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Geophysical Investigation in Bukit Merah Reservoir

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ABSTRACT: The suspected cavity presence in the bedrock of the outlet canal of Bukit Merah Reservoir in Malaysia raised concern that it could undermine the integrity of a check pier structure planned just ahead of the spillway. Boring into a cavity could also compromise reservoir containment capacity. A seismic refraction and electrical resistivity tomography carried out for the subsurface section spanning the two banks revealed not only the presence of a relatively porous zone towards one end but also the undulating material boundaries towards the other. The results called for review of the original foundation of the check pier structure involving bored piles of equal length. The suspected porous zone was avoided in the renewed bored pile design while the bedrock depressions were appointed with deeper bores for adequate pile embedment. The design review resulted in piles resting on a stratum of equal geotechnical quality with each new pile now having a different length.

Keywords: Bored pile foundation, Suspected cavity, Seismic refraction, Electrical resistivity, Relative porous zone, Design review

1. INTRODUCTION

The Bukit Merah Reservoir is a manmade lake formed by an earth dam. Built in 1906 to irrigate the 24000 hectares Kerian paddy scheme, it has also once provided domestic water. The reservoir covers 3500 hectares and is located on the geographical grid of 05° 01.756' latitude and 100°49.103' longitude. The reservoir and the dam are managed by the Kerian District Office of the Malaysian Drainage and Irrigation Department, located in nearby town of Bagan Serai. The reservoir receives input flows from two main rivers namely Sungai Kurau and Sungai Merah. The former has Sungai Jelutong, Sungai Ara, and Sungai Pulau as tributaries, whereas the latter has Sungai Selarung, Sungai Ijok, and the Ijok Canal flowing into it. The annual rainfall recorded in 2009 for the area was 3284.5 mm (Sani et al, 2012). The waters of Bukit Merah Reservoir would be visible towards the left if one travels south on the North-South Peninsular Expressway - the E1 - while bypassing the Bukit Merah Laketown Resort, as given in Figure 1.

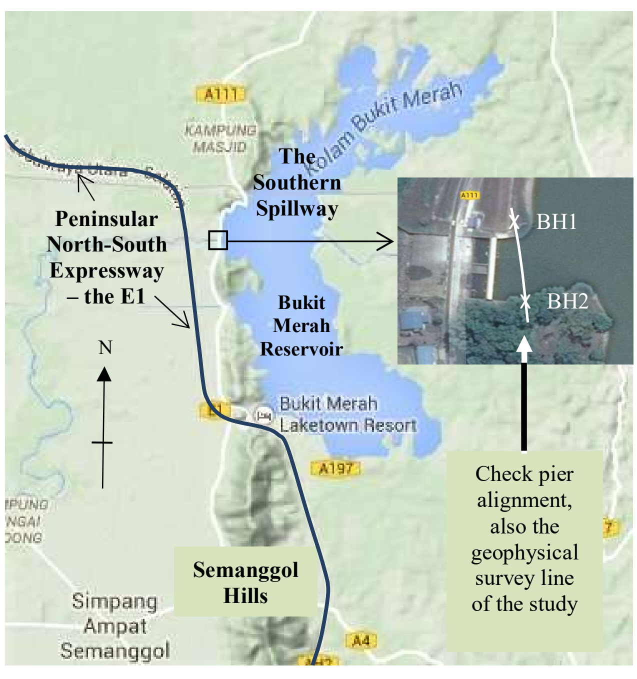

Figure 1 Map of Bukit Merah Reservoir and the vicinity

The geology of Bukit Merah Reservoir is represented by the Semanggol Formation. The nearby Semanggol Hill is part of the formation that extends 20 km to the north, to Kuala Ketil, in South Kedah. The western and eastern faces of the Semanggol Hills display sedimentary outcrops with bedded chert, sandstone faces inter-bedded with shale, and siltstone deposits. The North Semanggol Hill which borders the Bukit Merah reservoir bears characteristics of an ancient deep marine setting with deposition of the bedded chert, followed by the turbidite materials. A turbidite material is the geologic deposits of turbidity currents, distributing vast amounts of clastic sediment into depressions. A clastic sediment is composed of fragments, or clasts, of pre-existing minerals and rocks. The North Gunung Semanggol formation is Permian to Triassic in age, or about 250 million years old (Usop, 2014; Jasin and Harun, 2007).

The study was carried out in order to evaluate the veracity of a bored pile foundation planned to support a proposed check pier structure. The sedimentary bedrocks located under the outlet canal just ahead of the Southern Spillway, as given in Figure 1, were suspected to be relatively porous or hollowed at one point or another which might affect the stability of the structure or containment of the dam if it was bored into. A series of check piers was planned for construction along the geophysical survey alignment of this study. The reinforced concrete structure was to capture vegetative debris and floating weeds that had often crashed and choked the spillway especially during high current. The plan consisted of vertical and raked piles to take the lateral loads, support trash racks to trap the debris, and house an electrical winch to transfer the accumulated materials onto the maintenance deck for further disposal. A particular design of inclined drilled shafts is made available by Puppala et al (2011). The deck was to be furnished with railing and other maintenance facilities. The main concern that led to this study was the potential boring into the porous or cavity zone while the other concern was the unequal bearing capacity distribution among piles if all were to be driven to an equal depth.

The equal-pile-depth design was based solely on the results of a conventional site investigation (SI), i.e. the wash boring. With the advent of geophysical technology in the local scene however, the conventional SI results alone would be deemed insufficient if the design was to consider the jointed nature of the sedimentary rocks prevailing for the area. Unlike the conventional SI, the seismic refraction and the electrical resistivity procedures provide continuous subsurface tomography over distance and each geophysical method could be applied alone or simultaneously with the other. Nevertheless, the geophysical methods can neither be considered as replacement to the conventional SI methods nor to each other as each of these methods measures different properties of the materials.

The recent simultaneous use of the seismic refraction and electrical resistivity in local SI activities have been reported by Addai et al (2016), Ali et al (2013), and Rezaei et al (2013). The geographical vicinity of the Semanggol formation itself has also been subjected to recent geophysical studies involving both the seismic refraction and the electrical resistivity procedures (Nordiana et al,2017; Hisham et al,2017). Meanwhile, in nearby Penang Island where upscale developments involving high rise structures have become the common order of the day, the simultaneous seismic-resistivity procedure is known to have been regularly applied during the SI phase together with the wash boring procedure. In high risk projects, such as those involving a major slope disruption, the inclusion of the geophysical methods has become an almost standard procedure followed by developers. The geophysical applications in SI had in fact become indispensable especially when a major consequence was anticipated. As evidenced by this study, a potential catastrophe might have been avoided and financial saving has been realized through the application of appropriate geophysical technology.

2. METHODOLOGY

SI drillings were carried out for the positions of bore hole 1 (BH1) and bore hole 2 (BH2), on the north and south banks respectively, along the check pier alignment. The positions of BH1 and BH2 had a 4.5m difference in elevation, with BH1 being lower. The water level varies with time, however it may be assumed as 4.0m above BH1 elevation, which is the high water level that could occur for the site under normal circumstances and was the level used in check pier design. The SI data were later used in conjunction with the geophysical results. A Piezocone test was also carried out near BH2 position which nevertheless did not penetrate beyond the soil stratum.

The seismic and the resistivity surveys were carried out along the check pier alignment which also ran over the two SI boreholes. The lateral description of the survey line is given in Figure 2 with relative positions of BH1 and BH2 indicated. The first seismic geophone was positioned at the 65m mark, which was on the northern bank, while the last seismic geophone was positioned at 150m mark, which was on the southern bank. The seismic spread was thus 85m. The significant part of the exit canal was about 70m wide along the alignment. In the canal, the geophones were planted on the lake bed at 5m spacing between units. The seismic instruments consisted of 40kg drop hammer, 24Hz marsh geophones, and ABEM MK6 seismograph. For the 2D resistivity survey, similar 5m spacing between electrodes as in the seismic survey was applied. The electrodes were also planted on the lake bed with a total array length of 200m thus overshooting the seismic geophone points at both ends. The resistivity meter was the ABEM SAS4000 while the array type deployed was the Sclumberger.

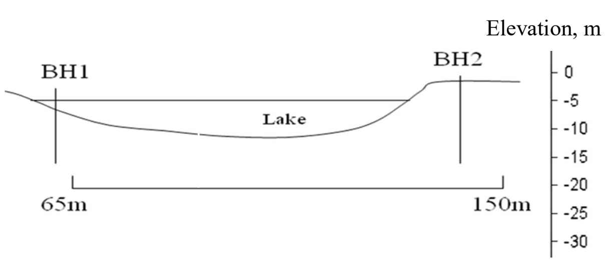

Figure 2 Study cross section showing the 65m and 150m marks on the check pier alignment

3. RESULTS AND ANALYSIS

3.1 Site investigation results

The SI data of BH1 and BH2 are given in Table 1 and Table 2 respectively. At BH1, low plasticity clays mixed with gravels dominated the depths down to 10.6m, where the SI terminated. At BH2, the soft, high plasticity clays mixed with sands and gravels filled the depths down to 4.5m. Thereafter, loose sands and silts followed to 6.0m. Firm silts, sands, and gravels then ensued to the final drilling depth of 15.1m, when bedrocks were met. These material names were however driller’s given. The expected names based on the USCS are as given in Column 3 of Table 1 and 2. The piezocone penetration near BH2 however identified materials for the top 1.5m as clays, silts, and sands, thus considered matching the driller’s description for the borehole. Part of the sedimentary bedrock might have been disturbed by the harsh washing of the SI method and appeared as dense sands and gravels, as described by the driller.

Table 1 SI Data from BH1

Depth, m	Driller’s Description	Expect. USCS class.	SPT(N), Blows per 30 cm	Depth SPT carried out, m
0	Soft sandy clay of low plasticity with gravel	CL		
1.5			4	1.50 -1.95
3	No recovery		3	3.00 -3.45
4.5	Hard clay of intermediate plasticity	CL	50/15 cm	4.50 -4.95
5				
6	Hard clay of low plasticity with sand	CL	50 /7cm	6.00 -6.45
7				
7.5	Hard clay of intermediate plasticity	CL	50 /7cm	7.50 -7.95
8				
9	No recovery		50/6cm	9.00 -9.45
10.5	Hard clay, low plasticity	CL	50 /6cm	10.5 -10.95
11				

Note: The positions of BH1 and BH2 had a 4.5m difference in elevation, with BH1 being lower. Termination depth was 10.6m.

Table 2 SI Data from BH2

Depth, m	Driller’s Description	Expect. USCS class.	SPT(N), Blows per 30 cm	Depth SPT carried out, m
1.5	Soft low plasticity clay	CL	4	1.50 -1.95
2				
3	Soft high plasticity silt	MH	4	3.00 -3.45
4.5	Loose sand with fine soil	SM	5	4.50 -4.95
5				
6	Firm high plasticity silt	MH	8	6.00 -3.45
7.5	Firm sand with fine soil	SM	7	7.50 -6.95
8				
9	Dense gravel, sand, and silt	GM	50 /19 cm	9.00 -9.45
10			50/6cm	10.50-10.95
12	Sandy fine soil	SM	50 /3cm	12.00 -12.45
13.5	Very dense sand	SW	50 /12 cm	13.50 -13.95
15	Dense gravel	GW	50 /7cm	15.00 -15.45

Note: The positions of BH1 and BH2 had a 4.5m difference in elevation, with BH2 being higher. Termination depth was 15.1m.

The initial bored piles plan was to have each pile embedded to about 5.4m beyond the borehole termination depths. The SPT(N) is a measure of penetration resistance thus at BH1 position the pile would be embedded into an 11.5m thick stratum with SPT(N)>50 while at BH2 position this thickness was 10.5m. With SI results as the only data considered, this arrangement which provided constant 21m long piles for the entire check pier structure was otherwise quite justified, except for being excessive, uneconomical, and imprecise for the purpose. Note that the termination depths at BH1 and BH2 were exactly vertically aligned thus the entire stretch was initially thought of having similar geotechnical profile anywhere underneath the canal bed.

3.2 Geophysical investigation results

The seismic refraction method uses the different velocities that seismic waves travel in materials of different densities. The seismic refraction interpretation for this work is given in Figure 3, which features a first layer with depths from 0 to 5m below lake bed, with seismic transmission velocities ranging between 300 and 800m/s, matching the velocities for river sediments such as clays, silts, sands, and gravels. The material presence was approximately corroborated by SI data for BH1. The second layer with depths ranging between 0 and 24m below lake bed, depending on the position along the alignment, was identified as having transmission velocities between 800 and 2300m/s and matching the velocities for hard or compact river sediments. The materials, as identified from BH2 as filling the depths between 0 and 4.5m, were similarly clays, sands, and gravels as in the first layer, but were more compact as reflected by the higher transmission velocities. The bedrock with transmission velocities above 2300m/s was positioned the deepest. Figure 3 shows that for any given depth, the material varies with lateral distance of the same depth, or that a material interface undulates with lateral distance. Notice that underneath BH2, a relatively loose material made a presence that extends into a great depth. The bored piles, each initially proposed to be 21m long from cap to embedment for the stretch between 40 and 130m marks, were no longer expected to have the same end bearing capacity between them with the seismic results given.

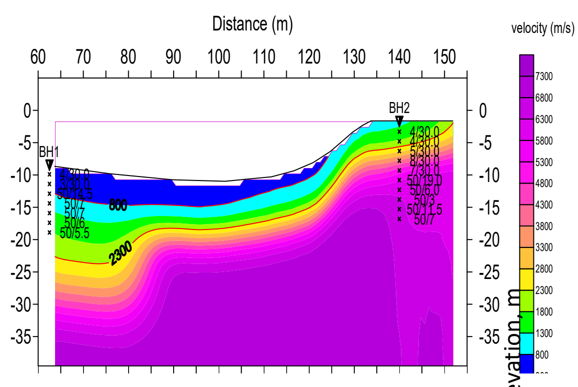

Figure 3 Seismic image for section under check pier alignment

The resistivity refraction method evaluates the different materials according to their respective ability to oppose or permit the flow of electric current. The method is especially adept at detecting the presence of water which is a relatively good electrical conductor and readily available in low lying voids, fractures, and depressions. The resistivity interpretation of Figure 4 features a conductive, first layer materials with resistivity value up to 40ohm.m, with varying depths from 0 to 10m, below lake bed. These are river sediments such as clays, silts, sands, and gravels, saturated with water, which may correspond to those of the top half of BH1 and the first layer given by the seismic results. The second layer, with materials with resistivity value of 40 to 1000ohm.m, extends down to 20m below lake bed. These are hard or compact river sediments corresponding to the second layer of the seismic results and materials of the bottom half of BH2. The bedrock with resistivity value greater than 1000ohm.m is the underlying material with the shallowest point positioned 7m below lake bed. This may correspond to the bedrock of the seismic results. Notice that the resistivity interpretation has the first and second layer materials occupying a deeply positioned fracture zone underneath BH2 position.

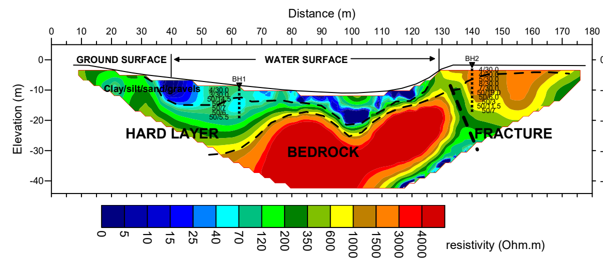

Figure 4 Resistivity image for section under check pier alignment

The light river sediments were found to be present over and surrounding the sound bedrock, but not within it as initially feared. The fracture zone, widening with increasing depth, can be seen traversing in the proximity of BH2 which is out of the way of the main canal section. Again, the 21m bored piles were no longer expected to have the same end bearing capacity with the geophysical results given.

3.3 Comparative results evaluation

BH1 and BH2 were located in entirely different grounds. The strata were mostly clays in BH1 while mostly sands in BH2. The SPT(N)=50 criterion was achieved at 4.5m below ground level in BH1 and at 9.0m below ground level in BH2. However, the 4.5m depth of BH1 was exactly level with the 9.0m depth of BH2. The termination depths of 10.5m and 15.0m for BH1 and BH2 respectively were also level to each other. It became reasonable then to design for equal embedment levels for all of the bored piles, as in the original plan.

The SPT(N) is a measure of material resistance against penetration, the seismic results are a measure of material density, while the resistivity values are a measure of electrical resistance or conductivity which is greatly affected by the presence of water. The measures between any two properties could correspond to each other such as in the case of SPT penetration versus seismic results where SPT(N) appears to increase with increasing seismic transmission velocity, and with increasing material density.

However the measures between any two properties could also be less related to each other such as in the case of seismic versus resistivity results where change in material density did not necessarily correspond to change in resistivity or conductivity as the latter was more affected by change in prevalence of water in the material. Thus in Bukit Merah, the SI data in terms of the SPT(N) appeared to be corroborated more by the seismic results but less by the resistivity results, more obviously for BH2 position. The correlations between the seismic and the resistivity results were even lesser, not to say that they were totally unrelated.

The incidence of river sediments was substantiated by drilling, seismic, and resistivity methods because the materials were simultaneously less resistant to SPT penetration, loose, and saturated with water. On the other hand, the saturated materials of BH1 were distinguished clearly against the dry materials of BH2 by both seismic and resistivity methods although the materials were both rated equally by the SPT(N) readings for the top one third of the boreholes. Thus the seismic and resistivity results appear to agree with the SI data in some ways but contradict in others. Each of the three methods provides independent evaluation of ground.

3.4 Revised plan

The revised plan proposed piles to be embedded into an equally rated stratum along the entire check pier alignment. The stratum might have been rated differently by the two geophysical methods but for a large portion of the section the rating appeared to agree. The original SPT(N) based specification was adhered to at BH1 where the penetration depth was decided to be 5.4m beyond the base of the borehole, or at 11.5m beyond where SPT(N)>50 first encountered. A line representing an equally rated material was drawn over the seismic profile, as given Figure 5 and over the resistivity profile, as given in Figure 6, to indicate the depths that piles should be embedded into in each case. These equal rate lines were made to pass through the embedment depth at BH1 of the initial plan. The length of each new pile was therefore the sum of height of pile cap above water which is 1.0m, and depths of water and ground penetration under lake bed. The results of carrying out the above summation, first considering the seismic image, and second the resistivity image, are given in Table 3. The lengths of each pile calculated from using the two criteria were compared, and the greater of these was selected as final for the respective position.

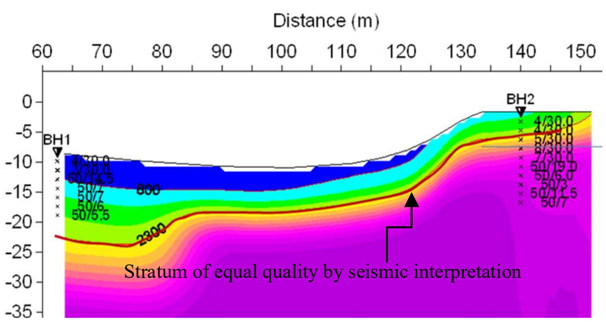

Figure 5 Stratum of equal quality by seismic image

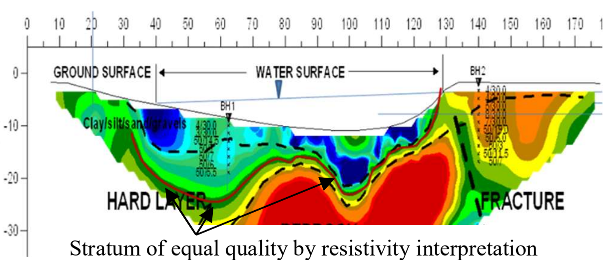

Figure 6 Stratum of equal quality by resistivity interpretation

4. CONCLUSION

The described work was about using the seismic refraction and electrical resistivity tomography in evaluating the veracity of an initial bored pile design involving piles of equal length. The initial design was based on the results of two borehole drillings and the anticipation of a flat stratum of equal bearing capacity straddling the two boreholes to support the piles. The use of geophysical methods revealed instead a varying subsurface feature over distance with undulating material interfaces and the generally increasing rock strength properties with depth, which altogether called for a review of the original design. The review instead proposed the presence of an undulating stratum of equal geotechnical rating, thus of equal bearing capacity also, as the bearing stratum for the piles to be rested upon. The initial design had a pile rested on a stratum 5.4m underneath the base of BH1 and the rest of piles to be of the same length. The new design identified an equally rated stratum to cover the entire section while passing a point 5.4m underneath the base of BH1.

The newly appointed piles were therefore of various lengths, to be rested upon the newly interpreted but undulating bearing stratum of equal geotechnical quality as given in Table 3 and Figure 7. The suspected presence of a porous zone was substantiated and avoided from being disturbed; nevertheless it was located so deep and out of the way that none of the new piles would extend into it. In completing the new pile design, the remaining work had required the estimation of end bearing capacity of a pile when rested on the bearing stratum, size and quantity of piles needed to support the check pier structure, and material specifications.

Table 3 Calculation of final pile lengths

	By resistivity		By seismic		
Position on the line	Depth below lakebed	Assumed depth of water	Depth below lakebed	Assumed depth of water	Final pile length
125m	4m	2m	5m	2m	8m
120	7	5	7	5	13
115	5	6	6	6	13
110	7	7	7	7	15
105	11	7	7	7	19
100	13	7	7	7	21
95	10	6	7	6	17
90	6	6	8	6	15
85	6	6	8	6	15
80	7	5	11	5	17
75	8	5	14	5	20
70	11	4	14	4	19
65	15	4	14	4	20
60	16	4			21
55	17	2			20
50	16	2			19
45	16	1			18
40	15	0			16

Note: It is asssumed that water level is 4.0m above BH1 elevation and length of piles above water is 1.0m.

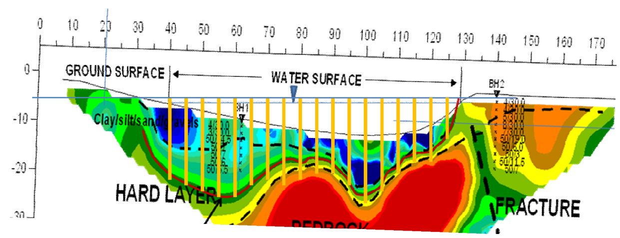

Figure 7 Final piling plan put against resistivity image

5. ACKNOWLEDGEMENT

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6. REFERENCES

Addai E., Asare V. S., and Aning A. A. (2016) Application of Shallow Seismic Refraction and 2D Electrical Resistivity Imaging to Site Investigations, International Journal of Scientific and Research Publications, Volume 6, Issue No. 5

Ali N., Saad R., and Nordiana M. M. (2013) Integration of Seismic Refraction and 2D Electrical Resistivity in Locating Geological Contact, Open Journal of Geology, 3, pp7-12

Hisham H., Nordiana M. M., and Jia T. Y. (2017) Evaluation of Semanggol Formation – Permian Facies – using Electrical

Resistivity Tomography and Seismic Refraction Tomography Parameter, South East Asian Conference on Geophysics, IOP Conf. Series: Earth and Environmental Science 62

Jasin B. and Harun Z. (2007) Stratigraphy and sedimentology of the chert unit of the Semanggol Formation, Geological Society of Malaysia, Bulletin 53, June, pp103 – 109

Nordiana A. N., Nordiana M. M., Jia T. Y., Hisyam H., Sulaiman N., Maslinda U., Taqiuddin Z. M., Nur Amalina M. K. A., and Saharudin M. A. (2017) Study of Sedimentary Outcrop of Semanggol Formation with the Correlation of Geology, Geotechnical, and Geophysical Technique, South East Asian Conference on Geophysics, IOP Conf. Series: Earth and Environmental Science 62

Puppala A. J., Wejrungsikul T., Williammee R. S., Witherspoon T, and Hoyos L. (2011) Design of Inclined Loaded Drilled Shafts in High-Plasticity Clay Environment, Technical Report 061461, Texas Department of Transportation, Austin, Texas, p225

Rezaei K., Amiri V., and Beitollahi A. (2013) The Contribution of Electrical Resistivity and Seismic Refraction Techniques to Site Characterization and Earthquake Risk Assessment, a Case Study: IKIA airport, Iran, Elixir Geoscience 62

Sani S. F., Ismail W. R., Najib S. A., and Omar M. A. (2012) Evaluation of Sediment Budget of Bukit Merah Reservoir and its Catchment Area, Perak, Malaysia, Malaysian Journal of Environmental Management 13(1): pp69-79

Usop N. (2014) General Geology of Northern Gunung Semanggol, Bukit Merah, Taiping with Emphasis on Tectono-Stratigraphic Evolution of Semanggol Formation, Final Year Project Report, Universiti Teknologi PETRONAS (Unpublished)