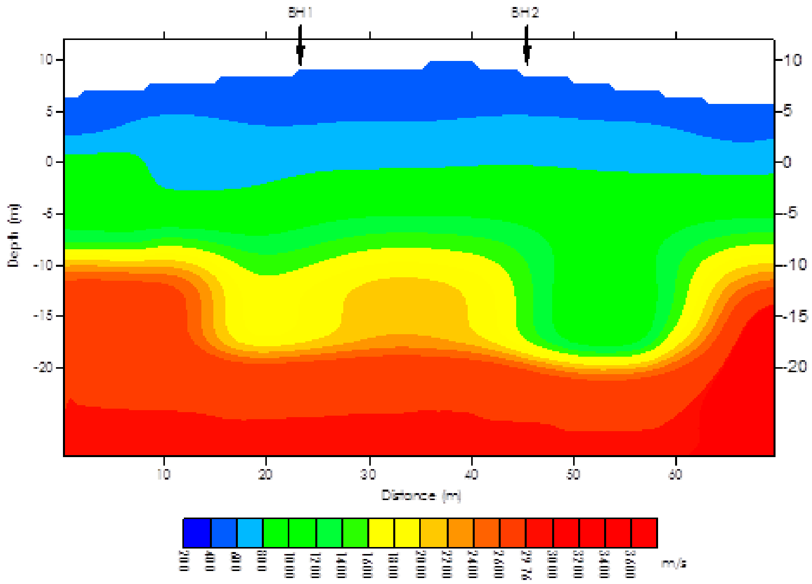


Figure 3 Subsurface velocity distribution of survey line

Table 1 Borehole record of BH 1 and BH 2

BH 1			BH 2		
Depth	**Description**	**SPT N-value**	**Depth**	**Description**	**SPT N-value**
1.50	Loose, silty GRAVEL	6	1.50	No Recovery	6
3.00	Very stiff, sandy SILT	19	3.00	Stiff, sandy SILT	9
4.50	Stiff, sandy SILT	13	4.50	Loose, SAND	8
6.00	Stiff, SILT	15	6.00	Stiff, sandy SILT	10
7.50	Very stiff, SILT	17	7.50	Stiff, sandy SILT	9
9.00	Very stiff, SILT.	14	9.00	Stiff, sandy SILT	11
10.50	Stiff, sandy SILT	19	10.50	Stiff, sandy SILT	14
12.00	Very stiff, sandy SILT	22	12.00	Very stiff, sandy SILT	16
13.50	Very stiff, sandy SILT	23	13.50	Very stiff, sandy SILT	17
15.00	Medium dense, SAND	21	15.00	Very stiff, sandy SILT	18
16.50	Medium dense, SAND.	9	16.50	Stiff, sandy SILT	15
18.00	Medium dense, SAND.	16	18.00	Medium dense , silty SAND	18
19.50	Medium dense, SAND	15	19.50	Very stiff, sandy SILT	20
21.00	No Recovery	39	21.00	Very stiff, sandy SILT	21
22.50	Very stiff, sandy SILT	15	22.50	Very stiff, sandy SILT	18
24.00	Very stiff, sandy SILT	43	24.00	Very stiff, sandy SILT	17
25.50	Stiff, sandy SILT	50	25.50	Medium dense, silty SAND	20
27.00	Hard, sandy SILT	30	27.00	Medium dense, silty / clayey SAND	23
28.50	Hard, sandy SILT	45	28.50	Very stiff, sandy SILT of	20
30.00	Stiff, sandy SILT	45	30.00	Medium dense, silty SAND of	26
31.50	Hard, sandy SILT	50	31.50	Medium dense, silty SAND	50
33.00	Hard, sandy SILT	50			
34.50	No Recovery	50			

Figure 4 shows the subsurface velocity distribution of SRT integrated with V_p and SPT-N value for BH1 and BH2 together with soil lithology at interval of 1.5 m. A graph of V_p and SPT-N value against depth for BH1 and BH2 were plotted (Figure 5). The result show direct correlation between V_p and SPT-N value in which V_p increases with SPT-N values. The lithology recorded from BH 1 shows a complex subsurface, which may affect the SPT-N values. This has been shown by fluctuated SPT-N values with increasing depth compared to BH 2, in which the SPT-N values consistently increasing with depth since no variation in lithology occurred.

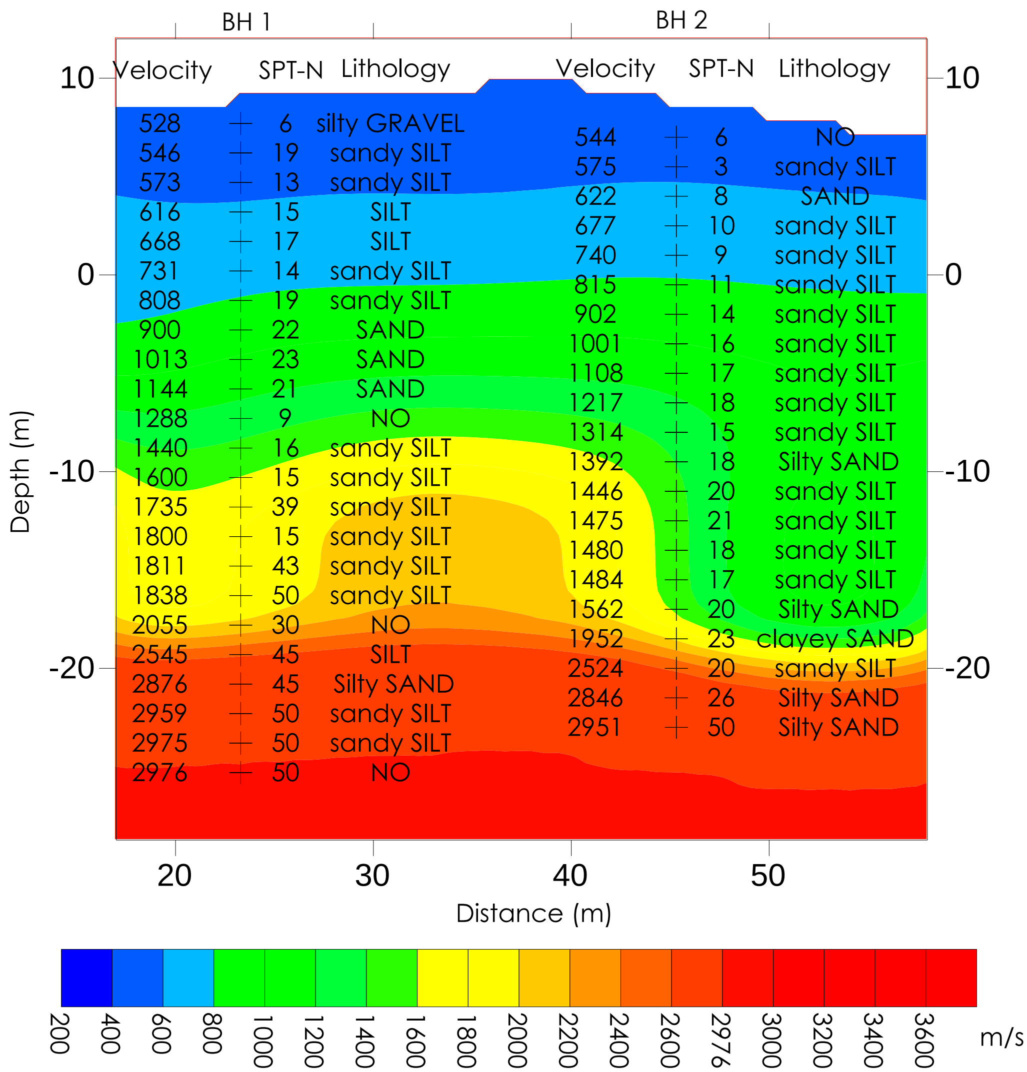


Figure 4 Subsurface velocity distribution of SRT, V_p and SPT-N value for BH1 and BH2 together with soil lithology at interval of 1.5 m

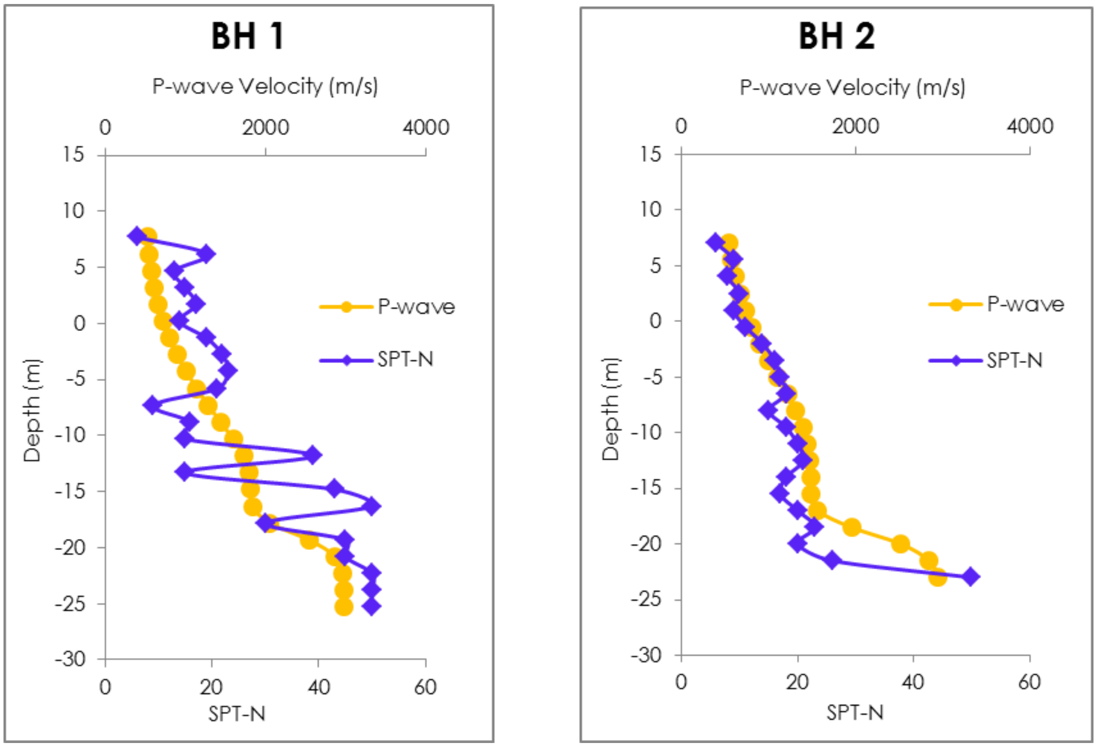


Figure 5 Relationship between V_p and SPT-N values with depth for BH 1 and BH 2

The V_p and SPT-N values were group based on soil strength obtained from standard penetration test and tabulated into cohesive and non-cohesive soils group (Table 2). Cohesive soil, was grouped into three categories based on the consistencies (stiff, very stiff and hard) with V_p value of 575-1314 m/s, 808-1483 m/s and 1735-2974 m/s; and SPT-N value are 9-15, 16-19 and 39-50, respectively. For non-cohesive soils, it is also divided into three categories based on the denseness or state of packing (loose, medium dense and dense) with V_p value of 528-622 m/s, 900-2846 m/s and 2876-2951 m/s; and SPT-N value are 6-8, 18-26 and 45-50, respectively. This study provides a cost effective alternative to generate a good estimation of SPT-N value using V_p obtained that can be applied on other sites with similar lithology, without in situ test.

Table 2 Soil strength classifications of P-wave velocity, V_p and SPT-N value

COHESIVE			
V_p (m/s)	**SPT N-value**	**Consistency**	**Description**
575 -- 1314	9 -- 15	Stiff	sandy SILT and SILT
808 -- 1483	16 -- 19	Very stiff	sandy SILT and SILT
1735 -- 2974	39 -- 50	Hard	sandy SILT and SILT

NON COHESIVE			
V_p (m/s)	**SPT N-value**	**Denseness**	**Description**
528 -- 622	6 -- 8	Loose	silty GRAVEL and SAND
900 -- 2846	18 -- 26	Medium dense	Silty SAND and SAND
2876 -- 2951	45 -- 50	Dense	Silty SAND

4.0 CONCLUSION

This study proposed a cost and time effective method of providing good estimation of SPT-N values using V_p. The results showed direct proportional of SPT-N and V_p values.

Acknowledgement

The authors would like to thanks USM geophysics staff and postgraduate students for their tremendous work and cooperation throughout this research.

References

[1] Hazreek, M. Z. A., Saad. R., Fauziah, A., Devapriya, C.W. and Mohamad, F. 2011. Application of Geophysical Methods in Civil Engineering. *Malaysian Technical Universities International Conference on Engineering and Technology (MUiCET 2011).*

[2] Azwin, I. N., Saad, R., and Nordiana, M. 2013. Applying the Seismic refraction Tomography for Site Characterization. *APCBEE Procedia 5. (2013):* 227 – 231.

[3] Harms, U., and Emmermann, R. 2007. *History and Status of the International Continental Scientific Drilling Program*. In: Harms, U., Koeberl, C., and Zoback, M.D., eds., Continental Scientific Drilling: A Decade of Progress and Challenge for the Future. *Springer*, New York, 366.

[4] Hardin, B. O. and Black W.L. 1968, Vibration Modulus of Normally Consolidated Clays, *Journal of the Soil Mechanics and Foundation Division, ASCE*, 94(2): 353-369.

[5] Hardin, B. O., and Drnevich, V. P. 1972. Shear Modulus and Damping in Soils. *J. Soil Mech. and Found. Div*. 98(7): 667-692.

[6] Imai, T., and Yoshimura, M. 1976. The Relation of Mechanical Properties of Soils to P and S Wave Velocities for Soil Ground in Japan. Urana Research Institute. OYO Corp.

[7] Ohkubo, T., and Terasaki, A. 1976. Physical Property and Seismic Wave Velocity of Rocks, OYO Corporation, Japan.

[8] Othman, A. A. 2005. Construed Geotechnical Characteristics of Foundation Beds by Seismic Measurements. *J. Geophysics. Eng.* 2**:** 126-138.

[9] Uyanik, O. 2010. Compressional and Shear-Wave Velocity Measurements in Unconsolidated the Top-Soil and Comparison of the Results. *International Journal of the Physical Sciences*, 5(7): 1034-1039.

[10] Uyanik, O. 2011. The Porosity of Saturated Shallow Sediments from Seismic Compressional and Shear Wave Velocities. *Journal of Applied Geophysics.* 73(1): 16-24.

[11] Seed, H. B., Wong, R. T., Idriss, E. M., and Tokimatsu, K. 1984. Moduli and Damping Factors for Dynamic Analyses of Cohesionless Soils, Report No. UCB/EERC – 84/11, Earthquake Engineering Research Center, University of California, Berkeley.

[12] Guliev, E. 2007. V_p/V_s Estimation from Multicomponent Seismic Data for Improved Characterization of a Tight sandstone Gas reservoir. Colorado School of Mines, A Thesis for the degree of Master of Science (Geophysics) Colorado School of Mine.

[13] Hicks, G.J. 2006. Extended Elastic Impedance and its Relation to AVO Crossplotting and V_p/V_s EAGE 68th Conference, Vienna, Austria.

[14] Jongmans, D. 1992. The Application of Seismic Methods for Dynamic Characterization of Soils. *Bulletin of International Association of Engineering Geology.* 46: 63-69.

[15] Philips, D. E., Han, D. H., and Zoback M. D. 1989. Empirical Relationships among Seismic Velocity, Effect Pressure, Porosity and Clay Content in Sandstone. *Geophysics.* 54(1): 82-89.

[16] Stuempel, H, Kahler S., Meissner R. and Milkereit B. 1984. The use of Seismic Shear Waves and Compressional Waves for Lithological Problems of Shallow Sediments: Geophys. Prospect. 32: 662-75.

[17] Tatham, R.H. 1982, V_p/V_s and Litholog. *Geophysics.* 47: 336-344.

[18] Wang, Z. 2001. Fundamentals of Seismic Rock Physics: Geophysics. 66(2): 398-412.

[19] Ulugergerli, E.U. and Uyanik, O. 2007. Statistical Correlations between Seismic Wave Velocities and SPT Blow Counts and the Relative Density of Soils. *Journal of Testing and Evaluation.* 35(2).

[20] Ong, W. S. 1993. The Geology and Engineering Geology of Penang Island. Geological Survey of Malaysia.