DESIGN AND CONSTRUCTION ASPECTS OF A RIVERWALL SYSTEM CONSIDERING STAGE-CONSTRUCTION TO MINIMISE EFFECTS OF DETRIMENTAL RIVERBANK SOIL MOVEMENTS

D. E. L. ONG

Research Centre for Sustainable Technologies,
Faculty of Engineering, Science and Computing,
Swinburne University of Technology Sarawak Campus,
93350 Kuching, Sarawak, Malaysia
E-mail: elong@swinburne.edu.my

This paper highlights the design and construction challenges of a riverwall constructed in soft riverbank deposits. Finite element modelling was carried out to develop the necessary construction stages so that the riverwall project can be safely executed. In the design of the riverwall system, amongst the important considerations include (i) low bearing capacity of the soft riverbank deposits, (ii) requirement of overall riverwall stability, (iii) effect of tidal variations, (iv) proposed dredged levels and (v) relatively shallow pile penetration depths. By adhering strictly to the construction stages, the riverwall project was successfully executed. Besides, some local case studies show that over-filling at such soft riverbank slope crest can induce instability and may eventually lead to failure. This observation reinforces the importance of performing stage-construction during the implementation of riverine infrastructure projects in soft riverbank deposits.

Keywords: Riverine infrastructure, soil movement, tidal fluctuation, pile foundation, riverwall

1 INTRODUCTION

The flood mitigation project site at a local tributary is located at the west of the Astana building (official residence of the Governor of Sarawak) at Petra Jaya. It is a tributary of Sg. Sarawak that flows through Kuching City Centre. **Figure 1** shows the locality plan of the project site. The site is located at a low-lying area with ground level generally at Land & Survey Datum (L.S.D.) +1.0m at the riverbank area and approximately L.S.D. -1.6m at the river bed. The soil condition generally consists of soft riverbank deposits that quickly changes to an underlying layer of stiff clay and dense sand with SPT rebound. 5 nos. of boreholes were carried out on the site.

Figure 1. Locality plan showing the tributary flowing into Sg. Sarawak.

2 GENERAL GEOLOGY

The geological formations as deduced from available geological maps and subsurface investigation document suggest the existence of the Quaternary formation of Pleistocene age, which is generally sedimentary in nature. This formation is made up of recent marine deposits of clay, silt and sand.

3 RESULTS OF SOIL INVESTIGATION WORKS

The subsurface investigation comprises 5 numbers of boreholes sunk to depths of about 9m terminating in either SPT N = 50 bearing layer or rock surface.

3.1 *Standard Penetration Test (SPT)*

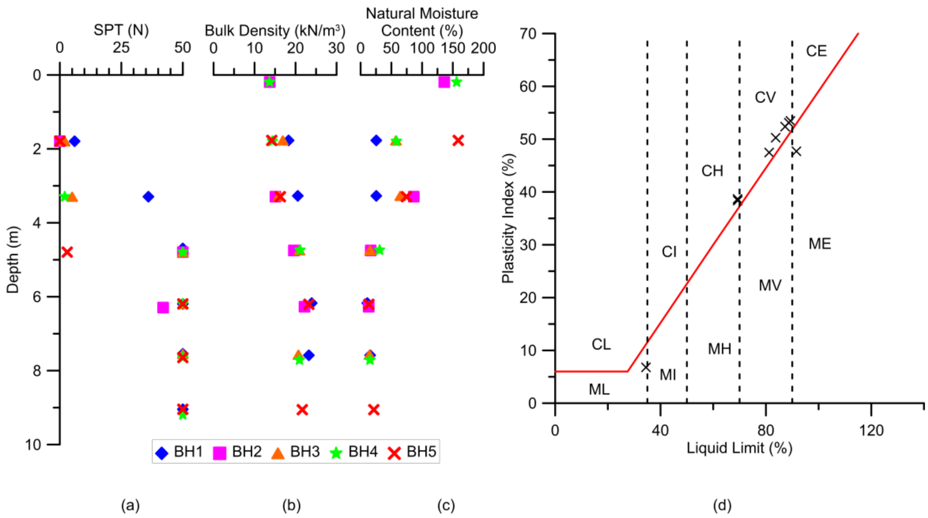


Figure 2. Variation of (a) SPT N values, (b) bulk density, (c) natural moisture content with depth and (d) plasticity A-Line chart.

Standard penetration test (SPT) was carried out in the boreholes to assess the stiffness of the ground. Figure 2(a) shows the distribution of the SPT blow count recorded. In general, the borelogs show the presence of 2.5m of very soft silty clay layer with SPT N-value of less than 3. Underlying the soft silty clay is a layer of very dense sand or hard clayey silt of approximately 3.5m thick with SPT N-value between 30 and 50. Dense sand with SPT N-value greater than 50 is suitable for pile bearing and socketing to prevent uplift.

3.2 *Soil Characterization*

Typical plots of bulk density and natural moisture content are shown Figure 2(b) and (c). The average bulk density for the first 3.5m of soil from the two boreholes is about 16.5kN/m^3, after which the bulk density would increase to a range of between 18kN/m^3 and 20kN/m^3 indicating closely packed soil particles leading to stiffer soils. Soil natural moisture, however, decreases with increasing depth as shown in Figure 2(c), because most voids would have been filled with the closely packed soil particles.

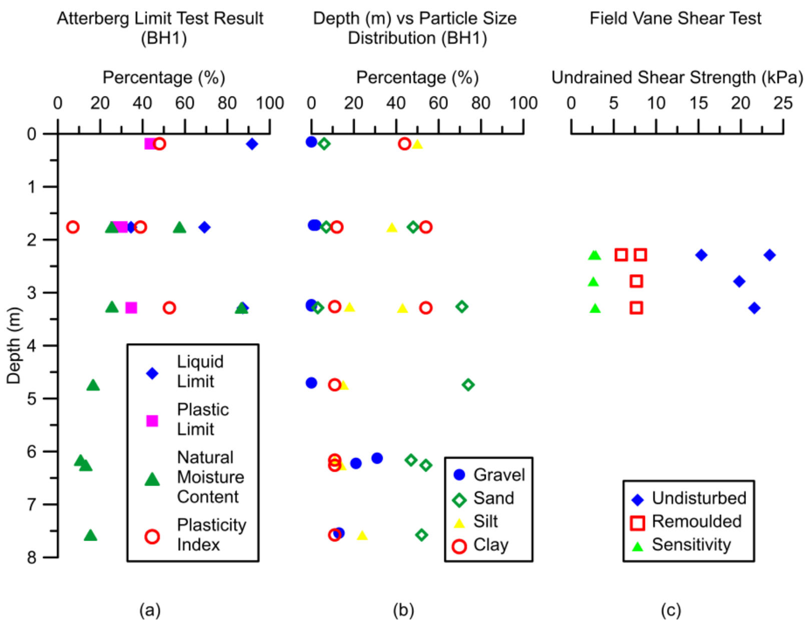


Figure 3. (a) Atterberg Limits, (b) particle size distribution and (c) vane shear strength vs. depth.

Figure 3(a) and (b) shows the Atterberg Limits and particle size distribution plotted against the depths where the samples were retrieved. In order to classify fine-grained soils into clays and silts, the A-line plasticity chart as shown in Figure 2(d) is plotted using results of plasticity indices and liquid limits of the disturbed soil samples from the boreholes. Figure 2(d) shows that all of the obtained samples have high to very high plasticity. Plasticity in soils involves irrecoverable deformations, whereby the soil volume remains constant or is reduced without any accompanying signs of cracking or disruption. As such, pile foundations embedded in such soils have to be adequately designed to resist the soil pressures or movements derived from the deformations of such soft soils in the event of any eventual riverbank movement.

The undisturbed (UD) samples obtained from soil sampling are used to perform unconsolidated undrained (UU) triaxial tests to obtain the undrained shear strength of the soils as shown in **Table 1**. Undisturbed samples are also used to perform 1-D oedometer tests to obtain soil compressibility parameters for settlement analysis.

Table 1. Unconsoliated Undrained triaxial result.

Sample	Average depth (m)	c_u (kN/m^2)
UD 1 (BH5)	3.25	26.5

3.3 *In-situ vane shear tests*

Vane shear tests were carried out to obtain the in-situ undrained shear strength of the soft soils. Figure 3(c) shows the undisturbed and remoulded shear strength results plotted against depth. The sensitivity or the ratio of undisturbed to remoulded shear strength values of the soft clays is between 2.5 and 3.0. It appears that the riverbank soils are overconsolidated (OC) or lightly overconsolidated (LOC) as the c_u/p_o' ratio is greater than 0.25. The over-consolidated ratio (OCR) is expected to be between 3 and 5.

4 Identification of Geotechnical Challenges

The geotechnical challenges faced in the design and subsequently the construction of the riverwall may be generally identified as follows:-

(i) The proposed site is overlain by soft layers (SPT N<5) at 2-3m depth and followed quickly by very dense SAND or hard SILT (SPT N≥50) from 3m depth onwards.

(ii) Retaining wall
- (a) The design of the retaining wall shall consider erosion protection, impact of possible riverbank soil movements and its overall stability.
- (b) The retaining wall shall be sufficiently socketed into dense or hard materials (SPT≥50) to ensure stability.
- (c) The longitudinal profile or alignment of the retaining wall system shall be aesthetically pleasing i.e. the wall should not deflect out of alignment during installation and during its service life
- (d) Stability of the riverbank to be safe-guarded to prevent soil slip or lateral soil movement, thus the importance of the construction sequence.

(iii) Ground treatment for infrastructure
- (a) If settlement estimated exceeds permissible limits for infrastructure such as roads and drainage then feasibility of ground treatment shall be considered.
- (b) In addition, the riverbank soft deposits appear to be from natural sedimentation process (erosion and deposition may have occurred over many cycles, hence soils are OC and LOC with OCR between 3 and 5) and not likely caused by recent alluvium deposition due to floods. This is evidenced by relatively high permeability and medium compressibility of the deposits.
- (c) Effective drainage system is recommended to prevent local scour of constructed embankment slope.

(iv) Slope stability
- (a) It is noticed that the potential slip beneath the retaining wall needs to be looked into. The slip could be intercepted or prevented by the riverwall thus resulting in minimal lateral soil load on piles.
- (b) Besides other potential instability situations need to be identified.

(v) Foundation support
- (a) Pile support looks necessary in view of the upper soft clays and the proposed reclaimed fill which is about 2-3m in height above the existing ground. The pile selected shall be strong enough to resist the horizontal load resulted from the tie beam supporting the riverwall.
- (b) Trial driving of non-working piles shall be carried out to ensure that foundation piles are properly socketed in the underlying dense sand or hard silt to ensure overall stability and to ensure that the lateral earth pressures can be resisted.

(vi) Construction sequence of proposed riverwall
- (a) As 2-3m of reclaimed fill is to be placed on the existing ground, correct construction sequence is very important in this riverwall construction so as to prevent over-loading of riverbank slope leading to detrimental movement of both riverbank and the installed unrestrained single piles or sheetpiles.

(vii) Dredging
- (a) As the stability of the riverwall is governed by the penetration depth of the sheetpile, it is important to ensure that the designed dredging depths are observed during construction to prevent scour of exposed toe of riverbank slope.
- (b) River water level will also govern the stability of the wall thus dredging of channel has to be carried out at a specified minimum water depth.

5 Geotechnical Analysis and Results

5.1 *Selection of riverwall system*

The selection of a suitable type of riverwall, considering its underlying geology and site geometry, should account for the following design criteria:

a) ability to resist lateral soil pressure exerted by the reclaimed fill and existing soils to meet both strength and serviceability requirements
b) ability to provide vertical restraining effect or acts as king posts which can be socketed into competent (N≥50) but shallow layer to support sheet pile lagging to form a vertical facing (this would maximize channel width with minimal cut back)
c) ability to conveniently conform to pre-determined dredged invert level profiles and channel width
d) ability to retain the riverbank deposits from potential scouring
e) ability to increase riverbank slope stability after the construction of the riverwall
f)can be effectively implemented at constrained areas limited by boundaries of river reserves
g) optimum construction period
h) aesthetically pleasing i.e. installed riverwall alignment has limited variation to its proposed longitudinal profile

Table 2 shows the various types of retaining wall systems considered with their corresponding advantages and disadvantages:

Table 2. Various types of riverwall systems considered with respect to design criteria.

Various types of riverwall systems	Advantages	Disadvantages
1. Reinforced earth slope and gabions	Account for (a), (e), (g), (h)	Does not account for (b), (c), (d), (f)
2. Sheetpile riverwall	Account for (a), (c), (d), (e), (g)	Does not account for (b), (h)
3. Box pile (king post) and sheetpile riverwall	Account for (a), (b), (c), (d), (e), (f), (g), (h)	-

It is clear that Option 3, i.e. riverwall consisting box pile (king post) and sheetpile is the most attractive option it fulfils all the design criteria outlined above.

The proposed riverwall will comprise a row of sheetpiles spanning between successive intervals of box piles and the system is stayed by a structural tie beam at the top of the wall acting as an equivalent ‘tie rod’ or ‘anchor’. The 400mm diameter spun pile, which is connected to this tie beam will be socketed at least 1.0 m into the dense sand or hard silt layer with N ≥50. The PU6 sheet piles serve as lagging to retain the soil and shall be penetrated into the soil until refusal (max. N≤25-30). The requirement is that the length of sheetpile penetration must be at least 1.0m below the proposed invert level of the channel to maintain long-term stability. Over-dredging of river channel must be prohibited as it could threaten the overall stability of the riverwall through scouring.

5.2 *Design methodology*

Piles installed in riverbanks will most likely experience lateral soil movements, which in turn may result in lateral soil pressures, when subjected to repeated fluctuation of river water level (Wong et al., 2015). These piles are then supported by the ground in return. As such, there is a soil-pile-soil interaction with the soil providing both the load (active) and also resistance (passive) due to low tide and high tide cycles, respectively. As the cycles continue, a significant permanent net relative displacement of pile foundation in relation to its original position may take place and such observations have been evidently recorded and measured by Ting (1997), Ting & Tan (1997) and Ting (2004). The potential movements to pile foundations could lead to pile damages due to distortion from their original configurations and also to the superstructure being supported, if this important design aspect is not considered.

Therefore, the design of the riverwall structure involves the interaction of the structure and the ground. The detrimental effects of uncontrolled soil movements have been well studied by Ong et al. (2006, 2009, 2011, 2015a, 2015b) and Leung et al. (2006). Therefore, the controlling factor is derived from the lateral loading arising from the inevitable retention and filling of the riverbank, which constitutes a critical part of the riverwall design requirement. Modelling is thus directed towards simulating the behaviour of the system as closely as possible via a stage construction process, which mimics the actual construction process that will eventually takes place. The selected model has to be realistic in simulating the performance of the system and also the stage construction, which will be vital to ensure the success of the project as over-loading the existing soft riverbank deposits will undoubtedly cause riverbank slope instability.

The sheet pile wall performs the basic function of retention and needs in this case to be anchored at the top of the wall to ensure overall stability.

The model proposed is as follows:

a) The riverwall (box pile interlocking with sheet piles) is designed as a 2.4 m section [width of box pile; (approx. 0.63 m) + 3 widths of PU sheet piles; (0.6 m x 3)]. As such the load imposed on the riverwall is also based on per 2.4 m width.
b) A 2D finite element software is used to compute the lateral loading arising from the retention and filling of the riverbank as well as for soil-structure interaction. This sophisticated software considers the construction sequence of the proposed works and its output includes forces induced in the combination of box pile-sheet pile wall as well as the tie beam. The shear and bending moment capacities of the combination of box pile-sheet pile wall are checked to ensure that the design

forces are within their allowable limits. The serviceability of the riverwall is also checked for adequacy. The axial force induced in the tie beam will then be extracted and used in a separate software called ALP.

c) A geotechnical software called ALP (laterally loaded single pile analysis) is then used to evaluate the maximum moment and shear induced in the 400mm diameter spun pile as a result of the lateral load caused by the tie beam. Finally, the spun pile is checked against strength and serviceability limits.

5.3 *Selection of soil strength*

Due to the absence of consistent soil strength test results due to difficulty in obtaining undisturbed samples as the underlying soils are rather silty, conservative empirical correlations of soil total strength parameters are suggested for analysis.

Table 3 shows the interpreted and suggested total and effective stress soil parameters used in the analysis.

Table 3. Suggested total and effective stress parameters used for analysis.

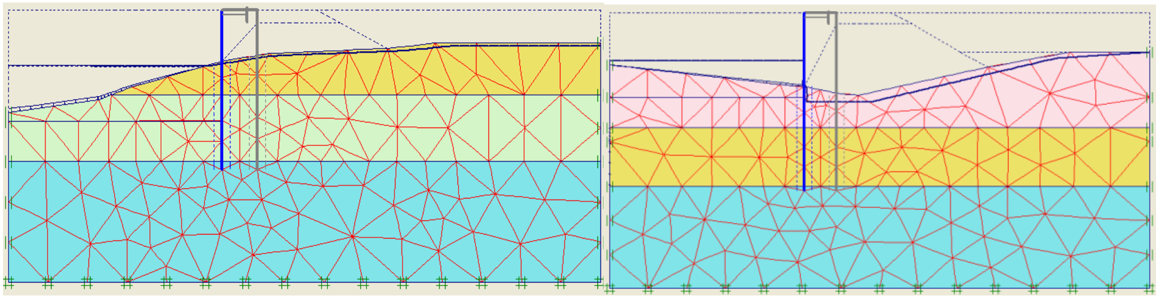
Soil type	**Total stress parameter**	**Effective stress parameter**	
	Undrained shear strength c_u = 5N (kPa), if applicable	c' (kPa)	ϕ' (kPa)
Backfill	30	0	28
Firm silty clay, SPT N = 5	25	5	28
Dense sand of hard silt, SPT N = 50	250	15	30

5.4 *Analysis results*

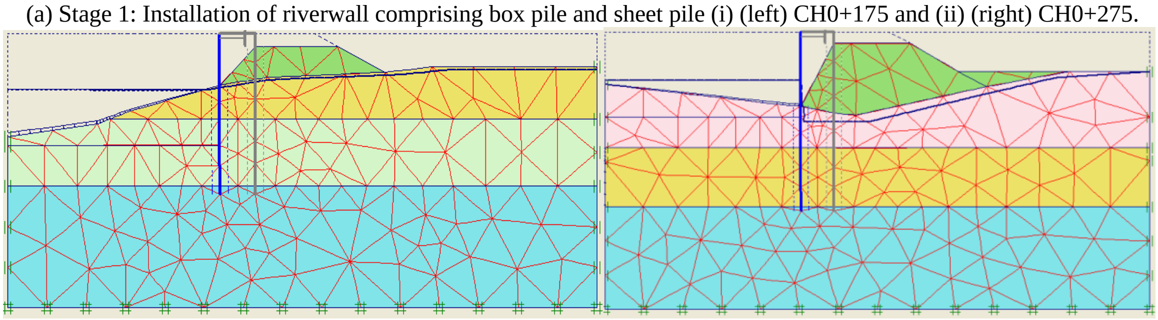
5.4.1 Design of box pile, sheetpile and spun pile

Figures 4(a) – (g) shows the proposed stage-construction that was modelled using the finite element code, PLAXIS to assess the induced forces in the structural components of the riverwall system. The design deflection, working forces and structural capacity of the riverwall at each construction stage for CH0+175 and CH0+275 are tabulated in Table 4 and Table 5, respectively.

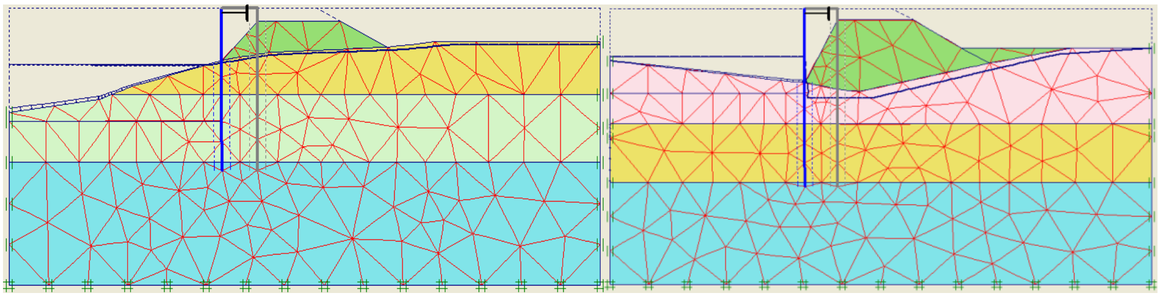
It is observed that the highest induced forces would be generated in the riverwall if post-construction maintenance work by dredging is to be carried out at low tide level at RL-0.5m. Even though the riverwall is designed for this, it is not recommended that maintenance dredging be carried out during low tide as accidental over-dredging may occur due to relatively narrow channel width. It is observed that bending moment is a governing criterion in the design of the riverwall.



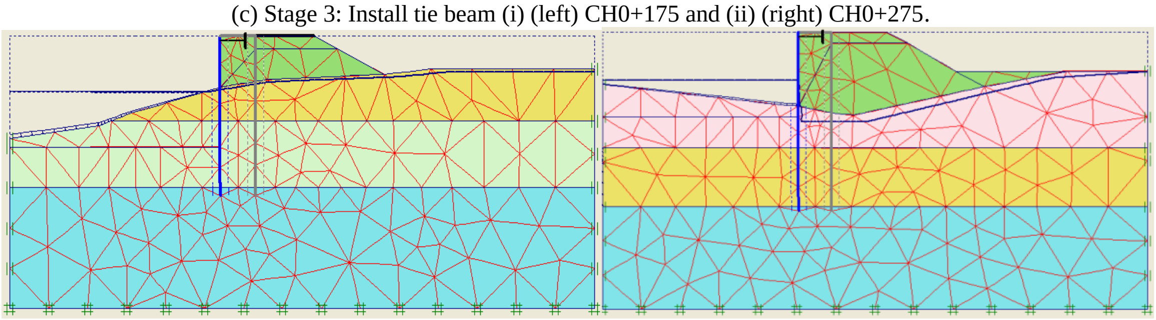
(a) Stage 1: Installation of riverwall comprising box pile and sheet pile (i) (left) CH0+175 and (ii) (right) CH0+275.



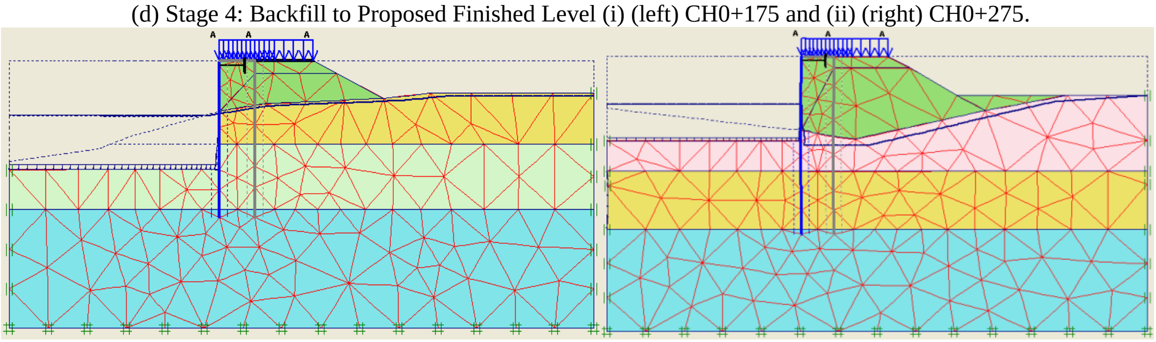
(b) Stage 2: Partial backfill to below tie beam level (i) (left) CH0+175 and (ii) (right) CH0+275.



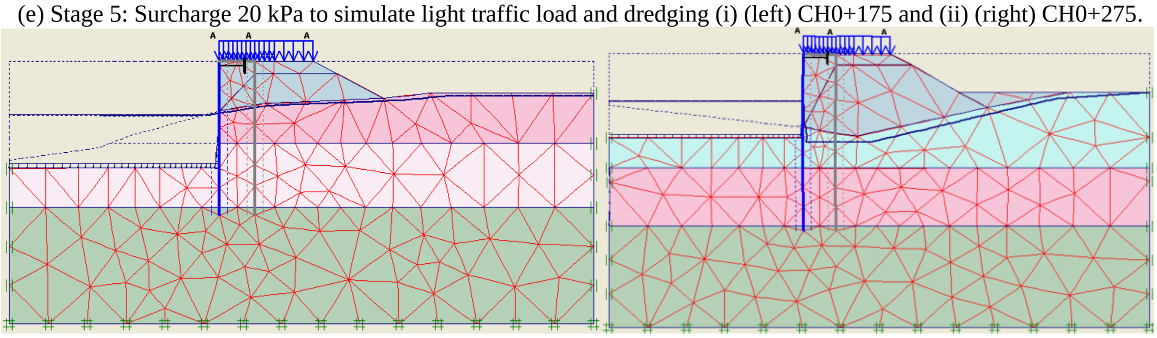
(c) Stage 3: Install tie beam (i) (left) CH0+175 and (ii) (right) CH0+275.



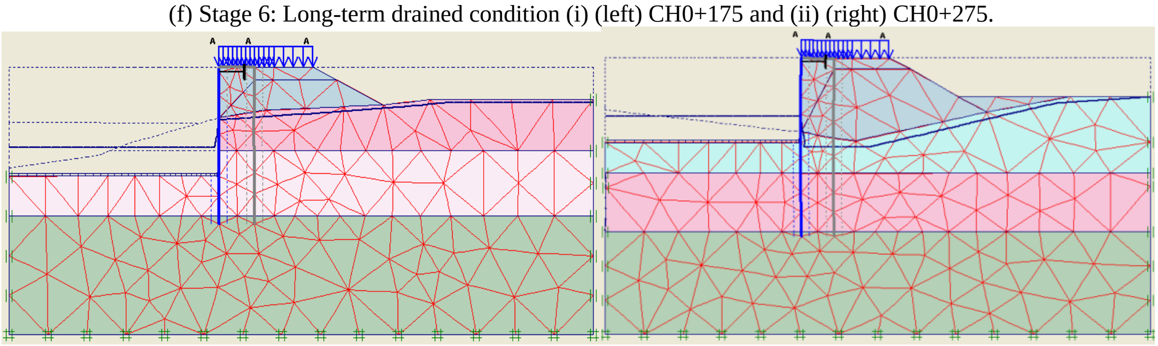
(d) Stage 4: Backfill to Proposed Finished Level (i) (left) CH0+175 and (ii) (right) CH0+275.



(e) Stage 5: Surcharge 20 kPa to simulate light traffic load and dredging (i) (left) CH0+175 and (ii) (right) CH0+275.



(f) Stage 6: Long-term drained condition (i) (left) CH0+175 and (ii) (right) CH0+275.



(g) Stage 7: Low tide stability (i) (left) CH0+175 and (ii) (right) CH0+275.

Figure 4 (a) – (g). Proposed stage-construction modelled in the finite element analyses and expected to be executed likewise during construction.

Table 4. Analysed and design values of deflection and working forces for proposed riverwall @ CH0+175 (BH3).

Stage	Riverwall retaining system (CU12+PU6)			Tie force (kN/m)
	Horizontal deflection (mm)	**Bending moment (kNm/m)**	**Shear force (kN/m)**	
1. Install box pile and sheet pile	-	-	-	-
2. Partial backfill to below tie beam level	5.5	2.0	9.1	-
3. Install tie beam	5.5	1.7	7.8	-
4. Backfill to Finished Level	5.4	9.0	8.2	7.6
5. Apply surcharge 20kPa	5.8	25.5	20.7	17.4
6. Dredging to proposed Invert Level	8.2	49.8	33.4	32.8
7. Long-term or drained case	9.6	60.1	45.3	47.4
8. Low tide (RL-0.5m) dredging in future maintenance	12.0	78.8	54.6	57.4
Allowable capacity	-	110.0 (OK)	1280.0 (OK)	-

Table 5. Analysed and design values of deflection and working forces for proposed riverwall @ CH0+275 (BH5).

Stage	Riverwall retaining system (CU12+PU6)			Tie force (kN/m)
	Horizontal deflection (mm)	**Bending moment (kNm/m)**	**Shear force (kN/m)**	
1. Install box pile and sheet pile	-	-	-	-
2. Partial backfill to below tie beam level	9.7	29.0	22.9	-
3. Install tie beam	9.7	29.0	22.9	-
4. Backfill to Finished Level	11.6	34.3	26.1	8.9
5. Apply surcharge 20kPa	11.7	34.7	26.3	9.3
6. Dredging to proposed Invert Level	19.6	60.0	36.3	29.6
7. Long-term or drained case	24.1	82.1	50.1	52.8
8. Low-tide (below RL0.35) dredging in future maintenance	27.3	96.2	57.7	61.0
Allowable capacity	-	110.0 (OK)	1280.0 (OK)	-

Figure 5. Typical ALP analyses for 400mm diameter spun pile (a) CH0+175 (fixed head) and (b) CH0+175 (pinned head).

and

Table 7 shows the summary of results for the analysis of a laterally loaded 400mm diameter spun pile (Class C: effective pre-stress 7.0N/mm^2) at CH0+175 and CH0+275, respectively, using a software called ALP. The advantage of using ALP in this kind of analysis is the ability of the program to facilitate the input of (i) pile head lateral restraint and also (ii) pile head rotational restraint, thus simulating realistically the anticipated tie beam (i) lateral stiffness and (ii) rotational fixity, respectively.

The tie force obtained from the finite element analysis is used as an input lateral load acting on the pile head. In order to derive a realistic value of the lateral stiffness of the tie beam, which is tied to the head of the spun pile, a parametric study is carried out by applying a unit load, P (from the tie beam) on the pile head to obtain the corresponding pile head deflection, x. The tie beam lateral stiffness, K is then calculated as P/x. An iteration process on K is then carried out so that each resulting deflection approximates closer to that of the finite element analysis result. From the calibration exercise, K value of 51,500 kN/m seems appropriate in the analyses to represent the lateral stiffness of the tie beam.

As the construction of pile cap will somewhat render the head of the spun pile to be intermediately fixed in rotation, the analyses are carried out for both extreme cases assuming a fully-fixed and a full-pinned pile head rotational condition. The actual scenario will perhaps lie somewhat in between these two extreme conditions. The pile responses simulated with a fixed and pinned head for cases CH0+175 and CH0275 are tabulated in

Figure 5. Typical ALP analyses for 400mm diameter spun pile (a) CH0+175 (fixed head) and (b) CH0+175 (pinned head).

and

Table 7, respectively. It is observed that the induced forces are all within the allowable capacity of the pile. Typical ALP analysis can be found in Figures 5(a) and (b).

Table 6. Analysed and design values of deflection and working forces for 400mm diameter spun pile @ CH0+175 (BH3) (Class C: 7N/mm^2 pre-stress).

Parameters	**Capacity**	**Fixed head**	**Pinned head**
Deflection (mm)	-	2.3	9.8
Bending moment (kNm)	67 (cracking)	28.8 (OK)	43.7 (OK)
Shear force from pile head to depth of plug (kN)	1200.0	32.0 (OK)	64.9 (OK)
Shear force along pile length (kN)	18.2	14.9 (OK)	12.4 (OK)

Table 7. Analysed and design values of deflection and working forces for 400mm diameter spun pile @ CH0+275 (BH5) (Class C: 7N/mm^2 pre-stress).

Parameters	**Capacity**	**Fixed head**	**Pinned head**
Deflection (mm)	-	2.3	9.6
Bending moment (kNm)	67 (cracking)	28.0 (OK)	43.7 (OK)
Shear force from pile head to depth of plug (kN)	1200.0	31.6 (OK)	64.9 (OK)
Shear force along pile length (kN)	18.2	14.5 (OK)	15.8 (OK)

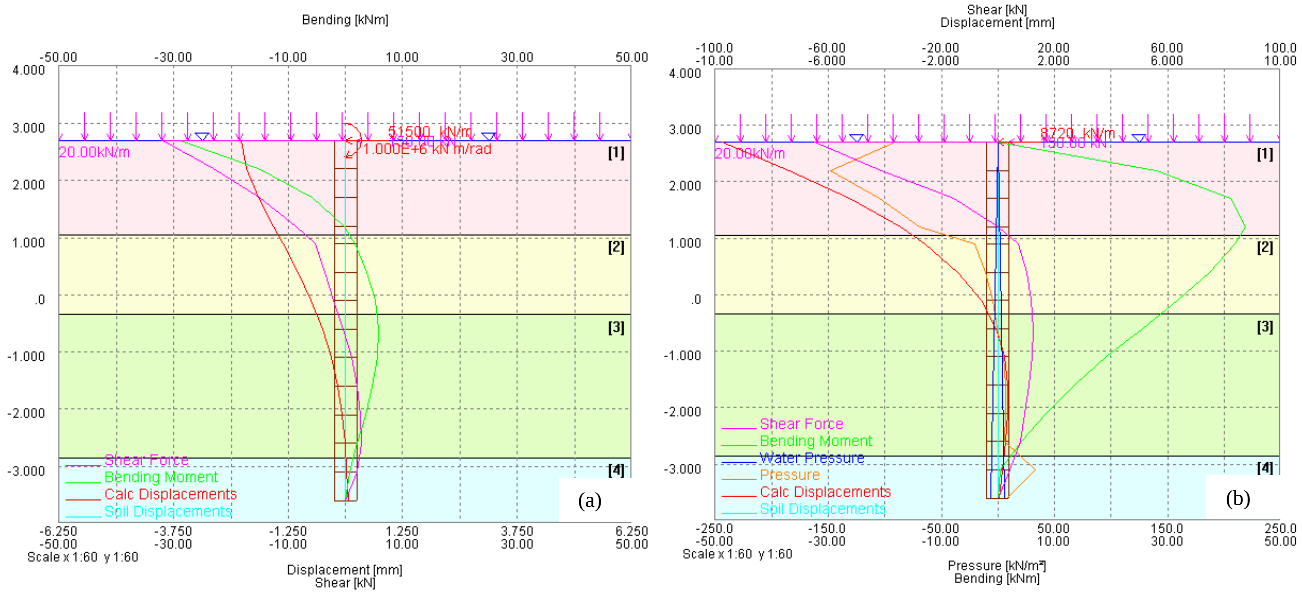


Figure 5. Typical ALP analyses for 400mm diameter spun pile (a) CH0+175 (fixed head) and (b) CH0+175 (pinned head).

Due to soil-structure interaction, shear forces will be resulted in the tie beam connecting the riverwall and the spun pile. Table 8 shows that the design shear forces are within the capacity of the starter bars provided at the pile plug length.

Table 8. Estimated shear force induced in tie beam.

Wall location	**Capacity of starter bars (8T25) at pile plug length (kN)**	**Allowable shear forces per m length (kN/m)**	**Allowable shear force (kN)**
CH0+175 (BH3)	1200	57.4 kN/m @ 2.4m	137.8 (OK)
CH0+275 (BH5)		61.0 kN/m @ 2.4m	146.4 (OK)

The estimation of geotechnical capacity of the ground to support vertical pile loading using total stress analysis has been carried out and the results are tabulated in Table 9.

Table 9. Design geotechnical pile capacities (vertical).

Parameter	**CU12 box pile (Grade 43)**	**400mm diameter spun pile (Class C: 7N/mm^2 pre-stress)**
Allowable capacity (kN)	975	400

Static load tests and high strain pile integrity (PDA) tests are used to calibrate pile penetration of at least 1m into dense sand with SPT N $\geq$ 50 to ensure proper socketing of pile tip to effectively resist lateral loads derived from the retention of backfill and existing ground. As such, it is advisable that preliminary trial driving on non-working piles (at least one each for box pile and spun pile) with PDA monitoring be carried out on site to calibrate hammer drop height and pile set criteria to prevent pile breakages and more importantly, to ensure sufficient pile socket length into the competent bearing layer as described above. Once the criteria to ensure proper pile penetration are successfully established, subsequent pile driving shall then be allowed to begin.

5.4.2 Slope stability

Table 10. Analysed factors of safety of the riverbank slopes.

Scenario	**Min. FOS**	**FOS @ CH0+175 (BH3)**	**FOS @ CH0+275 (BH5)**
Case 1: Fill on riverbank slope	1.5	1.634* 1.613^ (OK)	1.706* 1.489^ (OK)
Case 2: Riverbank slope after installation of riverwall		12.394^ (OK)	10.034^ (OK)

** finite element c'-ϕ' reduction method*
^ SLOPE/W limit equilibrium analysis

Slope stability analyses are performed to assess the stability of the earth fill slopes behind the riverwall as well as the riverbank slopes after installation of the riverwall. Table 10 shows that earth fill slopes at CH0+175 and CH0+275 graded at 1V:2H to a maximum height of about 2m yield a factor of safety (FOS) of greater than the minimum of 1.5 in undrained condition, thus acceptable. The very high FOS generated for Case 2 is due to the presence of the riverwall which intercepts potential slips from occurring, thus providing a stabilizing effect to the riverbanks. The benchmarking of slope stability analyses using GEOSTUDIE SLOPE/W and PLAXIS 2D (c'-ϕ' reduction method) can be found in Figure 6.

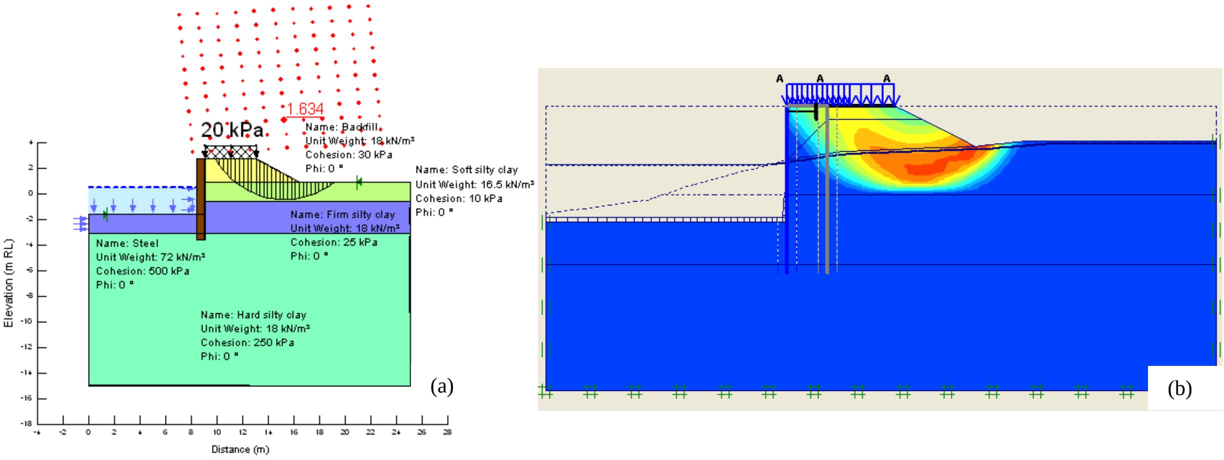


Figure 6. Benchmarking of slope stability analyses using (a) GEOSTUDIO SLOPE/W and (b) PLAXIS 2D.

5.5 *Typical design layout and cross-sections of the proposed riverwall system*

The detailed design analyses performed above are then translated into design drawings. Figures 7(a) – (c) show the plan, cross-section and front view of the proposed riverwall system.

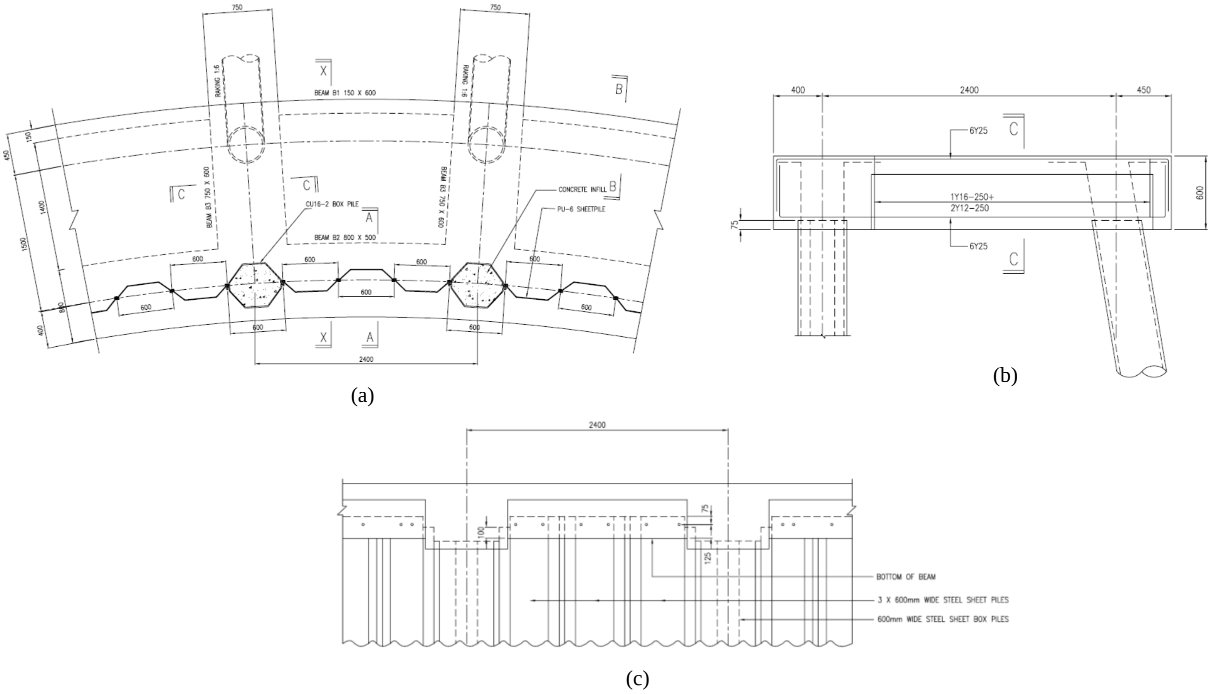


Figure 7. Typical (a) plan, (b) cross-section and (c) front elevation of the proposed riverwall system.

6 Restrictions Imposed on Contractor During Construction Stage

To ensure success of the project and to prevent circular slips from occurring on the soft riverbank slopes, the following restrictions have been enforced during construction stage:

a) Socketing of box pile and spun pile into 1.0m of SPT N≥50 material as recommended for stability of the riverwall.
b) Construction sequence proposed by Contractor shall be scrutinized in detail so as to prevent potential riverbank movement.

c) Dredging lower than the Proposed Invert Level is strictly prohibited as it would undermine the stability of the riverwall.
d) Surcharging (stacking of equipment/machineries, stockpile of fill etc) of riverbank slopes is strictly not permitted for a stretch of 25m from the riverbanks.
e) Backfilling and compaction immediately behind the newly installed box pile and sheet pile riverwall are strictly prohibited before the successful installation of tie beams and spun concrete piles.
f)Dredging is not allowed to be carried out during low tide or when river water level is below L.S.D +0.35m.

7 Construction Phase: Stage-construction was Emphasised

It is crucial that the proposed stage-construction as developed in Figures 4(a)-(g) is strictly implemented to prevent detrimental riverbank soil movements or circular slips from occurring that would threaten the structural integrity of the pile foundations of the riverwall system.

Figure 8. Good construction practices: (a) Use of overhead crane and piling equipment on barge, (b) stable berthing of barge for piling works, (c) use of long-reach concrete pump to relieve unnecessary surcharge load on the soft riverbank and (d) stage-construction of riverwall in progress (Stage 3, note that filling works was intentionally delayed from being placed under the platform until after successful completion of the tie team, which acts as a load transfer mechanism).

Figure 9. The completed riverwall in front of the Astana (official residence of the Governor of Sarawak).

The good construction practices that have been implemented in the project are highlighted as follows:

(a) Figure 8(a): Installation of steel box pile, sheet pile and spun pile from a piling rig seated on a self-propelled barge to prevent heavy machinery from over-loading the soft riverbank slopes.
(b) Figure 8(b): Berthing and anchoring of the piling barge ensures stability during piling works.
(c) Figure 8(c): Use of long-reach concrete pump for concreting works at opposite riverbank to minimise heavy machinery load and access that could over-load the soft riverbank slopes.
(d) Figure 8(d): A good example where stage-construction was emphasised i.e. filling works was intentionally delayed from being placed under the platform until all the foundation piles where tied together via the tie beam to ensure efficient resistance against any unwanted potential slope movements / circular slips that might be triggered.

Figure 9 shows the successfully completed riverwall standing majestically, lining the riverfront of the Astana (official residence of the Governor of Sarawak).

8 Some Riverwall Projects Marred by Unfortunate Failures, by Others

Figure 10. (a) Longitudinal view of 3 locations where circular slips most likely occurred that dragged parts of the concrete sheet pile riverwall system into the river, (b) close-up view showing the haphazard installation of the RC guide piles and anchorage system at grossly different lengths and angles, respectively and (c) close-up view of a major circular slip that might have taken place due to over-loading of the soft riverbank slopes by unplanned filling.

Figure 11. (a) Misaligned concrete sheet pile riverwall system and RC piles and (b) longitudinal view of a major circular slip that might have taken place due to over-loading of the soft riverbank slopes by unplanned filling.

Figures 10 and 11 show two local case studies where the proposed riverwall systems had been suspected to be undermined by riverbank slope failures. The aftermaths of such events are usually unforgiving as rectification works usually involve a lot of money and time. Even though forensic engineering on the actual causes of the failures has not been officially carried out, technical observation seems to suggest that the recommended stage-construction might not have been carefully planned and thus could have led to the formation of circular slips on the soft riverbank slopes, most likely due to rapid over-filling carried out on the soft riverbank slopes.

9 Conclusions

a) The proposed riverwall system that comprises steel box pile interlocking with sheet piles is designed as a 2.4 m section [width of C12 box pile; (approx. 0.63 m) + 3 widths of PU6 sheet piles; (0.6 m x 3)]. The presence of the spun pile forms a typical stable A-frame system to enhance the robustness of the retention system installed in challenging soft riverbank slopes.

b) Lateral loading arising from the retention of the riverbank as well as soil-structure interaction of the riverwall has been checked using a finite element code that considers the construction sequence of the proposed works. Its output includes forces induced in the combination of box pile-sheet pile wall as well as the tie beam. The shear and bending moment capacity of the combination of box pile-sheet pile wall have been checked to ensure that the design forces are within its allowable limits. The serviceability of the riverwall has also been checked for adequacy.
c) Analysis of a laterally loaded single pile is then carried out to evaluate the maximum moment and shear induced in the 400mm diameter spun pile (Class C with effective pre-stress of 7.0 N/mm^2) as a result of the lateral load transferred by the tie beam.
d) The allowable geotechnical capacity of the spun pile has also been adequately assessed. It is recommended that both box pile and spun pile be socketed at least 1.0m into the underlying SPT N≥50 materials.
e) Slope stability analyses have also been performed. The earth fill slopes and riverbank slopes after installation of the riverwall generate acceptable factors of safety.
f) With the emphasis on stage-construction and restrictions placed on the contractor during construction phase, the proposed riverwall system has been successfully constructed without any untoward incidents.

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ON THE PREDICTIVE LANDSLIDE SUSCEPTIBILITY UNDER CLIMATE CHANGE CONDITIONS

KJ Shou[1], CC Wu[1], JF Lin[1]

Department of Civil Engineering, National Chung-Hsing University 250, Kuo-Kuang Road, Taichung, Taiwan
E-mail: kjshou@dragon.nchu.edu.tw

Among the most critical issues, climatic abnormalities caused by global warming also affect Taiwan significantly for the past decade. The increasing frequency of extreme rainfall events, in which concentrated and intensive rainfalls generally cause geohazards including landslides and debris flows. The extraordinary Typhoon Morakot hit Southern Taiwan on August 8, 2009 and induced serious flooding and landslides. In this study, the Kao-Ping River watershed was adopted as the study area, and the typical events 2007 Krosa Typhoon and 2009 Morakot Typhoon were adopted to train the susceptibility model. This study employs rainfall frequency analysis together with the atmospheric general circulation model (AGCM) downscaling estimation to understand the temporal rainfall trends, distributions, and intensities in the Kao-Ping River watershed. The rainfall estimates were introduced in the landslide susceptibility model to produce the predictive landslide susceptibility for various rainfall scenarios, including abnormal climate conditions. These results can be used for hazard remediation, mitigation, and prevention plans for the Kao-Ping River watershed.

Keywords: landslide, climate change

1 Introduction

Due to the climatic abnormalities in the past decade, Taiwan has been significantly affected by the concentrated rainfall periods and high rainfall intensities. The frequency of extreme events is increasing, which subsequently increases the risk of natural hazards. With the majority of its geologically young strata fractured by the plate tectonic activities, in addition to the nature of rapid river morphological changes, it is particularly prone to landslides and debris flows during periods of torrential rain, especially in the west foothill of Taiwan Island. The Kao-Ping River watershed, one of the major watersheds prone to geohazards in southern Taiwan, was adopted as the study area (see Fig.1). Although there are studies on the landslides in this area, especially after the 2009 Morakot typhoon (Chen et al., 2011; Lin et al., 2011; Tsou et al., 2011; Shou, 2013; Lin et al., 2014), the impact of the climatic abnormalities is seldom considered in the landslide analysis, which motivates this study.

This study aimed to determine future changes in rainfall caused by climate change as a basis for the analysis of landslide susceptibility. This study used SPOT satellite images to calculate a normalized difference vegetation index (NDVI) and identified landslides in the Kao-Ping River watershed during 2007 Typhoon Krosa and 2009 Typhoon Morakot. The data of these two typhoons were used to train the susceptibility model. And the logistic regression model was compared with the instability index method before adopted for the predictive landslide susceptibility analysis.

In this study, slope angle, aspect, elevation, dip slope index (Ids), distance to the road, distance to river, distance to fault, and landslide-rainfall index(Id) were selected as the control factors. In addition, rainfall data estimated by the rainfall frequency analysis and the dynamic downscaling global circulation model were used for the predictive landslide susceptibility analyses.

2 Basics of the study area

2.1 *Geological background*

The Kao-Ping River catchment traverses two geological regions, including the alluvial plain and the Central Range of Taiwan Island (Ho, 1994). Since the Kao-Ping River flows from the northeast to the southwest and the linear structures mainly trend in the north–south direction, the Kao-Ping River crosses several sedimentary and metamorphic formations with different geological ages. Due to the vibrant tectonic activities, a series of imbricated structures (including folds and faults) were formed in the north–south direction. The major faults from the west to the east include Chaochou fault, Ailiao fault and Shiaotushan fault (see Fig. 1).

2.2 *Automatic identification of landslide*

To identify landslides, this study used SPOT satellite images to obtain NDVI data and used 5m digital terrain model (DTM) to obtain slope angle data. The two data layers, together with properly chosen threshold values, were used to identify the landslides automatically. The interpretation results from various NDVI and slope angle thresholds were compared with the landslide inventories provided by the Central Geological Survey of Taiwan. According to a preliminary comparison study (Wu, 2013), the most accurate threshold combination of NDVI=0.0 and slope=40% was adopted in this study. In addition, the influences of shadows in the satellite images were further treated before the automatic identification of landslides.

NDVI suffers from the poor spectral resolution in the shadow areas where most objects appear greyish so that the NDVI tends to 0. Therefore, the landslides detected by NDVI might be overestimated in the shadow areas (Beumier and Idrissa, 2014). Different screening indexes, including brightness (Hsieh et al., 2011), greenness (Liu et al., 2012; Lin et al., 2013), and vegetation mask (Beumier and Idrissa, 2014), were coupled with the NDVI criteria to improve the accuracy of landslide identification in shadow areas. Based on the suggestions of Lin et al. (2013) and Chen (2014), the greenness of 0.14 was adopted as the screening criterion in this study. The performance of the additional greenness criterion is shown in Table 1.

The comparison in Table 1 is based on the landslide inventories of 2007 Krosa and 2009 Morakot provided by the Central Geology Survey of Taiwan. The results in Table 1 also reveal that the accuracy is lower for 2009 Morakot, especially for the group of landslide cells. The reason could be the 2009 Morakot generated more landslides with lower slope, which cannot be totally interpreted by the criterion. The landslide identification accuracy of the total cells is reasonably good; therefore, the adopted slope-NDVI-greenness criterion can be applied in the study area in the future.

2.3 *The control factors of landslide*

To examine the correlation between the major control factors and the landslide susceptibility, this study reviewed the references of rainfall-induced landslides (Selby, 1993; Süzen and Doyuran, 2004; Hsu, 2007; Hong, 2010; Rossi et al., 2010) and adopted eight landslide control factors, that is, slope degree, aspect, dip slope index (Ids), distance from the road, water system, distance to fault, elevation, and landslide-rainfall index (Id). The data layers of those control factors were applied for the susceptibility analysis by geographic information system (GIS). Among the other common factors, for clarity, the dip slope index and the landslide-rainfall index are defined as below.

The dip slope index (Ids) is defined as the angle difference between the dip direction of weak planes (bedding planes or joints) and the dip direction of the slope, where the resulting angles are classified as a highly-dip slope (±0°-±30°), medium-dip slope (±30°-±60°), orthoclinal slope (±60°-±120°), medium-reverse slope (±120°-±150°), and highly-reverse slope (±150°- ±180°). This index can reflect the tendency of dip slope failure.

Considering the rainfall induced landslides, accumulative rainfall and rainfall intensity are all important control factors. However, they are highly correlated especially for the rainfalls of typhoons. In this study, the landslide-rainfall index (Id) was introduced to accommodate these two interdependent control factors. Fig. 2 illustrates the correlation between accumulated rainfall and rainfall intensity (we adopt maximum hourly rainfall as the rainfall intensity in this study) of the landslide locations. We can graphically obtain the upper and lower boundary linear thresholds from this graph. Such that the distances from the unknown point (to determine the landslide susceptibility with known rainfall data) to the upper and lower thresholds, i.e., the values d1 and d2, can be determined. The landslide-rainfall index (Id) is defined as

$$Id=d2/(d1+d2) \quad (1)$$

The landslide-rainfall index (Id) ranges between 0 and 1. As Id approaches 1, the slope becomes increasingly susceptible to rainfall-induced landslide. On the contrary, as the point of the rainfall of potential landslide approaches the lower threshold, or as Id approaches 0, the slope becomes less susceptible to rainfall-induced landslide.

3 Susceptibility analysis methods

3.1 *Instability Index Method*

Instability Index Method (IIM), also called Multiple Nonlinear Regression Analysis, or Dangerous Value Method, which is proposed by Jian (1992). IIM describes the unstable degree of slopes by some landslide causative factors (D). IIM has no input number limit, and any type (continuous or discontinuous) of landslide causative factors can be accepted; and this is the most advantage of IIM. The processing steps of IIM are: first, divided each factor into several ranks, and then sequentially calculated the landslide density (Gi) in grid based, the proportion of failure (Si) for every rank. The normalized grades (Di) defines as:

$$D_i = \frac{9(X_i - X_{min})}{(X_{max} - X_{min})} + 1 \quad (2)$$

in which Xmin is the minimum value of proportion of failure and Xmax is the maximum value of proportion of failure.

The weighting value wi of the i-th factor is defined as the ratio of individual variation coefficient with the sum of all factors', representing as the following formula

$$w_i = \frac{v_i}{(v_1+v_2+\cdots+v_n)} \quad (3)$$

vi represents coefficient of variation of the i-th factor In this model, we need to consider unbiasedness, so that the total weight must be equal to unity, i.e., the values of weighting
number（wi, i=1~n）are all less than 1, their sum equals 1.

After we get the landslide susceptibility index P (P□(0,1)), a normalized value of the total instability index number Dtotal, which includes the influence of all control factors. The instability index IP is defined in terms of weighting values wi (i=1~n) and grading values Di (i=1~n) of all control factors as

$$I_p = \log(D_{total}) = \log\left(D_1^{w1} \times D_2^{w2} \times \ldots \times D_n^{wn}\right) \quad (4)$$

It is worth noting that the value of Dtotal is between 1 and 10 and the value of P is between 0 and 1. The higher the values of Dtotal and P, the higher the landslide susceptibility. It is an index for the probability of landslide, i.e., the potential of landslide hazards.

3.2 *Logistic Regression Method*

In this study, the method of logistic regression (LRM) was adopted to analyze the landslide susceptibility. Based on the training samples, which comprised a group of data points or data locations, categorized as landslide and non-landslide. The data layer of each factor was then placed upon the landslide and non-landslide layers, and the correlation between each factor and landslides was used to conduct binary logistic regression (Atkinson and Massari, 1998; Süzen and Doyuran, 2004; Lee et al., 2008; Mathew et al., 2009; Rossi et al., 2010; Akgun, 2012; Lee, 2012; Devkota, 2013.).

The logistic regression model is a form of the logarithmic linear model where the dependent variable is binary. This model can be expressed as

$$ln\left[\frac{P_i}{1-P_i}\right] = \alpha + \sum_{i=1}^{k} \beta_k x_{ki} \quad (5)$$

where Pi=P (yi=1| x1i, x2i, …xki) and represents the probability of an event occurring when a series of given independent variables are equal to x1i, x2i, …xki, and α and βk are the constants. In the landslide susceptibility analysis, the probability Pi=1 for the landslide points, and the probability Pi=0 for the non-landslide points. Coefficients α, βk can be obtained following the regression of training data.

This study employed the receiver operating characteristic (ROC) curve (Swets, 1988) and the success rate (SR) curve (Chung and Fabbri, 2003) to verify the model. The area under the curve (AUC) of the ROC curve or the SR curve can be used to evaluate the prediction accuracy of a susceptibility model. Generally, the larger the AUC values the better. As the area approaches 0.5, the result may not necessarily be superior to that of a random selection. AUC values of less than 0.5 are not worth employing.

4 Rainfall estimation

This study used the method of Kriging to estimate the spatial distributions of rainfalls. The estimation of rainfalls primarily emploies (1) historical data and rainfall frequency analysis and (2) the climate change model estimates.

4.1 *Rainfall frequency analysis*

The rainfall data from the 7 weather monitoring stations of the Central Weather Bureau in the Kuo-Ping River watershed was collected for the rainfall analysis and prediction (see Fig. 1). The K-S (Kolmogorov–Smirnovest) test was employed to eliminate unsuitable distributions, and the standard error was used to select the optimal rainfall distribution for each station.

According to the studies of Hong (2010) and Shou (2011) on the rainfall frequency in Taiwan area, the Hazen method (Kadoya, 1992; Hosking and Wallis, 1997; Castellarina et al., 2009; El Adlouni and Ouarda, 2010) was adopted for the return period frequency analysis. The obtained frequency analysis model was used to predict the rainfall (maximum hourly rainfall, accumulative annual precipitation, and 24-, 48-, and 72-hour accumulative rainfall) in the Kao-Ping River watershed for the return periods of 10, 20, and 100 years.

The results of the rainfall frequency analysis for each station, i.e., the rainfall values for different return periods, were interpolated using the Geostatistical Analyst Kriging function of the GIS. We can determine the spatial distributions of rainfall intensity and accumulative rainfall for various return periods in the Kao-Ping River watershed (see Figs. 3~5).

4.2 *The climate change models for rainfall estimates*

The Taiwan Climate Change Projection and Information Platform Project (TCCIP), analyzes the results from the assessment reports of the United Nations Intergovernmental Panel on Climate Change (IPCC), intended to assess the information concerning climate change, including the scientific and socio-economic information, its potential effects of, and the options for management and mitigation (IPCC, 2013; TCCIP, 2013). TCCIP applied the method of statistical downscaling to 24 Global Climate Models (GCMs) from the IPCC assessment report to obtain regionally downscaled results for Taiwan. The predictive rainfall data in this study was provided by the TCCIP, which uses the high-resolution climate simulation of MRI-JMA AGCM (Matsueda et al., 2009) as the initial and boundary conditions for the dynamical downscaling to produce 5-km high-resolution climate simulations of the near future (2015-2039) and the far future (2075-2099).

MRI-JMA AGCM was developed based on the numerical model used by the Japan Meteorological Agency for weather forecasts. With a horizontal resolution of approximately 20 km, the MRI-JMA AGCM is a super high-resolution global model (Matsueda et al., 2009). The model simulates climate estimates for three time periods, i.e., the present (1979-2003), the near future (2015-2039), and the far future (2075-2099). For the future emission consideration of the IPCC data, this study adopted the Scenarios A1B which emphasizes economic growth and a convergence of global socioeconomic conditions (IPCC, 2013). The ocean-atmosphere general circulation modeling with A1B scerinio suggests that sea-surface temperatures (SST) exhibit a linearly increasing trend. The variation of present SST was added to the linearly increasing SST for the AGCM estimation.

The estimation of MRI-JMA AGCM (Matsueda et al., 2009) was used as the initial and boundary conditions for the dynamic downscaling. The regional model adopted to execute dynamic downscaling was the Weather Research and Forecasting (WRF) modeling system developed by the National Center for Atmospheric Research (NCAR). By the coupled MRI- AGCM dynamic downscaling approach, we can estimate the seasonal rainfall changes in Taiwan at the end of the twenty-first century (TCCIP, 2013). Based on the MRI-WRF dynamical downscaling data provided by TCCIP, we can estimate the future distributions of rainfalls with the consideration of climate change. Kriging interpolation was conducted on the data of the thirty five 5km*5km domains within the Kao-Ping River watershed to estimate the distribution of accumulative rainfall and rainfall intensity of the future (see Figs. 6 and 7).

5 Results

Considering the comparison basis and future applicability of landslide susceptibility model, this study adopted landslide interpreted by the same slope-NDVI-greenness criterion for 2007 Krosa and 2009 Morakot. Based on the obtained databases and the methodologies described in the previous sections, the landslide susceptibility analysis was performed. The data layers of the control factors based on the collected geology, topography, and rainfall data were generated and illustrated in Fig. 8.

5.1 *Landslide susceptibility analysis*

After normalizing the values of control factors of the landslide groups, we can obtain the data layers for the logistic regression analysis, which can be performed by the SPSS software.

The results of the instability index analysis can be expressed as below:

$$I_P = F_1^{0.101} \times F_2^{0.115} \times F_3^{0.081} \times F_4^{0.156} \times F_5^{0.098} \times F_6^{0.255} \times F_7^{0.118} \times F_8^{0.078} \qquad (6)$$

for 2001 Krosa typhoon, and

$$I_P = F_1^{0.115} \times F_2^{0.095} \times F_3^{0.064} \times F_4^{0.152} \times F_5^{0.127} \times F_6^{0.250} \times F_7^{0.099} \times F_8^{0.099} \qquad (7)$$

for 2009 Morakot typhoon, where IP is the instability index, F1 is the slope angle, F2 is the elevation, F3 is the aspect, F4 is the distance to fault, F5 is the distance to river, F6 is the distance to road, F7 is the dip slope index (Ids), and F8 is the landslide-rainfall index (Id). The landslide susceptibility maps induced by Krosa and Morakot using Equations (6) and (7) are shown in Fig. 9.

The results of logistic regression analysis can be expressed as below:

$$= \ln\left[\frac{P}{1-P}\right] 371F2-0.361F3-0.318F4-0.438F5+0.363F6-0.206F7+0.477F8- 0.096 \quad (8)$$

for 2001 Krosa typhoon, and

$$= \ln\left[\frac{P}{1-P}\right] 107F2-0.242F3-0.106F4-0.500F5+0.217F6-0.197F7+0.240F8-0.077 \quad (9)$$

for 2009 Morakot typhoon. In which P is the logistic function, F1~F8 are the same control factors defined previously. The landslide susceptibility maps induced by Krosa and Morakot using Equations (8) and (9) are shown in Fig. 10.
Figs. 9 and 10 reveal that a larger area with high landslide susceptibility during Morakot than during Krosa, indicates that Typhoon Morakot generated more severe landslides in the Kao- Ping River watershed. The landslide susceptibility models were verified using the AUC values of the ROC curves. The results in Figs. 11 and 12 show that the AUC values of the instability index method are 0.655 for 2007 Krosa and 0.620 for 2009 Morakot, and the AUC values of the logistic regression method is 0.680 for 2007 Krosa and 0.672 for 2009 Morakot. For both typhoon events, the logistic regression method can obtain higher AUC values. Although the results suggest that the logistic regression susceptibility models with Eqs. (8) and (9) are all reasonable and acceptable, the model with higher AUC value, i.e. the Eq.(8) of 2007 Krosa was adopted for the predictive landslide analyses.

5.2 *Landslide susceptibility predictions*

Introducing the results of rainfall frequency analysis (Figs. 3 and 4) into the landslide susceptibility model, 9 rainfall scenarios (24-, 48-, and 72-hour with return periods of 10, 20, and 100 years) can be analyzed. It should be noted that, due to the length limitation of the paper, only the major landslide susceptibility maps with the predicted rainfall scenarios were included. The major landslide susceptibility distributions for various return periods are shown

in Figs. 13 and 14. The results in Figs. 13 and 14 show that the longer the rainfall the more the landslide susceptibility, and the longer the return period the more the landslide susceptibility. In other words, the area with higher landslide susceptibility will increase if the rainfall is longer or the return period is longer.
The rainfalls predicted by the climate change dynamic downscaling method (Figs. 6 and 7) can also be introduced to the landslide susceptibility model. It can help to identify the potential landslide hazards in the near future (2015-2039) and in the far future (2075-2099). The results in Figs. 16 and 17 suggest that the landslide susceptibility is higher in the far future (2075-2099) than in the near future (2015-2039). And the high landslide susceptibility area increases significantly in the up-stream area, i.e., the southeast side of the watershed.

6 Conclusions and suggestions

In this study, focusing on the Kao-Ping watershed, predictive analyses of landslide susceptibility were performed with the consideration of climate change. Based on the training with the data of 2007 Krosa and 2009 Morakot, the logistic regression landslide susceptibility model was developed. The AUC of the model is in the level of 0.65~0.70, which indicates its applicability for identify potential landslides.

The susceptibility maps calculated by the susceptibility model all showed that the mid- upstream and up-stream areas of the Kao-Ping River were highly susceptible to landslides. The predictive susceptibility analyses suggest that the new high landslide susceptibility areas are mainly distributed in the upstreams, including the south side and the southeast side of the watershed. The southeast side of the watershed is more critical because the analysis results of the far future also reveal the same finding.

The prediction capability of the susceptibility model is influenced by the weight of landslide- inducing factors, the limit of these factors (e.g. Id has a maximum value of 1), and rainfall distributions. Therefore, the model's prediction ability is limited. More modification of the susceptibility based on more training data is essential to improve the accuracy. This study used rainfall frequency analysis and AGCM to estimate rainfall and predict future rainfall trends and intensity under climate change conditions. Rainfall frequency analysis with more data and a better AGCM can help to obtain a better rainfall estimation to more accurately predict the landslide susceptibility. The slope-NDVI-greenness criterion can identify landslides with an acceptable accuracy, however, the interpretation accuracy of landslide cells is still improvable, especially for the extreme events. More effort is suggested for a better landslide interpretation accuracy (Martha et al., 2010).

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Table 1. The accuracy of landslide interpretation by the slope-NDVI-greenness criterion.

Event				f A1+A2+
2007 Kro				
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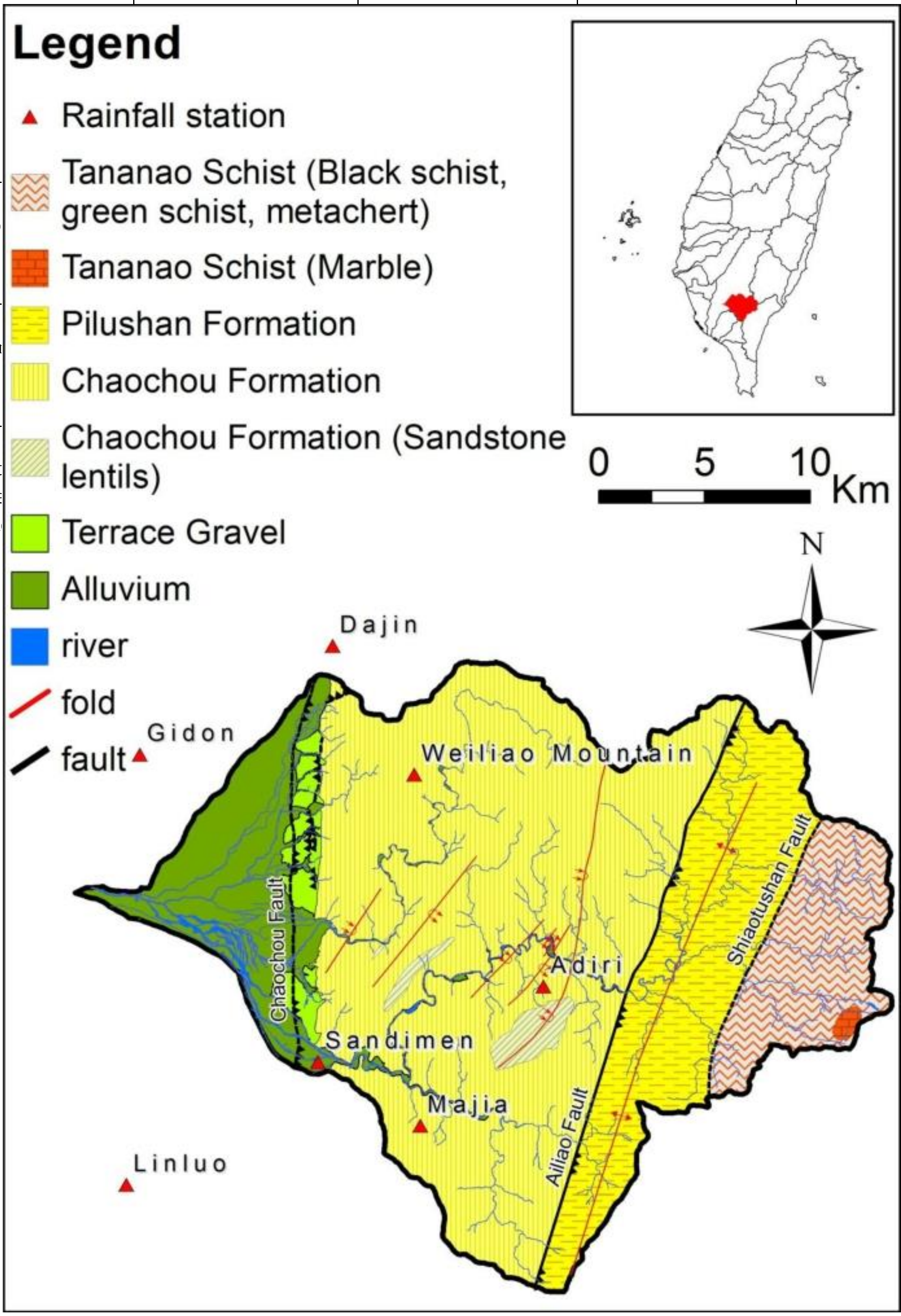
*A1 is t … reted as landslide … ide cells interpret…



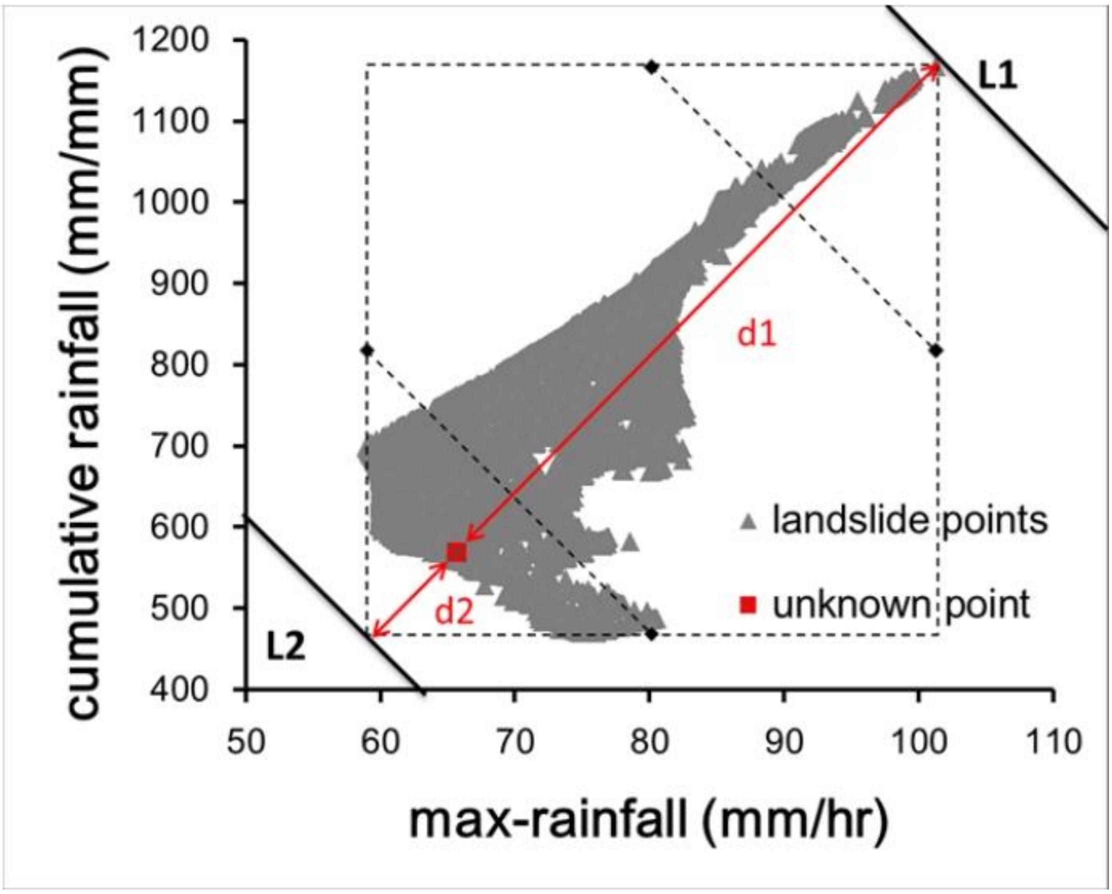
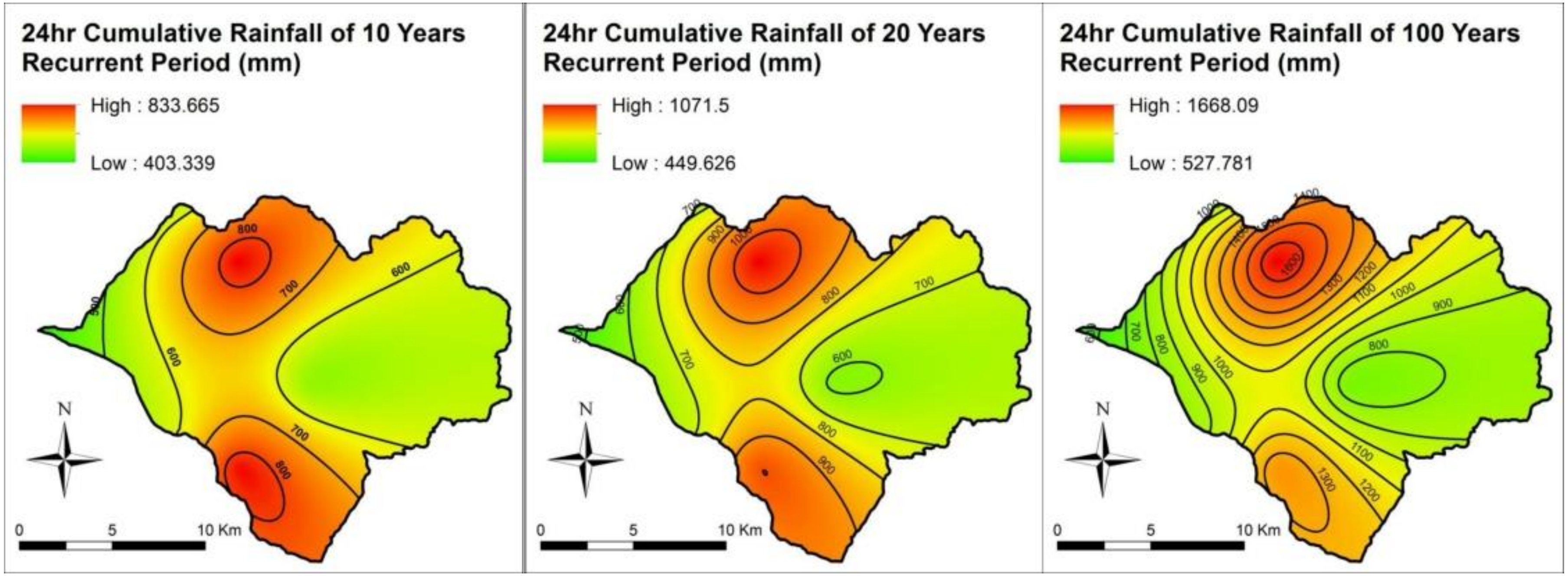


Figure 1. The rainfall stations and the geology of the Kao-Ping River watershed.

Figure 2. The illustration of the landslide-rainfall index (Id), defined by the distances d1 and d2 from the unknown point to the upper and lower linear thresholds as d1/(d1+d2).



(a)10 year return period (b)20 year return period (c)100 year return period

Figure 3. The spatial distributions of 24-hour accumulative rainfall for various return periods in the Kao-Ping River watershed.

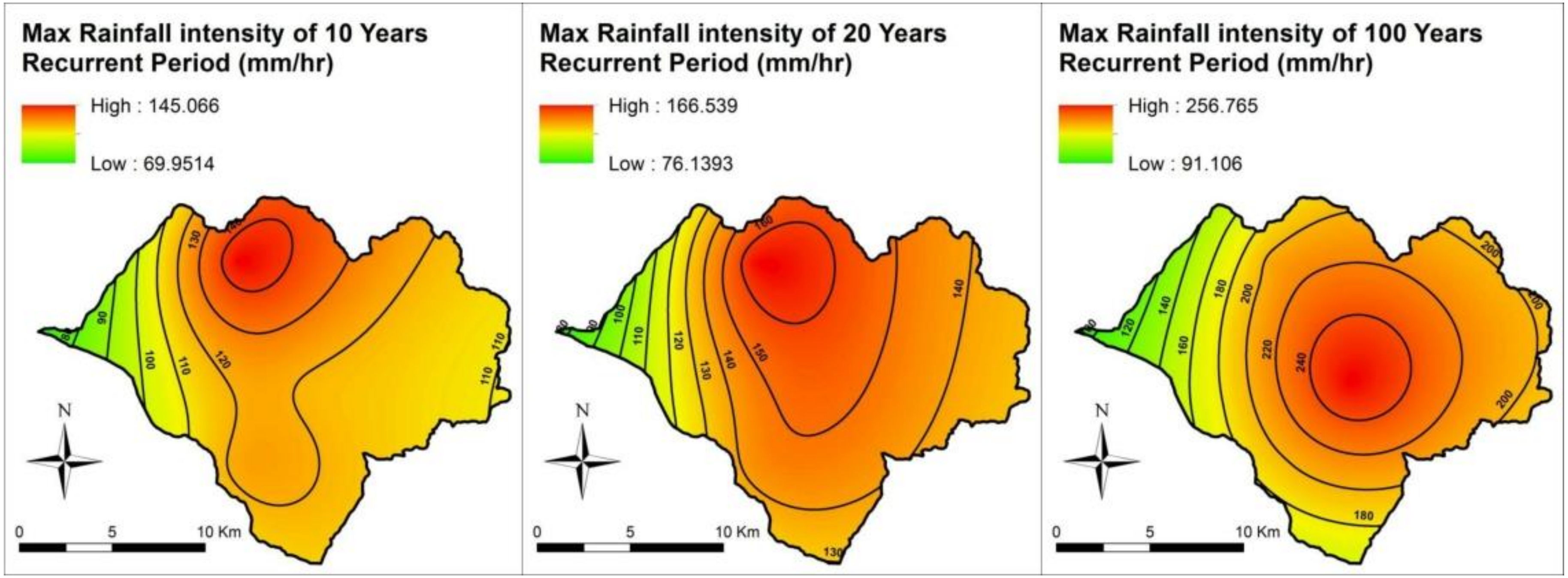
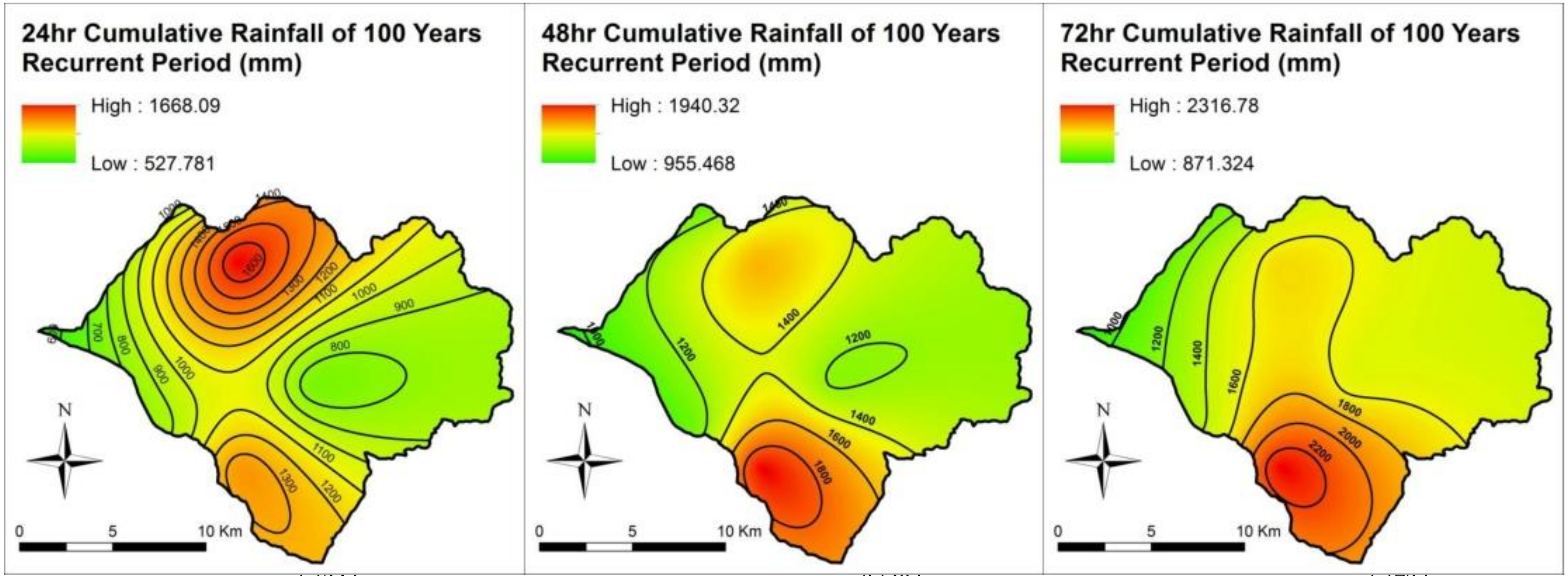


Figure 4. The spatial distributions of the maximum rainfall intensity for various return periods in the Kao-Ping River watershed.



(a)24 hour (b)48 hour (c)72 hour

Figure 5. The spatial distributions of accumulative rainfall for various rain periods (with the same recurrent period of 100 years) in the Kao- Ping River watershed.

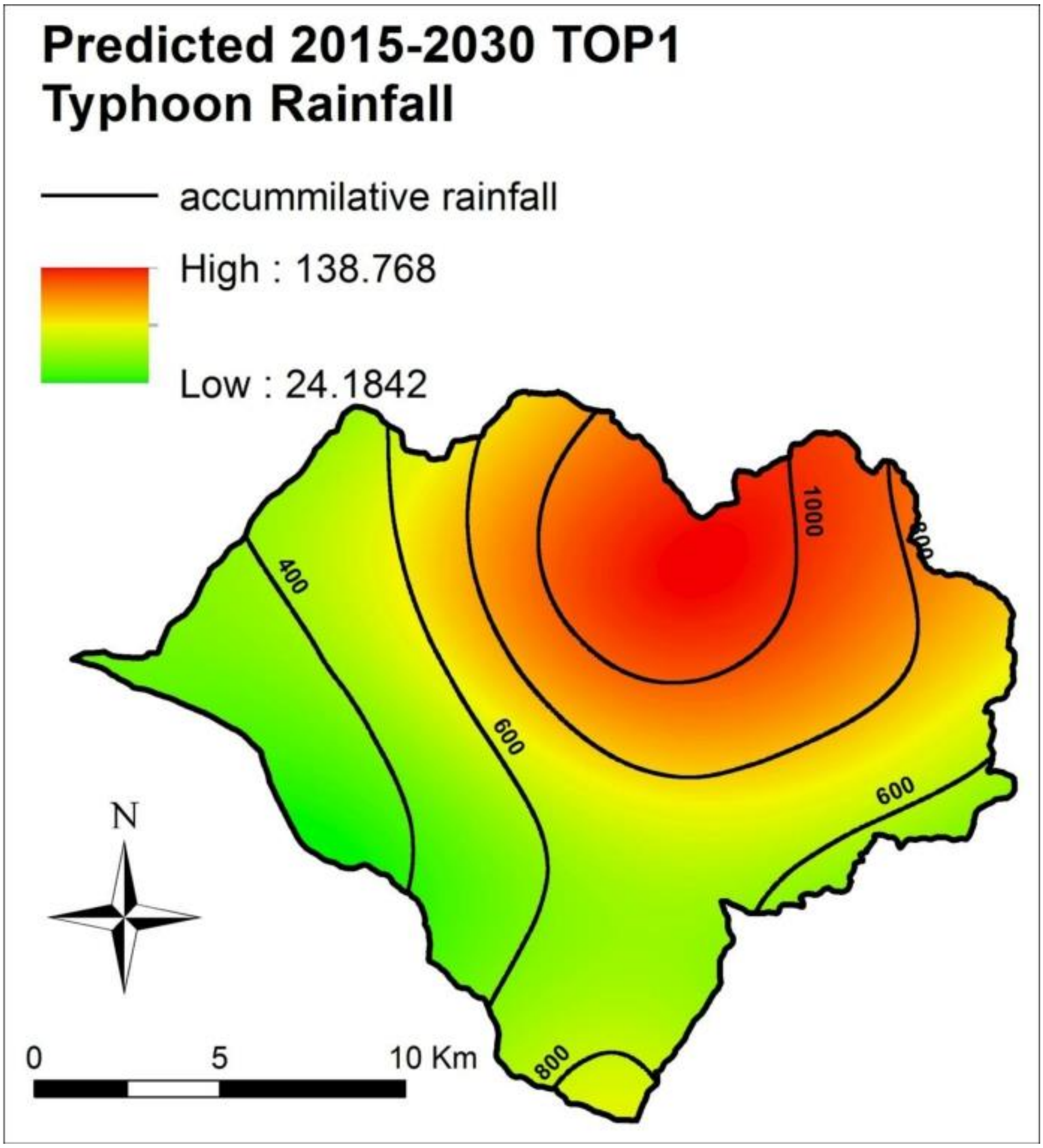


Figure 6. The predicted rainfall distributions in the Kao-Ping River watershed for the near future (2015~2039), based on the MRI-WRF dynamical downscaling data provided by TCCIP.

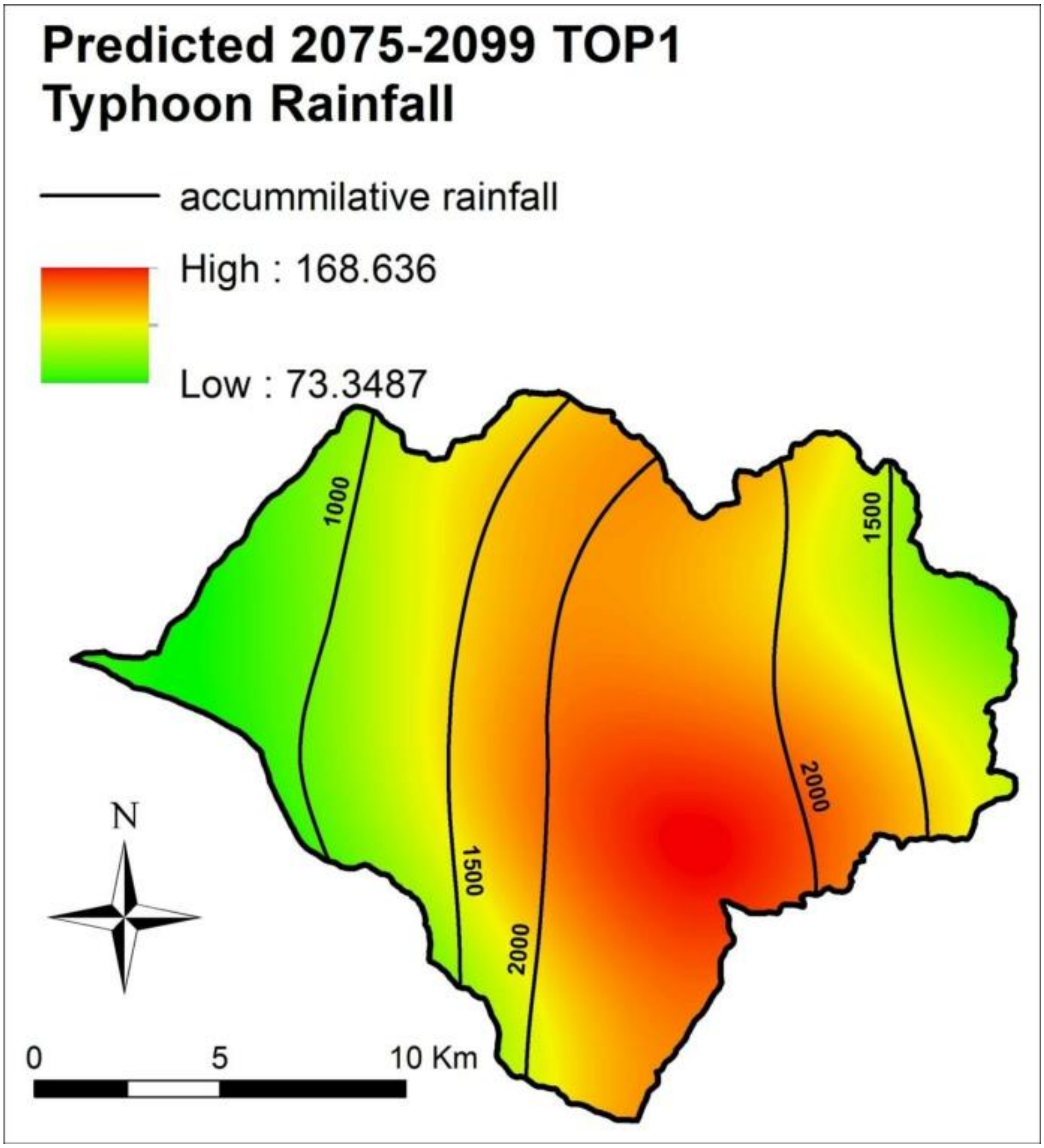
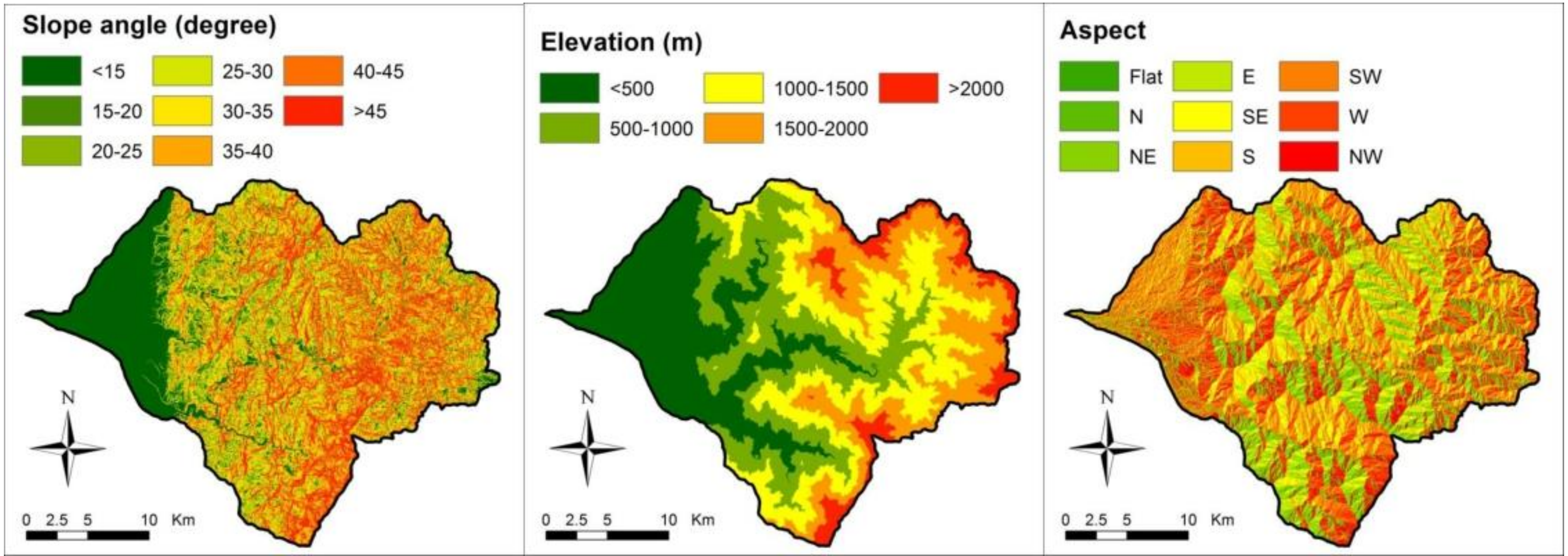
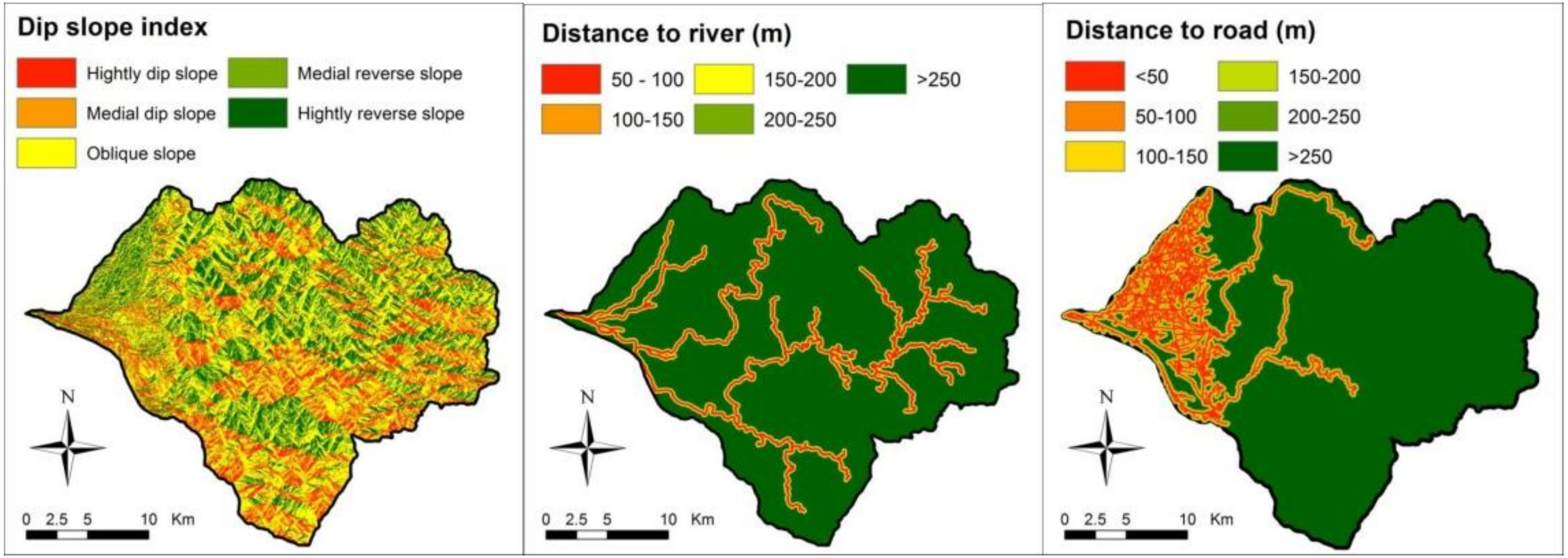


Figure 7. The predicted rainfall distributions in the Kao-Ping River watershed for the far future (2075~2099), based on the MRI-WRF dynamical downscaling data provided by TCCIP.



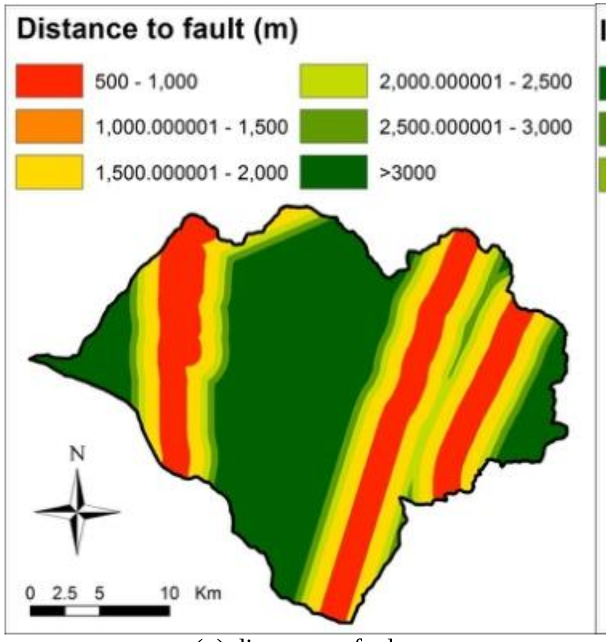
(a) slope angle (b) aspect (c) elevation

Figure 8. The data layers of the selected control factors in the Kao-Ping River watershed.

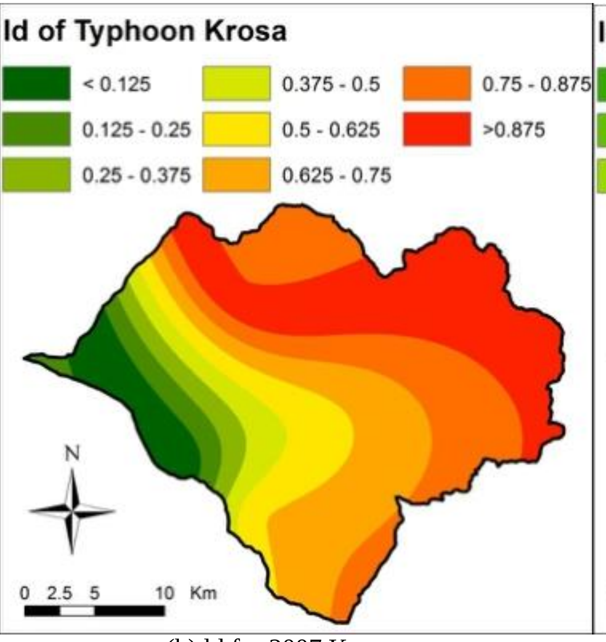


(d) dip slope index (Ids) (e) distance to river (f) distance to road

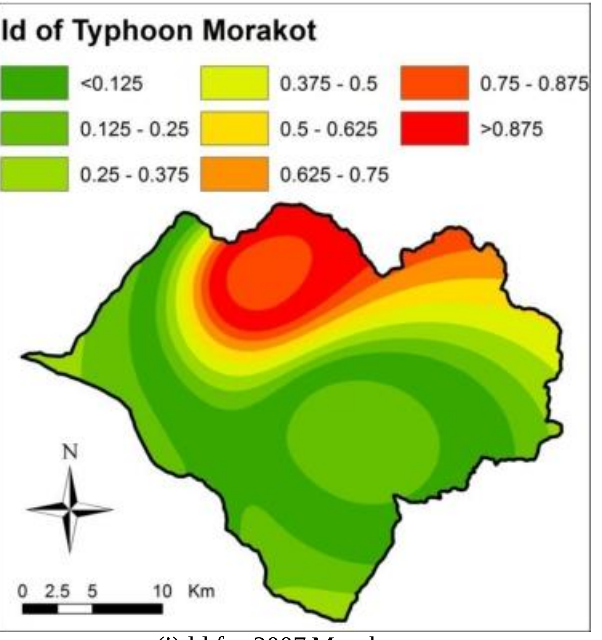
Figure 8. The data layers of the selected control factors in the Kao-Ping River watershed (continued).



(g) distance to fault



(h) ld for 2007 Krosa



(i) ld for 2007 Morakot

Figure 8. The data layers of the selected control factors in the Kao-Ping River watershed (continued).

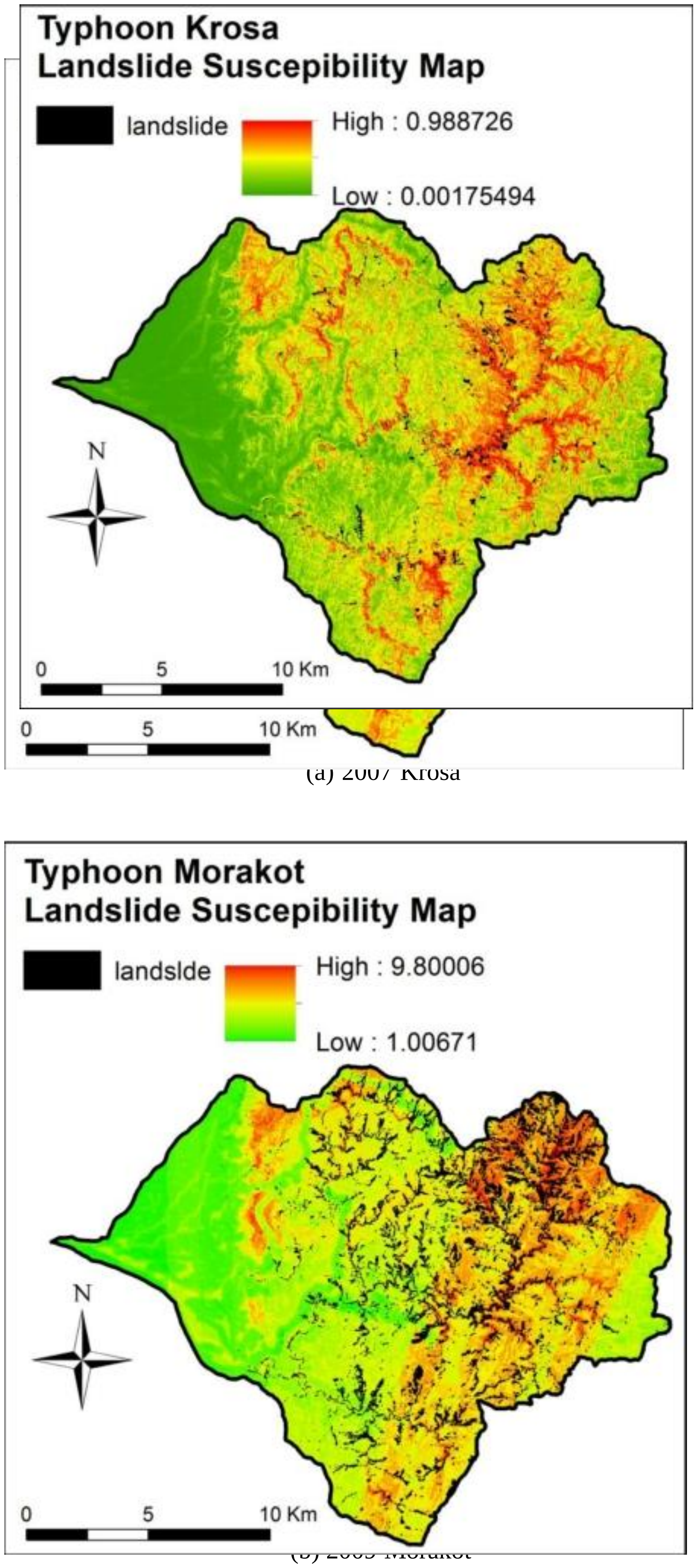


Figure 9. The landslide susceptibility maps obtained by the Instability Index method for 2007 Krosa Typhoon and 2009 Morakot Typhoon.

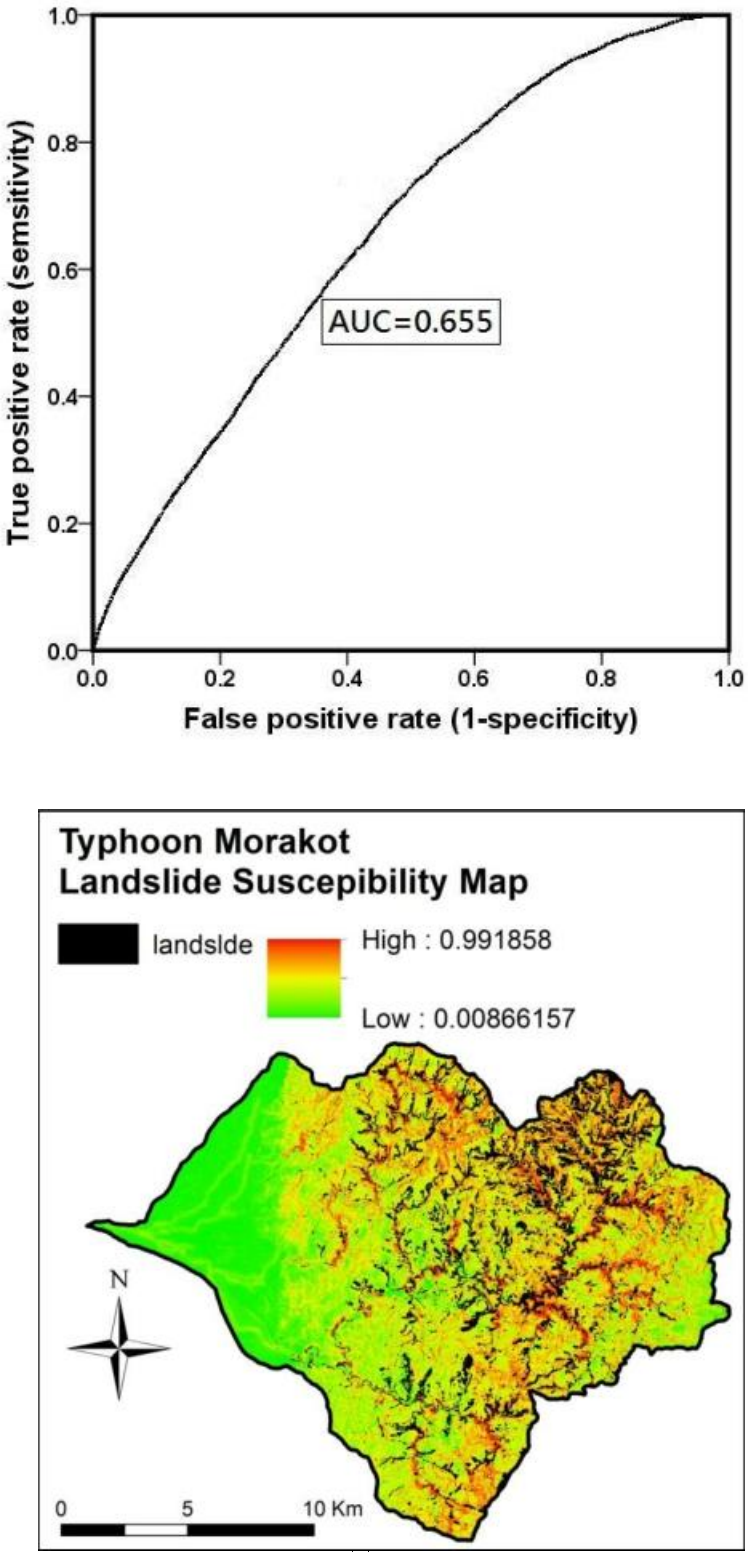
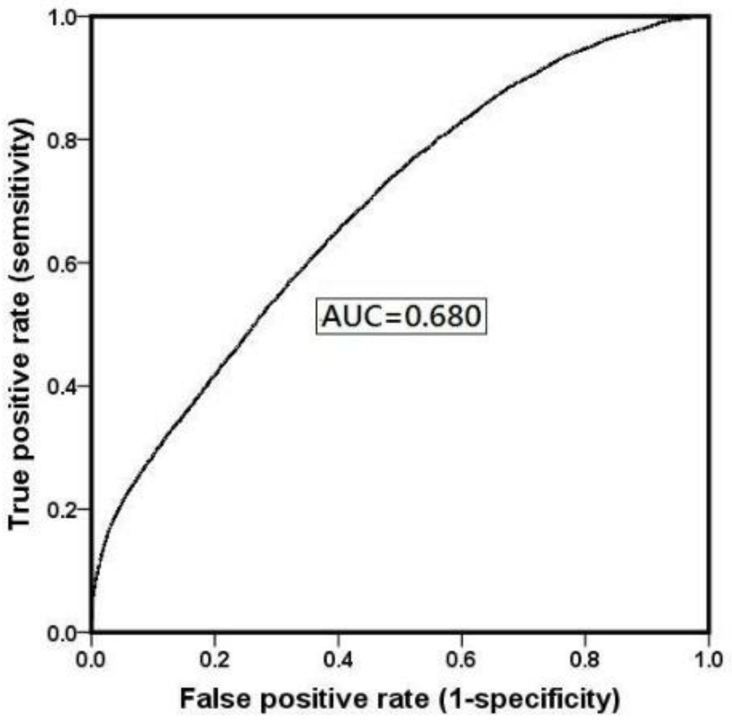


Figure 10. The landslide susceptibility maps obtained by the Logistic Regression analysis of 2007 Krosa Typhoon and 2009 Morakot Typhoon.



(a) 2007 Krosa

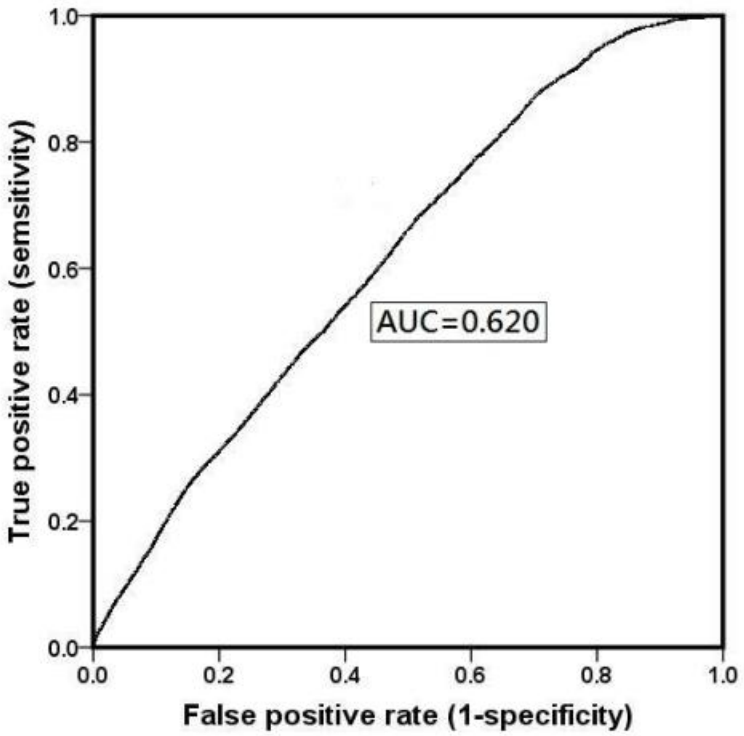


Figure 11. The ROC curves of the landslide susceptibility results by Instability Index method for 2007 Krosa Typhoon and 2007 Morakot Typhoon.

(a) 2007 Krosa

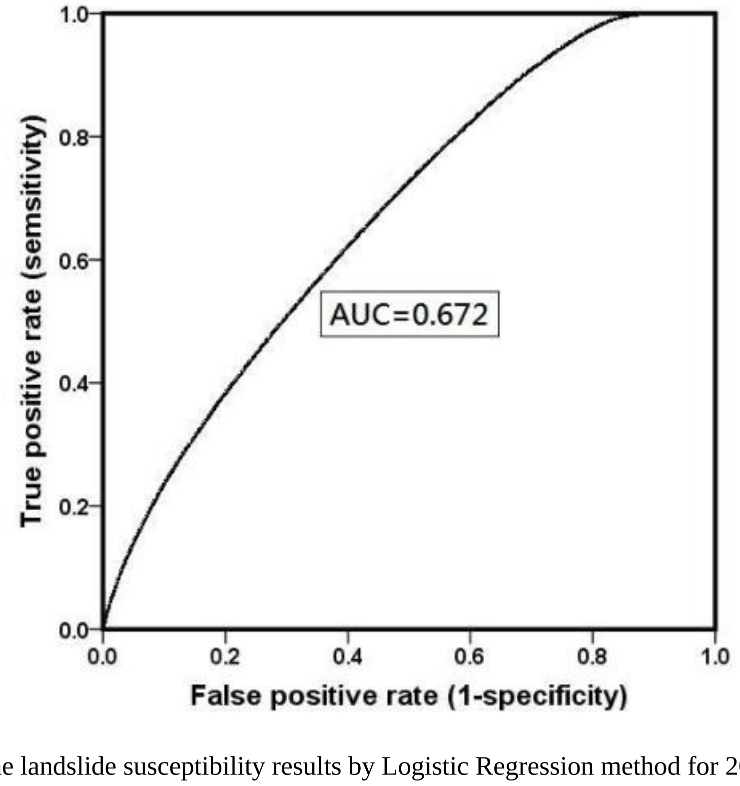
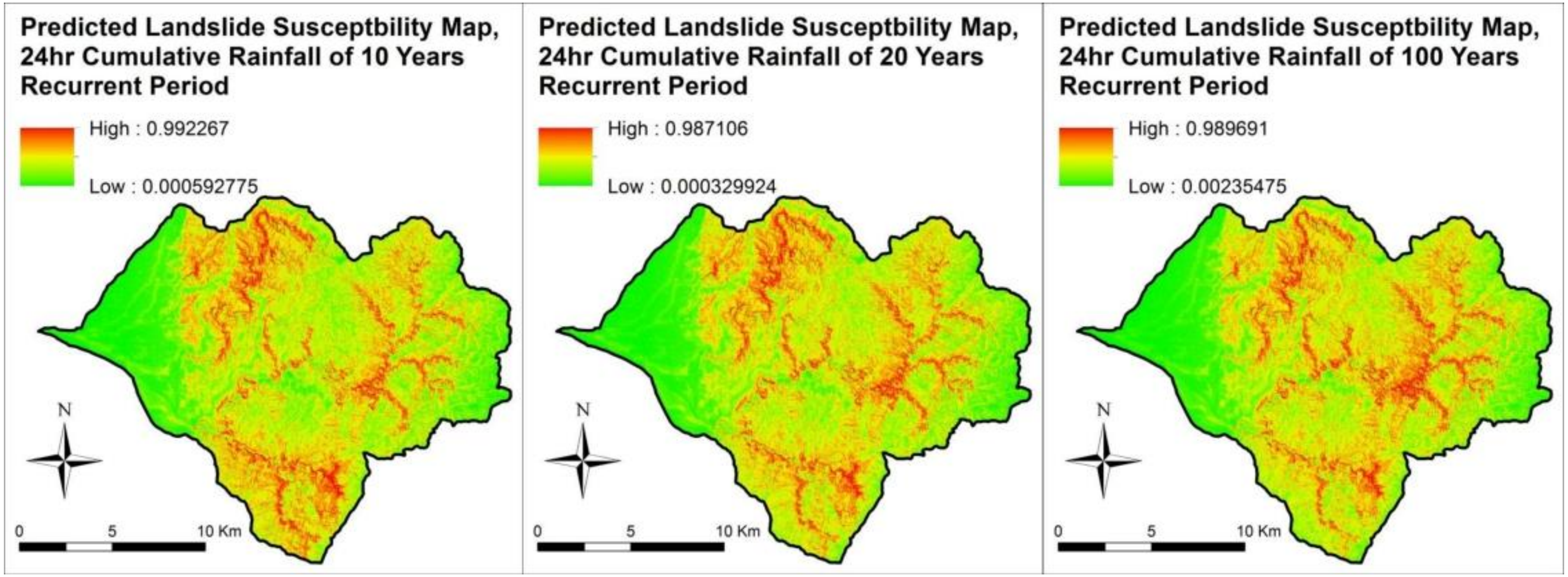


Figure 12. The ROC curves of the landslide susceptibility results by Logistic Regression method for 2007 Krosa Typhoon and 2007 Morakot Typhoo



(a)10 year return period (b)20 year return period (c)100 year return period

Figure 13. The spatial distributions of landslide susceptibility with 24-hour accumulative rainfall and rainfall intensity for various return periods in the Kao-Ping River watershed.

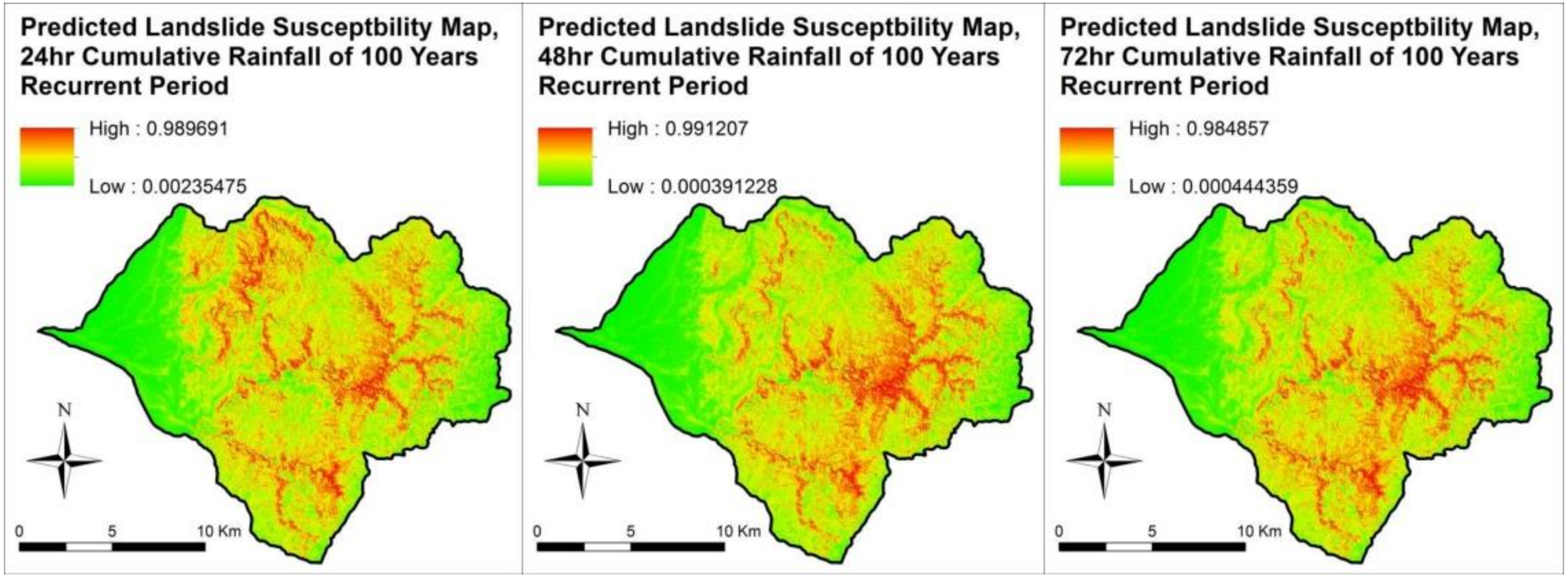
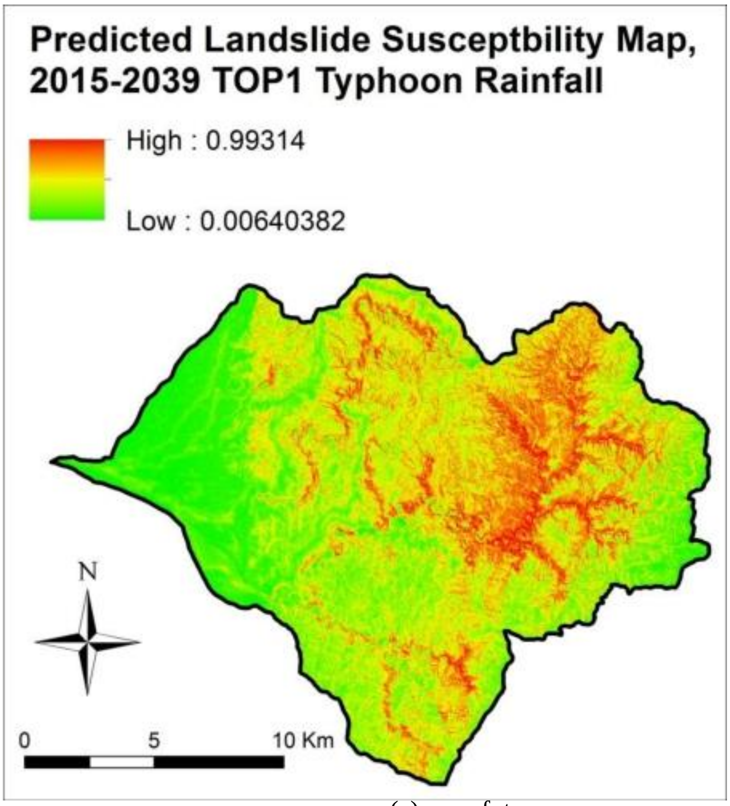
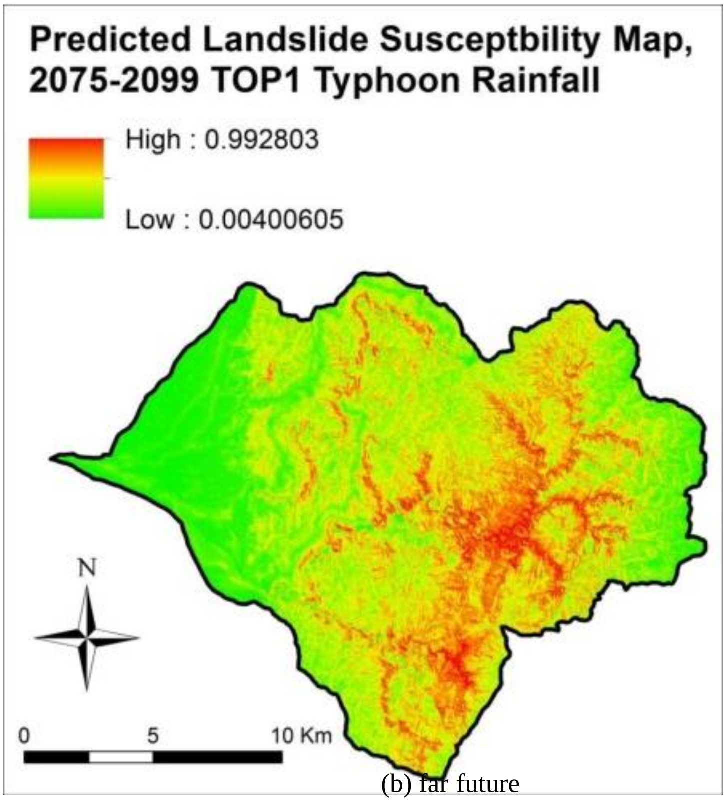


Figure 14. The spatial distributions of landslide susceptibility with 100 year return period for various rainfall periods in the Kao-Ping River watershed.



(a) near future



(b) far future

Figure 15. The spatial distributions of predicted landslide susceptibility for the near future (2015~2039) and the far future (2075~2099) in the Kao-Ping River watershed.

Climate Change and its Implications on Coastal Structures

KEK-KIONG YIN[1] , TERENCE LEUNG[2] and ANDER CHOW[3]

[1]Ove Arup and Partners, Hong Kong Limited, 80 Tat Chee Avenue, Kowloon Tong, Hong Kong.
E-mail: Kek-kiong.yin@arup.com
[2]Ove Arup and Partners, Hong Kong Limited, 80 Tat Chee Avenue, Kowloon Tong, Hong Kong.
E-mail: Terence.Leung@arup.com
[3]Ove Arup and Partners, Hong Kong Limited, 80 Tat Chee Avenue, Kowloon Tong, Hong Kong.
E-mail: Ander.Chow@arup.com

Climate Change refers to any change in climate over time, whether due to natural variability or as a result of human activity. Whether climate change refers to a change of climate that is attributed directly or indirectly to human activity; or natural climate variability; the impact it has on existing structures should not be neglected. Dealing with climate change is no longer a scientific subject, the engineering world has embraced the principle of sustainable development which highlighted the complexity of climate change

Coastline are high-energy, dynamic environment with spatial variations occurring over a wide range of temporal scales. The shoreline is part of the coastal interface which is exposed to a wide range of erosional processes arising from fluvial, aeolian and terrestrial Given the natural forces to which seawalls are constantly subjected, maintenance/replacement is an ongoing requirement if they are to provide an effective long-term solution. Hitherto, existing code of practices, though aptly considered the design resilience including durability, have not considered the impacts resulting from climatic changes

With the observed data recorded by the Hong Kong Observatory, it is prudent for the government of the day to assess the impact of the rising trend due to climate change on its coastal structures. This paper sets out a case study on an on-going project - The Hong Kong-Zhuhai-Macau Bridge Hong Kong Boundary Crossing Facilities (HKBCF) Reclamation, and its implication due to climate change for a given design criteria of the day.

Keywords: Climate Change, Sea Level Rise, Coastal Structures, Hong Kong Boundary Crossing Facilities

1 Introduction

Hong Kong will probably be subject to more extreme weather conditions due to climate change, based on the studies by the Intergovernmental Panel on Climate Change (IPCC) and analysis of tide level measurements by the Hong Kong Observatory. This was demonstrated when Typhoon Hagupit attacked Hong Kong in September 2008, when serious damage, erosion and coastal flooding occurred at various locations in Hong Kong. Sea level rise and increase in storminess are effected from the climate change, and these effects when combined with the effects of typhoon will likely aggravate the damage to the nearshore areas, in particular the low-lying areas. Historically nearshore areas are the centres of human activities and dwelling due to their proximity to the sea and the availability of waterborne transport for trading and business. Development at nearshore areas are however limited by the availability of land. To sustain the development and support the increase in population and associated economic activities, the sea is reclaimed to provide more land for all kinds of developments. A 150-hectare artificial island is being reclaimed from the open waters off the northeast of the Hong Kong International Airport for the development of the Hong Kong-Zhuhai-Macau Bridge (HZMB) Hong Kong Boundary Crossing Facilities (HKBCF). This island will be the immigration control point for visitors from Macau/Zhuhai to Hong Kong.

There is a price for the proximity to the sea; there could be potential flooding when sea water roses and/or surged into the land. Property could be at stake when wave hit the shore, and overtopped into the land. Structures at the shore could be damaged by wave actions, where wave energy was released when it hit the structures. With the climate change effects more pronounced, coastal structures are more vulnerable to the attack by the sea, and the nearshore facilities could be damaged resulting in economic loss and fatality. This paper will present the design of the seawall structures of HKBCF for the effects of climate change.

2 Climate Change

2.1 *General*

The IPCC represents the largest scientific intergovernmental body who has collectively an interest in the climate change and actively evidences the existence of climate change. The IPCC reviews researches on the origin and trend of climate change, and formulates a set of scientific and administrative guidelines for the governmental bodies to enforce in their own countries of various emission-free and reduction initiatives and collaborate amongst themselves for the benefit of the global community to combat the damage that could be bought by climate change. IPCC issued the First Assessment Report in year 1990, and the Second, Third and Fourth Assessments were released in year 1995, 2001 and 2007 respectively. The latest assessment is the Fifth Assessment Report issued in 2014.

Climate change is believed to be resulted in increase in global temperature that brings other atmospheric and meterological changes including change in rainfall pattern, increase in sea water temperature, melting of ice sheets and glaciers, change in atmospheric pressures and associated wind fields. The effects of sea water temperature increase, melting of ice sheets and glaciers contribute to the phenomenon commonly known as “sea level rise”.

Due to the increase in atmospheric temperature, the surface temperature of the ocean increases and such increase propagates to deeper regions of the sea. When ocean water temperature increases, the ocean heat content increases and the ocean water expands physically that result in elevation of sea level. Another major mechanism contributing to sea level rise is the melting of ice sheets and glaciers. Ice mass stores a significant mass of freshwater in the globe. This “solid” water or glacier is formed when water evaporates from the ocean and precipitates onto the ice sheets to form the glacial ice. The exchange of water from evaporation and precipitation, and melting of ice sheets continues for centuries and centuries. The unbalanced exchange results in either increase or drop of water surface. Gravimetry measurements from satellites indicate clearly that the extents of Greenland and the Antarctic are retreating meaning that melting is evident.

Projects of climate changes are made using a set of climate models ranging from simple climate models to comprehensive climate models and Earth System Models. The complex process of exchange of heat between the atmosphere and the ocean is modelling in the Atmosphere-Ocean General Circulation Models (AOGCMs). The model consists of two components. Its atmospheric component embraces a handful of evolving atmospheric variables such as temperature, pressure, humidity and winds; their behavior are governed by laws of thermodynamics, fluid dynamics and expressions describing an ideal gas. The absorption and emission of solar radiation and infrared radiation by atmospheric particles, i.e. radiative transfer processes, are also modelled. Variables are usually defined in a spatial grid, horizontal resolution of the Atmospheric General Circulation Models (AGCMs) ranges from a hundred to several hundred kilometres for different models. In Ocean General Circulation Models (OGCMs), physical equations for an incompressible fluid flow are solved numerically similar to those in AGCMs. In the AOGCM, the atmospheric, oceanic, sea-ice and land-surface components are “coupled” in the sense that there is exchange of heat, momentum, mass, water vapour and salinity at the interface among different components.

2.2 AR4

These models simulate changes based on a set of scenarios of anthropogenic forcing. In IPCC Fourth Assessment Report (AR4), the concentrations of greenhouse gases and aerosols are derived from various emission scenarios. A set of four “scenario families” were developed. The storyline of each scenario family describes one possible demographic, politico-economic, societal and technological future. The four emissions scenario families in AR4 do not take into account policy actions that mitigate climate change and so, climate initiatives such as the emission targets of the Kyoto Protocol are not incorporated. The emission scenarios in AR4 are termed as Special Report on Emission Scenario (SRES), and they compared and summarised in Table 1. A1 scenarios represent a more integrated world with subsets A1FI as fuel-intensive, A1B emphasizing on all energy sources scenario and A1T on non-fossil energy sources. A2 represent a more divided world. On the other hand, B1 represent a more integrated and ecologically friendly world and B2 represent a more divided but ecologically friendly world.

Table 1 Comparison of Different Emission Scenarios in AR4 (IPCC, 2007)

SRES	Demographics	Socio-political and economic development	Fossil fuels
A1	Global population peaks in the mid-21st century and declines thereafter	Very rapid economic growth, with convergence among countries and increased social and cultural interaction	Introduction of new and more efficient technologies
A1FI	Global population peaks in the mid-21st century and declines thereafter	Very rapid economic growth, with convergence among countries and increased social and cultural interaction	Fossil fuel-intensive, assuming that fossil fuel supplies are unlimited
A1T	Global population peaks in the mid-21st century and declines thereafter	Very rapid economic growth, with convergence among countries and increased social and cultural interaction	Reliance on non-fossil energy sources
A1B	Slow population growth	Very rapid economic growth with economic and cultural convergence. The global population pursues personal wealth over environmental quality.	Energy supply balanced between fossil fuels and non-fossil sources
A2	Increasing population due to slow convergence of fertility patterns	A more fragmented world with slow economic and cultural convergence	Relatively slower technological change
B1	Global population peaks in the mid-21st century and declines thereafter	Move towards a service and information economy, emphasis on sustainability and equity	Introduction of clean and resource-efficient technologies
B2	Increasing population, at a rate slower than A2	Focus on sustainability and equity but on local rather than regional levels, intermediate economic growth	Less rapid and more diverse technological change

Projections of sea level rise are commonly referenced to a base year; in AR4, the base year was 1990. The global mean sea level rise varies from 18cm to 59cm between 1990 and 2100 for all SRES scenarios and emission sensitivity considerations.

2.3 AR5

The latest findings by the IPCC are the Fifth Assessment Report (AR5), which were published in 2014, In IPCC AR5, most AOGCMs are upgraded to include carbon and nitrogen cycles. The objectives of AR5 are different from those of AR4. Now it focuses more on the regional climate and extreme climate projections. It attempts to address some short-term climate change in decadal time scale. The horizontal resolution is reduced to better represent regional features and better model the occurrence of extreme events. AR5 projections also extend beyond the 2100 end point in AR4 to year 2300 due to the increasing interest in modelling a long-term equilibrium across different components of climate systems.

In AR5, a new set of scenarios, called the Representative Concentration Pathways (RCPs), were used for the new climate model simulations under CMIP5. This new approach focuses on radiative forcing, which refers to the balance between incoming and outgoing radiation to the atmosphere as a result of changes in atmospheric constituents, instead of atmospheric greenhouse gas and aerosol concentrations. RCPs do not have unique socioeconomic factors nor emission scenarios that rely on a combination of various economic, social, policy and technological factors In AR5, the classification of emission intensity to define scenarios is dropped. It is purely based on temperature change. This is rationalized in this matter such that only the components of radiative forcing are used to serve as the starting force for climate modelling. The climate change from the RCP scenarios in the AR5 is framed as a combination of adaptation and mitigation. Each RCP depicts only one of the many possible scenarios that would give rise to certain radiative forcing characteristics. There are four RCPs considered in AR5, and their characteristics are shown in Table 2. The equivalent SRESs in AR4 are also given in the table.

Table 2 Comparison of Different Emission Scenarios in AR5 (Moss et al, 2010)

Name	Target Radiative Forcing (W/m^2)	CO_2 equivalent (ppm)	Temp. Anomaly (°C)	Pathway	AR4 SRES Temp. Anomaly equiv.
RCP 8.5	8.5 in 2100	1350	4.9	Rising	A1FI
RCP 6.0	6 post 2100	850	3.0	Stabilization without overshoot	B2
RCP 4.5	4.5post 2100	650	2.4	Stabilization without overshoot	B1
RCP 2.6	3 before 2100, declining to 2.6 by 2100	450	1.5	Peak and decline	None

In AR5, the base level is 1996, which is the representative of the average of the period between 1986 and 2005.The global mean sea level rise values for AR5 RCP scenarios from base year 1996 are presented in.

Table 3 Global Mean Sea Level Rise Values for AR5 RCP Scenarios from Base Year 1996 (cm)

Scenario	2010	2030	2050	2100
RCP8.5	4	13	25	74
RCP6.0	4	12	22	55
RCP4.5	4	13	23	53
RCP2.6	4	13	22	44

2.4 Comparison of Global Sea Level Rise between AR4 and AR5

A comparison between the scenarios of AR4 and AR5 is shown in Figure 1.

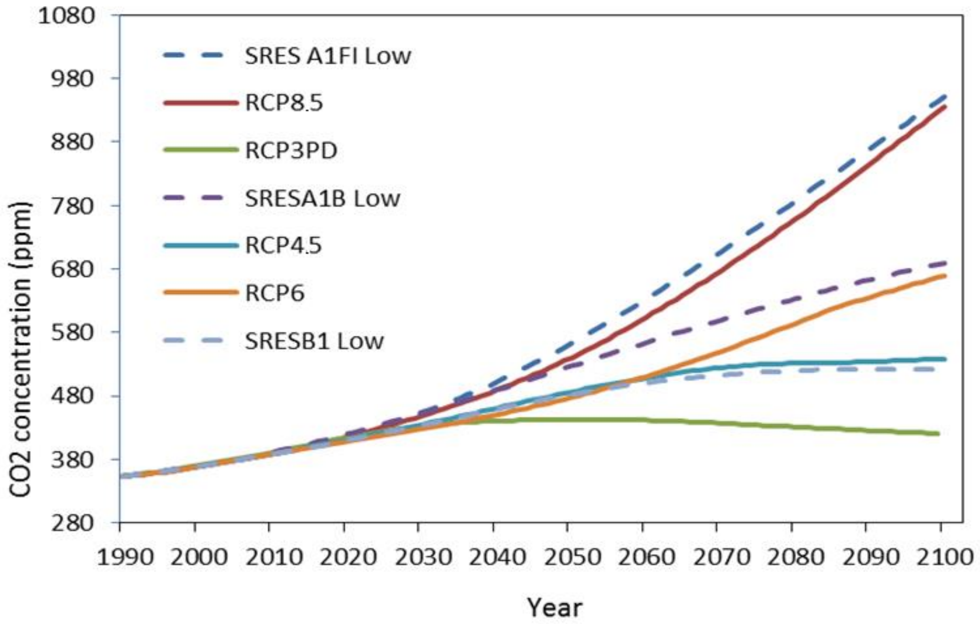


Figure 1 Comparison of CO_2 concentrations in AR4 and AR5 (Moss et al, 2008; Moss et al 2010)

It can be seen that the CO_2 concentrations in AR5 RCP8.5 by year 2100 are similar to those in AR4 SRES A1FI Low sensitivity case. The CO_2 concentration in AR5 RCP6 by year 2100 are similar to those in AR4 SRES A1B Low sensitivity case. In the case of AR5 RCP4.5, the CO_2 concentrations by year 2100 are similar to those in AR4 SRES B1 Low sensitivity case.

Regarding the global mean sea level rise, the projections in AR4 and AR5 are shown together in Figure 2.

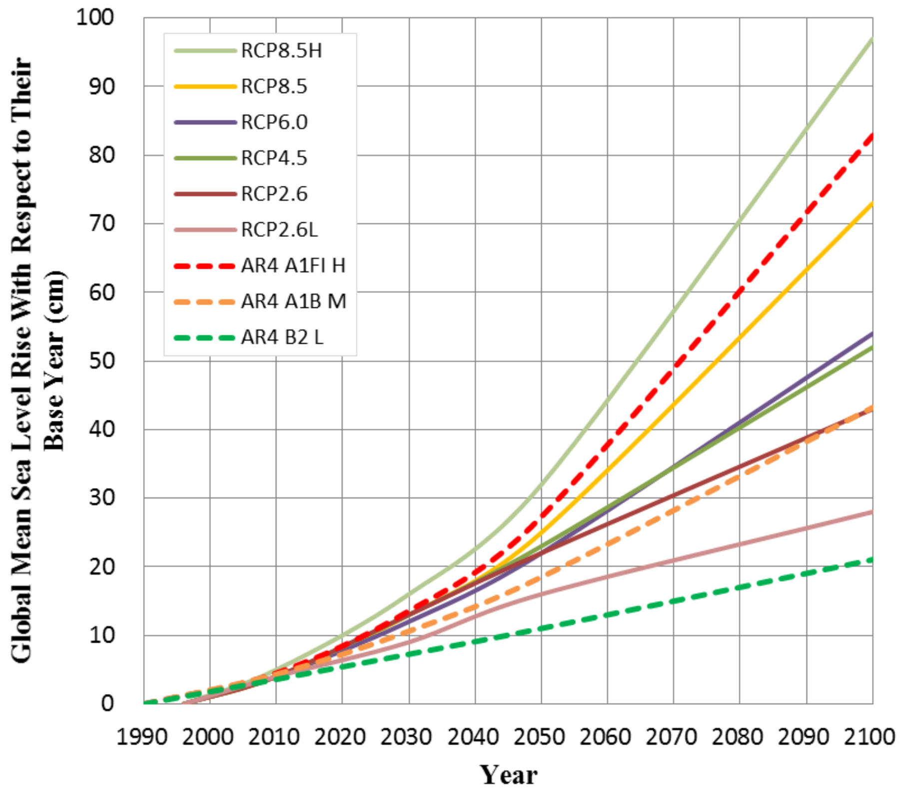


Figure 2 Comparison Plot of Global Mean Sea Level Rise Predicted in AR4 and AR5 (Base Year = 1990 (AR4) and 1996 (AR5))

2.5 Sea Level Rise in Hong Kong

Based on the tidal measurements in Hong Kong, the sea levels in the Victoria Harbour of Hong Kong in a 60-year period between 1954 and 2014 have been rising at an average rate of about 30mm/decade or 3mm/year (http://www.hko.gov.hk/climate_change/obs_hk_sea_level_e.htm).

3 HZMB HKBCF Edge Structures

3.1 *Project Description*

The Hong Kong Boundary Crossing Facilities (HKBCF) reclamation is part of the Hong Kong-Zhuhai-Macao Bridge (HZMB) project as shown in Figure 3, which will provide a direct road connection between Macau and Hong Kong, and will reduce the travel time from several hours to less than an hour. The HZMB project consists of three sections. The western section comprises a 14km link road within Zhuhai and the Zhuhai-Macao Boundary Crossing Facilities. The middle section is the 30km long HZMB Main Bridge comprising a 30km long sea viaduct and 7km immersed tube tunnel. The eastern section will be within the Hong Kong boundary and comprises a12km dual 3-lane HKLR and HKBCF reclamation.

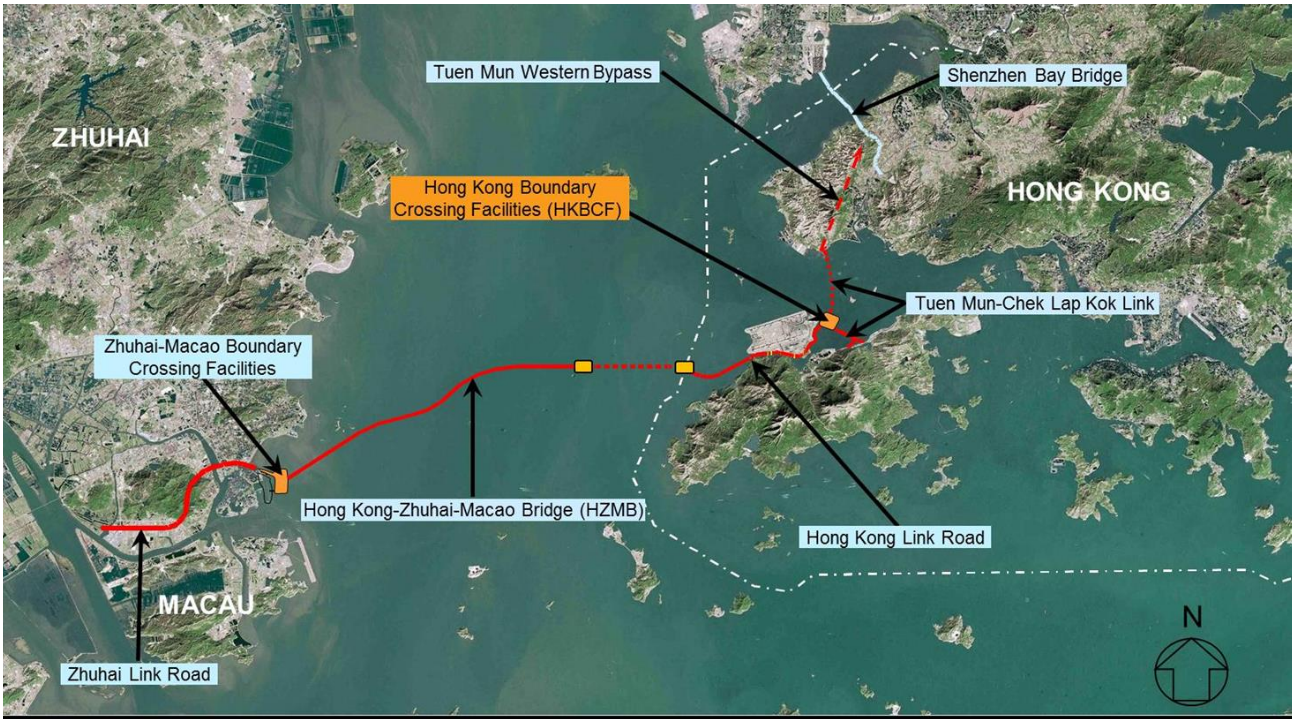


Figure 3 HZMB Project

Reclamations require deposition of materials, usually sand fill and public fill, onto the seabed until it reaches the required elevation above the sea level. The edges of reclamation require some protection against the attack of wave and swell. These edge protections can either be vertical or sloping, depending on the functionality, aesthetics and sensitivity of the surrounding environment. A total length of 6km seawall surrounds the HKBCF reclamation, and all seawalls are sloping seawalls with natural rubble at the surface to uphold the natural aesthetics and to enhance biodiversity in the voids of the rubble.

The HKBCF is an area of known complex ground conditions. The seabed of HKBCF is underlain by 15 to 25m thick soft silty clay of marine origin. Ground improvement in the form of a 6m high surcharge will be placed to ensure that the long-term settlement of the reclamation be within the acceptable design criteria.

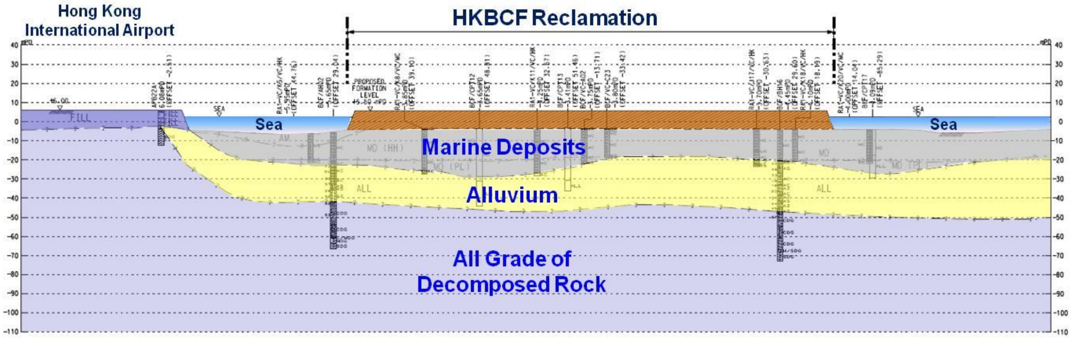


Figure 4 Typical Geological Stratification below HKBCF Reclamation

Due to the very low strength and high compressibility of the soft marine clay, this soft marine clay is conventionally dredged down to the top of the more competent alluvium stratum and the dredged trench is backfilled to form the sloping seawall. The dredged mud would be transported off site and disposed in the assigned locations. In upholding the principle of sustainability, Arup designed an innovative non-dredged seawall scheme to avoid dredging of the soft mud. In addition, the non-dredged solution can reduce the total volume of backfill required to form the reclamation, the associated volume of marine traffic for the construction as dredgers are not required and reduces the impact on the water quality.

3.2 *Non-dredged Cellular Seawall*

The non-dredged cellular structure consists of large diameter circular cells formed by interlocking straight-web steel sheet piles vibrated through the soft marine clay into the alluvium. The circular cells are then filled with soil to allow the cells to form free-standing gravity structures. These individual circular cells are then joined together by connecting arc sections constructed using the same sheet piles and backfilled to form a continuous gravity-type seawall structure. The main cells are up to 31.2m in diameter. To enhance the strength of the soft marine clay, ground treatment in the form of stone columns is implemented to provide structural support to the backfill and rubble mound within and in front of the cells. These columns also act as porous drain to help consolidation of the marine clay and alluvium. The seabed level varies from -2.5mPD to -11mPD, and the seawall sections more exposed to wind waves and swells are at the deeper water locations where the seabed is between -4mPD to -11mPD.

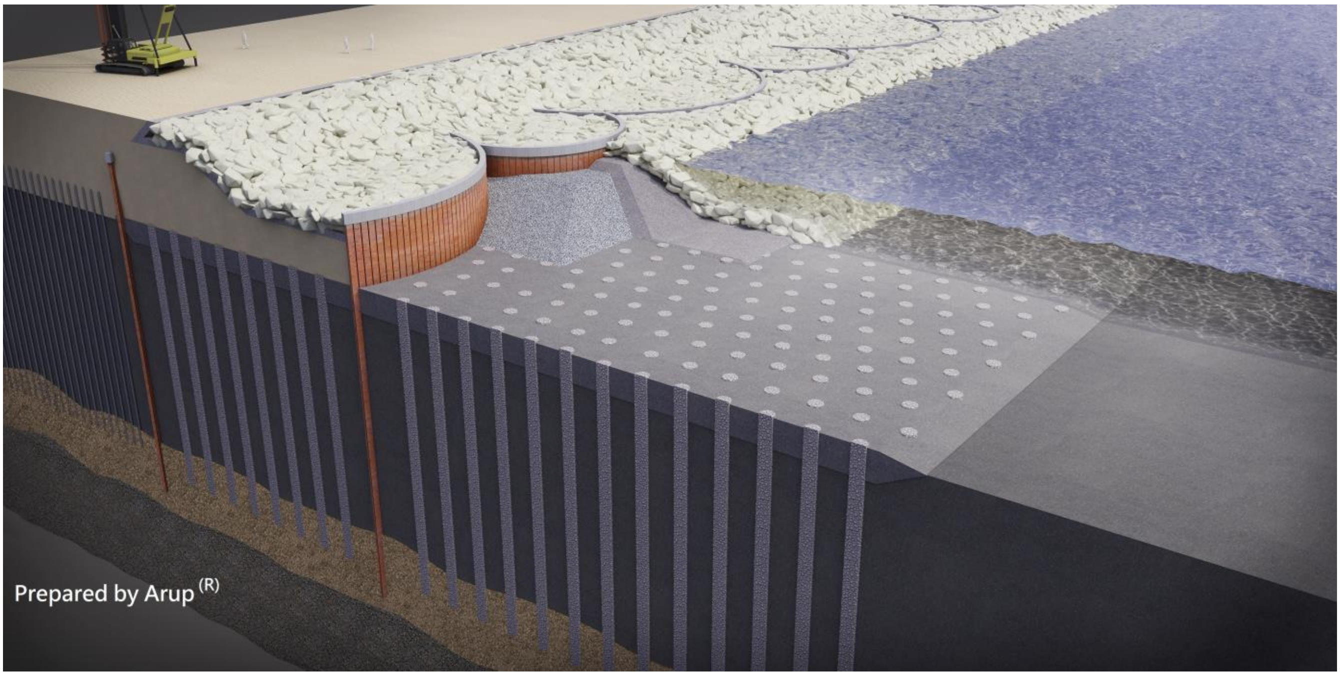


Figure 5 ***Non-dredge Cellular Seawall Structure***

3.3 *Tidal and Extreme Sea Levels*

The mean sea level at HKBCF is about +1.2mPD, and the tidal variation is about 2m giving the Mean Higher High Water (MHHW) level at +2.1mPD and the Mean Lower Low Water (MLLW) level at +0.3mPD. The armours of the seawall were designed according to the loading combinations in Port Works Design Manual (PWDM), in which both “Normal” and “Extreme” loading conditions need to be considered. Extreme loading conditions represent the conditions when typhoon occurs and it is likely that the seawall needs to protect the reclamation behind against more severe wave. The extreme loading conditions need to consider water levels at various return periods, as shown in Table 4.

Table 4 ***Extreme Water Levels at Lok On Pai Station***

Return Period	10-year	50-year	100-year
Water Level	+3.1mPD	+3.3mPD	+3.5mPD

3.4 *Sea Level Rise*

As explained in Section 2.5, the average sea level rise in Victoria Harbour is about 3mm/year based on historical tidal records between 1954 and 2014. A linear projection of this historical rate to a design life of 120 years for the seawall would translate to a sea level rise of 36cm within the design life.

The seawall design was undertaken in 2010, before the publication of the IPCC AR5 results. Therefore, the global mean sea level rise in AR4 was considered in the seawall design. As mentioned in Section 2.4, the global mean sea level rise varies between 0.18m and 0.59m from base year of 1990 to year 2100. This is equivalent to approximately 2.0 to 5.0mm per year. These rates in AR4 are expressed by some researchers to be on the low side, as the sea level rise rates in AR4 consider the thermal expansion in the ocean water only, and exclude ice sheet melting. To account for the uncertainty in sea level rise projections, it was considered prudent to adopt the upper end of 5.0mm/year. For a design life of 120 years, the sea level rise allowance for the seawall design is 60cm. When compared with the global sea level rise projections in AR5, the 60cm allowance is close to the SLR in 120 years for RCP6.0.

3.5 *Overtopping*

Overtopping occurs when the wave train reaches the seawall and rises in response to the wall geometry. For sloping seawall, it runs up the inclined surface until it reaches the top of the seawall, and then runs into the land behind the seawall. For vertical seawall, the wave hits on the vertical face and reflects backward. The reflected wave joins in with the incident wave to create waves of greater height. The higher superimposed wave hits on the wall and climbs up and surpasses the seawall top. Overtopping is dependent on the inclination of the seawall face, the top level of the seawall and the roughness of the surface. Overtopping is a key issue when sea level rise is considered, as the potential of overtopping and the associated overtopping rate would substantially increase when the water level increases.

The armoured profile of the seawall was designed to have composite gradients with a wide berm at +2.25mPD between the upper and lower slopes of 1v:2h. The berm is included at the section to help dissipation of energy from the incident waves. The overtopping and run-up can be reduced by 40% maximum as a result of the inclusion of this berm, as recommended in EuroTop (2007).

Overtopping was calculated using the EuroTop recommended approach of first approximating the composite slope as a single theoretical slope. The run-up and overtopping was then determined for a smooth slope, and the results were then be modified to take into account of the increased roughness. These overtopping rates were compared with those using the Owen formula.

The analyses showed that:

(i) The horizontal area of the berm needs be placed with rock armour to increase the roughness to dissipate sufficient wave energy in order to meet the required overtopping limits.

(ii) The reclamation formation level at +6.0mPD is required to maintain the overtopping rate at acceptable level, when sea level rise is considered.

4. Conclusion

Climate change effects have been evident from the recent tidal measurements and damage recorded after storms. It is undoubtedly reasonable to consider sea level rise in engineering design, taking into account the latest findings from the scientific and meteorological fields. The IPCC published their findings on the global mean sea level through the Fourth Assessment Report (AR4) in year 2007. The global mean sea level rise is about 2.0 to 5.0mm per year.

In designing the seawall for the 150-ha HKBCF reclamation, a sea level rise rate of 5.0mm per year was adopted to give a total sea level rise of 60cm for a design life of 120 years. This allowance is similar to that will be considered in the RCP6.0 scenario in the more recent AR5. A composite slope is adopted for the sloping armoured face of the seawall, and a berm at +2.25mPD is proposed to dissipate the wave energy. With the berm structure, the formation level can be maintained at +6mPD whilst considering sea level rise.

References

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IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Clhange,* Cambridge University Press, Cambridge, U.K. and New York

Moss, R.H. et al (2008 Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies Intergovernmental Panel on Climate Change, Geneva, 132 pp.Tow

Moss, R.H. et al (2010) The next generation of scenarios for climate change research and assessment. *Nature* **463**: 747 – 756.

Subsurface Investigation for Design and Construction of Foundations of Buildings in Sabah Coastal Areas, Malaysia

Foundations for all buildings, even the most simple one, must satisfy three (3) requirements

- The bearing capacity must be sufficiently less than the ultimate bearing capacity of the soil to assure a safe foundation.

- The total and differential settlements must be within the tolerably small to assure the structure will not be damaged by any foundation movements.

- The effects of the structure and its construction on adjacent properties must be evaluated and necessary protective measures be taken

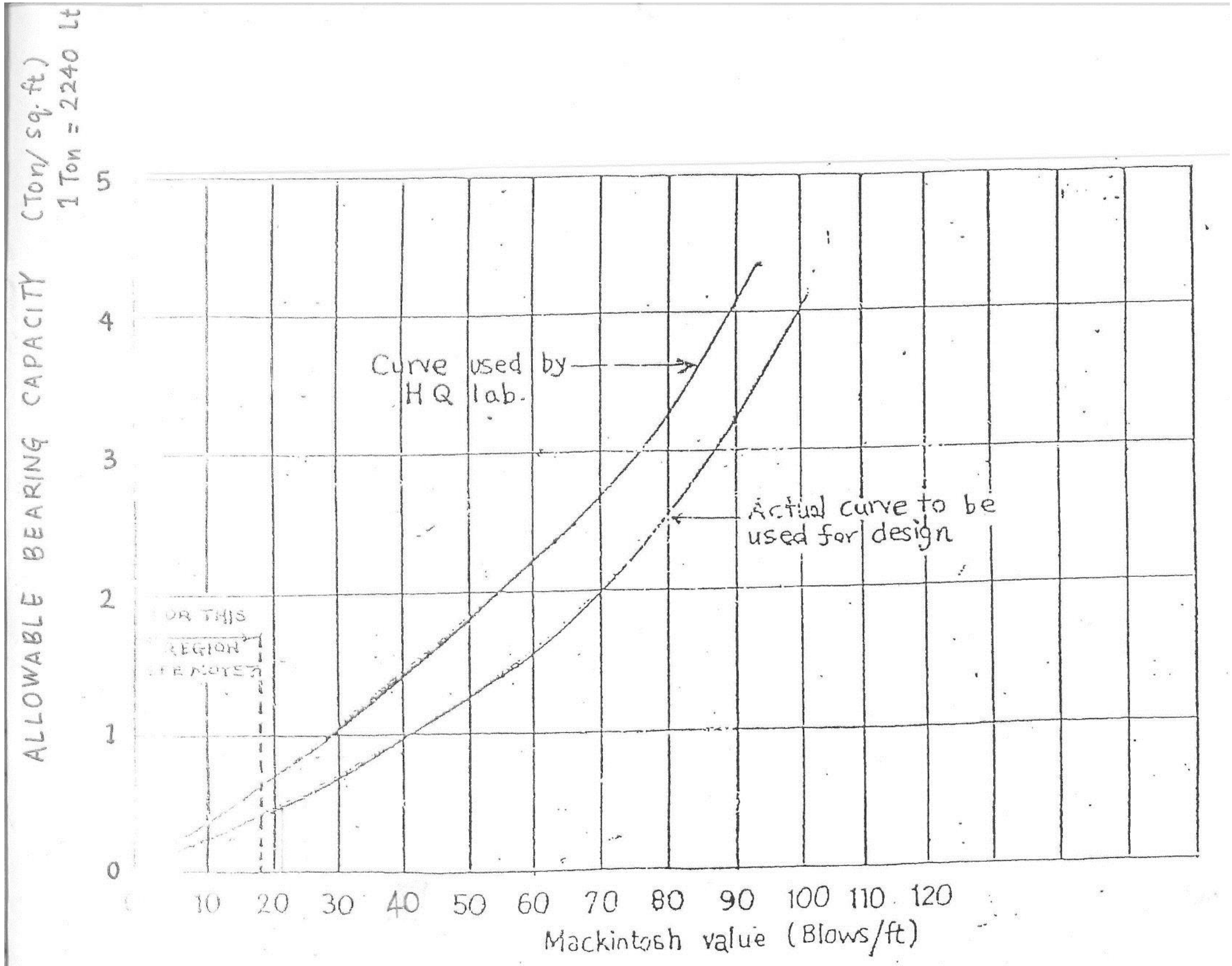
To achieve these objectives, Subsurface Investigation together with Feasibility Study of Project Site is absolutely necessary.

- The characteristics of subsurface soils or rocks and their behavior when loaded were determined, and interpreting these data to determine soil or rock parameters for design.

- To make modifications and adjustments based on actual site conditions encountered during construction to ensure that the foundations are as-built to design specifications and requirements

Subsurface Investigation

- Method : Mackintosh Probe Test or JKR Probe Test



Subsurface Investigation

- Method

➢ Wash Boring and Rotary Drilling

✓ Sampling - Undisturded and Disturbed Samples

✓ In-Situ Tests - Standard Penetration Test (SPT)

- Vane Shear Test

-Pressuremeter Test

Standard Penetration Test (SPT)

SAND

Table 3. Relationship for ϕ' and In situ Tests in Clean Sands

Sand Density (SW,SP)	Relative Density	Standard Penetration Test N blows/300 mm	Static Dutch-Cone Resistance q_c - MPa	Angle of Internal Friction * ϕ' Degrees
Very Loose	< 0.2	< 4	2	< 28
Loose	0.2 - 0.4	4 - 10	2 - 4	28 - 30
Medium	0.4 - 0.6	10 - 30	4 - 12	30 - 37
Dense	0.6 - 0.8	30 - 50	12 - 20	37 - 42
Very Dense	> 0.8	> 50	> 20	> 42

* Decrease 5° for non-plastic silts (ML,MH with PI < 6) and silty sands (SM)

Increase 5° for gravel or gravel sand mixtures (GW,GP,GM)

CLAY

Table 4. Consistency of Saturated Clay Soils

Consistency	Unconfined Compressive Shearing Strength kPa	Shearing Strength c_u kPa
Very Soft	< 25	< 12.5
Soft	25 - 50	12.5 - 25
Medium	50 - 100	25 - 50
Stiff	100 - 200	50 - 100
Very Stiff	200 - 400	100 - 200
Hard	> 400	> 200

Typical Sabah Coast Line – Sandy Beaches

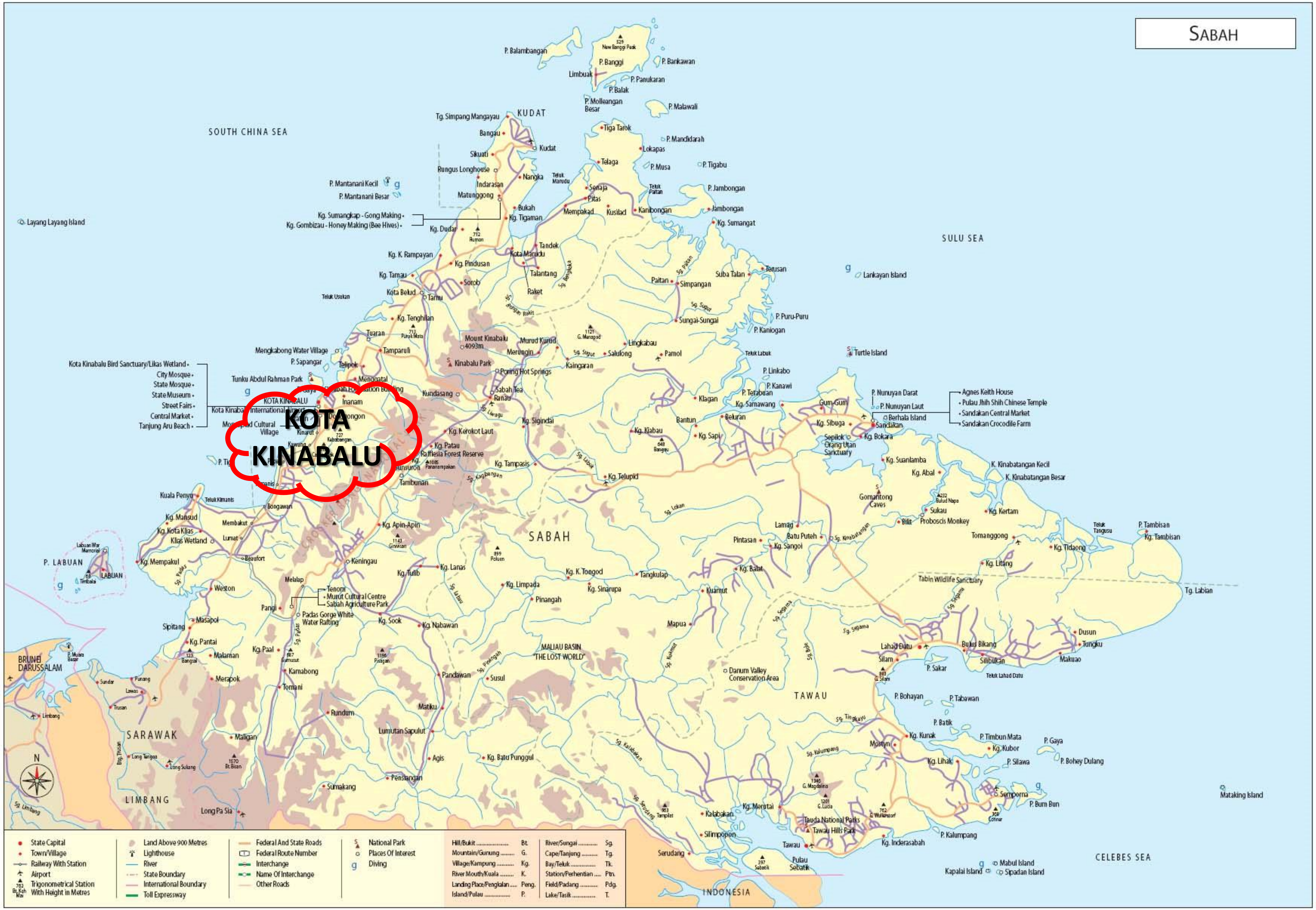
Typical Sabah Coast Line – Bakau Swamp

Typical Sabah Coast Line – Bakau Swamp

Typical Sabah Coast Line – Fresh and Brackish Water Swamp

Typical Sabah Coast Line – Fresh and Brackish Water Swamp

Typical Sabah Coast Line – Coral



SABAH
KOTA KINABALU
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
SABAH
SARAWAK
LIMBANG
TAWAU
KUDAT
INDONESIA
BRUNEI DARUSSALAM
P. LABUAN
LABUAN
N
P. Balambangan
P. Banggi
P. Bankawan
Limbuak
P. Panukaran
P. Balak
P. Molleangan Besar
P. Malawali
Tg. Simpang Mangayau
Bangau
Kudat
Sikuati
Rungus Longhouse
Indarasan
Matunggong
Nangka
Bukah
Kg. Tigaman
Tiga Tarok
Lokapas
P. Mandidarah
Telaga
P. Musa
P. Tigabu
Senaja
Pitas
Mempakad
Kusilad
Kanibongan
P. Jambongan
Jambongan
Kg. Sumangat
P. Mantanani Kecil
P. Mantanani Besar
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
Layang Layang Island
Kg. Dudar
Kg. K. Rampayan
Kg. Pindusan
Tandek
Kota Marudu
Talantang
Kg. Tamau
Kota Belud
Sorob
Tamu
Rakit
Paitan
Simpangan
Suba Talan
Terusan
Lankayan Island
Kg. Tenghilan
Tuaran
Tamparuli
Mount Kinabalu 4093m
Murud Kurud
Lingkabau
Sungai-Sungai
P. Puru-Puru
P. Kaniogan
Mengkabong Water Village
P. Sapangar
Telipok
Kinabalu Park
Merungin
Salulong
Pamol
Kaingaran
Turtle Island
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Tunku Abdul Rahman Park
Menggatal
Poring Hot Springs
Sabah Foundation Building
Kundasang
Sabah Tea
Ranau
Inanam
Kota Kinabalu International Airport
Donggongon
Monsopiad Cultural Village
Kinarut
Kawang
Kg. Kerokot Laut
Kg. Patau
Rafflesia Forest Reserve
Tambunan
Kg. Sigindai
Klagan
P. Linkabo
P. Kanawi
P. Tetabuan
Kg. Samawang
Gum-Gum
P. Nunuyan Darat
P. Nunuyan Laut
Berhala Island
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Sandakan
Kg. Sibuga
Kg. Bokara
Sepilok Orang Utan Sanctuary
Bantun
Beluran
Kg. Kiabau
Kg. Sapi
Kg. Tampasis
Kg. Telupid
Kg. Suanlamba
Kg. Abai
K. Kinabatangan Kecil
K. Kinabatangan Besar
Gomantong Caves
Sukau
Proboscis Monkey
Bilit
Kg. Kertam
Kuala Penyu
Teluk Kimanis
Bongawan
Kg. Mansud
Membakut
Kg. Kota Klias
Klias Wetland
Lumat
Kg. Apin-Apin
Labuan War Memorial
Kg. Mempakul
Beaufort
Keningau
Lamag
Batu Puteh
Kg. Sangoi
Pintasan
Tomanggong
P. Tambisan
Kg. Tambisan
Kg. Tidaong
Kg. Litang
Tabin Wildlife Sanctuary
Tg. Labian
Weston
Melalap
Tenom
Murut Cultural Centre
Sabah Agriculture Park
Padas Gorge White Water Rafting
Pangi
Kg. Tulib
Kg. Lanas
Kg. Limpada
Kg. K. Tongod
Kg. Sinarupa
Tangkulap
Kg. Balat
Kuamut
Pinangah
Sipitang
Masapol
Kg. Pantai
Kg. Sook
Kg. Nabawan
Mapua
Malaman
Kg. Paal
Kamabong
Merapok
Tomani
MALIAU BASIN "THE LOST WORLD"
Pandawan
Susui
Danum Valley Conservation Area
Lahad Datu
Silam
Bukit Bikang
Silibukan
Dusun
Tungku
Makuao
P. Sakar
P. Bohayan
P. Tabawan
P. Batik
Kg. Kunak
Mostyn
P. Timbun Mata
Kg. Kubor
P. Gaya
P. Silawa
P. Bohey Dulang
Kg. Lihak
Semporna
P. Bum Bum
Mataking Island
Rundum
Matiku
Lumutan Sapulut
Maligan
Agis
Kg. Batu Punggul
Sumakang
Pensiangan
Long Pa Sia
Kalabakan
Kg. Merutai
Tawau Hills Park
Tawau
Silimpopon
Serudang
Kg. Inderasabah
P. Kalumpang
Pulau Sebatik
Mabul Island
Kapalai Island
Sipadan Island
Sundar
Punang
Lawas
Trusan
Limbang
Long Semadoh
Long Sukang
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

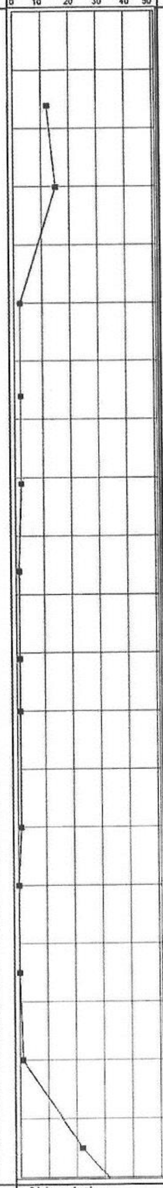
Location : Kota Kinabalu
Date Started : 05/10/2013
Date Completed : 06/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0 – 4.10m	Stiff, yellowish brown, Silty Clayey SAND with some gravel.	UD	0			Depth : 1.50-1.60m, Rec=0cm
		N-1	D-1		12	Depth : 1.60-2.05m 1/2/3/3/3/3, Rec=8cm
		N-2	D-2		15	Depth : 3.00-3.45m 3/3/3/4/4/4, Rec=15cm
4.10m – 7.10m	Very soft, blackish grey and dark grey, Silty PEAT with decayed matter.	UD	0			Depth : 4.50-5.00m Rec=0cm
		N-3	D-3		2	Depth : 5.00-5.45m 1/0/0/1/0/1, Rec=15cm
		UD	1			Depth : 6.00-6.60m Rec=30cm
		N-4	D-4		2	Depth : 6.60-7.05m 1/0/1/0/1/0, Rec=25cm
7.10m – 17.00m	Very soft, greenish grey, Clayey SILT/Silty CLAY, occasional with traces of seashell fragments.	UD	2	C_u=12kN/m^2		Depth : 7.60-8.10m Rec=50cm
		N-5	D-5		2	Depth : 8.10-8.55m 1/0/1/0/1/0, Rec=45cm
		UD	3			Depth : 9.00-9.60m Rec=55cm
		N-6	D-6		1	Depth : 9.60-10.05m 1/0/0/1/0/0, Rec=43cm
		UD	4			Depth : 10.50-11.10m Rec=45cm
		N-7	D-7		1	Depth : 11.10-11.55m 1/0/0/1/0/0, Rec=24cm
		N-8	D-8		1	Depth : 12.00-12.45m 1/0/0/1/0/0, Rec=45cm
		UD	0			Depth : 13.50-14.00m Rec=0cm
		N-9	D-9		1	Depth : 14.00-14.45m 0/0/0/0/1/0, Rec=43cm
		N-10	D-10		0	Depth : 15.00-15.45m 0/0/0/0/0/0, Rec=44cm
		N-11	D-11		0	Depth : 16.50-16.95m 0/0/0/0/0/0, Rec=46cm
17.00m – 19.00m	Very loose, brownish grey, Silty fine SAND.	N-12	D-12		1	Depth : 18.00-18.45m 0/1/0/0/1/0, Rec=45cm
19.00m –	Very stiff, brownish grey, Silty CLAY.	N-13	D-13		22	Depth : 19.50-19.95m 4/5/5/5/6/6, Rec=20cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

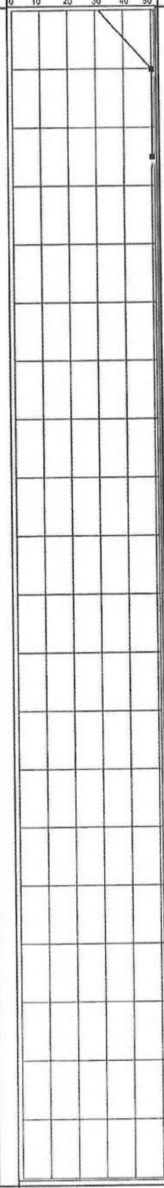
Location : Kota Kinabalu
Date Started : 05/10/2013
Date Completed : 06/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
– 22.50m	Hard, dark grey, Clayey SILT.	N-14	D-14		>50	Depth : 21.00-21.43m 6/10/12/13/14/11(55mm), Rec=32cm
		N-15	D-15		>50	Depth : 22.50-22.55m 50(50mm), Rec=4cm
22.50m – 25.55m	Medium strong to weak, dark grey, fresh to slightly weathered SILTSTONE interbedded with very weak, dark grey, fresh to moderately weathered and highly fractured SHALE.	C	1			Depth : 22.55-24.05m Rec=120cm RQD=0%
		C	2			Depth : 24.05-25.55m Rec=120cm RQD=0%
	END OF BH-1 At 25.55m					Groundwater Level : 05.10.13 - 2.80m (4.50pm) 06.10.13 - 3.00m (8.50am) 06.10.13 - 3.00m (11.40am)

SPT, N-Value Vs Depth



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SUBSURFACE EXPLORATION LOG

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

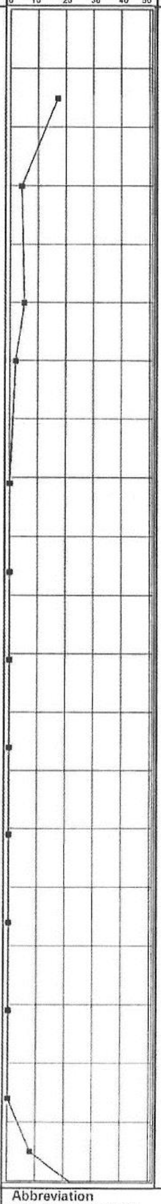
Location : Kota Kinabalu
Date Started : 06/10/2013
Date Completed : 07/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
	Loose to medium dense, yellowish brown and dark grey, Silty SAND with some gravel.	N-1	D-1		17	Depth : 1.50-1.95m 3/3/4/4/5/4, Rec=16cm
4.00m		N-2	D-2		4	Depth : 3.00-3.45m 3/2/1/1/1/1, Rec=16cm
	Very soft, blackish brown, Clayey SILT with some decayed matter.	UD	0			Depth : 4.50-5.00m Rec=0cm
		N-3	D-3		5	Depth : 5.00-5.45m 1/0/1/1/1/2, Rec=21cm
7.10m		N-4	D-4		2	Depth : 6.00-6.45m 1/0/1/0/0/1, Rec=26cm
	Very soft, greenish grey, Clayey SILT/Silty CLAY, occasional with traces of seashell fragments.	UD	1			Depth : 7.50-8.10m Rec=55cm
		N-5	D-5		0	Depth : 8.10-8.55m 0/0/0/0/0/0, Rec=45cm
		UD	2			Depth : 9.00-9.60m Rec=55cm
		N-6	D-6		0	Depth : 9.60-10.05m 0/0/0/0/0/0, Rec=45cm
		UD	3	C_u=6kN/m^2		Depth : 10.50-11.10m Rec=55cm
		N-7	D-7		0	Depth : 11.10-11.55m 0/0/0/0/0/0, Rec=45cm
		UD	4			Depth : 12.00-12.60m Rec=55cm
		N-8	D-8		0	Depth : 12.60-13.05m 0/0/0/0/0/0, Rec=45cm
		UD	5			Depth : 13.50-14.10m Rec=55cm
		N-9	D-9		0	Depth : 14.10-14.55m 0/0/0/0/0/0, Rec=45cm
		UD	6			Depth : 15.00-15.60m Rec=55cm
16.50m		N-10	D-10		0	Depth : 15.60-16.05m 0/0/0/0/0/0, Rec=44cm
	Very soft, dark grey, Clayey SILT with traces of decayed matter.	UD	7	C_u=19kN/m^2		Depth : 16.50-17.10m Rec=55cm
		N-11	D-11		0	Depth : 17.10-17.55m 0/0/0/0/0/0, Rec=44cm
		UD	8			Depth : 18.00-18.60m Rec=55cm
19.00m		N-12	D-12		0	Depth : 18.60-19.05m 0/0/0/0/0/0, Rec=45cm
	Stiff, dark grey, Clayey SILT.	N-13	D-13		8	Depth : 19.50-19.95m 1/0/1/2/2/3, Rec=25cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

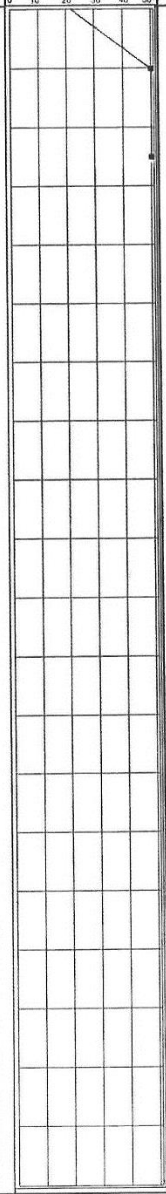
Location : Kota Kinabalu
Date Started : 06/10/2013
Date Completed : 07/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
22.50m	Hard, dark grey, Clayey SILT.	N-14	D-14		>50	Depth : 21.00-21.44m 4/7/10/12/15/13(65mm), Rec=29cm
	Medium strong to weak, dark grey, fresh to slightly weathered SILTSTONE interbedded with very weak, dark grey, fresh to moderately weathered and highly fractured SHALE.	N-15	D-0		>50	Depth : 22.50-22.54m 50(40mm), Rec=0cm
		C	1			Depth : 22.54-24.04m Rec=110cm RQD=0%
		C	2			Depth : 24.04-25.54m Rec=120cm RQD=25%
	END OF BH-2 At 25.54m					Groundwater Level : 06.10.13 - 1.60m (3.40pm) 07.10.13 - 1.65m (9.00am) 07.10.13 - 1.70m (12.30pm) 07.10.13 - 1.80m (1.30pm) 07.10.13 - 2.80m (4.30pm)

SPT, N-Value Vs Depth



Project :

Abbreviation
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D-Disturbed Sample
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VS- Vane Shear Test
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Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

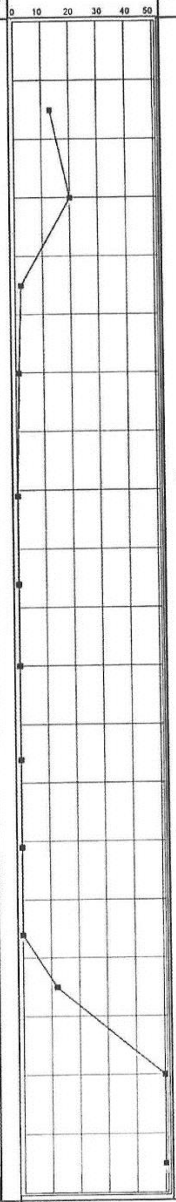
Location : Kota Kinabalu
Date Started : 08/10/2013
Date Completed : 09/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH- 3
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Medium dense, yellowish brown, Silty SAND with some gravel.	N-1	D-1		13	Depth : 1.50-1.95m 2/3/3/3/3/4, Rec=24cm
	N-2	D-2		20	Depth : 3.00-3.45m 3/5/5/5/5/5, Rec=18cm
4.00m					
Very soft, blackish grey and dark grey, Silty PEAT with decayed matter.	N-3	D-3		2	Depth : 4.50-4.95m 1/0/1/0/1/0, Rec=24cm
	N-4	D-4		1	Depth : 6.00-6.45m 1/0/0/1/0/0, Rec=40cm
	UD	1	C_u=6kN/m^2		Depth : 7.50-8.10m Rec=55cm
	N-5	D-5		0	Depth : 8.10-8.55m 0/0/0/0/0/0, Rec=43cm
8.60m					
Very soft, greenish grey, Clayey SILT/Silty CLAY, occasional with traces of seashell fragments.	UD	2			Depth : 9.00-9.60m Rec=55cm
	N-6	D-6		0	Depth : 9.60-10.05m 0/1/0/0/0/0, Rec=45cm
	UD	0			Depth : 10.50-11.00m Rec=45cm
	N-7	D-7		0	Depth : 11.00-11.45m 0/0/0/0/0/0, Rec=45cm
	UD	3			Depth : 12.00-12.60m Rec=55cm
	N-8	D-8		0	Depth : 12.60-13.05m 1/0/0/0/0/0, Rec=40cm
	UD	4	C_u=11kN/m^2		Depth : 13.50-14.10m Rec=55cm
	N-9	D-9		0	Depth : 14.10-14.55m 0/0/0/0/0/0, Rec=45cm
	UD	5			Depth : 15.00-15.60m Rec=55cm
	N-10	D-10		0	Depth : 15.60-16.05m 0/0/0/0/0/0, Rec=39cm
16.50m					
Stiff, dark grey and dark brown, Clayey SILT.	N-11	D-11		12	Depth : 16.50-16.95m 2/3/3/2/3/4, Rec=45cm
18.00m					
Hard, dark brown, Clayey SILT.	N-12	D-12		>50	Depth : 18.00-18.32m 6/6/13/24/13(20mm), Rec=30cm
19.50m					
- refer to next page -	N-13	D-0		>50	Depth : 19.50-19.54m 50(40mm), Rec=0cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Big Boy
Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

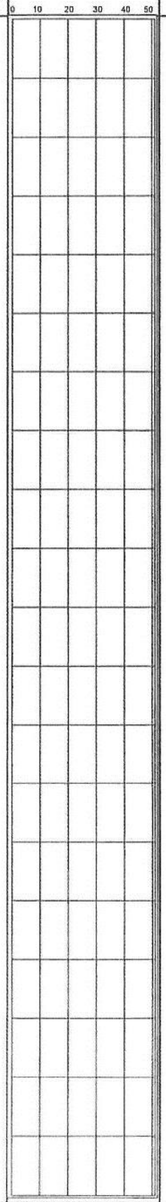
Location : Kota Kinabalu
Date Started : 08/10/2013
Date Completed : 09/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH- 3
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Medium strong to weak, dark grey, fresh to slightly weathered SILTSTONE interbedded with very weak, dark grey, fresh to moderately weathered and highly fractured SHALE.	C	1			Depth : 19.54-21.04m Rec=100cm RQD=0%
	C	2			Depth : 21.04-25.54m Rec=130cm RQD=30%
END OF BH-3 At 22.54m					Groundwater Level : 08.10.13 - 1.20m (4.00pm) 09.10.13 - 1.25m (9.00am) 09.10.13 - 1.30m (11.30am) 09.10.13 - 1.30m (1.30pm) 09.10.13 - 1.40m (3.40pm) 10.10.13 - 0.05m (9.00am) 10.10.13 - 0.05m (5.00pm)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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SUBSURFACE EXPLORATION LOG

Operator : Big Boy
Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

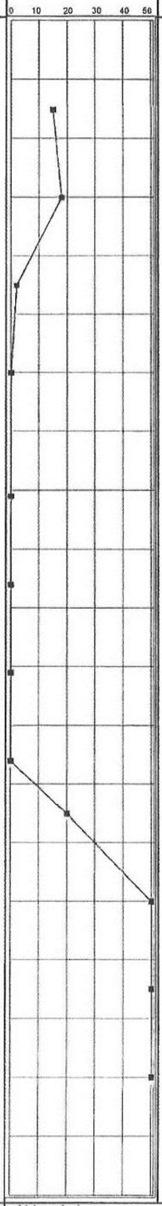
Location : Kota Kinabalu
Date Started : 10/10/2013
Date Completed : 10/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH- 4
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–4.00m	Medium dense, yellowish brown, Silty SAND with some gravel.	N-1	D-1		15	Depth : 1.50-1.95m 2/2/3/4/4/4, Rec=6cm
		N-2	D-2		18	Depth : 3.00-3.45m 2/2/3/5/5/5, Rec=16cm
4.00m–5.10m	Very soft, blackish grey, Silty PEAT with decayed matter.	N-3	D-3		2	Depth : 4.50-4.95m 1/0/1/0/1/0, Rec=34cm
5.10m–9.00m	Very soft, dark brown, Clayey SILT with traces of decayed matter.	N-4	D-4		0	Depth : 6.00-6.45m 0/1/0/0/0/0, Rec=25cm
		UD	1			Depth : 7.50-8.10m Rec=51cm
		N-5	D-5		0	Depth : 8.10-8.55m 0/0/0/0/0/0, Rec=45cm
9.00m–13.50m	Very soft, greenish grey, Clayey SILT/Silty CLAY, occasional with traces of seashell fragments.	UD	2	C_u=13kN/m^2		Depth : 9.00-9.60m Rec=55cm
		N-6	D-6		0	Depth : 9.60-10.05m 0/0/0/0/0/0, Rec=45cm
		UD	0			Depth : 10.50-11.10m Rec=0cm
		N-7	D-7		0	Depth : 11.10-11.55m 0/0/0/0/0/0, Rec=45cm
		UD	3	C_u=12kN/m^2		Depth : 12.00-12.60m Rec=55cm
		N-8	D-8		0	Depth : 12.60-13.05m 0/0/0/0/0/0, Rec=45cm
13.50m–16.00m	Very stiff, yellowish brown, Sandy SILT.	N-9	D-9		20	Depth : 13.50-13.95m 2/2/4/4/6/6, Rec=40cm
		N-10	D-10		>50	Depth : 15.00-15.32m 6/11/16/24/10, Rec=24cm
16.00m–18.00m	Hard, dark grey, Clayey SILT.	N-11	D-11		>50	Depth : 16.50-16.80m 8/15/20/30(75mm), Rec=20cm
18.00m–	Medium strong to weak, dark grey, fresh to slightly weathered SILTSTONE interbedded with very weak, dark grey, fresh to moderately weathered and highly fractured SHALE.	N-12	D-0		>50	Depth : 18.00-18.03m 50(30mm), Rec=0cm
		C	1			Depth : 18.03-19.53m Rec=100cm RQD=0%

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

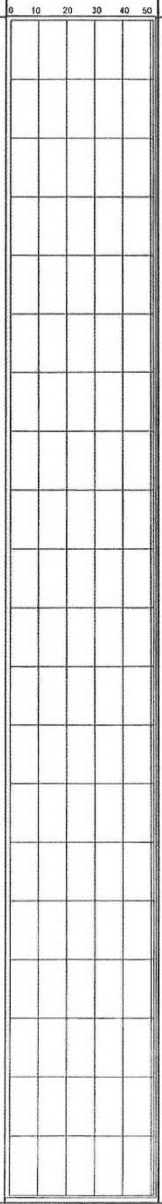
Location : Kota Kinabalu
Date Started : 10/10/2013
Date Completed : 10/10/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH- 4
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20–21.03m	Medium strong to weak, dark grey, fresh to slightly weathered SILTSTONE interbedded with very weak, dark grey, fresh to moderately weathered and highly fractured SHALE.	C	2			Depth : 19.63-21.03m Rec=100cm RQD=0%
	END OF BH-4 At 21.03m					Groundwater Level : 10.10.13 - 1.80m (12.00pm) 10.10.13 - 1.90m (1.00pm) 10.10.13 - 2.00m (4.30pm) 10.10.13 - 0.06m (5.05pm)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
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C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

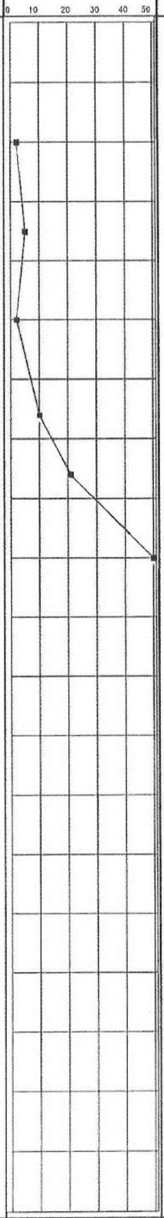
Location : Kota Kinabalu
Date Started : 08/09/2014
Date Completed : 08/09/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 6.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 1
Borehole No. : BH-2
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–5.00m	Soft to medium stiff, dark brown, Sandy Clayey SILT with some gravel.	UD	1			Depth : 1.50-2.10m Rec=51cm
		N-1	D-1		2	Depth : 2.10-2.55m 1/0/1/0/1/0, Rec=36cm
		UD	2	cu=75kN/m²		Depth : 3.00-3.50m Rec=48cm
		N-2	D-2		5	Depth : 3.50-3.95m 1/1/1/2/1/1, Rec=39cm
		UD	3	cu=17kN/m²		Depth : 4.50-5.00m Rec=42cm
5.00m–6.50m	Very loose, black, Silty fine SAND with decayed matters.	N-3	D-3		2	Depth : 5.00-5.45m 1/0/1/0/1/0, Rec=37cm
		UD	4	cu=21kN/m²		Depth : 6.00-6.50m Rec=50cm
6.50m–9.00m	Stiff to very stiff, reddish brown and dark grey, Sandy Clayey SILT with some parental rock fragment.	N-4	D-4		10	Depth : 6.50-6.95m 1/1/2/2/3/3, Rec=29cm
		N-5	D-5		21	Depth : 7.50-7.95m 3/3/4/5/6/6, Rec=30cm
9.00m–13.71m	Very weak to weak, dark grey, highly to extremely weathered, highly to extremely fractured, SHALE.	N-6	D-6		>50	Depth : 9.00-9.21m 8/28/50(60mm), Rec=14cm
		C	1			Depth : 9.21-10.71m Rec=100cm RQD=0%
		C	2			Depth : 10.71-12.21m Rec=137cm RQD=0%
		C	3			Depth : 12.21-13.71m Rec=138cm RQD=0%
	END OF BH-2 AT 13.71m					

SPT, N-Value Vs Depth



Groundwater levels below the existing ground level:
08/09/2014 - 0.50m (6:30pm)
09/09/2014 - 0.52m (7:00am)
09/09/2014 - 0.55m (4:20pm)
10/09/2014 - 0.56m (9:00am)
10/09/2014 - 0.59m (12:00pm)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

Operator : Julaspi | Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Vera C. | Confirmed By : Roger YONG

Location : Kota Kinabalu
Date Started : 13/11/2014
Date Completed : 16/11/2014
Type of Boring : Rotary Wash Boring

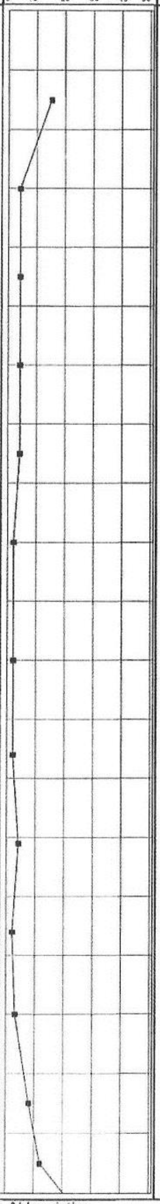
Rig Type : YWE D45
Casing Depth : 22.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-7A
Ground Elev. : Existing Ground Level
Coordinate : N 664087.354 E 709337.986

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
0 – 1.50m	Dark brown and dark grey, Silty SAND with gravel.				
1.50m – 5.00m	Strong, angular GRAVEL/BOULDER with loose to medium dense, dark brown and dark grey, Silty fine to coarse SAND matrix.	N-1	D-1	15	Depth : 1.50-1.95m 4/9/3/4/4/4, Rec=36cm
		C	1		Depth : 1.95-3.00m Rec=0cm RQD=0%
		N-2	D-2	4	Depth : 3.00-3.45m 2/1/2/1/0/1, Rec=36cm
		C	2		Depth : 3.45-4.50m Rec=0cm RQD=0%
		N-3	D-3	4	Depth : 4.50-4.95m 4/3/2/1/0/1, Rec=15cm
5.00m – 10.00m	Very loose, dark grey, Silty fine SAND with traces of seashell fragments.	N-4	D-4	4	Depth : 6.00-6.45m 1/0/1/1/1/1, Rec=27cm
		N-5	D-5	4	Depth : 7.50-7.95m 1/1/1/1/1/1, Rec=43cm
		N-6	D-6	2	Depth : 9.00-9.45m 1/0/1/0/1/0, Rec=25cm
10.00m – 17.00m	Very loose, dark grey, fine SAND with traces of seashell fragments.	UD	1		Depth : 10.50-11.10m Rec=35cm
		N-7	D-7	2	Depth : 11.10-11.55m 0/1/0/1/0/1, Rec=45cm
		UD	2		Depth : 12.00-12.60m Rec=55cm
		N-8	D-8	2	Depth : 12.60-13.05m 1/0/1/0/1/0, Rec=45cm
		UD	3		Depth : 13.50-14.10m Rec=45cm
		N-9	D-9	4	Depth : 14.10-14.55m 1/0/1/1/1/1, Rec=45cm
		UD	0		Depth : 15.00-15.60m Rec=0cm
		N-10	D-10	2	Depth : 15.60-16.05m 1/0/1/0/1/0, Rec=45cm
		UD	0		Depth : 16.50-17.00m Rec=0cm
17.00m – 18.50m	Soft, dark grey, Clayey SILT.	N-11	D-11	3	Depth : 17.00-17.45m 1/0/1/0/1/1, Rec=45cm
		UD	4		Depth : 18.00-18.50m Rec=50cm
18.50m –	Stiff, dark grey, Clayey SILT.	N-12	D-12	8	Depth : 18.50-18.95m 2/2/2/2/2/2, Rec=32cm
		N-13	D-13	12	Depth : 19.50-19.95m 2/2/3/3/3/3, Rec=30cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
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RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Rayhan
Recorded By : Suhaizal
Checked By : Alex Leong
Confirmed By : Roger YONG

Location : Kota Kinabalu
Date Started : 13/11/2014
Date Completed : 16/11/2014
Type of Boring : Rotary Wash Boring

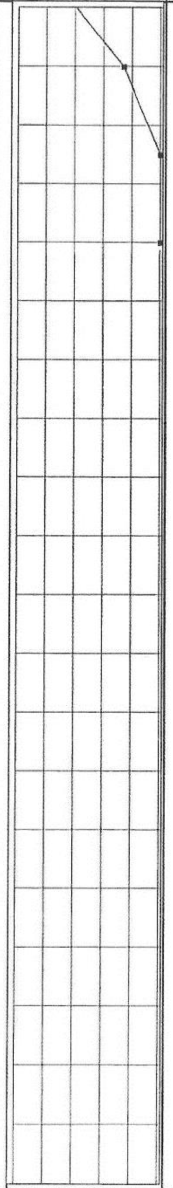
Rig Type : YWE D45
Casing Depth : 22.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-7A
Ground Elev. : Existing Ground Level
Coordinate : N 664087.354 E 709337.986

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
– 21.00m	Stiff, dark grey, Clayey SILT.	N-14	D-14	37	Depth : 21.00-21.45m 5/6/7/8/10/12, Rec=25cm
21.00m – 22.50m	Hard, dark grey, Clayey SILT.				
22.50m – 24.00m	Hard, dark grey, Sandy SILT with some parental rock fragments.	N-15	D-15	>50	Depth : 22.50-22.95m 4/6/8/12/14/16(75mm), Rec=27cm
24.00m –	Very dense, dark grey, fine SAND.	N-16	D-16	>50	Depth : 24.00-24.14m 26/50(65mm), Rec=14cm
– 34.64m	Very weak to weak, light grey and yellowish brown, moderately to highly weathered and highly to extremely fractured SANDSTONE/SILTSTONE interbedded with very weak, dark grey and reddish brown, highly weathered and extremely fractured SHALE.	C	3		Depth : 24.14-25.64m Rec=150cm RQD=8%
		C	4		Depth : 25.64-27.14m Rec=120cm RQD=0%
		C	5		Depth : 27.14-28.64m Rec=121cm RQD=0%
		C	6		Depth : 28.64-30.14m Rec=126cm RQD=0%
		C	7		Depth : 30.14-31.64m Rec=115cm RQD=0%
		C	8		Depth : 31.64-33.14m Rec=125cm RQD=0%
		C	9		Depth : 33.14-34.64m Rec=115cm RQD=0%
	END OF BH-7A AT 34.64m				

SPT, N-Value Vs Depth



Groundwater Levels from below the Existing Ground Level:
13/11/2014 - 2.80m (6:00pm)
14/11/2014 - 3.20m (7:00am)
14/11/2014 - 4.10m (4:00pm)
15/11/2014 - 4.80m (8.00am)
15/11/2014 - 5.00m (6:00pm)
16/11/2014 - 5.00m (8:20am)
16/11/2014 - 5.10m (2:40pm)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Rayhan
Recorded By : Suhaizal
Checked By : Alex Leong
Confirmed By : Roger YONG

Location : Kota Kinabalu
Date Started : 17/01/2014
Date Completed : 19/01/2014
Type of Boring : Rotary Wash Boring

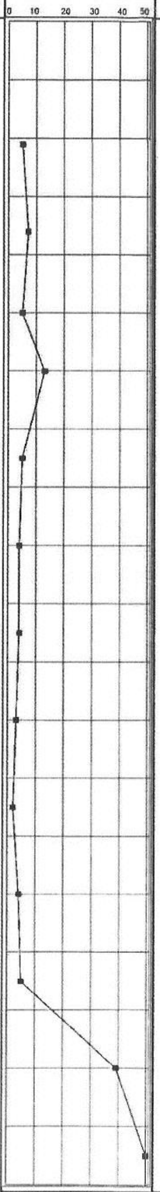
Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 2
Ground Elev. : Existing Ground Level
Coordinate : N.664008; E. 709320

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
0.00 – 5.80m	Loose, dark brown and dark grey, fine SAND to slightly Silty fine to coarse SAND with some gravel and seashell fragments.	UD	0		Depth : 1.50-2.10m Rec=0cm
		N-1	D-1	5	Depth : 2.10-2.55m 1/2/1/1/1/2, Rec=5cm
		UD	0		Depth : 3.00-3.60m Rec=0cm
		N-2	D-2	7	Depth : 3.60-4.05m 1/2/2/1/2/2, Rec=24cm
		UD	0		Depth : 4.50-4.95m Rec=0cm
		N-3	D-3	5	Depth : 4.95-5.40m 1/0/1/1/2/1, Rec=15cm
5.80m – 8.00m	Loose to medium dense, dark grey, CORAL and SEASHELL fragments (Coarse SAND to Gravel size).	N-4	D-4	13	Depth : 6.00-6.45m 2/3/5/3/2/3, Rec=25cm
		N-5	D-0	5	Depth : 7.50-7.95m 4/3/2/1/1/1, Rec=0cm
8.00m – 17.40m	Very loose to loose, dark grey, slightly Silty fine SAND with some CORAL and SEASHELL fragments.	N-6	D-6	4	Depth : 9.00-9.45m 1/0/1/1/1/1, Rec=34cm
		N-7	D-7	4	Depth : 10.50-10.95m 1/1/1/1/1/1, Rec=20cm
		N-8	D-8	3	Depth : 12.00-12.45m 0/1/0/1/1/1, Rec=22cm
		N-9	D-9	2	Depth : 13.50-13.95m 1/0/1/0/0/1, Rec=21cm
		N-10	D-10	4	Depth : 15.00-15.45m 1/1/1/1/1/1, Rec=24cm
		N-11	D-11	5	Depth : 16.50-16.95m 1/1/1/1/1/2, Rec=23cm
17.40m – 18.80m	Dense, light grey, fine SAND with some parental rock fragments.	N-12	D-12	39	Depth : 18.00-18.45m 5/6/9/7/11/12, Rec=16cm
18.80m – 20	Very dense, light grey, Silty fine SAND.	N-13	D-13	>50	Depth : 19.50-19.755m 12/21/31/19(30mm), Rec=24cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Liyok | Recorded By : Joseph
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Alex Leong | Confirmed By : Roger YONG

Location : Kota Kinabalu
Date Started : 17/01/2014
Date Completed : 19/01/2014
Type of Boring : Rotary Wash Boring

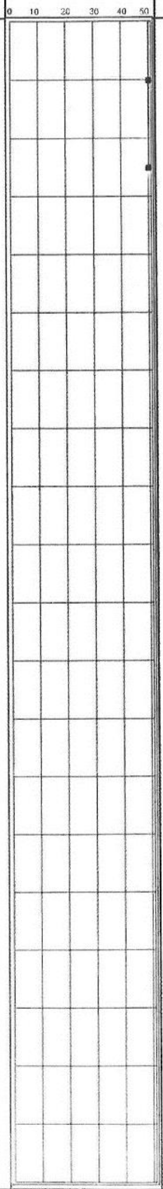
Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 2
Ground Elev. : Existing Ground Level
Coordinate : N.664008; E. 709320

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
20 – 23.10m	Hard, dark grey, Clayey Sandy SILT with rock fragments.	N-14	D-14	>50	Depth : 21.00-21.265m 11/22/30/20(40mm), Rec=20cm
		N-15	D-15	>50	Depth : 22.50-22.755m 7/19/31/19(30mm), Rec=16cm
23.10m – 30.60m	Very weak and weak, dark grey, fresh to slightly weathered and highly fractured SANDSTONE/SILTSTONE interbeded very weak, dark grey, highly weathered and highly fractured SHALE.	C	1		Depth : 23.10-24.60m Rec=103cm RQD=0%
		C	2		Depth : 24.60-26.10m Rec=113cm RQD=0%
		C	3		Depth : 26.10-27.60m Rec=126cm RQD=0%
		C	4		Depth : 27.60-29.10m Rec=116cm RQD=0%
		C	5		Depth : 29.10-30.60m Rec=130cm RQD=0%
30.60m – 32.10m	Weak, light grey, fresh and highly fractured SANDSTONE.	C	6		Depth : 30.60-32.10m Rec=138cm RQD=10%
	END OF BH-2 At 32.10m				

SPT, N-Value Vs Depth

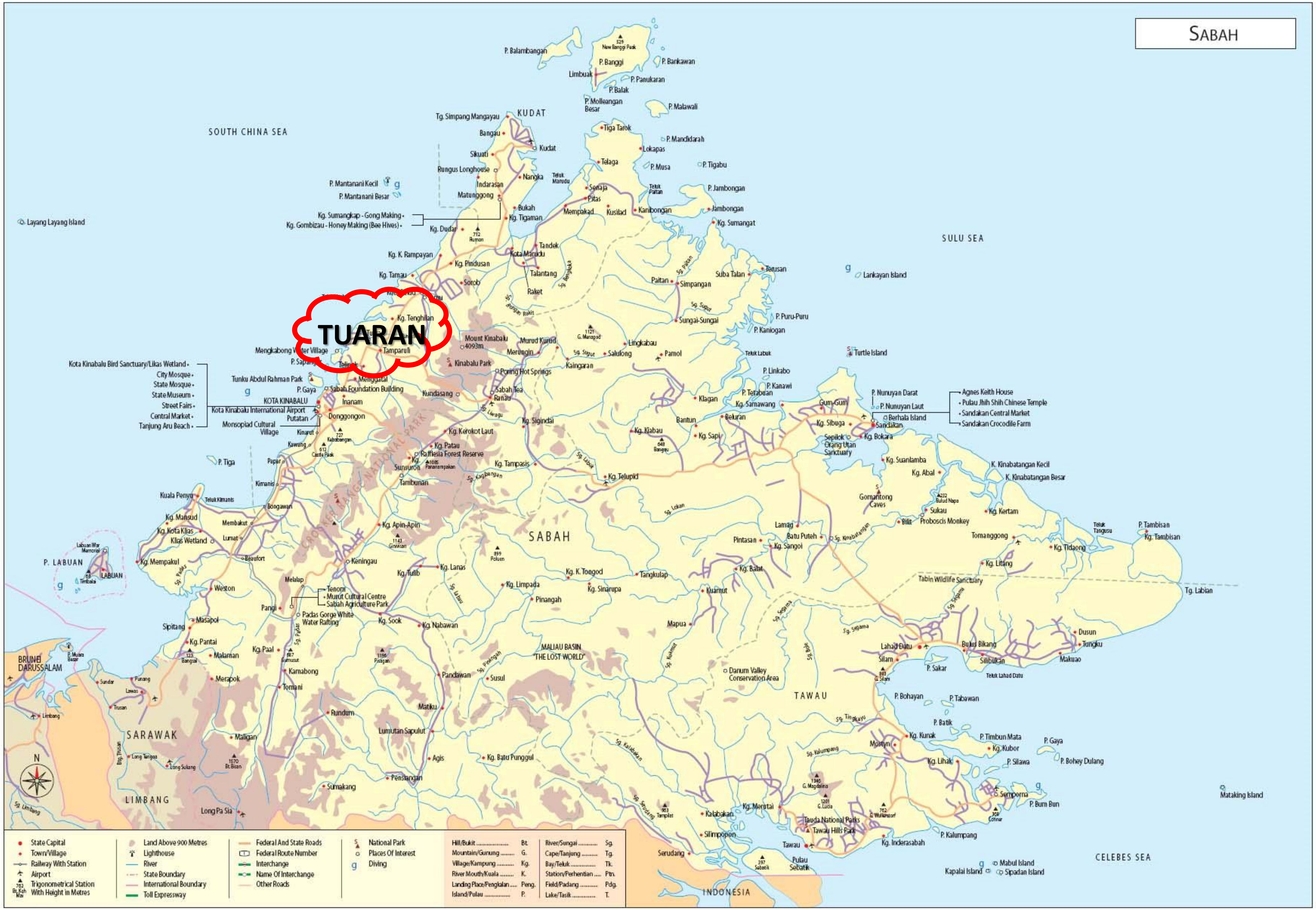


Groundwater Levels :
17.01.14 - 0.50m (5.30pm)
18.01.14 - 2.33m (7.00am)
18.01.14 - 4.10m (5.30pm)
19.01.14 - 2.15m (7.15am)
19.01.14 - 3.15m (2.00pm)
20.01.14 - 2.20m (8.00am)
20.01.14 - 1.38m (4.00pm)
21.01.14 - 1.35m (8.30am)
22.01.14 - 1.40m (8.00am)
23.01.14 - 1.40m (8.00am)
24.01.14 - 1.44m (10.40am)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Liyok | Recorded By : Joseph
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Alex Leong | Confirmed By : Roger YONG



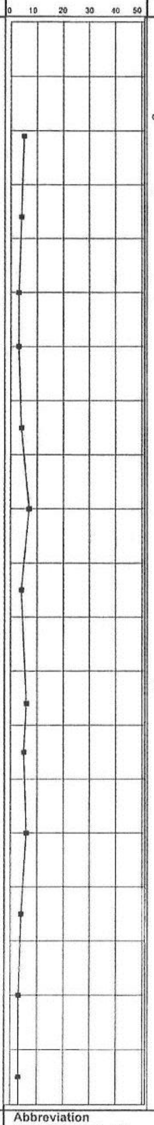
SABAH
TUARAN
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
TAWAU
SARAWAK
LIMBANG
INDONESIA
BRUNEI DARUSSALAM
P. LABUAN
KOTA KINABALU
Kota Kinabalu International Airport
Tunku Abdul Rahman Park
Mount Kinabalu 4093m
Kinabalu Park
Poring Hot Springs
Sandakan
Lahad Datu
Tawau
Semporna
Kudat
Kota Marudu
Tamparuli
Kg. Tenghilan
Mengkabong Water Village
Ranau
Kundasang
Keningau
Tenom
Beaufort
Papar
MALIAU BASIN "THE LOST WORLD"
Danum Valley Conservation Area
Tabin Wildlife Sanctuary
Sepilok Orang Utan Sanctuary
Gomantong Caves
Tawau Hills Park
CROCKER RANGE NATIONAL PARK
P. Banggi
P. Balambangan
Layang Layang Island
Lankayan Island
Turtle Island
Mataking Island
Sipadan Island
Mabul Island
Kapalai Island
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

Location : Tuaran
Date Started : 04/04/2014
Date Completed : 05/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 36.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0–1.00m	Yellowish brown, Silty SAND.							
1.00m–4.50m	Loose, dark grey, Silty Clayey SAND.		UD	1		c_u = 13kN/m^2		Depth : 1.50-2.10m Rec= 60cm
			N-1	D-1			5	Depth : 2.10-2.55m 1/1/1/1/1/2, Rec= 45cm
			UD	2		c_u = 9kN/m^2		Depth : 3.00-3.60m Rec= 60cm
			N-2	D-2			4	Depth : 3.60-4.05m 1/1/1/1/1/1, Rec= 45cm
4.50m–9.50m	Very loose to loose, light grey, fine SAND.		UD	0				Depth : 4.50-5.00m, Rec= 0cm
			N-3	D-3			3	Depth : 5.00-5.45m 1/0/1/0/1/1, Rec= 40cm
			N-4	D-4			3	Depth : 6.00-6.45m 1/1/1/0/1/1, Rec= 28cm
			N-5	D-5			4	Depth : 7.50-7.95m 1/1/1/1/1/1, Rec= 30cm
			N-6	D-6			7	Depth : 9.00-9.45m 1/2/2/2/1/2, Rec= 32cm
9.50m–18.00m	Soft to medium stiff, dark grey, Sandy SILT.		N-7	D-7			4	Depth : 10.50-10.95m 1/2/1/1/1/1, Rec= 45cm
			UD	3		c_u = 6kN/m^2		Depth : 12.00-12.60m Rec= 58cm
			N-8	D-8			6	Depth : 12.60-13.05m 1/1/1/1/2/2, Rec= 45cm
			N-9	D-9			5	Depth : 13.50-13.95m 1/1/1/1/1/2, Rec= 45cm
			N-10	D-10			6	Depth : 15.00-15.45m 1/1/1/1/2/2, Rec= 45cm
			N-11	D-11			4	Depth : 16.50-16.95m 1/0/1/1/1/1, Rec= 45cm
18.00m–	Soft, dark grey, Sandy SILT.		N-12	D-12			3	Depth : 18.00-18.45m 1/0/1/0/1/1, Rec= 45cm
			N-13	D-13			3	Depth : 19.50-19.95m 1/1/1/1/1/0, Rec= 45cm



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

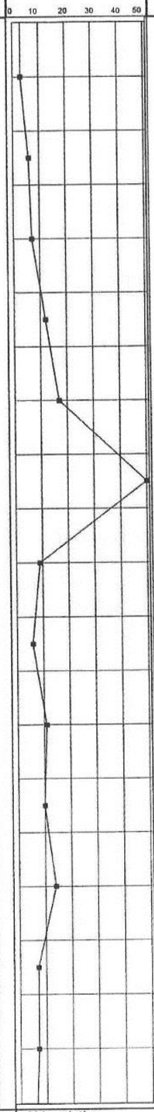
Operator : Ricky
Recorded By : Nizam
Checked By : Ridho Fadhliy
Confirmed By : Roger YONG

Location : Tuaran
Date Started : 04/04/2014
Date Completed : 05/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 36.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
–25.50m	Soft to medium stiff, dark grey, Sandy SILT.		N-14	D-14			3	Depth : 21.00-21.45m 1/0/1/1/0/1, Rec= 45cm
			N-15	D-15			6	Depth : 22.50-22.95m 1/1/1/1/2/2, Rec= 45cm
			N-16	D-16			7	Depth : 24.00-24.45m 1/1/1/2/2/2, Rec= 45cm
25.50m–28.50m	Stiff to very stiff, Sandy Clayey SILT.		N-17	D-17			12	Depth : 25.50-25.95m 1/2/2/3/3/4, Rec= 40cm
			N-18	D-18			17	Depth : 27.00-27.45m 2/2/3/4/5/5, Rec= 41cm
28.50m–30.00m	Very dense, yellowish brown, Silty SAND.		N-19	D-19			>50	Depth : 28.50-28.795m 5/13/19/31(70mm), Rec= 10cm
30.00m–36.00m	Loose to medium dense, light grey, fine SAND.		N-20	D-20			9	Depth : 30.00-30.45m 1/1/2/2/2/3, Rec= 23cm
			N-21	D-21			6	Depth : 31.50-31.95m 1/1/1/2/1/2, Rec= 39cm
			N-22	D-22			11	Depth : 33.00-33.45m 2/2/2/3/3/3, Rec= 33cm
			N-23	D-23			10	Depth : 34.50-34.95m 1/2/2/2/3/3, Rec= 32cm
36.00m–38.00m	Loose to medium dense, dark grey, fine SAND.		N-24	D-24			14	Depth : 36.00-36.45m 2/2/3/4/4/3, Rec= 38cm
			N-25	D-25			7	Depth : 37.50-37.95m 1/2/1/2/2/2, Rec= 29cm
38.00m–	Loose, dark grey, Silty Clayey SAND.		N-26	D-26			7	Depth : 39.00-39.45m 1/0/1/2/2/2, Rec= 30cm



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

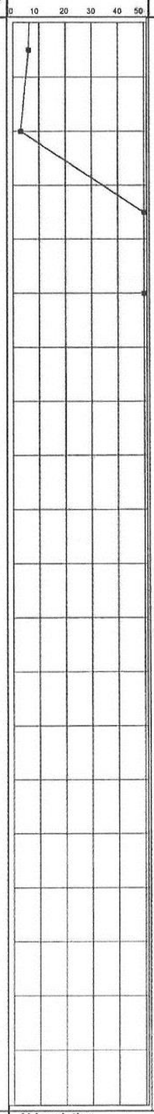
Operator : Ricky
Recorded By : Nizam
Checked By : Ridho Fadhliy
Confirmed By : Roger YONG

Location : Tuaran
Date Started : 04/04/2014
Date Completed : 05/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 36.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 3 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
–42.60m	Very loose to medium dense, dark grey, Silty Clayey SAND.		N-27	D-27			6	Depth : 40.50-40.95m 1/1/1/2/1/2, Rec= 32cm
			N-28	D-28			3	Depth : 42.00-42.45m 1/2/1/0/1/1, Rec= 36cm
42.60m–	Very dense, light grey, fine SAND.		N-29	D-29			>50	Depth : 43.50-43.95m 19/38/50(50mm), Rec= 6cm
			N-30	D-30			>50	Depth : 45.00-45.115m 35/50(40mm), Rec= 4cm
	END of BH-1 at 45.115m							
								Groundwater levels: 04.04.2014 - 2.00m (6.10pm) 05.04.2014 - 2.15m (7.30am) 05.04.2014 - 2.30m (1.50pm)



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Ricky
Recorded By : Nizam
Checked By : Ridho Fadhliy
Confirmed By : Roger YONG

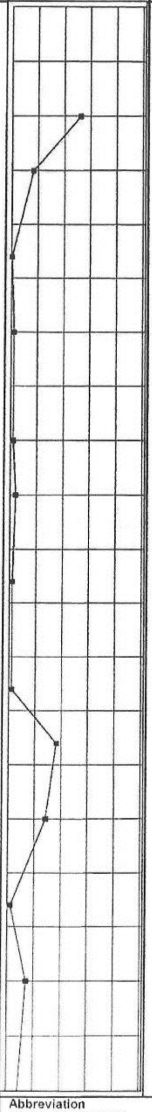
Location : Tuaran
Date Started : 19/08/2014
Date Completed : 20/08/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 45.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine/Cloudy

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–2.80	Medium dense, light brown, fine SAND.	UD	0			Depth : 1.50-2.10m Rec=0cm
		N-1	D-1		26	Depth : 2.10-2.55m 3/6/6/7/7/6, Rec=43cm
2.80–19.00	Very loose to medium dense, dark grey, fine SAND with traces of seashell fragments.	N-2	D-2		8	Depth : 3.00-3.45m 1/2/2/2/2/2, Rec=45cm
		N-3	D-0		0	Depth : 4.50-4.95m 1/0/0/0/0/0, Rec=0cm
		N-4	D-3		1	Depth : 6.00-6.45m 1/0/0/1/0/0, Rec=34cm
		UD	0		0	Depth : 7.50-8.10m Rec=0cm
		N-5	D-4		1	Depth : 8.10-8.55m 1/0/0/0/1/0, Rec=45cm
		N-6	D-5		2	Depth : 9.00-9.45m 0/0/0/0/1/1, Rec=45cm
		N-7	D-6		1	Depth : 10.50-10.95m 1/1/0/0/0/1, Rec=45cm
		UD	1	Cu=16kN/m²		Depth : 12.00-12.60m Rec=41cm
		N-8	D-7		1	Depth : 12.60-13.05m 1/1/0/0/1/0, Rec=45cm
		N-9	D-8		18	Depth : 13.50-13.95m 2/3/4/4/5/5, Rec=45cm
		N-10	D-9		14	Depth : 15.00-15.45m 2/2/3/3/3/5, Rec=45cm
		N-11	D-0		1	Depth : 16.50-16.95m 1/1/0/0/1/0, Rec=0cm
		N-12	D-0		7	Depth : 18.00-16.45m 2/2/3/4/0/0, Rec=0cm
19.00–	Medium stiff, dark grey, Sandy Clayey SILT with traces of seashell fragments.	UD	0			Depth : 19.50-20.10m Rec=0cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample D-Disturbed Sample C-Core
SPT-Standard Penetration Test N-SPT-N Value Rec-Recovery
RQD-Rock Quality Designation VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Vera C.
Confirmed By : Roger YONG

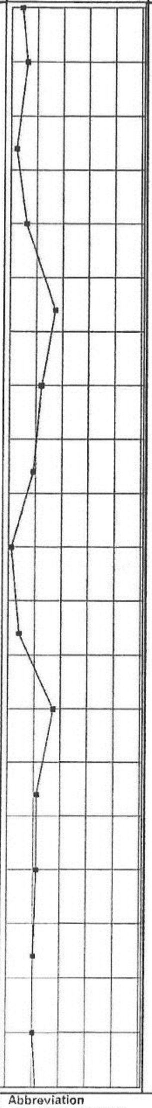
Location : Tuaran
Date Started : 19/08/2014
Date Completed : 20/08/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 45.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine/Cloudy

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
–20.80	Medium stiff, dark grey, Sandy Clayey SILT with traces of seashell fragments.	N-13	D-10		4	Depth : 20.10-20.55m 1/1/1/1/1/1, Rec=45cm
20.80–28.00	Very loose to medium dense, dark grey, fine SAND with traces of seashell fragments.	N-14	D-11		6	Depth : 21.00-21.45m 1/0/1/1/2/2, Rec=45cm
		N-15	D-12		2	Depth : 22.50-22.95m 1/1/1/0/1/0, Rec=42cm
		N-16	D-13		6	Depth : 24.00-24.45m 1/2/2/3/1/0, Rec=34cm
		N-17	D-14		17	Depth : 25.50-25.95m 2/2/3/4/5/5, Rec=45cm
		N-18	D-15		12	Depth : 27.00-27.45m 1/2/2/3/4/3, Rec=39cm
28.00–29.50	Loose, dark grey, Clayey Silty SAND with traces of seashell fragments.	N-19	D-16		9	Depth : 28.50-28.95m 1/2/2/3/2/2, Rec=39cm
29.50–32.60	Very loose, dark grey, fine SAND with traces of seashell fragments.	N-20	D-17		1	Depth : 30.00-30.45m 1/0/1/0/0/0, Rec=26cm
		N-21	D-18		4	Depth : 31.50-31.95m 1/0/1/1/1/1, Rec=18cm
32.60–	Medium dense, dark grey, fine SAND.	N-22	D-19		17	Depth : 33.00-33.45m 2/3/4/4/4/5, Rec=39cm
		N-23	D-20		11	Depth : 34.50-34.95m 2/2/2/3/2/4, Rec=45cm
		N-24	D-21		11	Depth : 36.00-36.45m 1/2/2/3/2/4, Rec=45cm
		N-25	D-22		10	Depth : 37.50-37.95m 3/2/2/3/2/3, Rec=30cm
		N-26	D-23		10	Depth : 39.00-39.45m 2/2/2/3/2/3, Rec=45cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample D-Disturbed Sample C-Core
SPT-Standard Penetration Test N-SPT-N Value Rec-Recovery
RQD-Rock Quality Designation VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jo
Checked By : Vera C.
Confirmed By : Roger Y

Location : Tuaran
Date Started : 19/08/2014
Date Completed : 20/08/2014
Type of Boring : Rotary Wash Boring

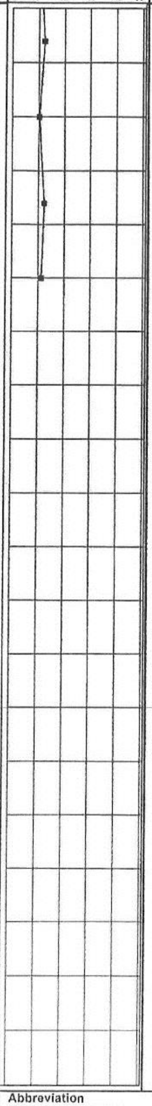
Rig Type : YWE D45
Casing Depth : 45.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine/Cloudy

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
40.00–45.45	Medium dense, dark grey, fine SAND.	N-27	D-24		12	Depth : 40.50-40.95m 2/3/2/3/3/7, Rec=39cm
		N-28	D-25		10	Depth : 42.00-42.45m 1/2/2/2/3/3, Rec=40cm
		N-29	D-26		12	Depth : 43.50-43.95m 3/2/3/2/3/4, Rec=42cm
		N-30	D-0		11	Depth : 45.00-45.45m 2/3/2/2/3/4, Rec=0cm
	END OF BH-1 AT 45.45m					

Groundwater Levels:
19/08/2014 - Full (6:10pm)
20/08/2014 - Full (8:00am)
20/08/2014 - Full (6:40pm)

SPT, N-Value Vs Depth

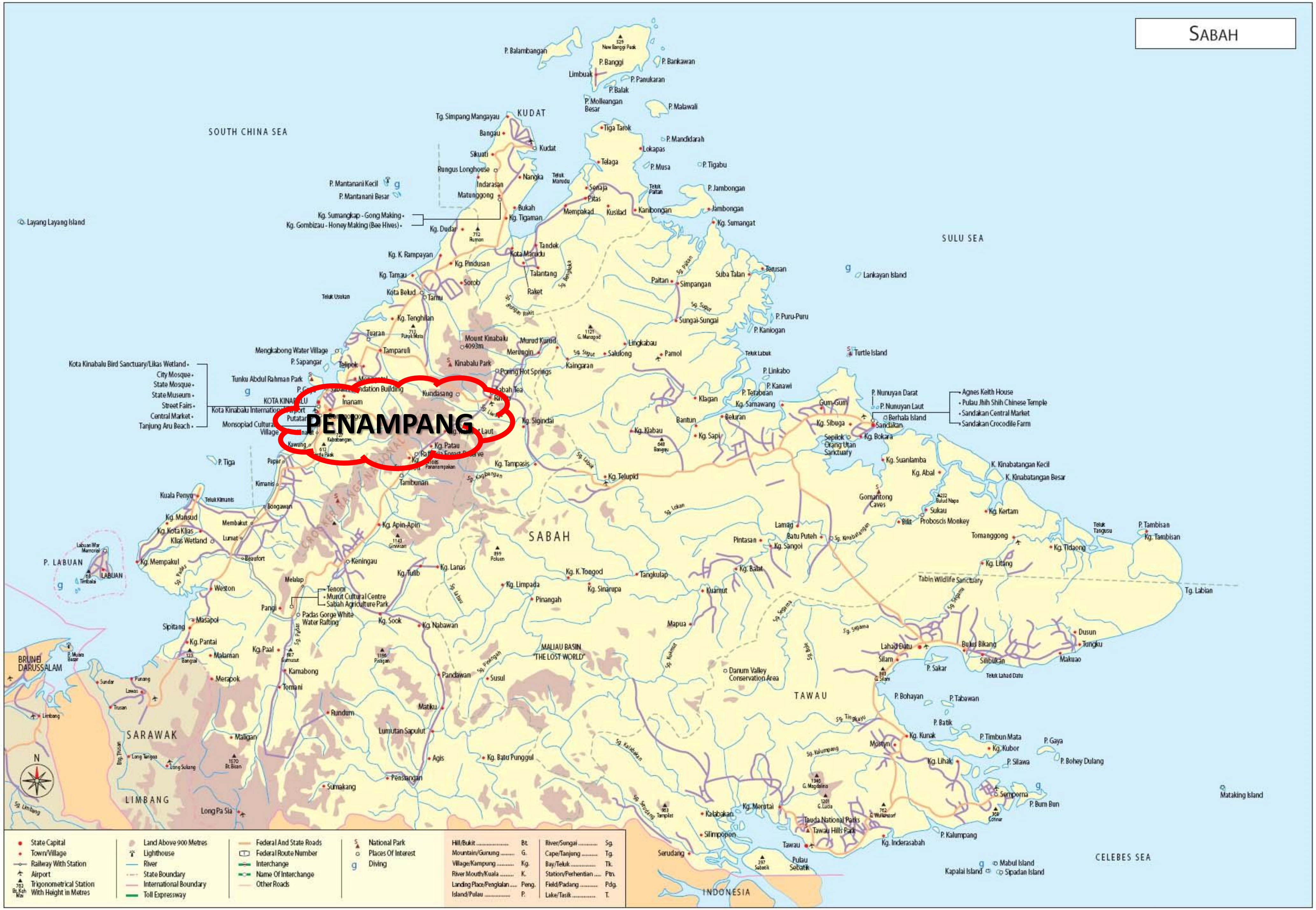


Project :

Abbreviation
UD-Undisturbed Sample D-Disturbed Sample C-Core
SPT-Standard Penetration Test N-SPT-N Value Rec-Recovery
RQD-Rock Quality Designation VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Vera C.
Confirmed By : Roger YONG


SABAH
PENAMPANG
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
SABAH
SARAWAK
LIMBANG
TAWAU
KUDAT
BRUNEI DARUSSALAM
INDONESIA
P. LABUAN
KOTA KINABALU
Mount Kinabalu 4093m
MALIAU BASIN "THE LOST WORLD"
Sandakan
Lahad Datu
Semporna
Tawau
Keningau
Tenom
Beaufort
Papar
Tambunan
Ranau
Kota Belud
Kota Marudu
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

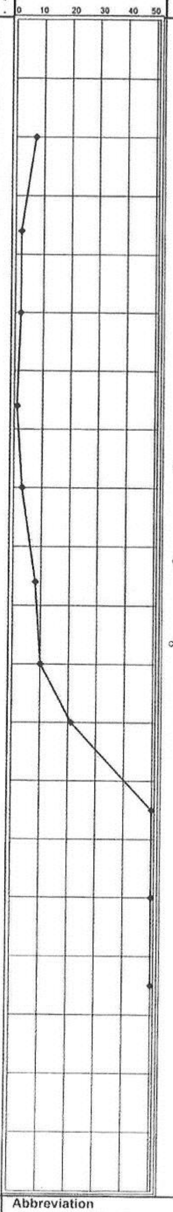
Location : Penampang
Date Started : 08/09/2013
Date Completed : 09/09/2013
Type of Boring : Rotary Wash Boring

Rig Type : JACRO 200
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-2
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Loose, dark brown and light grey, Silty fine SAND with some decayed matters.	UD	1			Depth : 1.50-2.00 Rec=50cm
	N-1	D-1		7	Depth : 2.00-2.45m 1/0/0/1/5/1, Rec=45cm
2.50m					
Very soft, black, Silty PEAT with decayed vegetations and wood fragments.	UD	0			Depth : 3.00-3.50m Rec=0cm
	N-2	D-0		2	Depth : 3.50-3.95m 1/1/0/1/1/0, Rec=0cm
	UD	0			Depth : 4.50-5.00m Rec=0cm
	N-3	D-2		2	Depth : 5.00-5.45m 1/1/0/1/1/0, Rec=45cm
	UD	0			Depth : 6.00-6.50m Rec=0cm
	N-4	D-3		1	Depth : 6.50-6.95m 1/0/0/0/1/0, Rec=19cm
	UD	2	cu=13kN/m²		Depth : 7.50-8.00m Rec=50cm
	N-5	D-4		3	Depth : 8.00-8.45m 1/0/1/1/0/1, Rec=45cm
8.60m					
Medium stiff, dark grey, Sandy Clayey SILT with some gravel.	UD	3	cu=27kN/m²		Depth : 9.00-9.50m Rec=32cm
	N-6	D-5		8	Depth : 9.50-9.95m 1/1/1/2/2/3, Rec=23cm
10.50m					
Stiff to very stiff, dark grey, Sandy SILT with some parental rock fragments.	UD	4	cu=166kN/m²		Depth : 10.50-11.00m Rec=38cm
	N-7	D-6		10	Depth : 11.00-11.45m 1/2/2/2/3/3, Rec=26cm
	N-8	D-7		21	Depth : 12.00-12.45m 2/2/3/5/6/7, Rec=27cm
13.10m					
Very dense, dark brown, Silty SAND with some parental rock fragments.	N-9	D-8		>50	Depth : 13.50-13.78m 16/23/27/23(55mm), Rec=17cm
	N-10	D-9		>50	Depth : 15.00-15.22m 19/28/50(75mm), Rec=13cm
16.50m					
Very weak to weak, yellowish brown, highly to extremely weathered and extremely fractured, SANDSTONE.	N-11	D-0		>50	Depth : 16.50m Hammer Rebound
	C	1			Depth : 16.50-18.00m Rec=86cm RQD=0%
18.20m					
Medium strong to strong, light grey, fresh to slightly weathered and highly fractured SANDSTONE interbedded with very weak, dark grey, highly weathered and extremely fractured SHALE.	C	2			Depth : 18.00-19.50m Rec=100cm RQD=0%

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

Operator : Tan
Checked By : Vera C.
Recorded By : L.S. Keang
Confirmed By : Roger YONG

Location : Penampang
Date Started : 08/09/2013
Date Completed : 09/09/2013
Type of Boring : Rotary Wash Boring

Rig Type : JACRO 200
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-2
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Medium strong to strong, light grey, fresh to slightly weathered and highly fractured SANDSTONE interbedded with very weak, dark grey, highly weathered and extremely fractured SHALE.	C	3			Depth : 19.50-21.00m Rec=110cm RQD=0%
	C	4			Depth : 21.00-22.50m Rec=125cm RQD=0%
	C	5			Depth : 22.50-24.00m Rec=128cm RQD=0%
	C	6			Depth : 24.00-25.50m Rec=108cm RQD=0%
25.50m					
Medium strong to strong, light grey, fresh to slightly weathered and highly fractured, SANDSTONE.	C	7			Depth : 25.50-27.00m Rec=123cm RQD=23%
	C	8			Depth : 27.00-28.50m Rec=134cm RQD=16%
	C	9			Depth : 28.50-30.00m Rec=138cm RQD=22%
	C	10			Depth : 30.00-31.50m Rec=124cm RQD=10%
END OF BH-2 AT 31.50m					

Groundwater Levels:
09/09/2013 - 0.34m (7:30am)
10/09/2013 - 0.28m (7:50am)

Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
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D-Disturbed Sample
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C-Core
Rec-Recovery

Operator : Tan
Checked By : Vera C.
Recorded By : L.S. Keang
Confirmed By : Roger YONG

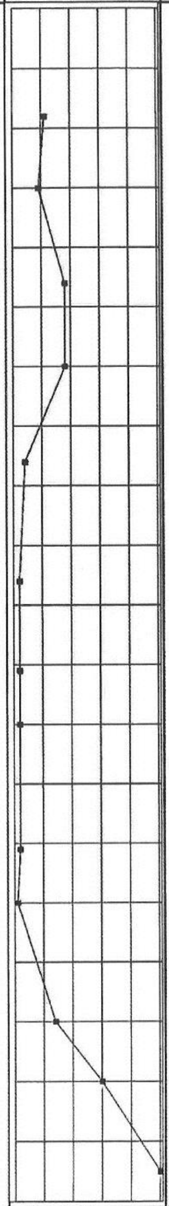
Location : Penampang
Date Started : 27/11/2014
Date Completed : 28/11/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 19.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-4
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–10.40m	Very loose to medium dense, dark grey and dark brown, Clayey Silty SAND with some gravel.		UD	0				Depth: 1.50-1.80m Rec=0cm
			N-1	D-1			11	Depth: 1.80-2.25m 1/2/2/2/3/4, Rec=18cm
			N-2	D-2			9	Depth: 3.00-3.45m 2/2/2/2/2/3, Rec=17cm
			N-3	D-3			18	Depth: 4.50-4.95m 2/4/3/4/5/6, Rec=17cm
			N-4	D-4			18	Depth: 6.00-6.45m 4/4/4/4/5/5, Rec=13cm
			N-5	D-5			4	Depth: 7.50-7.95m 0/0/1/1/1/1, Rec=30cm
			UD	0				Depth: 9.00-9.60m Rec=0cm
			N-6	D-6			2	Depth: 9.60-10.05m 0/0/0/0/1/1, Rec=22cm
10.40m–13.50m	Very soft, black, Silty PEAT with decayed matters.		UD	1		c_u=12kN/m²		Depth: 10.50-11.10m Rec=50cm
			N-7	D-7			2	Depth: 11.10-11.55m 1/0/1/0/1/0, Rec=45cm
			N-8	D-8			2	Depth: 12.00-12.45m 0/1/0/1/0/1, Rec=45cm
13.50m–17.10m	Very loose, dark grey, Silty Clayey SAND.		UD	2		c_u=15kN/m²		Depth: 13.50-14.10m Rec=52cm
			N-9	D-9			2	Depth: 14.10-14.55m 0/0/1/0/0/1, Rec=38cm
			N-10	D-10			1	Depth: 15.00-15.45m 0/0/0/1/0/0, Rec=36cm
			UD	3		c_u=15kN/m²		Depth: 16.50-17.10m Rec=50cm
17.10m–19.30m	Medium dense, light to dark grey, Silty fine SAND.		N-11	D-11			14	Depth: 17.10-17.55m 2/2/2/4/4/4, Rec=45cm
			N-12	D-12			30	Depth: 18.00-18.45m 4/5/5/6/8/11, Rec=21cm
19.30m–	Very dense, dark grey, Silty fine SAND.		N-13	D-13			>50	Depth: 19.50-19.84m 9/13/16/19/15(40mm), Rec=20cm

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

Operator : Big Boy
Recorded By : Nizam
Checked By : Vera C.
Confirmed By : Roger YONG

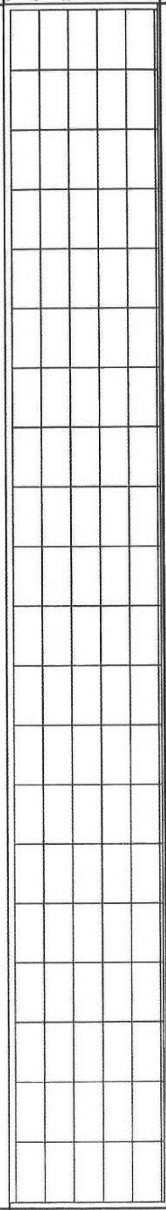
Location : Penampang
Date Started : 27/11/2014
Date Completed : 28/11/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 19.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-4
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20.00–23.00m	Very weak to weak, light grey and light brown, highly to extremely weathered and highly to extremely weathered, SANDSTONE.		C	1				Depth: 20.00-21.50m Rec=150cm RQD=0%
			C	2				Depth: 21.50-23.00m Rec=150cm RQD=22%
23.00m	END OF BH-4 AT 23.00m							**Groundwater tables below the existing ground level:** 27/11/2014 - 0.28m (4:50pm) 28/11/2014 - 0.49m (10:00am) 28/11/2014 - 0.15m (12:00pm)

SPT, N-Value Vs Depth



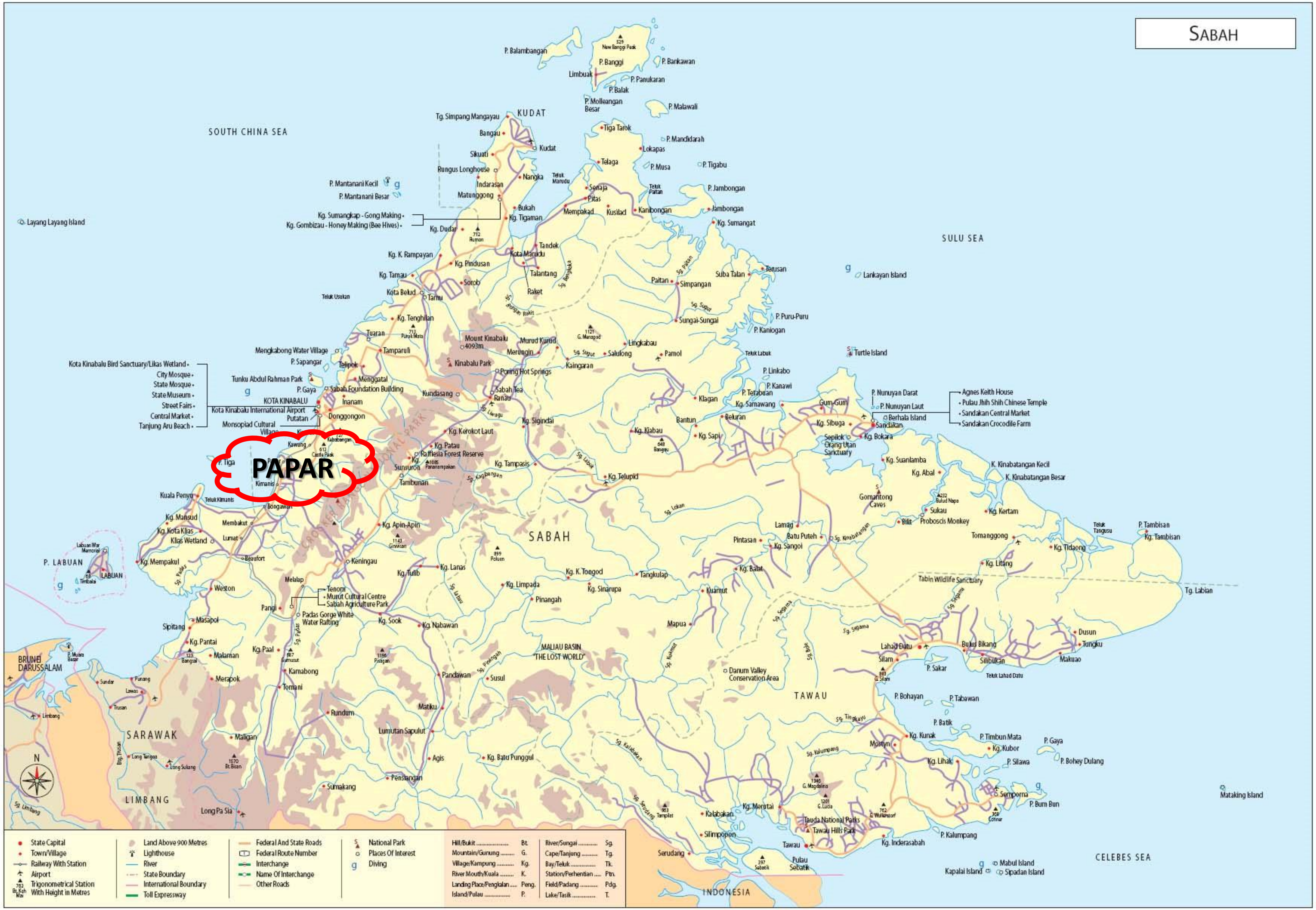
Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

Operator : Big Boy
Recorded By : Nizam
Checked By : Vera C.
Confirmed By : Roger YONG


SABAH
PAPAR
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
TAWAU
SARAWAK
LIMBANG
INDONESIA
BRUNEI DARUSSALAM
P. LABUAN
LABUAN
KOTA KINABALU
Kota Kinabalu International Airport
Putatan
Donggongon
Kimanis
Bongawan
Kuala Penyu
Beaufort
Tenom
Keningau
Tambunan
Ranau
Kota Belud
Tuaran
Tamparuli
Kota Marudu
Pitas
Kudat
Sandakan
Lahad Datu
Semporna
Tawau
Kunak
Sipitang
Weston
Mount Kinabalu 4093m
Kinabalu Park
Poring Hot Springs
Tabin Wildlife Sanctuary
Danum Valley Conservation Area
MALIAU BASIN "THE LOST WORLD"
Sepilok Orang Utan Sanctuary
Turtle Island
P. Banggi
P. Balambangan
Layang Layang Island
Sipadan Island
Mabul Island
Kapalai Island
Mataking Island
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit
Mountain/Gunung
Village/Kampung
River Mouth/Kuala
Landing Place/Pengkalan
Island/Pulau
River/Sungai
Cape/Tanjung
Bay/Teluk
Station/Perhentian
Field/Padang
Lake/Tasik

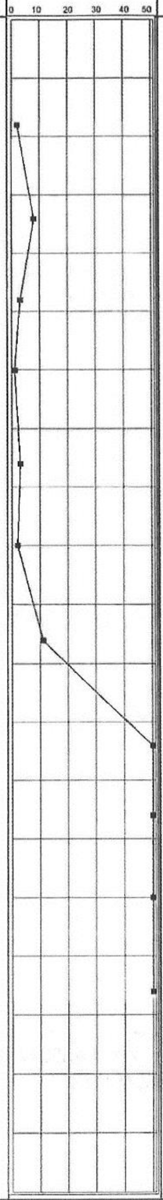
Location : Papar
Date Started : 13/04/2012
Date Completed : 15/04/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 3
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1	Dark brown, Silty SAND with sandstone fragments. 1.50m					
2	Very loose to loose, light grey, fine SAND with traces of seashell fragments.	UD	0			Depth : 1.50-1.87m Rec=0cm
		N-1	D-1		2	Depth : 1.87-2.32m 1/0/0/0/1/1, Rec=28cm
3		UD	0			Depth : 3.00-3.34m Rec=0cm
4	4.50m	N-2	D-2		8	Depth : 3.34-3.79m 1/1/2/2/2/2, Rec=30cm
5	Very loose, light grey, fine SAND with traces of seashell fragments. 6.00m	UD	0			Depth : 4.50-4.88m Rec=0cm
		N-3	D-3		3	Depth : 4.88-5.33m 1/1/1/0/1/1, Rec=38cm
6	Very loose, dark grey, fine to coarse SAND with some seashell and coral fragments.	UD	0			
		N-4	D-4		1	Depth : 6.00-6.02m, Rec=0cm Depth : 6.02-6.47m 1/0/0/1/0/0, Rec=9cm
7		UD	0			
8		N-5	D-5		3	Depth : 7.50-7.53m, Rec=0cm Depth : 7.53-7.98m 1/1/1/0/1/1, Rec=13cm
9		UD	0			
10	10.58m	N-6	D-6		2	Depth : 9.00-9.04m, Rec=0cm Depth : 9.04-9.49m 1/1/0/1/0/1, Rec=19cm
	Medium dense, dark grey, Silty fine SAND with traces of seashell fragments.	UD	0			
11		N-7	D-7		11	Depth : 10.50-10.58m, Rec=0cm Depth : 10.58-11.03m 3/1/1/2/3/5, Rec=38cm
12	12.30m	UD	1	C_u=27kN/m^2		Depth : 12.00-12.30m Rec=29cm
	Very dense, reddish brown, Silty SAND.	N-8	D-8		>50	Depth : 12.30-12.75m 5/5/12/18/20(75mm), Rec=33cm
13–14		N-9	D-9		>50	Depth : 13.50-13.745m 14/19/32/18(20mm), Rec=37cm
15	15.00m					
	Very dense, dark grey, Silty SAND.	N-10	D-10		>50	Depth : 15.00-15.24m 16/25/36/14(15mm), Rec=28cm
16	16.70m	N-11	D-0		>50	Depth : 16.50m Hammer Rebound
17–18	Very weak to weak, dark grey, fresh to moderately weathered and highly to moderately fractured SANDSTONE.	C	1			Depth : 16.70-18.20m Rec=150cm RQD=0%
19		C	2			Depth : 18.20-19.70m Rec=150cm RQD=15%
20	END OF BH-3 At 19.70m					

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Rayhan
Recorded By : Suhaizal

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

Location : Papar
Date Started : 13/04/2012
Date Completed : 15/04/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 3
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21						**Groundwater Level :** 13.04.12 - 1.27m (5.52pm) 14.04.12 - 1.52m (9.42am) 14.04.12 - 1.17m (6.54pm) 15.04.12 - 2.72m (8.37am) 15.04.12 - 1.55m (12.18pm) 16.04.12 - 1.38m (8.25am) 17.04.12 - 1.26m (8.45am) 18.04.12 - 1.24m (8.30am)
22						
23						
24						
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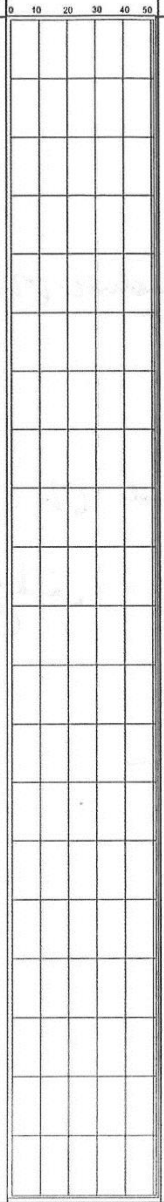
38						
39						
40						

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Rayhan
Recorded By : Suhaizal

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

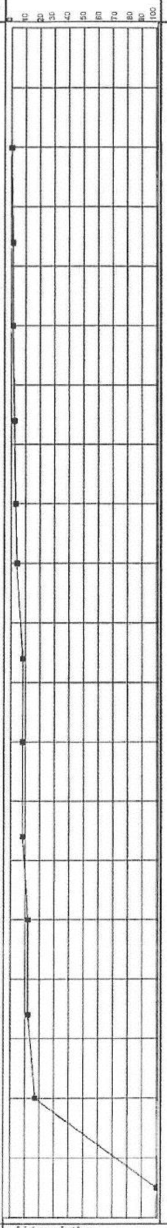
Location : Papar
Date Started : 25/10/2014
Date Completed : 25/10/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-3
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0–1.00	Light to dark brown, Silty Clayey SAND. 1.00m					
1.00–6.00	Very loose, blackish and dark grey, Silty Clayey SAND with decayed matters. 6.00m	UD	1			Depth: 1.50-2.10m Rec=59cm
		N-1	D-1		0	Depth: 2.10-2.55m 1/0/0/0/0/0, Rec=31cm
		UD	2	cu=9kN/m²		Depth: 3.00-3.60m Rec=36cm
		N-2	D-2		1	Depth: 3.60-4.05m 0/0/0/1/0/0, Rec=11cm
		UD	3			Depth: 4.50-5.10m Rec=16cm
		N-3	D-3		1	Depth: 5.10-5.55m 0/0/0/0/1/0, Rec=25cm
6.00–12.00	Very loose to loose, dark grey, Silty fine SAND with traces of seashell fragments. 12.00m	UD	4	cu=22kN/m²		Depth: 6.00-6.60m Rec=45cm
		N-4	D-4		2	Depth: 6.60-7.05m 1/0/0/1/0/1, Rec=33cm
		UD	5			Depth: 7.50-7.90m Rec=2cm
		N-5	D-5		3	Depth: 7.90-8.35m 1/1/1/0/1/1, Rec=23cm
		N-6	D-6		4	Depth: 9.00-9.45m 1/0/1/1/1/1, Rec=45cm
		N-7	D-7		8	Depth: 10.50-10.95m 1/2/2/2/2/2, Rec=45cm
12.00–15.00	Loose, dark grey and dark brown, Silty Clayey SAND with decayed matters. 15.00m	N-8	D-8		8	Depth: 12.00-12.45m 1/1/2/2/2/2, Rec=45cm
		N-9	D-9		8	Depth: 13.50-13.95m 2/2/2/2/2/2, Rec=45cm
15.00–16.50	Medium dense, light grey, Silty SAND. 16.50m	N-10	D-10		12	Depth: 15.00-15.45m 3/3/4/3/3/1, Rec=38cm
16.50–19.40	Medium dense, ligth grey, Silty Clayey SAND. 19.40m	N-11	D-11		12	Depth: 16.50-16.95m 3/3/3/3/3/3, Rec=45cm
		N-12	D-12		17	Depth: 18.00-18.45m 3/2/2/3/6/6, Rec=45cm
19.40–20	Medium strong to strong, light grey, fresh to slightly weathered, slightly fractured, SANDSTONE.	N-13	D-0		>100	Depth: 19.50m 100, Rec=0cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Rayhan
Recorded By : Suhaizal
Checked By : Vera C
Confirmed By : Roger YONG

Location : Papar
Date Started : 25/10/2014
Date Completed : 25/10/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-3
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20–22.50	Medium strong to strong, light grey, fresh to slightly weathered, slightly fractured, SANDSTONE.	C	1			Depth: 19.50-21.00m Rec=150cm RQD=86%
		C	2			Depth: 21.00-22.50m Rec=150cm RQD=75%
22.50	END OF BH-3 AT 22.50m					

Groundwater levels below the existing ground level:
25/10/2014 - 1.12m (4:52pm)
26/10/2014 - 0.42m (7:31am)
26/10/2014 - Full (5:02pm)
27/10/2014 - Full (7:55am)
27/10/2014 - Full (5:16pm)
28/10/2014 - Full (8:00am)
28/10/2014 - Full (5:15pm)
29/10/2014 - Full (8:23am)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Rayhan
Recorded By : Suhaizal
Checked By : Vera C.
Confirmed By : Roger YONG

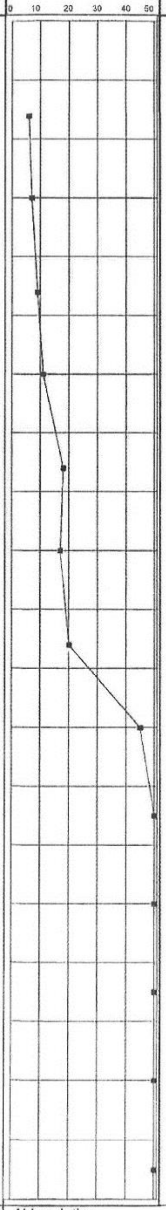
Location : Papar
Date Started : 30/12/2014
Date Completed : 31/12/2014
Type of Boring : Rotary Wash Boring

Rig Type : Toho-D1
Casing Depth : 12.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1								
2			N-1	D-1			6	Depth: 1.50-1.95m 1/1/2/1/1/2, Rec=16cm
3			N-2	D-2			7	Depth: 3.00-3.45m 1/2/2/1/2/2, Rec=18cm
4								
5			N-3	D-3			9	Depth: 4.50-4.95m 2/1/2/1/3/3, Rec=17cm
6	Loose to medium dense, dark grey, fine SAND/Silty fine SAND with traces of seashell fragments.		N-4	D-4			11	Depth: 6.00-6.45m 2/4/3/2/3/3, Rec=15cm
7								
8			N-5	D-5			18	Depth: 7.50-7.95m 3/4/4/5/4/5, Wash Sample
9			N-6	D-6			17	Depth: 9.00-9.45m 2/3/4/4/4/5, Wash Sample
10	10.50m							
11	Medium dense, dark grey, CORAL fragments with SILT. 11.50m		N-7	D-7			20	Depth: 10.50-10.95m 3/5/5/4/5/6, Rec=22cm
12	Dense, dark grey, Clayey fine SAND.		N-8	D-8			45	Depth: 12.00-12.45m 7/7/8/10/11/16, Rec=25cm
13	13.40m							
14			N-9	D-9			>50	Depth: 13.50-13.89m 9/11/13/15/18/4(15mm), Rec=14cm
15			N-10	D-10			>50	Depth: 15.00-15.34m 7/10/14/19/17(40mm), Rec=11cm
16								
17	Very dense, dark grey, Clayey Silty SAND with some rock fragments.		N-11	D-11			>50	Depth: 16.50-16.87m 10/12/16/17/17(70mm), Rec=9cm
18			N-12	D-12			>50	Depth: 18.00-18.29m 12/15/24/26(65mm), Rec=8cm
19			N-13	D-13			>50	Depth: 19.50-19.68m 18/37/50(30mm), Rec=7cm
20								

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Rynaldo | Recorded By : Lin Sie Keang
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C. | Confirmed By : Roger YONG

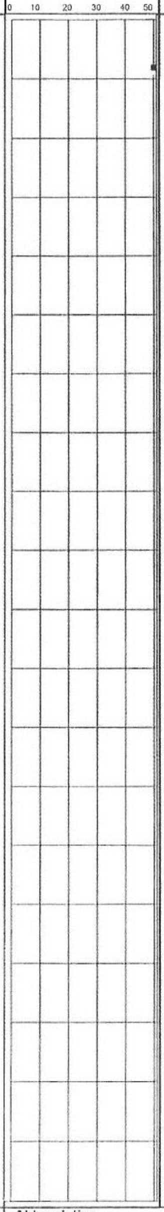
Location : Papar
Date Started : 30/12/2014
Date Completed : 31/12/2014
Type of Boring : Rotary Wash Boring

Rig Type : Toho-D1
Casing Depth : 12.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
	Very dense, dark grey, Clayey Silty SAND with some rock fragments.							
21	21.00m		N-14	D-0			>50	Depth: 21.00m Hammer Rebound
22	Very weak to medium strong, dark grey, fresh to moderately weathered and highly fractured, SANDSTONE.		C	1				Depth: 21.00-22.50m Rec=146cm RQD=0%
23	END OF BH-1 AT 22.50m							
24								Groundwater level below the existing ground level 31/12/2014 - Full
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								
37								
38								
39								
40								

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Rynaldo | Recorded By : Lin Sie Keang
STL GEOTECHNICAL ENGINEERING SDN. BHD.
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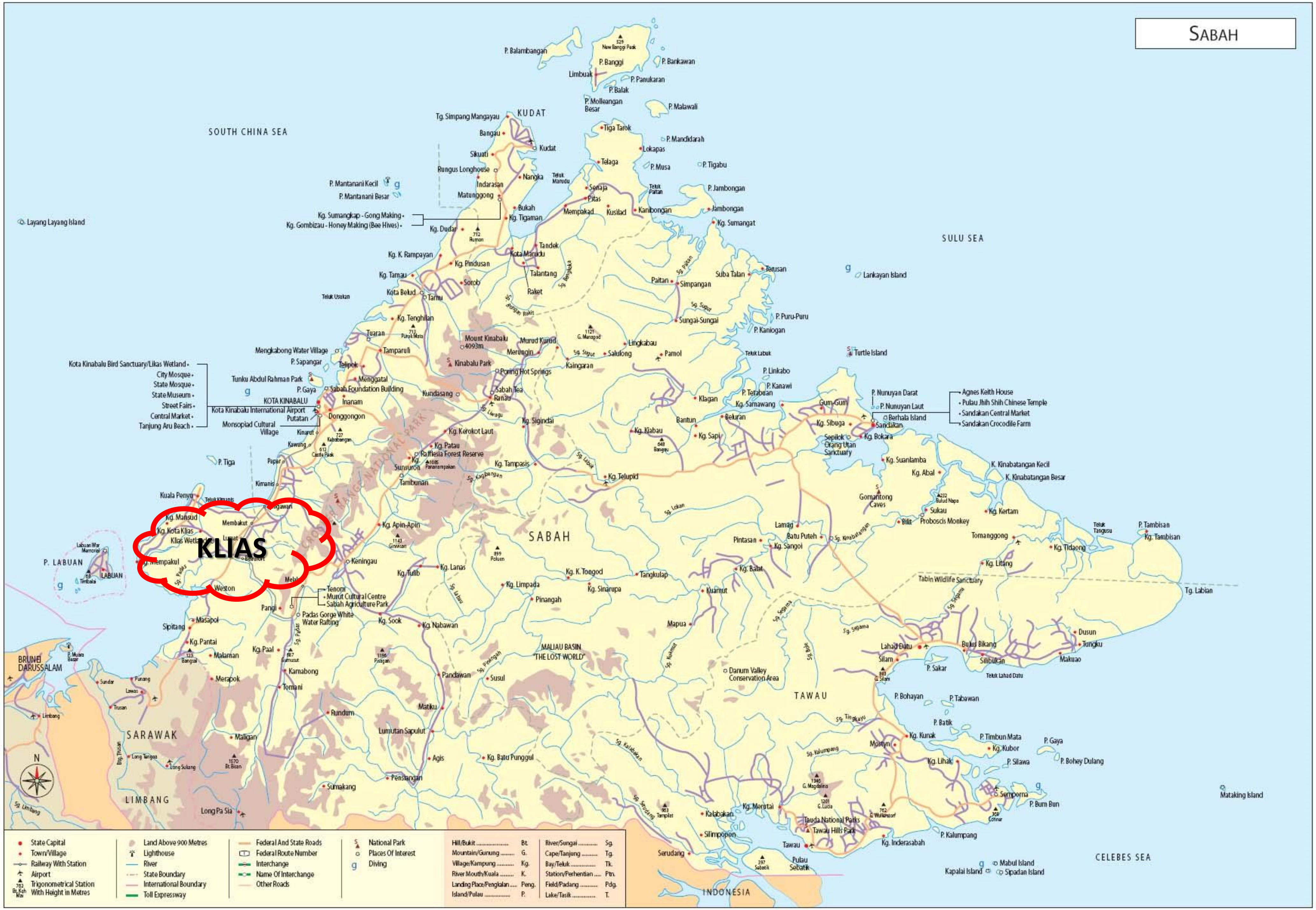


SABAH
KLIAS
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
SABAH
TAWAU
SARAWAK
LIMBANG
BRUNEI DARUSSALAM
INDONESIA
P. LABUAN
LABUAN
KUDAT
Kudat
P. Balambangan
P. Banggi
P. Bankawan
Limbuak
P. Panukaran
P. Balak
P. Molleangan Besar
P. Malawali
Tiga Tarok
P. Mandidarah
Lokapas
Telaga
P. Musa
P. Tigabu
Tg. Simpang Mangayau
Bangau
Sikuati
Rungus Longhouse
Indarasan
Matunggong
Nangka
Senaja
Pitas
P. Jambongan
Jambongan
Bukah
Kg. Tigaman
Mempakad
Kusilad
Kanibongan
Kg. Sumangat
P. Mantanani Kecil
P. Mantanani Besar
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
Kg. Dudar
Layang Layang Island
Kg. K. Rampayan
Kota Marudu
Tandek
Talantang
Raket
Kg. Pindusan
Kg. Tamau
Sorob
Kota Belud
Tamu
Teluk Usukan
Paitan
Simpangan
Suba Talan
Terusan
Lankayan Island
Kg. Tenghilan
P. Puru-Puru
P. Kaniogan
Sungai-Sungai
Tuaran
Tamparuli
Mengkabong Water Village
P. Sapangar
Telipok
Mount Kinabalu 4093m
Murud Kurud
Merungin
Kinabalu Park
Lingkabau
Salulong
Pamol
Kaingaran
Poring Hot Springs
Turtle Island
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Tunku Abdul Rahman Park
P. Gaya
KOTA KINABALU
Kota Kinabalu International Airport
Putatan
Menggatal
Sabah Foundation Building
Inanam
Donggongon
Monsopiad Cultural Village
Kinarut
Kawang
Kundasang
Sabah Tea
Ranau
Kg. Sigindai
Klagan
P. Linkabo
P. Kanawi
P. Tetabuan
Kg. Samawang
Gum-Gum
P. Nunuyan Darat
P. Nunuyan Laut
Berhala Island
Sandakan
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Kg. Sibuga
Kg. Bokara
Sepilok Orang Utan Sanctuary
Bantun
Beluran
Kg. Sapi
Kg. Kiabau
Kg. Kerokot Laut
Kg. Patau
Rafflesia Forest Reserve
Sunsuron
Tambunan
Kg. Tampasis
Kg. Telupid
Kg. Suanlamba
Kg. Abal
K. Kinabatangan Kecil
K. Kinabatangan Besar
P. Tiga
Papar
Kimanis
Kuala Penyu
Kg. Mansud
Membakut
Kg. Kota Klias
Klias Wetland
Lumat
Beaufort
Mempakul
Weston
Bongawan
Kg. Apin-Apin
Keningau
Gomantong Caves
Sukau
Proboscis Monkey
Bilit
Kg. Kertam
Lamag
Batu Puteh
Kg. Sangoi
Pintasan
Tomanggong
Kg. Tidaong
P. Tambisan
Kg. Tambisan
Kg. Litang
Tabin Wildlife Sanctuary
Tg. Labian
Kg. Lanas
Kg. Tulib
Kg. K. Tongod
Kg. Sinarupa
Kg. Limpada
Pinangah
Tangkulap
Kg. Balat
Kuamut
Tenom
Murut Cultural Centre
Sabah Agriculture Park
Padas Gorge White Water Rafting
Pangi
Kg. Sook
Kg. Nabawan
Mapua
MALIAU BASIN "THE LOST WORLD"
Danum Valley Conservation Area
Lahad Datu
Silam
Bukit Bikang
Silibukan
Dusun
Tungku
Makuao
P. Sakar
Teluk Lahad Datu
Sipitang
Masapol
Kg. Pantai
Malaman
Kg. Paal
Kamabong
Merapok
Tomani
Pandawan
Susul
Sundar
Punang
Lawas
Trusan
Limbang
Rundum
Matiku
Lumutan Sapulut
Maligan
Long Tengoa
Long Sukang
Agis
Kg. Batu Punggul
Sumakang
Pensiangan
Long Pa Sia
P. Bohayan
P. Tabawan
P. Batik
Kg. Kunak
Mostyn
P. Timbun Mata
Kg. Kubor
P. Gaya
P. Silawa
P. Bohey Dulang
Kg. Lihak
Semporna
P. Bum Bum
Mataking Island
Kalabakan
Kg. Merotai
Tawau National Parks
Tawau Hills Park
Simpopon
Serudong
Tawau
Pulau Sebatik
Kg. Inderasabah
P. Kalumpang
Mabul Island
Kapalai Island
Sipadan Island
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

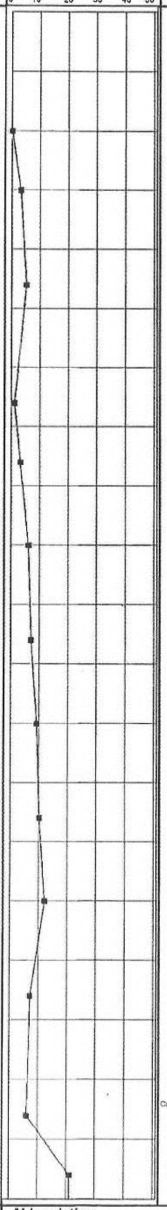
Location : Beaufort
Date Started : 04/09/2014
Date Completed : 06/09/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 36.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine/ Cloudy

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0–15.80	Very loose to loose, dark grey, Silty fine SAND with traces of decayed matters.	UD	0			Depth : 1.50-2.10m Rec=0cm
		N-1	D-0		0	Depth : 2.10-2.55m 1/0/0/0/0, Rec=0cm
		N-2	D-1		3	Depth : 3.00-3.45m 2/1/0/1/1/1, Rec=43cm
		N-3	D-2		5	Depth : 4.50-4.95m 2/2/1/1/2/1, Rec=44cm
		UD	0			Depth : 6.00-6.60m Rec=0cm
		N-4	D-3		1	Depth : 6.60-7.05m 1/0/1/0/0/0, Rec=34cm
		N-5	D-4		3	Depth : 7.50-7.95m 2/2/0/1/2/0, Rec=12cm
		N-6	D-5		6	Depth : 9.00-9.45m 2/1/2/2/1/1, Rec=36cm
		N-7	D-6		7	Depth : 10.50-10.95m 1/1/2/1/2/2, Rec=45cm
		N-8	D-7		9	Depth : 12.00-12.45m 2/1/2/2/2/3, Rec=42cm
		N-9	D-8		10	Depth : 13.50-13.95m 2/2/2/3/2/3, Rec=45cm
		N-10	D-9		12	Depth : 15.00-15.45m 3/2/3/2/3/4, Rec=42cm
15.80m						
15.80–19.30	Loose, dark grey, Clayey Silty SAND.	N-11	D-10		7	Depth : 16.50-16.95m 4/1/2/2/1/2, Rec=45cm
		UD	1	c_u=11-16kN/m^2		Depth : 18.00-18.60m Rec=60cm
		N-12	D-11		6	Depth : 18.60-19.05m 3/2/1/2/2/1, Rec=45cm
19.30m						
19.30–20	Medium dense, dark grey, Silty fine SAND with traces of seashell fragments.	N-13	D-12		21	Depth : 19.50-19.95m 3/5/4/6/5/6, Rec=38cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Operator : Hendry
Checked By : Vera C.
Recorded By : Joseph
Confirmed By : Roger YONG

Location : Beaufort
Date Started : 04/09/2014
Date Completed : 06/09/2014
Type of Boring : Rotary Wash Boring

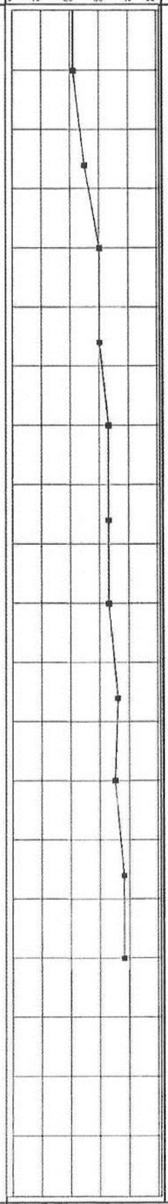
Rig Type : YWE D45
Casing Depth : 36.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Weather : Fine/ Cloudy

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20–23.00	Medium dense, dark grey, Silty fine SAND with traces of seashell fragments.	N-14	D-0		21	Depth : 21.00-21.45m 4/5/6/5/5/5, Rec=0cm
		N-15	D-0		25	Depth : 22.50-22.95m 6/8/6/7/6/6, Rec=0cm
23.00m						
23.00–28.00	Dense, dark grey, fine SAND.	N-16	D-13		30	Depth : 24.00-24.45m 6/8/8/7/7/8, Rec=15cm
		N-17	D-14		30	Depth : 25.50-25.95m 6/6/7/7/8/8, Rec=45cm
		N-18	D-15		33	Depth : 27.00-27.45m 7/6/8/8/9/8, Rec=43cm
28.00m						
28.00–36.45	Dense, light brown, fine SAND.	N-19	D-16		33	Depth : 28.50-28.95m 5/5/6/7/9/11, Rec=45cm
		N-20	D-17		33	Depth : 30.00-30.45m 5/6/6/8/9/10, Rec=39cm
		N-21	D-18		36	Depth : 31.50-31.95m 6/7/6/8/10/12, Rec=36cm
		N-22	D-19		35	Depth : 33.00-33.45m 6/7/7/8/10/10, Rec=43cm
		N-23	D-20		38	Depth : 34.50-34.95m 7/7/8/8/10/12, Rec=36cm
		N-24	D-21		38	Depth : 36.00-36.45m 7/8/7/9/11/11, Rec=34cm
	END OF BH-1 AT 36.45m					

Groundwater Levels:
04/09/2014 - 1.40m (1:00pm)
04/09/2014 - 1.36m (5:10pm)
05/09/2014 - 0.77m (1:00pm)
05/09/2014 - 0.23m (6:30pm)
06/09/2014 - Full (8:00am)
06/09/2014 - Full (11:30am)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Operator : Hendry
Checked By : Vera C.
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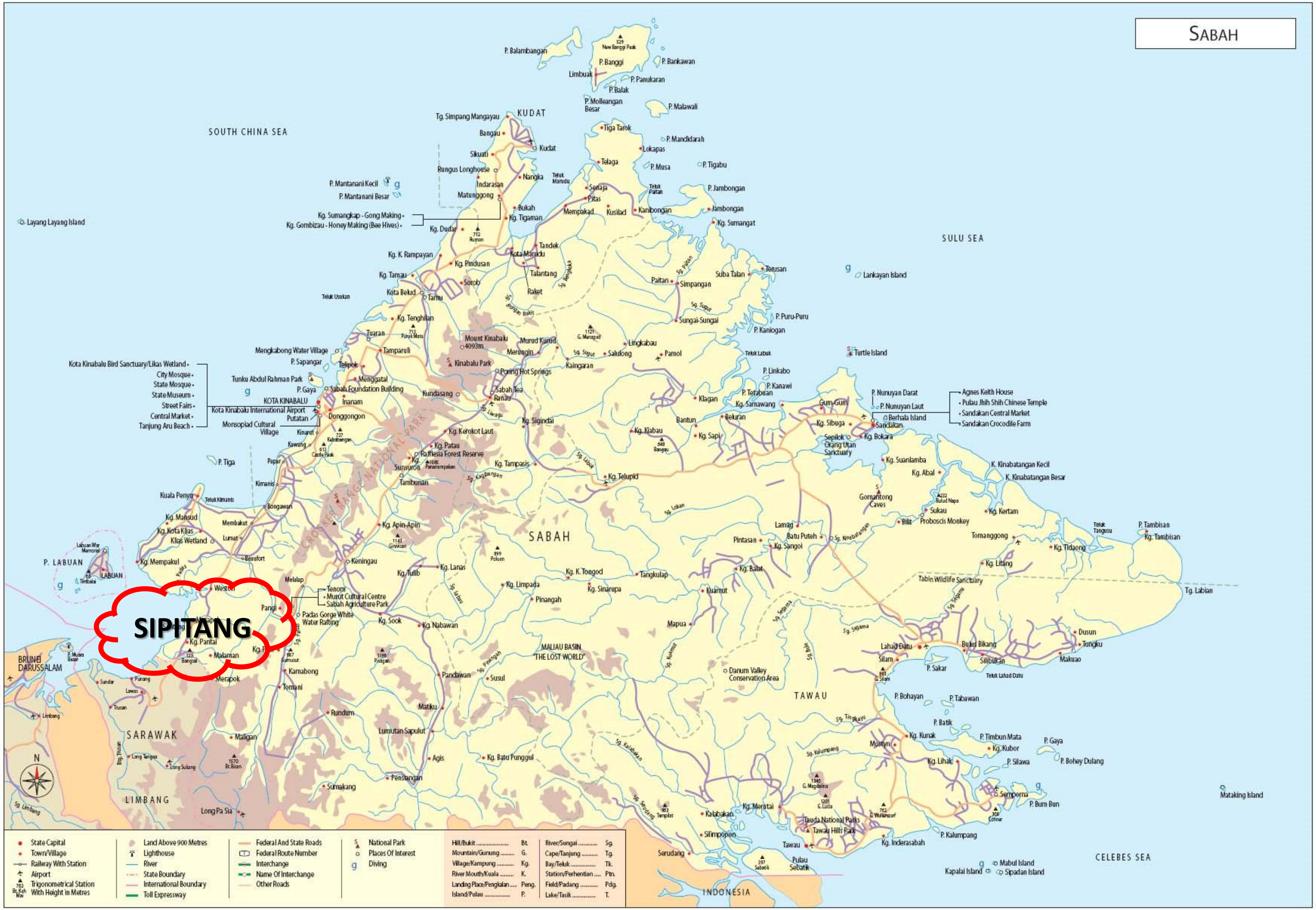
SABAH
SIPITANG
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
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BRUNEI DARUSSALAM
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P. LABUAN
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CROCKER RANGE NATIONAL PARK
MALIAU BASIN "THE LOST WORLD"
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Kinarut
Kawang
Papar
Kimanis
Bongawan
Membakut
Beaufort
Kuala Penyu
Klias Wetland
Kg. Mempakul
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Berhala Island
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Sukau
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K. Kinabatangan Kecil
K. Kinabatangan Besar
Tabin Wildlife Sanctuary
Lahad Datu
Kunak
Semporna
Tawau
Tawau Hills Park
Danum Valley Conservation Area
Kalabakan
Serudang
Sapulut
Pensiangan
Long Pa Sia
Sipadan Island
Mabul Island
Kapalai Island
Mataking Island
P. Bohey Dulang
Tg. Labian
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

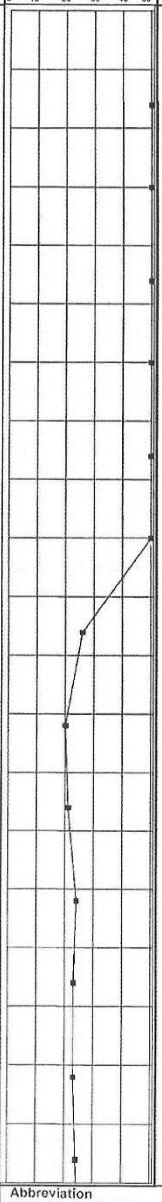
Location : Sipitang
Date Started : 18/05/2010
Date Completed : 20/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : S2-BH-2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
Strong, subangular GRAVEL with whitish grey, fine SAND matrix.	N-1	D-1	>50	Depth : 1.50-1.67m 50(70mm), Rec=7cm
	UD N-2	0 D-2	>50	Depth : 3.00-3.06m, Rec=0cm Depth : 3.06-3.18m 31/50(45mm), Rec=13cm
	C	1		Depth : 3.18-4.50m Rec= 36cm
	N-3	D-0	>50	Depth : 4.50-4.55m 50(50mm), Rec=0cm
	C	2		Depth : 4.55-6.00m Rec= 40cm
	UD N-4	0 D-4	>50	Depth : 6.00-6.05m, Rec=0cm Depth : 6.05-6.18m 20/50(55mm), Rec=8cm
	C	3		Depth : 6.18-7.50m Rec= 45cm
	N-5	D-5	>50	Depth : 7.50-7.63m 27/50(55mm), Rec=7cm
	C	4		Depth : 7.63-9.00m Rec= 35cm
	UD N-6	0 D-6	>50	Depth : 9.00-9.05m, Rec=0cm Depth : 9.05-9.19m 25/50(65mm), Rec=6cm
	C	5		Depth : 9.19-10.50m Rec= 37cm
11.40m	N-7	D-7	26	Depth : 10.50-10.95m 5/5/5/6/7/8, Rec=20cm
Very stiff, whitish grey, Clayey SILT with some GRAVEL. 13.00m	UD N-8	1 D-8	20	Depth : 12.00-12.20m, Rec=7cm Depth : 12.20-12.65m 5/5/5/5/5/5, Rec=45cm
Very stiff, dark grey, Clayey SILT.	N-9	D-9	21	Depth : 13.50-13.95m 5/5/5/5/5/6, Rec=30cm
	UD N-10	2 D-10	24	Depth : 15.00-15.15m, Rec=6cm Depth : 15.15-15.60m 5/5/5/7/6/6, Rec=32cm
	N-11	D-11	23	Depth : 16.50-16.95m 5/5/6/5/6/6, Rec=45cm
	UD N-12	3 D-12	23	Depth : 18.00-18.10m, Rec=5cm Depth : 18.10-18.55m 5/5/5/6/6/6, Rec=30cm
	N-13	D-13	24	Depth : 19.50-19.95m 5/6/5/5/6/7, Rec=29cm

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
N-Standard Penetration Test
VS- Vane Shear Test
RQD-Rock Quality Designation
D-Disturbed Sample
C-Core
Rec-Recovery

Recorded By : Jotirip
Checked By : Alex

Location : Sipitang
Date Started : 18/05/2010
Date Completed : 20/05/2010
Type of Boring : Rotary Wash Boring

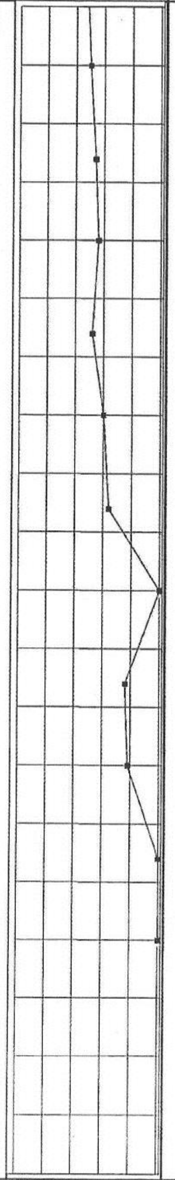
Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : S2-BH-2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
Very stiff to hard, dark grey, Clayey SILT.	UD N-14	4 D-14	25	Depth : 21.00-21.06m, Rec=4cm Depth : 21.06-21.51m 5/6/6/6/6/7, Rec=31cm
	N-15	D-15	27	Depth : 22.50-22.95m 6/6/6/6/7/8, Rec=35cm
	UD N-16	5 D-16	28	Depth : 24.00-24.05m, Rec=0cm Depth : 24.05-24.50m 6/6/6/7/7/8, Rec=32cm
	N-17	D-17	26	Depth : 25.50-25.95m 6/6/6/6/7/7, Rec=30cm
	UD N-18	6 D-18	30	Depth : 27.00-27.05m, Rec=0cm Depth : 27.05-27.50m 7/7/7/7/8/8, Rec=25cm
30.00m	N-19	D-19	32	Depth : 28.50-28.95m 6/7/7/7/8/10, Rec=31cm
Very dense, dark grey, fine SAND. 31.50m	UD N-20	0 D-20	>50	Depth : 30.00-30.20m, Rec=0cm Depth : 30.20-30.64m 8/9/10/11/14/15(65mm), Rec=28cm
Hard, dark grey, Clayey SILT.	N-21	D-21	38	Depth : 31.50-31.95m 6/7/8/10/10/10, Rec=29cm
	UD N-22	0 D-22	39	Depth : 33.00-33.00m, Rec=0cm Depth : 33.00-33.45m 7/7/9/10/10/10, Rec=27cm
	N-23	D-23	>50	Depth : 34.50-34.95m 9/10/10/12/13/15(75mm), Rec=36cm
END OF S2-BH-2 AT 36.44m	UD N-24	0 D-24	>50	Depth : 36.00-36.00m, Rec=0cm Depth : 36.00-36.44m 6/11/12/12/15/11(65mm), Rec=15cm

Groundwater Level :
18.05.10 - Full (5.00pm)
19.05.10 - 0.10m (7.00am)
20.05.10 - 0.28m (4.30pm)

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
N-Standard Penetration Test
VS- Vane Shear Test
RQD-Rock Quality Designation
D-Disturbed Sample
C-Core
Rec-Recovery

Recorded By : Jotirip
Checked By : Alex

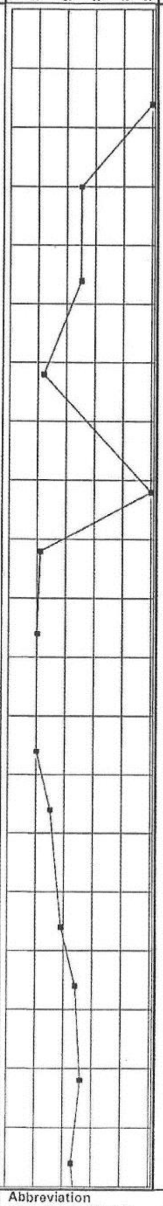
Location : Sipitang
Date Started : 01/06/2010
Date Completed : 04/06/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 19.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : S2-BH-3
Ground Elev. : Existing Ground Level.
Weather : Fine/Dizzling

Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
Strong GRAVEL with light brown and light grey, fine SAND matrix. (2.60m)	N-1	D-1	>50	Depth : 1.50-1.915m 8/10/12/13/15/10(40mm), Rec=21cm
Medium dense, light brown, fine SAND with some subangular GRAVEL. (5.40m)	UD / N-2	0 / D-2	25	Depth : 3.00-3.05m, Rec=0cm Depth : 3.05-3.50m 5/7/8/8/5/4, Rec=16cm
	N-3	D-3	25	Depth : 4.50-4.95m 5/5/6/6/7/6, Rec=21cm
Medium dense, light grey, fine SAND with some subangular GRAVEL. (6.65m)	UD / N-4	0 / D-4	12	Depth : 6.00-6.10m, Rec=0cm Depth : 6.10-6.55m 4/4/4/3/3/2, Rec=19cm
Medium strong, light grey, slightly weathered and highly fractured SANDSTONE. (8.15m)	C	1		Depth : 6.65-8.15m Rec= 105cm RQD= 0%
Medium dense, light grey, fine SAND with some subangular GRAVEL. (11.60m)	N-5	D-5	>50	Depth : 8.15-8.415m 12/29/38/12(40mm), Rec=14cm
	UD / N-6	0 / D-6	11	Depth : 9.00-9.15m, Rec=0cm Depth : 9.15-9.60m 2/3/3/3/2/3, Rec=29cm
	N-7	D-7	10	Depth : 10.50-10.95m 3/2/3/2/3/2, Rec=30cm
Stiff to very stiff, dark grey, Clayey SILT.	UD	1		Depth : 12.00-12.50m Rec=32cm
	N-8	D-8	10	Depth : 12.50-12.95m 3/2/2/3/2/3, Rec=23cm
	N-9	D-9	15	Depth : 13.50-13.95m 3/4/4/4/3/4, Rec=29cm
	UD	2		Depth : 15.00-15.50m Rec=39cm
	N-10	D-10	19	Depth : 15.50-15.95m 4/4/4/4/5/6, Rec=20cm
	N-11	D-11	24	Depth : 16.50-16.95m 4/5/5/6/6/7, Rec=24cm
	UD / N-12	0 / D-12	26	Depth : 18.00-18.10m, Rec=5cm Depth : 18.10-18.55m 4/5/6/6/7/7, Rec=22cm
	N-13	D-13	23	Depth : 19.50-19.95m 5/6/5/6/5/7, Rec=22cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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RQD-Rock Quality Designation
D-Disturbed Sample
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Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Recorded By : Jotirip
Checked By : Alex

Location : Sipitang
Date Started : 01/06/2010
Date Completed : 04/06/2010
Type of Boring : Rotary Wash Boring

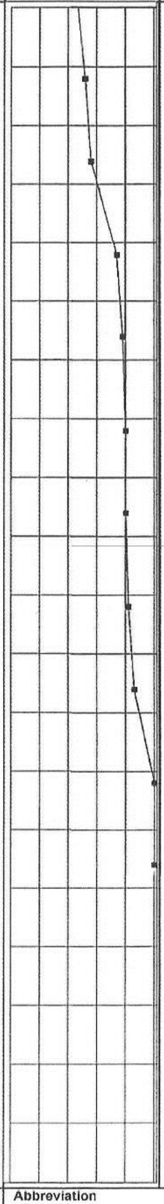
Rig Type : YWE D45
Casing Depth : 19.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : S2-BH-3
Ground Elev. : Existing Ground Level.
Weather : Fine/Dizzling

Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
Very stiff to hard, dark grey, Clayey SILT. (26.40m)	UD / N-14	0 / D-14	26	Depth : 21.00-21.10m, Rec=0cm Depth : 21.10-21.55m 5/5/6/6/7/7, Rec=21cm
	N-15	D-15	28	Depth : 22.50-22.95m 7/8/8/8/6/6, Rec=19cm
	UD / N-16	0 / D-16	37	Depth : 24.00-24.10m, Rec=0cm Depth : 24.10-24.55m 6/6/6/9/10/12, Rec=18cm
	N-17	D-17	39	Depth : 25.50-25.95m 4/5/11/11/8/9, Rec=29cm
Dense, dark grey, Silty SAND. (31.00m)	UD / N-18	0 / D-18	40	Depth : 27.00-27.10m, Rec=0cm Depth : 27.10-27.55m 4/5/7/8/11/14, Rec=27cm
	N-19	D-19	40	Depth : 28.50-28.95m 10/9/10/10/10/10, Rec=25cm
	UD / N-20	0 / D-20	41	Depth : 30.00-30.10m, Rec=0cm Depth : 30.10-30.55m 9/9/10/10/10/11, Rec=28cm
Hard, dark grey, Clayey SILT.	UD / N-21	0 / D-21	43	Depth : 31.50-31.60m, Rec=0cm Depth : 31.60-32.05m 10/10/10/11/11/11, Rec=30cm
	UD / N-22	0 / D-22	>50	Depth : 33.00-33.10m, Rec=0cm Depth : 33.10-33.52m 9/10/12/14/14/10(45mm), Rec=33cm
	N-23	D-23	>50	Depth : 34.50-34.87m 10/1/15/15/20(70mm), Rec=30cm
END OF S2-BH-3 AT 34.87m				

Groundwater Level :
01.06.10 - 1.00m (12.00pm)
01.06.10 - 2.10m (1.30pm)
02.06.10 - 2.90m (7.00am)
02.06.10 - 1.30m (1.15pm)
02.06.10 - 1.30m (2.20pm)
02.06.10 - 2.40m (6.15pm)
03.06.10 - 2.10m (7.30am)
03.06.10 - 1.60m (12.00pm)
03.06.10 - 2.10m (1.30pm)
03.06.10 - 3.40m (6.20pm)
04.06.10 - 1.80m (7.50am)
04.06.10 - 2.30m (11.30am)
04.06.10 - 2.10m (2.30pm)
04.06.10 - 2.80m (4.40pm)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
N-Standard Penetration Test
VS- Vane Shear Test
RQD-Rock Quality Designation
D-Disturbed Sample
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Recorded By : Jotirip
Checked By : Alex

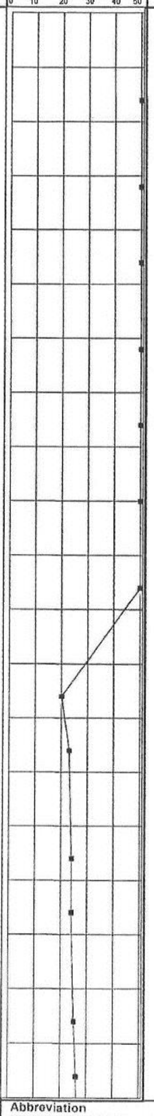
Location : Sipitang
Date Started : 22/05/2010
Date Completed : 24/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 3
Borehole No. : S2-BH-5
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1								
2			N-1	D-1			>50	Depth : 1.50-1.72m 10/25/50(70mm), Rec=10cm
3			UD N-2	0 D-2			>50	Depth : 3.00-3.15m, Rec=0cm Depth : 3.15-3.42m 8/20/30/20(45mm), Rec=13cm
4			C	1				Depth : 3.42-4.50m Rec= 30cm
			N-3	D-3			>50	Depth : 4.50-4.62m 30/50(45mm), Rec=7cm
5	Strong, subangular GRAVEL with whitish grey, fine SAND matrix.		C	2				Depth : 4.62-6.00m Rec= 30cm
6			UD N-4	0 D-4			>50	Depth : 6.00-6.10m, Rec=0cm Depth : 6.10-6.17m 50(70mm), Rec=6cm
7			C	3				Depth : 6.17-7.50m Rec= 35cm
			N-5	D-5			>50	Depth : 7.50-7.64m 20/50(65mm), Rec=10cm
8			C	4				Depth : 7.64-9.00m Rec= 46cm
9			UD N-6	0 D-6			>50	Depth : 9.00-9.05m, Rec=0cm Depth : 9.05-9.12m 50(70mm), Rec=6cm
10			C	5				Depth : 9.12-10.50m Rec= 36cm
			N-7	D-7			>50	Depth : 10.50-10.575m 50(75mm), Rec=5cm
11	11.50m		C	6				Depth : 10.575-11.50m Rec= 30cm
12			UD	1				Depth : 12.00-12.55m Rec=49cm
13			N-8	D-8			20	Depth : 12.55-13.00m 5/5/5/5/5/5, Rec=40cm
14			N-9	D-9			23	Depth : 13.50-13.95m 5/5/5/6/6/6, Rec=32cm
15			UD	2				Depth : 15.00-15.55m Rec=55cm
16	Very stiff, dark grey, Sandy Clayey SILT.		N-10	D-10			24	Depth : 15.55-16.00m 5/6/6/6/6/6, Rec=28cm
17			N-11	D-11			24	Depth : 16.50-16.95m 5/5/6/6/6/6, Rec=25cm
18			UD	3				Depth : 18.00-18.50m Rec=40cm
19			N-12	D-12			25	Depth : 18.50-18.95m 5/5/6/6/6/7, Rec=19cm
20			N-13	D-13			26	Depth : 19.50-19.95m 5/5/6/6/7/7, Rec=29cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample RQD-Rock Quality Designation C-Core
N-Standard Penetration Test D-Disturbed Sample Rec-Recovery
VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Recorded By : Jotirip Checked By : Alex

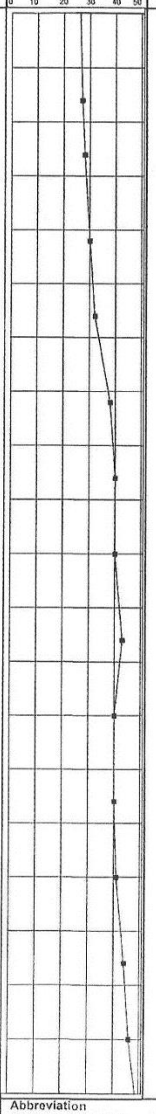
Location : Sipitang
Date Started : 22/05/2010
Date Completed : 24/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 3
Borehole No. : S2-BH-5
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21	Very stiff, dark grey, Sandy Clayey SILT.		UD	4				Depth : 21.00-21.55m Rec=54cm
22			N-14	D-14			27	Depth : 21.55-22.00m 5/6/6/7/7/7, Rec=39cm
23	22.50m		N-15	D-15			28	Depth : 22.50-22.95m 6/6/7/7/7/7, Rec=28cm
24			UD N-16	5 D-16			30	Depth : 24.00-24.20m, Rec=15cm Depth : 24.20-24.65m 6/7/7/7/8/8, Rec=25cm
25								
26			N-17	D-17			32	Depth : 25.50-25.95m 7/7/7/8/8/9, Rec=29cm
27			UD N-18	6 D-18			38	Depth : 27.00-27.10m, Rec=8cm Depth : 27.10-27.55m 7/7/8/10/10/10, Rec=28cm
28								
29			N-19	D-19			40	Depth : 28.50-28.95m 7/8/9/10/10/11, Rec=25cm
30	Very stiff hard, dark grey, Clayey SILT.		UD N-20	0 D-20			40	Depth : 30.00-30.07m, Rec=0cm Depth : 30.07-30.52m 7/9/9/10/10/11, Rec=26cm
31								
32			N-21	D-21			43	Depth : 31.50-31.95m 7/9/10/10/11/12, Rec=22cm
33			UD N-22	0 D-22			40	Depth : 33.00-33.02m, Rec=0cm Depth : 33.02-33.47m 7/7/8/10/10/12, Rec=25cm
34								
35			N-23	D-23			40	Depth : 34.50-34.95m 7/8/9/10/10/11, Rec=24cm
36			UD N-24	0 D-24			41	Depth : 36.00-36.01m, Rec=0cm Depth : 36.01-36.46m 8/9/9/10/11/11, Rec=40cm
37								
38			N-25	D-25			44	Depth : 37.50-37.95m 8/9/10/11/11/12, Rec=30cm
39			UD N-26	0 D-26			46	Depth : 39.00-39.00m, Rec=0cm Depth : 39.00-39.45m 8/9/10/12/12/12, Rec=36cm
40								

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample RQD-Rock Quality Designation C-Core
N-Standard Penetration Test D-Disturbed Sample Rec-Recovery
VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Recorded By : Jotirip Checked By : Alex

Location : Sipitang
Date Started : 22/05/2010
Date Completed : 24/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 3 of 3
Borehole No. : S2-BH-5
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
41	Hard, dark grey, Clayey SILT with shale fragment.		N-27	D-27			>50	Depth : 40.50-40.94m 9/10/11/12/15/12(65mm), Rec=23cm
42	END OF S2-BH-5 AT 42.36m		N-28	D-28			>50	Depth : 42.00-42.00m, Rec=0cm Depth : 42.00-42.36m 11/13/15/18/17(60mm), Rec=16cm
43								Groundwater Level : 23.05.10 - 0.80m (12.10pm) 23.05.10 - 0.80m (1.30pm) 23.05.10 - 0.80m (5.30pm) 24.05.10 - 1.50m (12.50pm) 24.05.10 - 1.30m (6.10pm)
44								
45								
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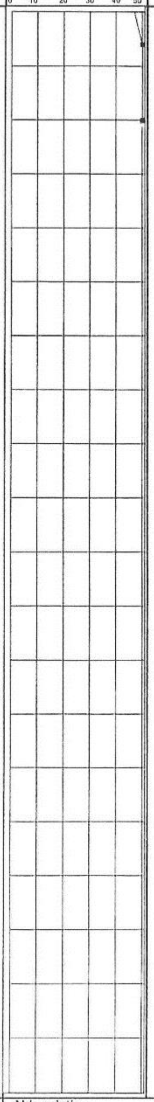
SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample RQD-Rock Quality Designation C-Core
N-Standard Penetration Test D-Disturbed Sample Rec-Recovery
VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Recorded By : Jotirip Checked By : Alex

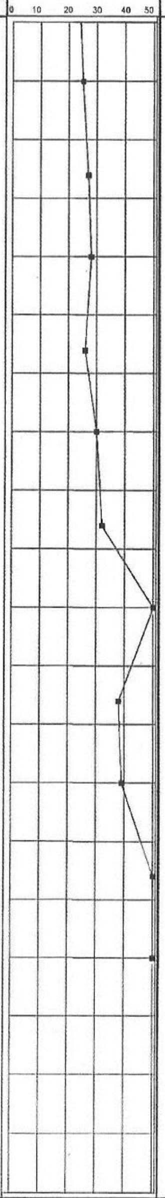
Location : Sipitang
Date Started : 18/05/2010
Date Completed : 20/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : S2-BH-2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
21	Very stiff to hard, dark grey, Clayey SILT.	UD N-14	4 D-14	25	Depth : 21.00-21.06m, Rec=4cm Depth : 21.06-21.51m 5/6/6/6/6/7, Rec=31cm
22-23		N-15	D-15	27	Depth : 22.50-22.95m 5/6/6/6/7/8, Rec=35cm
24		UD N-16	5 D-16	28	Depth : 24.00-24.05m, Rec=0cm Depth : 24.05-24.50m 6/6/6/7/7/8, Rec=32cm
25-26		N-17	D-17	26	Depth : 25.50-25.95m 6/6/6/6/7/7, Rec=30cm
27		UD N-18	6 D-18	30	Depth : 27.00-27.05m, Rec=0cm Depth : 27.05-27.50m 7/7/7/7/8/8, Rec=25cm
28-29		N-19	D-19	32	Depth : 28.50-28.95m 6/7/7/7/8/10, Rec=31cm
30	30.00m Very dense, dark grey, fine SAND.	UD N-20	0 D-20	>50	Depth : 30.00-30.20m, Rec=0cm Depth : 30.20-30.64m 8/9/10/11/14/15(65mm), Rec=28cm
31-32	31.50m Hard, dark grey, Clayey SILT.	N-21	D-21	38	Depth : 31.50-31.95m 6/7/8/10/10/10, Rec=29cm
33		UD N-22	0 D-22	39	Depth : 33.00-33.00m, Rec=0cm Depth : 33.00-33.45m 7/7/9/10/10/10, Rec=27cm
34-35		N-23	D-23	>50	Depth : 34.50-34.95m 9/10/10/12/13/15(75mm), Rec=36cm
36		UD N-24	0 D-24	>50	Depth : 36.00-36.00m, Rec=0cm Depth : 36.00-36.44m 6/11/12/12/15/11(65mm), Rec=15cm
37-40	END OF S2-BH-2 AT 36.44m				Groundwater Level : 18.05.10 - Full (5.00pm) 19.05.10 - 0.10m (7.00am) 20.05.10 - 0.28m (4.30pm)

SPT, N-Value Vs Depth



Shear Strength

Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
N-Standard Penetration Test
VS- Vane Shear Test
RQD-Rock Quality Designation
D-Disturbed Sample
C-Core
Rec-Recovery

Recorded By : Jotirip

Checked By : Alex

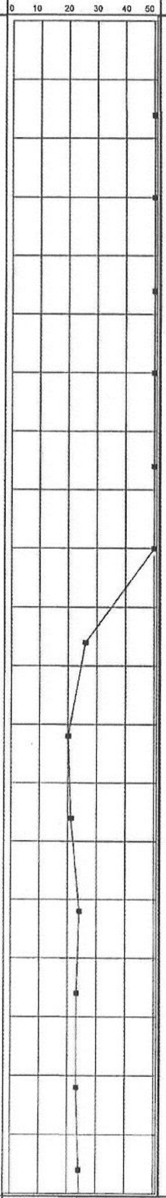
Location : Sipitang
Date Started : 18/05/2010
Date Completed : 20/05/2010
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 25.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : S2-BH-2
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
1-2	Strong, subangular GRAVEL with whitish grey, fine SAND matrix.	N-1	D-1	>50	Depth : 1.50-1.57m 50(70mm), Rec=7cm
3		UD N-2	0 D-2	>50	Depth : 3.00-3.06m, Rec=0cm Depth : 3.06-3.18m 31/50(45mm), Rec=13cm
4		C	1		Depth : 3.18-4.50m Rec= 36cm
5		N-3	D-0	>50	Depth : 4.50-4.55m 50(50mm), Rec=0cm
		C	2		Depth : 4.55-6.00m Rec= 40cm
6		UD N-4	0 D-4	>50	Depth : 6.00-6.05m, Rec=0cm Depth : 6.05-6.18m 20/50(55mm), Rec=8cm
7		C	3		Depth : 6.18-7.50m Rec= 45cm
8		N-5	D-5	>50	Depth : 7.50-7.63m 27/50(65mm), Rec=7cm
		C	4		Depth : 7.63-9.00m Rec= 35cm
9		UD N-6	0 D-6	>50	Depth : 9.00-9.05m, Rec=0cm Depth : 9.05-9.19m 25/50(65mm), Rec=6cm
10		C	5		Depth : 9.19-10.50m Rec= 37cm
11		N-7	D-7	26	Depth : 10.50-10.95m 5/5/5/6/7/8, Rec=20cm
12	11.40m Very stiff, whitish grey, Clayey SILT with some GRAVEL.	UD N-8	1 D-8	20	Depth : 12.00-12.20m, Rec=7cm Depth : 12.20-12.65m 5/5/5/5/5/5, Rec=45cm
13-14	13.00m Very stiff, dark grey, Clayey SILT.	N-9	D-9	21	Depth : 13.50-13.95m 5/5/5/5/5/6, Rec=30cm
15-16		UD N-10	2 D-10	24	Depth : 15.00-15.15m, Rec=6cm Depth : 15.15-15.60m 5/5/5/7/6/6, Rec=32cm
17		N-11	D-11	23	Depth : 16.50-16.95m 5/5/6/5/6/6, Rec=45cm
18-19		UD N-12	3 D-12	23	Depth : 18.00-18.10m, Rec=5cm Depth : 18.10-18.55m 5/5/5/6/6/6, Rec=30cm
20		N-13	D-13	24	Depth : 19.50-19.95m 5/6/5/6/6/7, Rec=29cm

SPT, N-Value Vs Depth



Shear Strength

Project :

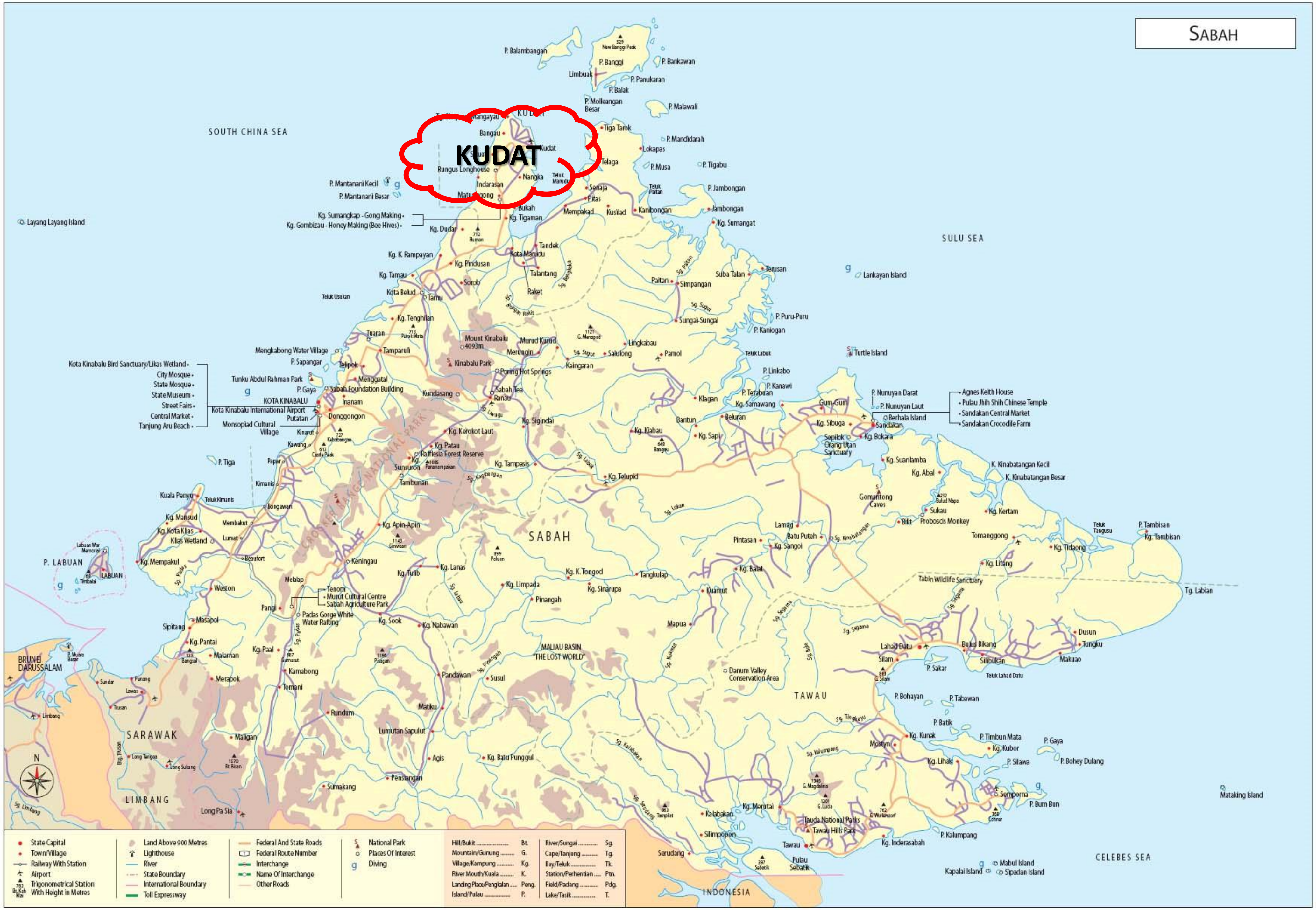
SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
N-Standard Penetration Test
VS- Vane Shear Test
RQD-Rock Quality Designation
D-Disturbed Sample
C-Core
Rec-Recovery

Recorded By : Jotirip

Checked By : Alex


SABAH
KUDAT
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
SABAH
TAWAU
SARAWAK
LIMBANG
BRUNEI DARUSSALAM
INDONESIA
P. LABUAN
LABUAN
KOTA KINABALU
Kudat
Bangau
Rungus Longhouse
Indarasan
Nangka
Matunggong
P. Banggi
P. Balambangan
P. Malawali
Kota Marudu
Kota Belud
Tuaran
Tamparuli
Mount Kinabalu 4093m
Kinabalu Park
Poring Hot Springs
Ranau
Kundasang
Penampang
Papar
Kimanis
Bongawan
Membakut
Beaufort
Kuala Penyu
Sipitang
Tenom
Keningau
Tambunan
Nabawan
Sook
Pensiangan
Sandakan
Sepilok Orang Utan Sanctuary
Gomantong Caves
Kinabatangan
Lahad Datu
Kunak
Semporna
Tawau
Tabin Wildlife Sanctuary
Danum Valley Conservation Area
MALIAU BASIN "THE LOST WORLD"
Crocker Range National Park
Tawau Hills Park
Turtle Island
Sipadan Island
Mabul Island
Kapalai Island
Mataking Island
Layang Layang Island
Tunku Abdul Rahman Park
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Kota Kinabalu International Airport
Sabah Foundation Building
Monsopiad Cultural Village
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
Murut Cultural Centre
Sabah Agriculture Park
Padas Gorge White Water Rafting
Rafflesia Forest Reserve
Proboscis Monkey
Klias Wetland
Labuan War Memorial
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit ... Bt.
Mountain/Gunung ... G.
Village/Kampung ... Kg.
River Mouth/Kuala ... K.
Landing Place/Pengkalan ... Peng.
Island/Pulau ... P.
River/Sungai ... Sg.
Cape/Tanjung ... Tg.
Bay/Teluk ... Tk.
Station/Perhentian ... Ptn.
Field/Padang ... Pdg.
Lake/Tasik ... T.

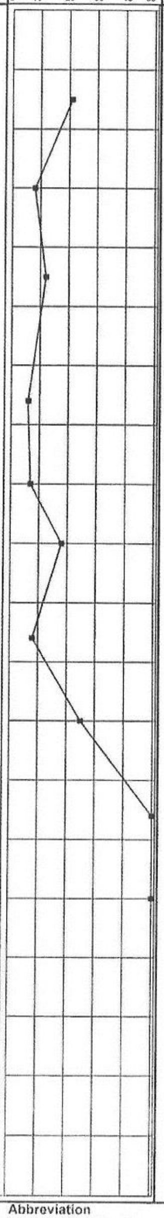
Location : Kudat
Date Started : 07.05.2014
Date Completed : 08.05.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-7
Ground Elev. : Existing Ground Level
Coordinate : N. 746822; E. 770743

Weather : Fine

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Medium dense, whitish grey, fine to coarse SAND with some coral fragments. (to 2.70m)	N-1	D-1		21	Depth : 1.50-1.95m 3/4/4/4/6/7, Rec=27cm
Medium dense, dark grey, fine to coarse SAND with some coral fragments. (2.70m to 5.60m)	N-2	D-2		8	Depth : 3.00-3.45m 4/3/2/2/3/1, Rec=10cm
	N-3	D-3		12	Depth : 4.50-4.95m 3/2/3/3/2/4, Rec=17cm
Medium stiff, dark grey, Sandy Clayey SILT with traces of seashell fragments. (5.60m to 8.80m)	UD	1	c_u=13kN/m²		Depth : 6.00-6.50m Rec=50cm
	N-4	D-4	c_u=6kN/m²	6	Depth : 6.50-6.95m 1/1/1/2/1/2, Rec=45cm
	UD	2	c_u=12kN/m²		Depth : 7.50-8.00m, Rec=47cm
	N-5	D-5	c_u=20kN/m²	7	Depth : 8.00-8.45m 1/0/1/1/2/3, Rec=24cm
Loose to medium dense, dark grey, Silty SAND with some gravel. (8.80m to 13.50m)	N-6	D-6		18	Depth : 9.00-9.45m 3/2/4/2/5/7, Rec=13cm
	N-7	D-7		8	Depth : 10.50-10.95m 4/2/2/2/1/3, Rec=27cm
	N-8	D-8		25	Depth : 12.00-12.45m 4/4/5/6/7/7, Rec=24cm
Very dense, dark grey, Silty SAND with some sandstone fragments. (13.50m to 14.70m)	N-9	D-9		>50	Depth : 13.50-13.86m 8/10/15/17/18(60mm), Rec=23cm
Hard, dark grey, Sandy Clayey SILT with some sandstone fragments. (14.70m to 15.50m)	N-10	D-10		>50	Depth : 15.00-15.29m 8/12/26/24(65mm), Rec=15cm
Very weak to weak, dark grey, fresh to moderately weathered and highly to extremely fractured SILTSTONE/SANDSTONE interbedded with very weak, dark grey, extremely weathered and extremely fractured MUDSTONE/SHALE. (from 15.50m)	C	1			Depth : 15.50-17.00m Rec=35cm RQD=0%
	C	2			Depth : 17.00-18.50m Rec=37cm RQD=0%
	C	3			Depth : 18.50-20.00m Rec=39cm RQD=0%



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Sabri
Checked By : Ridho Fadhliy
Recorded By : Delvian
Confirmed By : Roger YONG

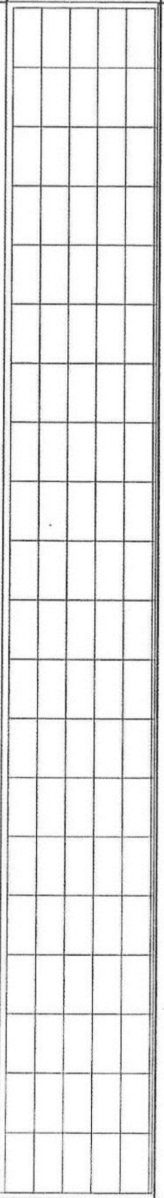
Location : Kudat
Date Started : 07.05.2014
Date Completed : 08.05.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 15.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-7
Ground Elev. : Existing Ground Level
Coordinate : N. 746822; E. 770743

Weather : Fine

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Very weak to weak, dark grey, fresh to moderately weathered and highly to extremely fractured SILTSTONE/SANDSTONE interbedded with very weak, dark grey, extremely weathered and extremely fractured MUDSTONE/SHALE.	C	4			Depth : 20.00-21.50m Rec=140cm RQD=0%
END OF BH-7 at 21.50m					



Groundwater Levels below the existing ground level:

07.05.2014 - 1.60m (6.30pm)
08.05.2014 - 1.20m (7.30am)
08.05.2014 - 1.30m (5.20pm)
09.05.2014 - 1.70m (8.00am)
10.05.2014 - 1.70m (8.00am)

Project :

Abbreviation
UD-Undisturbed Sample
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SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Sabri
Checked By : Ridho Fadhliy
Recorded By : Delvian
Confirmed By : Roger YONG

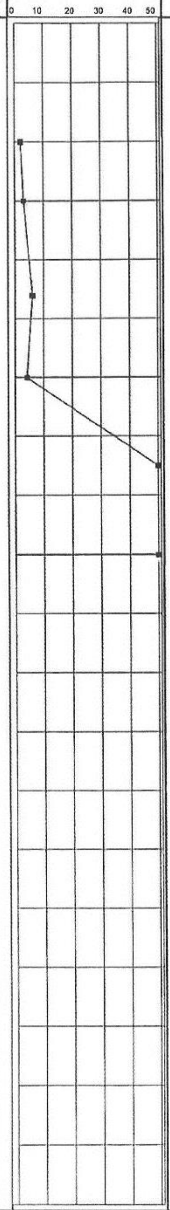
Location : Kudat
Date Started : 11/01/2015
Date Completed : 12/01/2015
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 9.00m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-3
Ground Elev. : Existing Ground Level
Weather : Fine/Rain

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1.50	Very loose to loose, dark grey and brownish grey, fine SAND/Silty fine SAND with traces of seashell fragments.		UD	0				Depth: 1.50-2.10m Rec=0cm
2.10			N-1	D-1			2	Depth: 2.10-2.55m 1/0/0/1/1/0, Rec=21cm
3.00			N-2	D-2			3	Depth: 3.00-3.45m 1/1/0/1/1/1, Rec=45cm
4.50			N-3	D-3			6	Depth: 4.50-4.95m 1/1/2/1/2/1, Rec=31cm
6.00	6.90m		N-4	D-4			4	Depth: 6.00-6.45m 1/1/1/1/1/1, Rec=33cm
7.50	Hard,dark grey, Sandy SILT with traces of seashell and coral fragments. 9.00m		N-5	D-5			>50	Depth: 7.50-7.795m 12/15/27/23(70mm), Rec=15cm
9.00	Very weak to weak, dark grey, highly to extremely weathered and highly to extremely fractured, SHALE interbeded with very weak to weak, dark grey, highly to extremely weathered and highly to extremely fractured, SANDSTONE.		N-6	D-0			>50	Depth: 9.00m Hammer Rebound
9.00			C	1				Depth: 9.00-10.50m Rec=110cm RQD=0%
10.50			C	2				Depth: 10.50-12.00m Rec=125cm RQD=0%
12.00			C	3				Depth: 12.00-13.50m Rec=120cm RQD=0%
13.50			C	4				Depth: 13.50-15.00m Rec=128cm RQD=0%
15.00	END OF BH-3 AT 15.00m							

SPT, N-Value Vs Depth



Groundwater table below the existing ground level:
11/01/2015 - 3.06m (6:15pm)
12/01/2015 - 0.82m (8:08am)
12/01/2015 - 3.17m (1:42pm)
13/01/2015 - 0.82m (8:15am)
13/01/2015 - 0.82m (5:21pm)
14/01/2015 - 0.81m (8:30am)
14/01/2015 - 0.81m (6:15pm)
15/01/2015 - 0.81m (8:17am)
15/01/2015 - 0.81m (6:07pm)
16/01/2015 - 0.82m (8:00am)
16/01/2015 - 0.82m (5:08pm)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

Operator : Rayhan
Recorded By : Suhaiza

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Vera C.
Confirmed By : Roger YONG


SABAH
SANDAKAN
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
TAWAU
SARAWAK
LIMBANG
BRUNEI DARUSSALAM
INDONESIA
P. LABUAN
Kota Kinabalu
KOTA KINABALU
Kudat
Kota Belud
Kota Marudu
Ranau
Mount Kinabalu 4093m
Kinabalu Park
Poring Hot Springs
Sandakan
Sepilok Orang Utan Sanctuary
Gomantong Caves
Sukau
Proboscis Monkey
Tabin Wildlife Sanctuary
Lahad Datu
Kunak
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Tawau
Tawau Hills Park
Kalabakan
Keningau
Tenom
Beaufort
Papar
Tambunan
Telupid
Danum Valley Conservation Area
MALIAU BASIN "THE LOST WORLD"
P. Banggi
P. Balambangan
Turtle Island
Sipadan Island
Mabul Island
Kapalai Island
Mataking Island
Layang Layang Island
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
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Central Market
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Kota Kinabalu International Airport
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Sabah Foundation Building
Monsopiad Cultural Village
Rafflesia Forest Reserve
Murut Cultural Centre
Sabah Agriculture Park
Padas Gorge White Water Rafting
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
Rungus Longhouse
Mengkabong Water Village
Klias Wetland
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

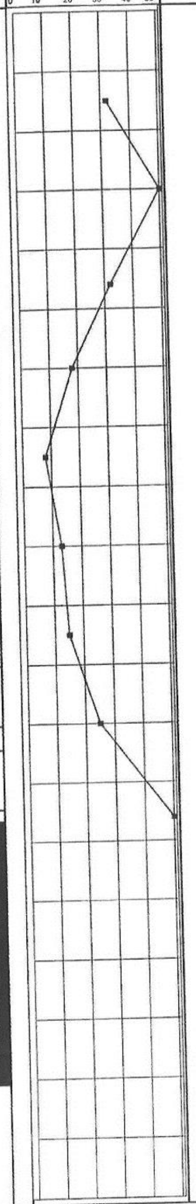
Location : Sandakan
Date Started : 24.08.2014
Date Completed : 24.08.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 13.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 1
Borehole No. : BH-1
Ground Elev. : Existing Ground Level
Coordinate: N646741.1559, E930898.948

Weather : Fine

SPT, N-Value Vs Depth



Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1								
2	Dense to very dense, yellowish and greyish brown, Silty Clayey SAND with traces of gravels.		N-1	D-1			32	Depth : 1.50-1.95m 4/5/7/7/8/10, Rec=20cm
3			N-2	D-2			>50	Depth ; 3.00-3.36m 8/10/15/20/15(60mm), Rec=15cm
4	4.50m							
5			N-3	D-3			32	Depth ; 4.50-4.95m 6/7/7/8/8/9, Rec=40cm
6			N-4	D-4			18	Depth ; 6.00-6.45m 3/3/4/4/5/5, Rec=23cm
7			N-5	D-5			8	Depth ; 7.50-7.95m 2/2/2/2/2/2, Rec=29cm
8	Loose to dense, light to dark greyish brown, fine to medium SAND with traces of seashell and coral fragments.							
9			N-6	D-6			13	Depth ; 9.00-9.45m 2/2/3/3/3/4, Rec=35cm
10								
11			N-7	D-7			15	Depth ; 10.50-10.95m 2/3/3/4/4/4, Rec=43cm
12	12.00m		N-8	D-8			25	Depth ; 12.00-12.45m 3/4/5/6/6/8, Rec=35cm
13	Medium dense to very dense, brownish grey, Silty Clayey SAND with some parental rock fragments. 13.52m		N-9	D-0			>50	Depth ; 13.50-13.52m 50(20mm), Rec=0cm
14			C	1				Depth ; 13.52-15.02m Rec=100cm RQD=0%
15								
16	Very weak to weak, light grey and slightly brownish light grey, highly to moderately weathered, highly to moderately fractured, SANDSTONE.		C	2				Depth ; 15.02-16.52m Rec=106cm RQD=0%
17			C	3				Depth ; 16.52-18.02m Rec=110cm RQD=9%
18	END OF BH-1 at 18.02m							
19								Groundwater levels below the existing ground level: 24.08.2014 - 1.62m (6.00pm) 25.08.2014 - 1.65m (7.12am) 25.08.2014 - 1.66m (5.00pm)
20								

Project :

Abbreviation
UD-Undisturbed Sample
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D-Disturbed Sample
N-SPT-N Value
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Rec-Recovery

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Checked By : Ridho Fadhlly
Recorded By : Jotirip
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 17.08.2014
Date Completed : 17.08.2014
Type of Boring : Rotary Wash Boring

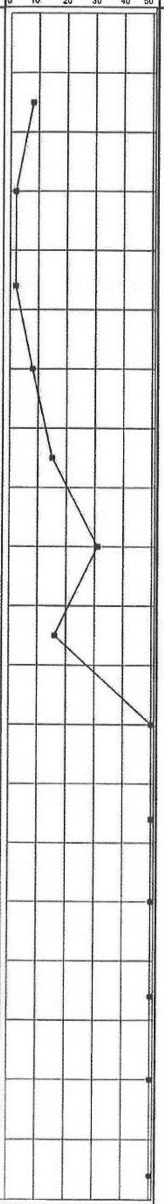
Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH-4
Ground Elev. : Existing Ground Level
Coordinate: N648569.6813, E935626.9263

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
1 – 3.00m	Loose, greyish brown, Silty SAND with some coral fragments. 3.00m	N-1	D-1	8	Depth : 1.50-1.95m 1/2/2/2/2/2, Rec=31cm
3.00 – 9.00m	Very loose to loose, dark grey, Silty Clayey SAND with some seashell fragments. 9.00m	N-2	D-2	2	Depth ; 3.00-3.45m 3/2/1/0/1/0, Rec=4cm
		N-3	D-3	2	Depth ; 4.50-4.95m 1/0/1/0/1/0, Rec=3cm
		N-4	D-4	8	Depth ; 6.00-6.45m 1/2/2/2/2/2, Rec=23cm
		N-5	D-5	15	Depth ; 7.50-7.95m 3/3/3/4/4/4, Rec=9cm
9.00 – 10.50m	Dense, dark brownish grey, fine to coarse SAND with plenty of parental rock fragments. 10.50m	N-6	D-6	31	Depth ; 9.00-9.45m 5/5/7/7/7/10, Rec=15cm
10.50 – 12.00m	Very stiff, yellowish and greyish brown, Silty Sandy CLAY with some parental rock fragments. 12.00m	N-7	D-7	16	Depth ; 10.50-10.95m 3/3/4/4/4/4, Rec=27cm
12.00 – 20	Very dense, dark grey, Clayey Silty SAND / Silty Clayey SAND with traces of parental rock fragments.	N-8	D-8	>50	Depth ; 12.00-12.35m 6/9/17/20/13(50mm), Rec=20cm
		N-9	D-9	>50	Depth ; 13.50-13.775m 10/17/23/27(50mm), Rec=16cm
		N-10	D-10	>50	Depth ; 15.00-15.265m 11/19/28/22(40mm), Rec=13cm
		N-11	D-11	>50	Depth ; 16.50-16.775m 12/16/26/24(50mm), Rec=14cm
		N-12	D-12	>50	Depth ; 18.00-18.25m 14/21/31/19(75mm), Rec=14cm
		N-13	D-13	>50	Depth ; 19.50-19.71m 15/29/50(60mm), Rec=21cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhily
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 17.08.2014
Date Completed : 17.08.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

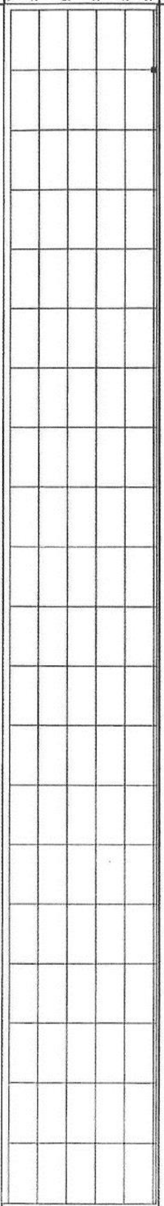
Sheet No. : 2 of 2
Borehole No. : BH-4
Ground Elev. : Existing Ground Level
Coordinate: N648569.6813, E935626.9263

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
20 – 21.15m	Very dense, dark grey, Clayey Silty SAND / Silty Clayey SAND with traces of parental rock fragments.	N-14	D-14	>50	Depth : 21.00-21.15m 28/50(75mm), Rec=10cm
21.15m	END OF BH-4 at 21.15m				

Groundwater levels below the existing ground level:
17.08.2014 - Full (12.00pm)
17.08.2014 - Full (1.00pm)
17.08.2014 - Full (4.00pm)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

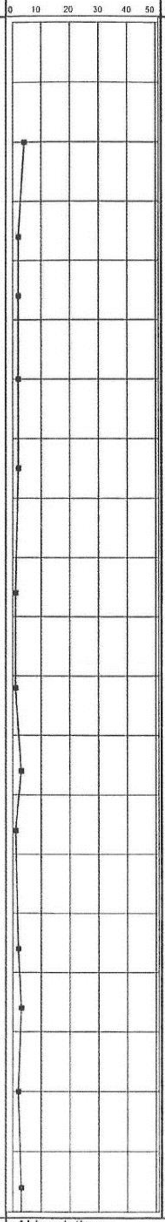
Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhily
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 18.08.2014
Date Completed : 21.08.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 27.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH-8
Ground Elev. : Existing Ground Level
Coordinate: N650095.3784, E935839.8274

Weather : Fine



Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00 – 3.00m	Soft, yellowish and greyish brown, Clayey Sandy SILT.	UD	1	c_u=21kN/m²		Depth : 1.50-2.00m, Rec=25cm
		N-1	D-1	c_u=45kN/m²	4	Depth ; 2.00-2.45m 1/1/1/1/1/1, Rec=20cm
3.00m – 7.50m	Very soft, dark brown, Sandy SILT with traces of gravels and seashell fragments.	UD	0			Depth ; 3.00-3.50m Rec=0cm
		N-2	D-2		2	Depth ; 3.50-3.95m 1/0/0/1/1/0, Rec=41cm
		N-3	D-3		2	Depth ; 4.50-4.95m 1/0/1/0/0/1, Rec=29cm
		N-4	D-4		2	Depth ; 6.00-6.45m 1/0/1/0/1/0, Rec=17cm
7.50m – 19.50m	Very soft to soft, dark grey, Clayey Sandy SILT.	N-5	D-5		2	Depth ; 7.50-7.95m 1/0/1/0/0/1, Rec=42cm
		UD	2	c_u=18kN/m²		Depth ; 9.00-9.60m Rec=55cm
		N-6	D-6	c'=0kN/m² φ=28°	1	Depth ; 9.60-10.05m 1/1/0/0/1/0, Rec=45cm
		UD	3	c_u=20kN/m²		Depth ; 10.50-11.10m Rec=55cm
		N-7	D-7		1	Depth ; 11.10-11.55m 1/0/0/1/0/0, Rec=44cm
		UD	4	c_u=18kN/m²		Depth ; 12.00-12.60m Rec=54cm
		N-8	D-8		3	Depth ; 12.60-13.05m 1/0/1/0/1/1, Rec=45cm
		N-9	D-9		1	Depth ; 13.50-13.95m 1/0/0/1/0/0, Rec=45cm
		UD	5	c_u=34kN/m²		Depth ; 15.00-15.60m Rec=50cm
		N-10	D-10	c_u=31kN/m²	2	Depth ; 15.60-16.05m 1/0/1/0/1/0, Rec=45cm
		N-11	D-11		3	Depth ; 16.50-16.95m 1/0/1/1/0/1, Rec=44cm
		N-12	D-12		2	Depth ; 18.00-18.45m 1/0/1/0/1/0, Rec=45cm
19.50m –	Soft to medium stiff, dark grey, Silty Sandy CLAY.	N-13	D-13		3	Depth ; 19.50-19.95m 1/1/0/1/1/1, Rec=45cm

Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

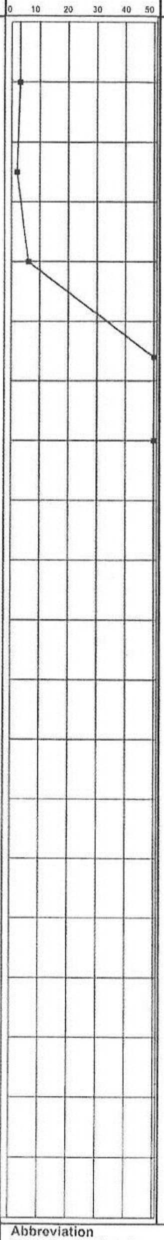
Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhlly
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 18.08.2014
Date Completed : 21.08.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 27.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH-8
Ground Elev. : Existing Ground Level
Coordinate: N650095.3784, E935839.8274

Weather : Fine



Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
– 25.50m	Soft to medium stiff, dark grey, Silty Sandy CLAY.	N-14	D-14		3	Depth : 21.00-21.45m 1/0/1/0/1/1, Rec=30cm
		N-15	D-15		2	Depth : 22.50-22.95m 1/1/0/1/0/1, Rec=20cm
		N-16	D-16		6	Depth : 24.00-24.45m 1/1/1/1/2/2, Rec=45cm
25.50m – 27.00m	Hard, brownish grey, Sandy Clayey SILT with pieces of parental rock fragments.	N-17	D-17		>50	Depth : 25.50-25.84m 7/11/17/21/12(40mm), Rec=22cm
27.00m – 31.52m	Very weak, dark grey, highly to moderately weathered, highly fractured, MUDSTONE.	N-18	D-0		>50	Depth : 27.00-27.02m 50(20mm), Rec=0cm
		C	1			Depth : 27.02-28.52m Rec=110cm RQD=0%
		C	2			Depth : 28.52-30.02m Rec=120cm RQD=0%
		C	3			Depth : 30.02-31.52m Rec=130cm RQD=0%
	END OF BH-8 at 31.52m					

Groundwater levels below the existing ground level:

18.08.2014 - 0.30m (5.10pm)
21.08.2014 - 0.28m (8.20am)
21.08.2014 - 1.00m (6.00pm)
22.08.2014 - 1.10m (7.30am)
22.08.2014 - 1.12m (4.42pm)
23.08.2014 - 1.15m (7.34am)
23.08.2014 - 1.16m (4.21pm)
24.08.2014 - 1.17m (8.45am)
24.08.2014 - 1.18m (5.00pm)
25.08.2014 - 1.20m (7.40am)
25.08.2014 - 1.21m (5.10pm)

Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

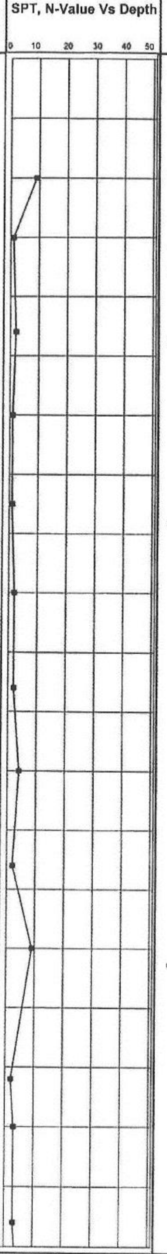
Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhlly
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 18.10.2014
Date Completed : 18.10.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH-17
Ground Elev. : Existing Ground Level
Coordinate: N651998.8833, E932409.1575

Weather : Fine



Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1.50	Very soft to medium stiff, brownish grey, Sandy Clayey SILT with traces of gravels.	UD	0			Depth : 1.50-1.80m, Rec=0cm
1.80		N-1	D-1		9	Depth : 1.80-2.25m 1/2/2/2/3/2, Rec=17cm
3.00		UD	1	c_u=24kN/m²		Depth : 3.00-3.60m Rec=60cm
3.60		N-2	D-2	c_u=32kN/m²	1	Depth : 3.60-4.05m 0/0/0/1/0/0, Rec=31cm
4.50m						
4.50	Very soft, dark grey, Clayey SILT.	UD	2	c_u=12kN/m²		Depth : 4.50-5.10m Rec=57cm
5.10		N-3	D-3		2	Depth : 5.10-5.55m 0/0/1/0/1/0, Rec=41cm
6.00		N-4	D-4		1	Depth : 6.00-6.45m 0/0/0/1/0/0, Rec=36cm
7.50		UD	3	c_u=10kN/m²		Depth : 7.50-8.10m Rec=53cm
8.10		N-5	D-5		1	Depth : 8.10-8.55m 0/0/0/0/1/0, Rec=40cm
9.00m						
9.00	Very soft to soft, dark grey, Sandy SILT.	N-6	D-6		2	Depth : 9.00-9.45m 0/0/1/0/1/0, Rec=42cm
10.50		N-7	D-7		2	Depth : 10.50-10.95m 1/0/1/0/1/0, Rec=43cm
12.00		N-8	D-8		4	Depth : 12.00-12.45m 1/0/1/1/1/1, Rec=45cm
13.50		N-9	D-9		2	Depth : 13.50-13.95cm 0/1/0/1/0/1, Rec=40cm
15.00		UD	4	c_u=12kN/m²		Depth : 15.00-15.60m Rec=55cm
15.60m						
15.60	Medium stiff, dark grey, Silty CLAY.	N-10	D-10		9	Depth : 15.60-16.05m 2/2/2/2/2/3, Rec=45cm
16.50m						
16.50	Soft, dark grey, Clayey SILT.	N-11	D-11		2	Depth : 16.50-16.95m 0/1/0/0/1/1, Rec=45cm
18.00		N-12	D-12		3	Depth : 18.00-18.45m 0/1/1/1/0/1, Rec=45cm
19.50		N-13	D-13		3	Depth : 19.50-19.95m 0/0/1/0/1/1, Rec=45cm

Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

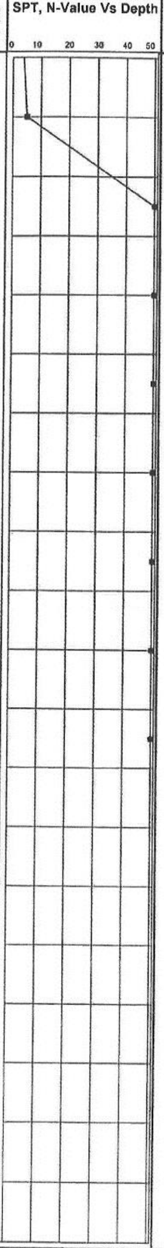
Operator : Big Boy
Recorded By : Nizam
Checked By : Ridho Fadhliy
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 18.10.2014
Date Completed : 18.10.2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 21.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH-17
Ground Elev. : Existing Ground Level
Coordinate: N651998.8833, E932409.1575

Weather : Fine



Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21.00	Medium stiff, dark grey, Clayey SILT.	N-14	D-14		5	Depth : 21.00-21.45m 0/1/1/1/1/2, Rec=45cm
22.50m						
22.50	Hard, dark grey, Clayey SILT.	N-15	D-15		>50	Depth : 22.50-22.645m 33/50(70mm), Rec=11cm
24.00		N-16	D-16		>50	Depth : 24.00-24.19m 15/36/50(40mm), Rec=9cm
25.50		N-17	D-17		>50	Depth : 25.50-25.69m 17/37/50(40mm), Rec=8cm
27.00		N-18	D-18		>50	Depth : 27.00-27.20m 28/41/50(50mm), Rec=10cm
28.50		N-19	D-19		>50	Depth : 28.50-28.61m 31/50(35mm), Rec=8cm
30.00		N-20	D-20		>50	Depth : 30.00-30.105m 43/50(30mm), Rec=7cm
31.50		N-21	D-21		>50	Depth : 31.50-31.54m 50(40mm), Rec=4cm
31.54	END OF BH-17 at 31.54m					

Groundwater level below the existing ground level:
18.10.2014 - 7.60m (6.00pm)

Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Big Boy
Recorded By : Nizam
Checked By : Ridho Fadhliy
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 23.08.2014
Date Completed : 23.08.2014
Type of Boring : Rotary Wash Boring

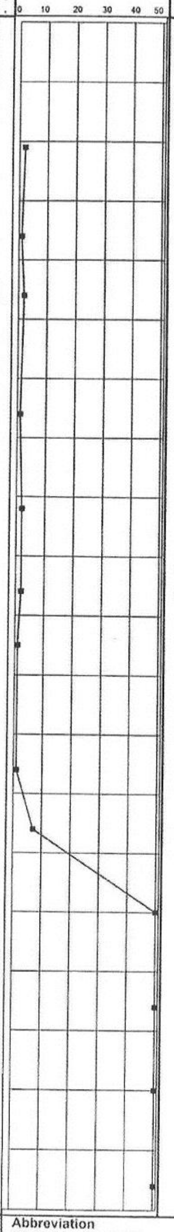
Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-18
Ground Elev. : Existing Ground Level
Coordinate: -

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
2		UD	1	c_u=10kN/m²		Depth : 1.50-2.10m Rec=28cm
		N-1	D-1		2	Depth ; 2.10-2.55m 1/0/0/1/1/0, Rec=11cm
3	Very soft, dark brown, Peaty SILT with traces of decayed matters.	UD	0			Depth ; 3.00-3.60m Rec=0cm
4		N-2	D-2		1	Depth ; 3.60-4.05m 1/0/0/1/0/0, Rec=27cm
5		N-3	D-3		2	Depth ; 4.50-4.95m 1/0/1/0/1/0, Rec=45cm
6	6.00m	UD	2	c_u=12kN/m²		Depth ; 6.00-6.60m Rec=55cm
7		N-4	D-4		1	Depth ; 6.60-7.05m 1/0/0/1/0/0, Rec=40cm
8		UD	0			Depth ; 7.50-8.10m Rec=0cm
	Very soft, dark grey, Sandy Clayey SILT.	N-5	D-5		2	Depth ; 8.10-8.55m 1/0/1/0/0/1, Rec=45cm
9		UD	3	c_u=15kN/m²		Depth ; 9.00-9.60m Rec=55cm
10		N-6	D-6	c_u=17kN/m²	2	Depth ; 9.60-10.05m 1/0/1/0/0/1, Rec=42cm
11	10.50m	N-7	D-7		1	Depth ; 10.50-10.95m 1/0/0/1/0/0, Rec=44cm
12	Very soft, dark grey, Clayey SILT.	UD	0			Depth ; 12.00-12.50m Rec=0cm
13		N-8	D-8		1	Depth ; 12.50-12.95m 0/1/0/0/0/1, Rec=44cm
14	13.50m Medium stiff, dark grey to brownish grey, Clayey SILT with traces of parental rock fragments.	N-9	D-9		7	Depth ; 13.50-13.95m 1/1/1/2/2/2, Rec=45cm
15	15.00m	N-10	D-10		>50	Depth ; 15.00-15.36m 5/8/11/16/23(60mm), Rec=20cm
16						
17		N-11	D-11		>50	Depth ; 16.50-16.82m 7/12/17/23/10(20mm), Rec=16cm
18	Hard, dark grey, Clayey Sandy SILT.	N-12	D-12		>50	Depth ; 18.00-18.265m 8/14/23/27(40mm), Rec=12cm
19						
20	(Refer to the next page) 19.50m	N-13	D-13		>50	Depth ; 19.50-19.765m 10/16/24/26(40mm), Rec=15cm

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhily
Confirmed By : Roger YONG

Location : Sandakan
Date Started : 23.08.2014
Date Completed : 23.08.2014
Type of Boring : Rotary Wash Boring

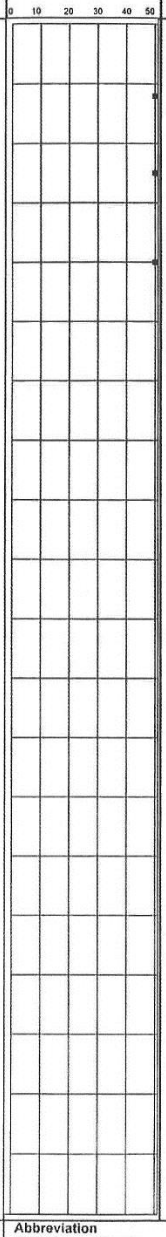
Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-18
Ground Elev. : Existing Ground Level
Coordinate: -

Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21	Very weak, dark grey, highly weathered, highly fractured, MUDSTONE. 21.265m	C	1			Depth ; 19.765-21.265m Rec=30cm RQD=0%
22		N-14	D-14		>50	Depth ; 21.265-21.54m 12/19/27/23(50mm), Rec=13cm
23	Hard, dark grey, Clayey Sandy SILT.	N-15	D-15		>50	Depth ; 22.50-22.575m 50(75mm), Rec=7cm
24	END OF BH-18 at 24.06m	N-16	D-16		>50	Depth ; 24.00-24.06m 50(60mm), Rec=5cm
25						
26						
27						<u>Groundwater levels below the existing ground level:</u> 23.08.2014 - Full (12.50pm) 23.08.2014 - Full (2.00pm) 23.08.2014 - Full (5.00pm) 24.08.2014 - Full (7.00am) 24.08.2014 - Full (5.00pm) 25.08.2014 - 0.05m (8.21am) 25.08.2014 - 0.06m (4.55pm)
28						
29						
30						
31						
32						
33						
34						
35						
36						
37						
38						
39						
40						

SPT, N-Value Vs Depth



Project :

SUBSURFACE EXPLORATION LOG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
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N-SPT-N Value
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C-Core
Rec-Recovery

Operator : Big Boy
Recorded By : Jotirip
Checked By : Ridho Fadhily
Confirmed By : Roger YONG

SABAH
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SARAWAK
LIMBANG
INDONESIA
BRUNEI DARUSSALAM
P. LABUAN
LABUAN
TAWAU
LAHAD DATU
MALIAU BASIN "THE LOST WORLD"
KOTA KINABALU
Mount Kinabalu 4093m
Kinabalu Park
CROCKER RANGE NATIONAL PARK
Sandakan
Tabin Wildlife Sanctuary
Danum Valley Conservation Area
Semporna
Kota Belud
Kota Marudu
Keningau
Tenom
Beaufort
Ranau
Kg. Telupid
Kunak
Tg. Labian
Layang Layang Island
P. Banggi
P. Balambangan
Sipadan Island
Mabul Island
Kapalai Island
Turtle Island
Lankayan Island
Mataking Island
Gomantong Caves
Sepilok Orang Utan Sanctuary
Tawau Hills Park
Tunku Abdul Rahman Park
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving

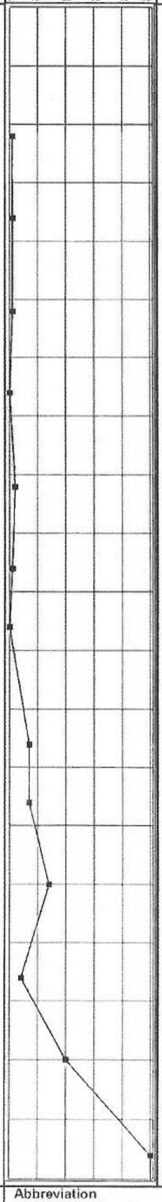
Location : Lahad Datu
Date Started : 08/08/2012
Date Completed : 09/08/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 2
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–1.50m	Light grey, Silty SAND with some gravel.					
1.50–7.50m	Very soft, dark grey and dark brown, Sandy Clayey SILT with decayed matters.	UD	1			Depth : 1.50-2.10m Rec=60cm
		N-1	D-1		1	Depth : 2.10-2.55m 1/0/0/0/1/0, Rec=34cm
		UD	2			Depth : 3.00-3.60m Rec=0cm
		N-2	D-2		1	Depth : 3.60-4.05m 0/0/1/0/0/0, Rec=45cm
		UD	3	C_u=16kN/m^2		Depth : 4.50-5.10m Rec=60cm
		N-3	D-3		1	Depth : 5.10-5.55m 0/0/1/0/0/0, Rec=45cm
		UD	4			Depth : 6.00-6.60m Rec=60cm
		N-4	D-4		0	Depth : 6.60-7.05m 1/0/0/0/0/0, Rec=45cm
7.50–12.80m	Very soft, dark grey, Clayey Sandy SILT with decayed matters.	UD	5			Depth : 7.50-8.10m Rec=60cm
		N-5	D-5		2	Depth : 8.10-8.55m 1/0/1/0/1/0, Rec=45cm
		UD	6	C_u=9kN/m^2		Depth : 9.00-9.60m Rec=60cm
		N-6	D-6		1	Depth : 9.60-10.05m 0/0/0/1/0/0, Rec=45cm
		N-7	D-7		0	Depth : 10.50-10.95m 0/1/0/0/0/0, Rec=45cm
12.80–19.00m	Loose to medium dense, dark grey, Silty fine to coarse SAND with small size gravels.	UD	7			Depth : 12.00-12.60m Rec=60cm
		N-8	D-8		7	Depth : 12.60-13.05m 0/1/1/2/2/2, Rec=45cm
		N-9	D-9		7	Depth : 13.50-13.95m 1/0/1/0/3/3, Rec=45cm
		N-10	D-10		14	Depth : 15.00-15.45m 2/2/3/3/3/5, Rec=45cm
		N-11	D-11		4	Depth : 16.50-16.95m 1/1/1/1/1/1, Rec=39cm
		N-12	D-12		20	Depth : 18.00-18.45m 10/7/5/5/5/5, Rec=17cm
19.00m–	Very dense, dark grey to blackish grey, fine to coarse SAND. (Densified coastal alluvium/riverine alluvial SAND).	N-13	D-13		>50	Depth : 19.50-19.615m 38/50(40mm), Rec=0cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Nurudin
Recorded By : Nizam

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

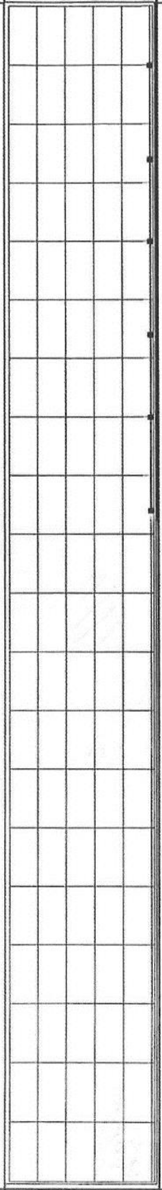
Location : Lahad Datu
Date Started : 08/08/2012
Date Completed : 09/08/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 18.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 2
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20.00–28.625m	Very dense, dark grey to blackish grey, fine to coarse SAND. (Densified coastal alluvium/riverine alluvial SAND).	N-14	D-14		>50	Depth : 21.00-21.145m 18/50(40mm), Rec=10cm
		N-15	D-15		>50	Depth : 22.50-22.635m 29/50(70mm), Rec=9cm
		N-16	D-16		>50	Depth : 24.00-24.37m 11/13/13/17/20(70mm), Rec=0cm
		N-17	D-17		>50	Depth : 25.50-25.70m 28/37/50(50mm), Rec=10cm
		N-18	D-18		>50	Depth : 27.00-27.125m 41/50(50mm), Rec=8cm
		N-19	D-19		>50	Depth : 28.50-28.625m 39/50(50mm), Rec=6cm
	END OF BH-1 At 28.625m					Groundwater Level : 08.08.12 - 0.60m (6.00pm) 09.08.12 - 1.13m (7.20am) 09.08.12 - 0.80m (9.40am)

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Nurudin
Recorded By : Nizam

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG

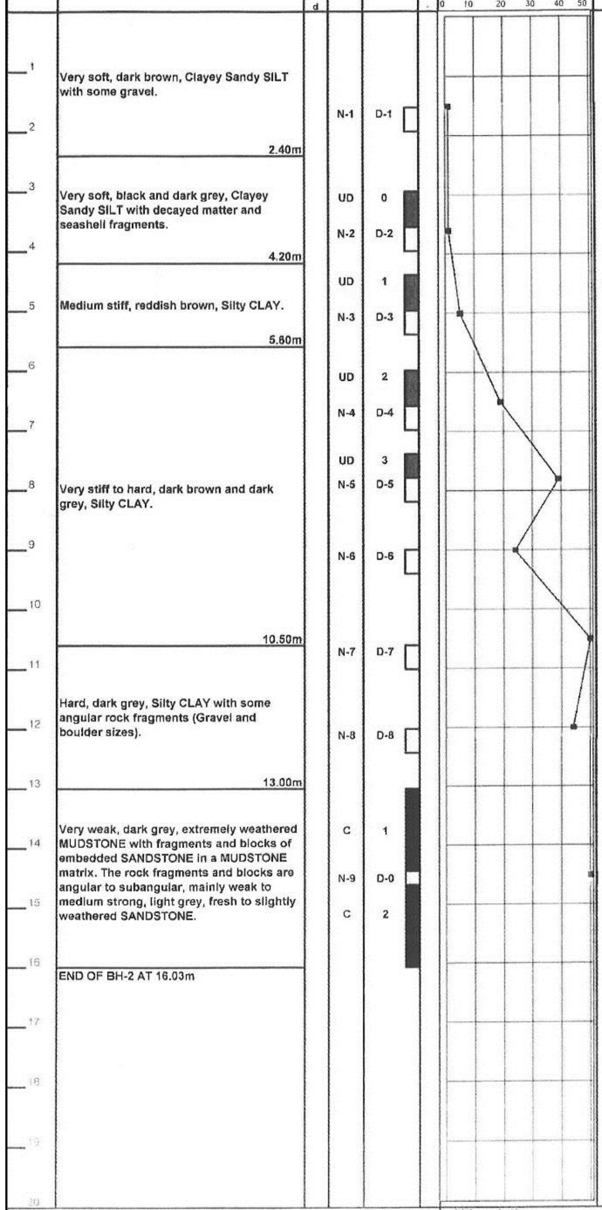
Location : Lahad Datu
Date Started : 13/09/2014
Date Completed : 14/09/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 13.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH-2
Ground Elev. : Existing Ground Level
Weather : Fine

Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
Very soft, dark brown, Clayey Sandy SILT with some gravel. (2.40m)	N-1	D-1		1	Depth : 1.50-1.95m 0/0/1/0/0/0, Rec=15cm
Very soft, black and dark grey, Clayey Sandy SILT with decayed matter and seashell fragments. (4.20m)	UD	0			Depth : 3.00-3.60m Rec=0cm
	N-2	D-2		1	Depth : 3.60-4.05m 1/0/0/1/0/0, Rec=40cm
Medium stiff, reddish brown, Silty CLAY. (5.60m)	UD	1	cu=18kN/m²		Depth : 4.50-5.00m Rec=21cm
	N-3	D-3		5	Depth : 5.00-5.45m 1/0/1/1/1/2, Rec=24cm
Very stiff to hard, dark brown and dark grey, Silty CLAY. (10.50m)	UD	2			Depth : 6.00-6.50m Rec=36cm
	N-4	D-4		19	Depth : 6.50-6.95m 2/3/4/5/5/5, Rec=28cm
	UD	3			Depth : 7.50-7.75m Rec=20cm
	N-5	D-5		39	Depth : 7.75-8.20m 2/4/7/10/10/12, Rec=25cm
	N-6	D-6		24	Depth : 9.00-9.45m 3/5/5/5/7/7, Rec=25cm
Hard, dark grey, Silty CLAY with some angular rock fragments (Gravel and boulder sizes). (13.00m)	N-7	D-7		>50	Depth : 10.50-10.93m 4/6/9/14/15/12(55mm), Rec=24cm
	N-8	D-8		44	Depth : 12.00-12.45m 5/5/7/9/13/15, Rec=16cm
Very weak, dark grey, extremely weathered MUDSTONE with fragments and blocks of embedded SANDSTONE in a MUDSTONE matrix. The rock fragments and blocks are angular to subangular, mainly weak to medium strong, light grey, fresh to slightly weathered SANDSTONE.	C	1			Depth : 13.00-14.50m Rec=70cm RQD=0%
	N-9	D-0		>50	Depth : 14.50-14.53m 50(30mm), Rec=0cm
	C	2			Depth : 14.53-16.03m Rec=100cm RQD=0%
END OF BH-2 AT 16.03m					

SPT, N-Value Vs Depth



<u>Groundwater Levels from below the Existing Ground Level:</u>

14/09/2014 - 0.90m (12:00pm)
15/09/2014 - 0.98m (7:50am)
16/09/2014 - 1.05m (8:00am)
17/09/2014 - 1.11m (8:14am)
18/09/2014 - 1.20m (8:26am)
19/09/2014 - 1.26m (8:01am)
20/09/2014 - 1.31m (8:05am)
21/09/2014 - 1.34m (7:51am)

Project :

Abbreviation

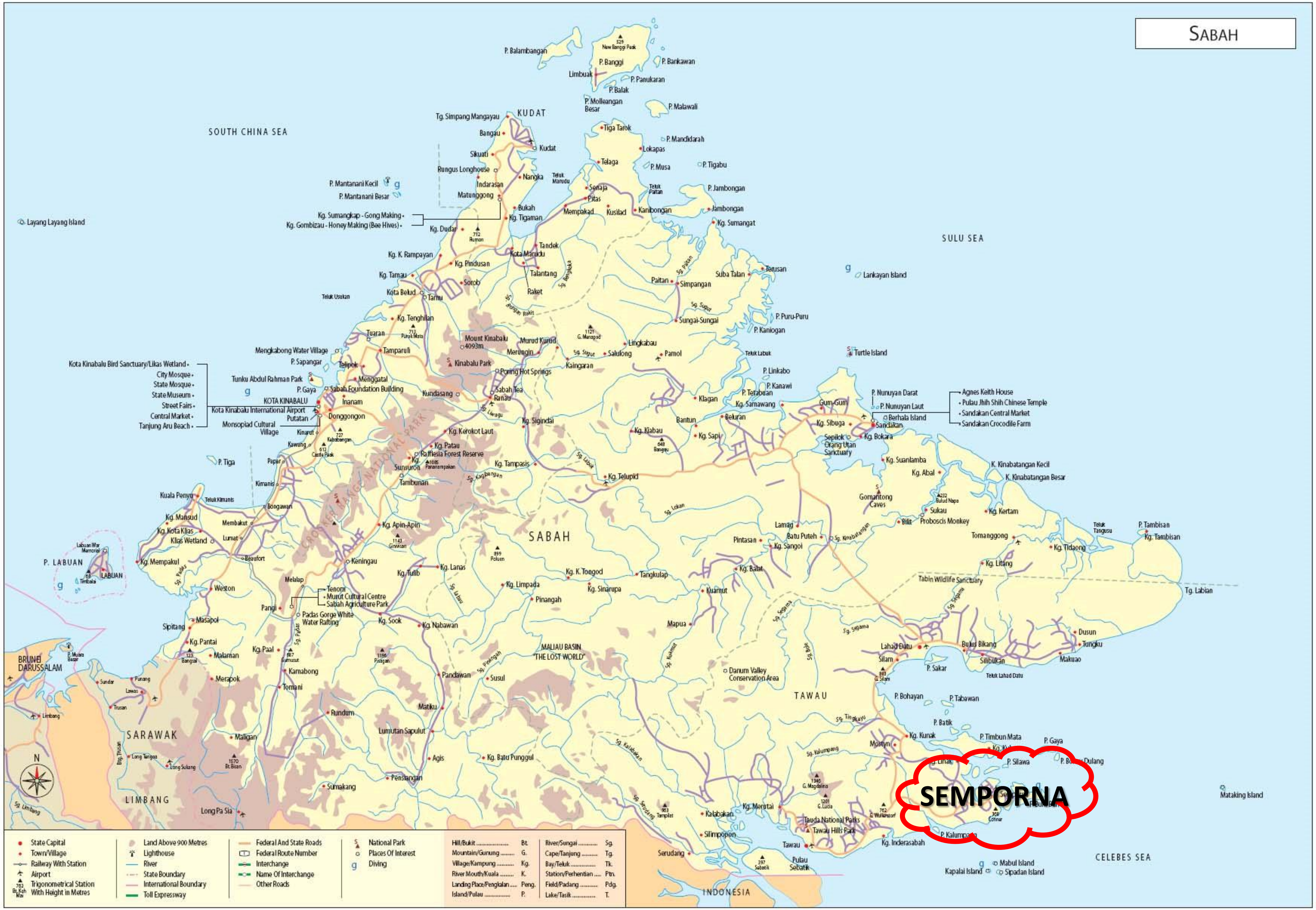
UD-Undisturbed Sample
D-Disturbed Sample
C-Core
SPT-Standard Penetration Test
N-SPT-N Value
Rec-Recovery
RQD-Rock Quality Designation
VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

Operator : Julaspi
Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong
Confirmed By : Roger YONG


SABAH
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
TAWAU
SARAWAK
LIMBANG
BRUNEI DARUSSALAM
INDONESIA
P. LABUAN
LABUAN
SEMPORNA
P. Balambangan
P. Banggi
P. Bankawan
Limbuak
P. Panukaran
P. Balak
P. Molleangan Besar
P. Malawali
Tg. Simpang Mangayau
Bangau
Kudat
Sikuati
Rungus Longhouse
Nangka
Indarasan
Matunggong
Bukah
Kg. Tigaman
Tiga Tarok
Lokapas
P. Mandidarah
Telaga
P. Musa
P. Tigabu
Senaja
Pitas
Mempakad
Kusilad
Kanibongan
P. Jambongan
Jambongan
Kg. Sumangat
P. Mantanani Kecil
P. Mantanani Besar
Kg. Sumangkap - Gong Making
Kg. Gombizau - Honey Making (Bee Hives)
Layang Layang Island
Kg. Dudar
Kg. K. Rampayan
Kota Marudu
Tandek
Kg. Pindusan
Talantang
Kg. Tamau
Sorob
Kota Belud
Tamu
Raket
Paitan
Simpangan
Suba Talan
Terusan
Lankayan Island
Kg. Tenghilan
Sungai-Sungai
P. Puru-Puru
P. Kaniogan
Tuaran
Mount Kinabalu 4093m
Murud Kurud
Lingkabau
Mengkabong Water Village
Tamparuli
Merungin
Salulong
Pamol
Turtle Island
P. Sapangar
Kinabalu Park
Kaingaran
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Tunku Abdul Rahman Park
Telipok
Menggatal
Poring Hot Springs
P. Linkabo
P. Kanawi
P. Tetabuan
P. Gaya
Sabah Foundation Building
Kundasang
Sabah Tea
Ranau
Klagan
Kg. Samawang
Gum-Gum
P. Nunuyan Darat
P. Nunuyan Laut
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
KOTA KINABALU
Kota Kinabalu International Airport
Inanam
Putatan
Donggongon
Kg. Sigindai
Bantun
Beluran
Kg. Sibuga
Berhala Island
Sandakan
Monsopiad Cultural Village
Kinarut
Kawang
Kg. Kerokot Laut
Kg. Kiabau
Kg. Sapi
Sepilok Orang Utan Sanctuary
Kg. Bokara
P. Tiga
Papar
Kg. Patau
Rafflesia Forest Reserve
Kg. Sunsuron
Kg. Tampasis
Kg. Telupid
Kg. Suanlamba
Kg. Abal
K. Kinabatangan Kecil
K. Kinabatangan Besar
Kimanis
Tambunan
Kuala Penyu
Teluk Kimanis
Bongawan
Gomantong Caves
Sukau
Proboscis Monkey
Kg. Kertam
Kg. Mansud
Membakut
Kg. Apin-Apin
Lamag
Batu Puteh
Bilit
Kg. Kota Klias
Klias Wetland
Lumat
SABAH
Pintasan
Kg. Sangoi
Tomanggong
P. Tambisan
Kg. Tambisan
Kg. Tidaong
Kg. Mempakul
Beaufort
Keningau
Kg. Litang
Tabin Wildlife Sanctuary
Weston
Melalap
Kg. Tulib
Kg. Lanas
Kg. K. Tongod
Tangkulap
Kg. Balat
Tg. Labian
Tenom
Murut Cultural Centre
Sabah Agricultural Park
Kg. Limpada
Kg. Sinarupa
Kuamut
Pangi
Padas Gorge White Water Rafting
Pinangah
Sipitang
Masapol
Kg. Sook
Kg. Nabawan
Mapua
Dusun
Tungku
Kg. Pantai
Kg. Paal
MALIAU BASIN "THE LOST WORLD"
Lahad Datu
Bukit Bikang
Silibukan
Makuao
Malaman
Kemabong
Pandawan
Susul
Danum Valley Conservation Area
Silam
P. Sakar
Teluk Lahad Datu
Merapok
Tomani
P. Bohayan
P. Tabawan
Rundum
Matiku
P. Batik
Kg. Kunak
P. Timbun Mata
P. Gaya
Maligan
Lumutan Sapulut
Mostyn
P. Silawa
Long Tanggoa
Long Sulang
Agis
Kg. Batu Punggul
Sumakang
Pensiangan
Long Pa Sia
Kg. Merotai
Kalabakan
Tawau National Parks
Tawau Hills Park
Mataking Island
Silimpopon
Serudang
Tawau
Pulau Sebatik
Kg. Inderasabah
P. Kalumpang
Mabul Island
Kapalai Island
Sipadan Island
Sundar
Punang
Lawas
Trusan
Limbang
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit .... Bt.
Mountain/Gunung .... G.
Village/Kampung .... Kg.
River Mouth/Kuala .... K.
Landing Place/Pengkalan .... Peng.
Island/Pulau .... P.
River/Sungai .... Sg.
Cape/Tanjung .... Tg.
Bay/Teluk .... Tk.
Station/Perhentian .... Ptn.
Field/Padang .... Pdg.
Lake/Tasik .... T.

Location : Semporna, Sabah
Date Started : 11/06/2012
Date Completed : 11/06/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : -
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 1
Borehole No. : BH-7C
Ground Elev. : -0.70m
Coordinate : N 976625.510, E 511056.906

Weather : Fine

Depth (m)	Soil Description (Existing Seabed Level)	Legend	Type	Sample No.	Piezo.	SPT, N-Value Vs Depth (0 10 20 30 40 50)	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1	Very dense, milky white, coral fragments. 1.50m								
2			N-1	D-0				> 50	Depth : 1.50-1.54m 50(40mm), Rec=0cm
			C	1					Depth : 1.54-3.04m Rec=90cm RQD=0%
3–4	Weak to medium strong, milky white, fresh to moderately weathered, slightly to highly fractured, CORALSTONE with most of the coral stones have been disolved/disintegrated with vesicles.		C	2					Depth : 3.04-4.54m Rec=100cm RQD=0%
5			C	3					Depth : 4.54-6.04m Rec=80cm RQD=0%
6	END OF BH-7C AT 6.04m								
7–8									*Floating pontoon was used for the drilling works.*
8–9									*Approximate Seawater Levels from seabed was about 0.40m during site investigation works. Measurements in this borehole were from below seabed level.*
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Project :

Abbreviation
UD-Undisturbed Sample — D-Disturbed Sample — C-Core
SPT-Standard Penetration Test — N-SPT-N Value — Rec-Recovery
RQD-Rock Quality Designation — VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Operator : Nurudin — Recorded By : Nizam
Checked By : Vera C. — Confirmed By : Roger YONG

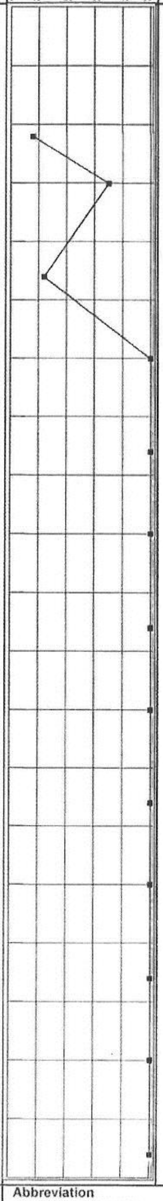
Location : Semporna
Date Started : 24/04/2013
Date Completed : 24/04/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 1
Swampy Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1	Very soft, dark grey, Clayey Sandy SILT with some decayed matter.					
2		UD	1	C_u=4kN/m^2		Depth : 1.50-2.10m Rec=60cm
	2.10m	N-1	D-1		8	Depth : 2.10-2.55m 1/2/2/2/2/2, Rec=45cm
3		N-2	D-2		35	Depth : 3.00-3.45m 6/4/9/9/8/9, Rec=45cm
4	Loose to dense, white, light brown and light grey, Silty Clayey SAND with some disintegrated limestone fragments.					
5		N-3	D-3		12	Depth : 4.50-4.95m 4/4/3/3/3/3, Rec=28cm
6	6.00m	N-4	D-4		>50	Depth : 6.00-6.34m 7/9/16/17/17(40mm), Rec=26cm
7						
8		N-5	D-5		>50	Depth : 7.50-7.825m 6/10/15/24/11(25mm), Rec=31cm
9		N-6	D-6		>50	Depth : 9.00-9.36m 4/6/11/17/22(60mm), Rec=24cm
10						
11		N-7	D-7		>50	Depth : 10.50-10.85m 8/10/14/19/17(50mm), Rec=22cm
12		N-8	D-8		>50	Depth : 12.00-12.36m 6/6/13/18/19(60mm), Rec=26cm
13	Very dense, white and light brown, Clayey Silty SAND with some disintegrated limestone fragments.					
14		N-9	D-9		>50	Depth : 13.50-13.81m 8/10/17/20/13(10mm), Rec=17cm
15		N-10	D-10		>50	Depth : 15.00-15.31m 6/10/16/21/13(10mm), Rec=23cm
16						
17		N-11	D-11		>50	Depth : 16.60-16.805m 7/10/18/23/9(5mm), Rec=26cm
18		N-12	D-12		>50	Depth : 18.00-18.30m 9/13/21/29(75mm), Rec=23cm
19						
20	END OF BH-1 At 19.77m	N-13	D-13		>50	Depth : 19.50-19.77m 11/18/27/23(45mm), Rec=19cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
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RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Nurudin
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Location : Semporna
Date Started : 24/04/2013
Date Completed : 24/04/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 16.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 1
Swampy Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	SPT, N-Value Vs Depth	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21							**Groundwater Level :** 24.04.13 - Full (12.00pm) 24.04.13 - Full (1.50pm) 24.04.13 - 0.10m (4.30pm)
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							

Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Nurudin
Recorded By : Jotirip
Checked By : Alex Leong
Confirmed By : Roger YONG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

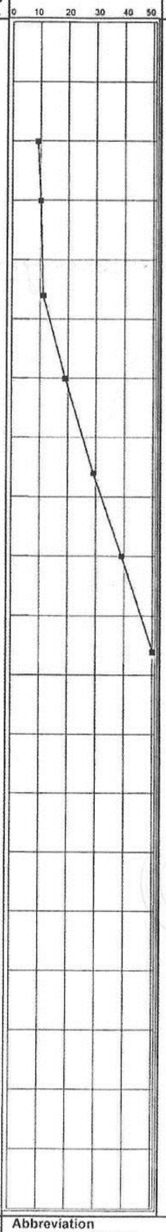
Date Started : 17/05/2013
Date Completed : 17/05/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 9.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 1
Borehole No. : BH- 3
Ground Elev. : Existing Ground Level.
Weather : Fine/Rain

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0.00–7.00m	Stiff to very stiff, light brown and light grey, Sandy Clayey SILT with some disintegrated limestone fragments.	UD	1	C_u=31kN/m^2		Depth : 1.50-1.90m Rec=38cm
		N-1	D-1		9	Depth : 1.90-2.35m 1/2/2/2/3/2, Rec=25cm
		N-2	D-2		10	Depth : 3.00-3.45m 2/2/2/3/2/3, Rec=28cm
		N-3	D-3		11	Depth : 4.50-4.95m 2/3/2/3/3/3, Rec=27cm
		N-4	D-4		19	Depth : 6.00-6.45m 4/4/5/4/5/6, Rec=30cm
7.00m–10.50m	Medium dense to dense, light brown and light grey, Silty Clayey SAND with some disintegrated limestone fragments.	N-5	D-5		29	Depth : 7.50-7.95m 5/5/7/7/8/7, Rec=24cm
		N-6	D-6		39	Depth : 9.00-9.45m 6/7/7/9/10/13, Rec=25cm
10.50m–13.53m	Very weak, dark brown, highly weathered and highly fractured LIMESTONE.	N-7	D-0		>50	Depth : 10.50-10.53m 50(30mm), Rec=0cm
		C	1			Depth : 10.53-12.03m Rec=100cm RQD=0%
		C	2			Depth : 12.03-13.53m Rec=105cm RQD=0%
13.53m–16.53m	Very weak to medium strong, dark brown, slightly to moderately weathered and moderately to slightly fractured LIMESTONE.	C	3			Depth : 13.53-15.03m Rec=110cm RQD=30%
		C	4			Depth : 15.03-16.53m Rec=130cm RQD=90%
	END OF BH-3 At 16.53m					

SPT, N-Value Vs Depth



Groundwater Level :
17.05.13 - 1.67m (2.30pm)
17.05.13 - 1.70m (5.30pm)
18.05.13 - 1.75m (8.42am)

Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Nurudin

Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong

Confirmed By : Roger YONG

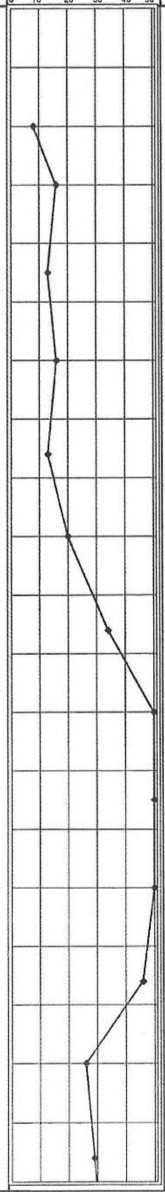
Location : Semporna
Date Started : 19.05.2013
Date Completed : 20.05.2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 28.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 1
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1.50	Medium stiff to very stiff, light grey, Sandy Clayey SILT with some coralstone fragments.	UD	1	c_u=40kN/m²		Depth : 1.50-2.00m Rec=38cm
2.00		N-1	D-1		8	Depth : 2.00-2.45m 1/1/1/3/2/2, Rec=18cm
3.00		N-2	D-2		16	Depth : 3.00-3.45m 2/2/3/4/4/5, Rec=32cm
4.50		N-3	D-3		13	Depth : 4.50-4.95m 2/2/3/3/4/3, Rec=39cm
6.00		N-4	D-4		16	Depth : 6.00-6.45m 3/3/3/4/4/5, Rec=42cm
7.50	8.40m	N-5	D-5		13	Depth : 7.50-7.95m 2/3/3/3/3/4, Rec=24cm
9.00	Very stiff to hard, light grey, Sandy Clayey SILT with some coralstone fragments.	N-6	D-6		20	Depth : 9.00-9.45m 4/4/4/5/5/6, Rec=14cm
10.50		N-7	D-7		34	Depth : 10.50-10.95m 5/5/7/8/10/9, Rec=26cm
12.00		N-8	D-8		>50	Depth : 12.00-12.44m 5/7/8/10/16/16(65mm), Rec=21cm
13.50		N-9	D-9		>50	Depth : 13.50-13.89m 6/7/10/15/17/8(15mm), Rec=22cm
15.00		N-10	D-10		>50	Depth : 15.00-15.40m 6/7/9/11/18/12(25mm), Rec=18cm
16.50	17.50m	N-11	D-11		46	Depth : 16.50-16.95m 8/9/9/9/12/16, Rec=20cm
18.00	Very stiff, light grey, Sandy Clayey SILT with some coralstone fragments.	N-12	D-12		26	Depth : 18.00-18.45m 5/6/6/7/6/7, Rec=29cm
19.50		N-13	D-13		29	Depth : 19.50-19.95m 4/4/5/6/8/10, Rec=11cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
Operator : Nuruddin
Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C.
Confirmed By : Roger YONG

Location : Semporna
Date Started : 19.05.2013
Date Completed : 20.05.2013
Type of Boring : Rotary Wash Boring

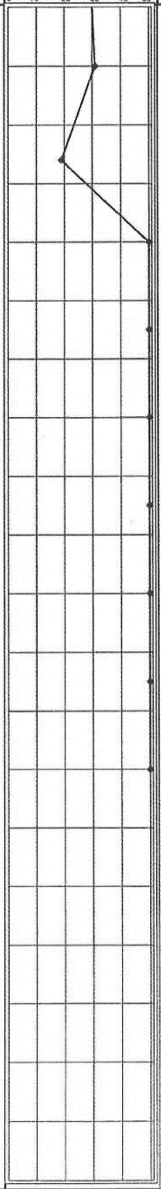
Rig Type : YWE D45
Casing Depth : 28.50m
Casing Size : NW
Boring Diameter : 76mm

Borehole No. : BH- 1
Ground Elev. : Existing Ground Level
Weather : Fine

Depth (m)	Soil Description	Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21.00	Very stiff, light grey, Sandy Clayey SILT with some coralstone fragments.	N-14	D-14		31	Depth : 21.00-21.45m 4/5/7/7/8/9, Rec=14cm
22.50	24.00m	N-15	D-15		19	Depth : 22.50-22.95m 3/4/4/5/5/5, Rec=10cm
24.00	Very dense, brownish and whitish grey, Silty SAND with some coralstone fragments.	N-16	D-16		>50	Depth : 24.00-24.30m 7/16/20/30(75mm), Rec=20cm
25.50		N-17	D-17		>50	Depth : 25.50-25.79m 10/18/29/22(65mm), Rec=16cm
27.00		N-18	D-18		>50	Depth : 27.00-27.28m 10/19/30/20(55mm), Rec=18cm
28.50		N-19	D-19		>50	Depth : 28.50-28.80m 8/16/24/26(75mm), Rec=11cm
30.00		N-20	D-20		>50	Depth : 30.00-30.30m 8/15/21/29(75mm), Rec=12cm
31.50		N-21	D-21		>50	Depth : 31.50-31.775m 9/16/30/20(50mm), Rec=10cm
33.00	END OF BH-1 AT 33.26m	N-22	D-22		>50	Depth : 33.00-33.26m 10/19/35/15(35mm), Rec=10cm

Groundwater Level:
19.05.2013 - 0.20m (6:00pm)
20.05.2013 - 0.20m (7:20am)
20.05.2013 - 0.10m (5:30pm)
21.05.2013 - 0.10m (8:00am)
21.05.2013 - 0.10m (5:00pm)
22.05.2013 - 0.10m (8:30am)
22.05.2013 - 0.10m (5:10pm)

SPT, N-Value Vs Depth

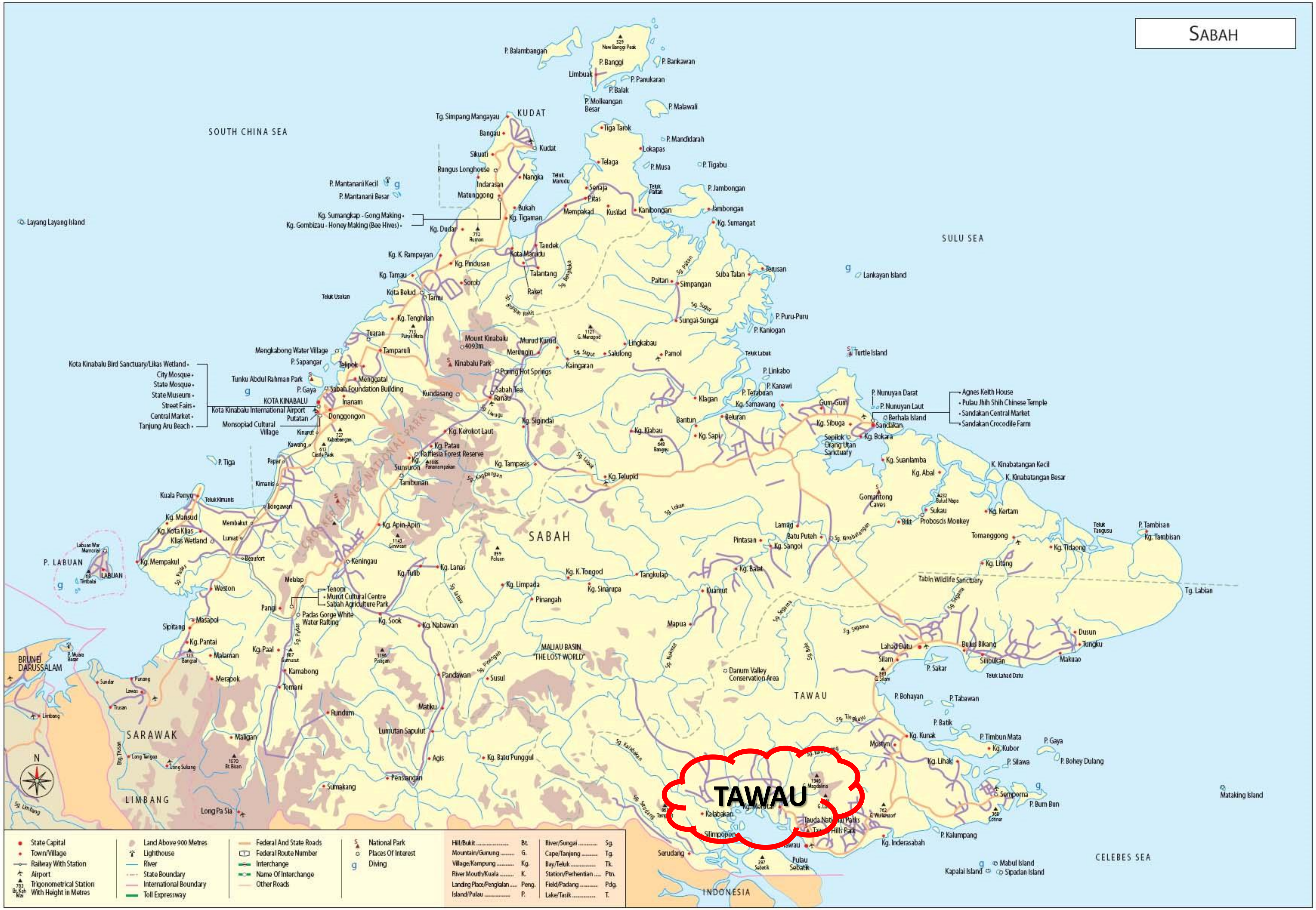


Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG
Operator : Nuruddin
Recorded By : Jotirip

STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C.
Confirmed By : Roger YONG


SABAH
TAWAU
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KUDAT
SABAH
TAWAU
SARAWAK
LIMBANG
INDONESIA
BRUNEI DARUSSALAM
P. LABUAN
LABUAN
KOTA KINABALU
Kota Kinabalu Bird Sanctuary/Likas Wetland
City Mosque
State Mosque
State Museum
Street Fairs
Central Market
Tanjung Aru Beach
Kota Kinabalu International Airport
Tunku Abdul Rahman Park
Mount Kinabalu 4093m
Kinabalu Park
Poring Hot Springs
Sandakan
Agnes Keith House
Pulau Jhih Shih Chinese Temple
Sandakan Central Market
Sandakan Crocodile Farm
Sepilok Orang Utan Sanctuary
Gomantong Caves
Tabin Wildlife Sanctuary
Danum Valley Conservation Area
MALIAU BASIN "THE LOST WORLD"
Lahad Datu
Semporna
Kunak
Kalabakan
Tawau Hills Park
Lankayan Island
Turtle Island
Layang Layang Island
Mataking Island
Sipadan Island
Mabul Island
Kapalai Island
Tenom
Keningau
Ranau
Kota Belud
Kota Marudu
Beaufort
Sipitang
Papar
Tambunan
Nabawan
Pensiangan
Long Pa Sia
State Capital
Town/Village
Railway With Station
Airport
Trigonometrical Station With Height in Metres
Land Above 900 Metres
Lighthouse
River
State Boundary
International Boundary
Toll Expressway
Federal And State Roads
Federal Route Number
Interchange
Name Of Interchange
Other Roads
National Park
Places Of Interest
Diving
Hill/Bukit Bt.
Mountain/Gunung G.
Village/Kampung Kg.
River Mouth/Kuala K.
Landing Place/Pengkalan Peng.
Island/Pulau P.
River/Sungai Sg.
Cape/Tanjung Tg.
Bay/Teluk Tk.
Station/Perhentian Ptn.
Field/Padang Pdg.
Lake/Tasik T.

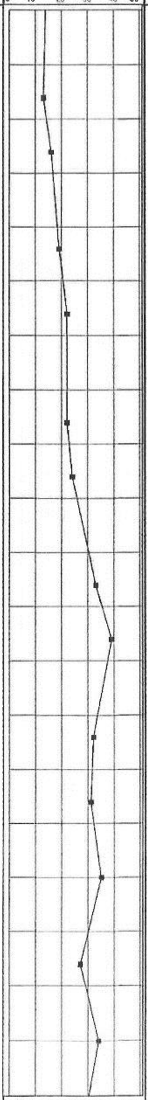
Location : Tawau
Date Started : 01/12/2012
Date Completed : 03/12/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 31.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
21			UD	11				Depth : 21.00-21.60m Rec=46cm
22			N-14	D-14			13	Depth : 21.60-22.05m 4/4/3/3/4/3, Rec=45cm
23			N-15	D-15			16	Depth : 22.50-22.95m 4/4/4/4/4/4, Rec=45cm
24			UD	12				Depth : 24.00-24.30m Rec=21cm
25			N-16	D-16			19	Depth : 24.30-24.75m 4/4/4/5/5/5, Rec=39cm
26			N-17	D-17			22	Depth : 25.50-25.95m 5/5/5/5/5/7, Rec=41cm
27			UD	13		C_u=50kN/m^2		Depth : 27.00-27.50m Rec=45cm
28	Stiff to hard, dark grey, Clayey Sandy SILT.		N-18	D-18			22	Depth : 27.50-27.95m 5/5/5/5/6/6, Rec=45cm
29			N-19	D-19			24	Depth : 28.50-28.95m 5/5/5/6/6/7, Rec=21cm
30			UD	14				Depth : 30.00-30.50m Rec=49cm
31			N-20	D-20			33	Depth : 30.50-30.95m 5/7/7/8/9/9, Rec=30cm
32			N-21	D-21			39	Depth : 31.50-31.95m 5/5/9/9/10/11, Rec=39cm
33			UD	15				Depth : 33.00-33.30m Rec=24cm
34			N-22	D-22			32	Depth : 33.30-33.75m 5/5/7/7/9/9, Rec=45cm
35			N-23	D-23			31	Depth : 34.50-34.95m 7/9/9/7/8/7, Rec=40cm
36	36.00m		N-24	D-24			35	Depth : 36.00-36.45m 7/7/9/8/9/9, Rec=29cm
37								
38	Very stiff to hard, dark grey, Clayey SILT.		N-25	D-25			27	Depth : 37.50-37.95m 4/7/7/7/6/7, Rec=24cm
39			N-26	D-26			34	Depth : 39.00-39.45m 7/8/8/8/9/9, Rec=30cm
40								

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Nurudin
Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Alex Leong
Confirmed By : Roger YONG

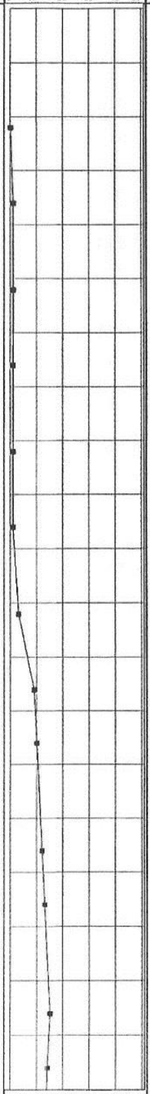
Location : Tawau
Date Started : 01/12/2012
Date Completed : 03/12/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 31.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
1	Dark brown and dark grey, Sandy SILT with some gravel. 1.00m							
2	Very soft, dark brown and dark grey, Clayey SILT with traces of decayed matter.		UD	1		C_u=27kN/m^2		Depth : 1.50-2.10m Rec=31cm
			N-1	D-1			0	Depth : 2.10-2.55m 0/0/0/0/0/0, Rec=22cm
3			UD	2				Depth : 3.00-3.60m Rec=50cm
4	4.00m		N-2	D-2			1	Depth : 3.60-4.05m 0/0/1/0/0/0, Rec=41cm
5			UD	3		C'=4kN/m^2 φ'=13°		Depth : 4.50-5.10m Rec=44cm
			N-3	D-3			1	Depth : 5.10-5.55m 0/0/0/0/1/0, Rec=45cm
6	Very soft, dark grey, Silty CLAY with traces of decayed matter.		UD	4		C_u=8kN/m^2		Depth : 6.00-6.60m Rec=45cm
7			N-4	D-4			1	Depth : 6.60-7.05m 0/0/0/0/0/1, Rec=45cm
8			UD	5				Depth : 7.50-8.10m Rec=42cm
			N-5	D-5			1	Depth : 8.10-8.55m 0/0/1/0/0/0, Rec=45cm
9	9.00m		UD	6				Depth : 9.00-9.60m Rec=45cm
10			N-6	D-6			1	Depth : 9.60-10.05m 0/0/0/1/0/0, Rec=35cm
11	Very soft to soft, brownish grey, Clayey SILT.		UD	7				Depth : 10.50-11.10m Rec=50cm
	11.80m		N-7	D-7			3	Depth : 11.10-11.55m 1/1/1/0/1/1, Rec=24cm
12	Stiff, reddish brown and light grey, Clayey SILT.		UD	8		C'=6kN/m^2 φ'=20°		Depth : 12.00-12.60m Rec=50cm
13	13.00m		N-8	D-8			9	Depth : 12.60-13.05m 2/2/3/2/2/2, Rec=36cm
14			N-9	D-9			10	Depth : 13.50-13.95m 1/2/2/3/3/2, Rec=45cm
15			UD	9		C_u=34kN/m^2		Depth : 15.00-15.60m Rec=56cm
16			N-10	D-10			12	Depth : 15.60-16.05m 2/2/2/3/3/4, Rec=40cm
17	Stiff, dark grey, Sandy Clayey SILT.		N-11	D-11			13	Depth : 16.50-16.95m 3/3/4/3/3/3, Rec=36cm
18			UD	10				Depth : 18.00-18.50m Rec=28cm
19			N-12	D-12			15	Depth : 18.50-18.95m 2/3/3/3/4/5, Rec=45cm
20			N-13	D-13			14	Depth : 19.50-19.95m 3/3/4/4/3/3, Rec=45cm

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Nurudin
Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Alex Leong
Confirmed By : Roger YONG

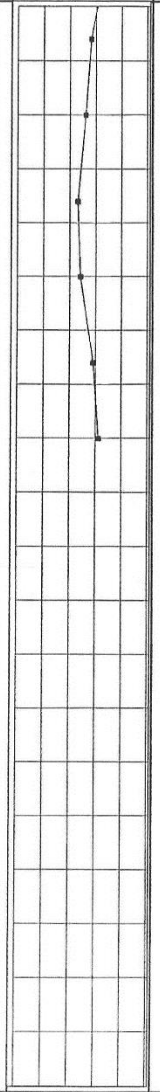
Location : Tawau
Date Started : 01/12/2012
Date Completed : 03/12/2012
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 31.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 3 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
41			N-27	D-27			28	Depth : 40.50-40.95m 4/5/7/7/7/7, Rec=29cm
42			N-28	D-28			26	Depth : 42.00-42.45m 4/4/4/7/7/8, Rec=45cm
43								
44	Very stiff to hard, dark grey, Clayey SILT.		N-29	D-29			23	Depth : 43.50-43.95m 6/4/5/6/6/6, Rec=30cm
45			N-30	D-30			24	Depth : 45.00-45.45m 5/5/6/6/6/6, Rec=39cm
46								
47			N-31	D-31			29	Depth : 46.50-46.95m 5/6/6/8/7/8, Rec=27cm
48			N-32	D-32			31	Depth : 48.00-48.45m 5/5/7/8/8/8, Rec=29cm
49	END OF BH-1 AT 48.45m							Groundwater Level : 02.12.12 - 1.91m (7.49am) 03.12.12 - 1.10m (7.30am) 04.12.12 - 0.91m (8.00am) 05.12.12 - 0.90m (8.21am) 06.12.12 - 0.91m (7.55am) 07.12.12 - 0.92m (8.31am)
50								
51								
52								
53								
54								
55								
56								
57								
58								
59								
60								

SPT, N-Value Vs Depth



Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Nurudin
Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Alex Leong
Confirmed By : Roger YONG

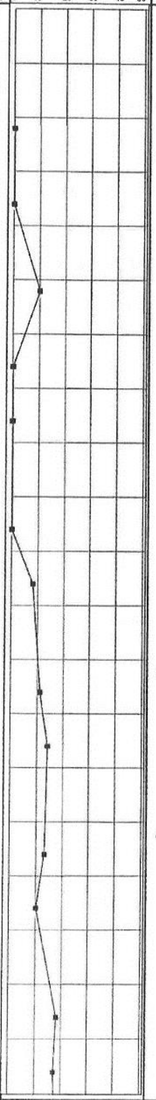
Location : Tawau
Date Started : 21/04/2013
Date Completed : 21/04/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 37.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Depth (m)	Soil Description
0.80m	Asphalt Ground and Fill Material.
4.10m	Very soft, reddish brown, Clayey Sandy SILT with traces of decayed matter.
4.10m	Very soft, dark grey, Silty CLAY with traces of decayed matter.
6.00m	Loose, dark grey, fine to coarse SAND with traces of seashell fragments.
10.30m	Very soft, dark grey, Clayey SILT.
17.40m	Stiff, reddish brown and dark grey, Clayey Sandy SILT with traces of seashell fragments and occasional small size gravel.
	Very stiff, dark grey, Clayey Sandy SILT with traces of decayed matter.

SPT, N-Value Vs Depth



Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
UD	1	cu=17kN/m²		Depth : 1.50-2.00m Rec=45cm
N-1	D-1		0	Depth : 2.00-2.45m 1/0/0/0/0/0, Rec=45cm
UD	2			Depth : 3.00-3.50m Rec=45cm
N-2	D-2		0	Depth : 3.50-3.95m 0/0/0/0/0/0, Rec=45cm
UD	0			Depth : 4.50-5.10m Rec=0cm
N-3	D-3		10	Depth : 5.10-5.55m 1/1/2/3/3/2, Rec=40cm
UD	3	cu=9kN/m²		Depth : 6.00-6.50m Rec=50cm
N-4	D-4		0	Depth : 6.50-6.95m 1/0/0/0/0/0, Rec=45cm
N-5	D-5		0	Depth : 7.50-7.95m 1/0/0/0/0/0, Rec=45cm
UD	4			Depth : 9.00-9.50m Rec=50cm
N-6	D-6		0	Depth : 9.50-9.95m 1/0/0/0/0/0, Rec=46cm
N-7	D-7		8	Depth : 10.50-10.95m 1/2/2/2/2/2, Rec=45cm
UD	5	cu=11kN/m²		Depth : 12.00-12.50m Rec=45cm
N-8	D-8		11	Depth : 12.50-12.95m 2/2/2/3/3/3, Rec=41cm
N-9	D-9		14	Depth : 13.50-13.95m 3/3/3/4/3/4, Rec=45cm
UD	6	cu=21kN/m²		Depth : 15.00-15.60m Rec=55cm
N-10	D-10		13	Depth : 15.60-16.05m 3/4/3/3/3/4, Rec=43cm
N-11	D-11		10	Depth : 16.50-16.95m 2/2/2/3/2/3, Rec=45cm
UD	7			Depth : 18.00-18.60m Rec=55cm
N-12	D-12		18	Depth : 18.60-19.05m 3/3/4/4/5/5, Rec=35cm
N-13	D-13		17	Depth : 19.50-19.95m 4/3/4/5/4/4, Rec=45cm

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Rayhan | Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C. | Confirmed By : Roger YONG

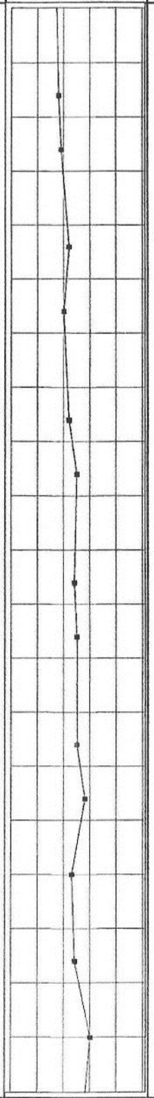
Location : Tawau
Date Started : 21/04/2013
Date Completed : 21/04/2013
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 37.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Soil Description: Very stiff, dark grey, Clayey Sandy SILT with traces of decayed matter.

SPT, N-Value Vs Depth



Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
UD	8			Depth : 21.00-21.60m Rec=46cm
N-14	D-14		18	Depth : 21.60-22.05m 4/4/3/3/4/3, Rec=45cm
N-15	D-15		19	Depth : 22.50-22.95m 4/4/4/4/4/4, Rec=45cm
UD	9	cu=85kN/m²		Depth : 24.00-24.30m Rec=21cm
N-16	D-16		22	Depth : 24.30-24.75m 4/4/4/5/5/5, Rec=39cm
N-17	D-17		20	Depth : 25.50-25.95m 5/5/5/5/5/7, Rec=41cm
UD	10			Depth : 27.00-27.50m Rec=45cm
N-18	D-18		22	Depth : 27.50-27.95m 5/5/5/5/6/6, Rec=45cm
N-19	D-19		25	Depth : 28.50-28.95m 5/5/5/6/6/7, Rec=21cm
UD	11	cu=71kN/m²		Depth : 30.00-30.50m Rec=49cm
N-20	D-20		24	Depth : 30.50-30.95m 5/7/7/8/9/9, Rec=30cm
N-21	D-21		25	Depth : 31.50-31.95m 5/5/9/9/10/11, Rec=39cm
UD	12			Depth : 33.00-33.30m Rec=24cm
N-22	D-22		25	Depth : 33.30-33.75m 5/5/7/7/9/9, Rec=45cm
N-23	D-23		28	Depth : 34.50-34.95m 7/9/9/7/8/7, Rec=40cm
N-24	D-24		28	Depth : 36.00-36.45m 7/7/9/8/9/9, Rec=29cm
N-25	D-25		23	Depth : 37.50-37.95m 4/7/7/7/6/7, Rec=24cm
N-26	D-26		24	Depth : 39.00-39.45m 7/8/8/8/9/9, Rec=30cm

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Rayhan | Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C. | Confirmed By : Roger YONG

Location : Tawau
Date Started : 21/04/2013
Date Completed : 21/04/2013
Type of Boring : Rotary Wash Boring

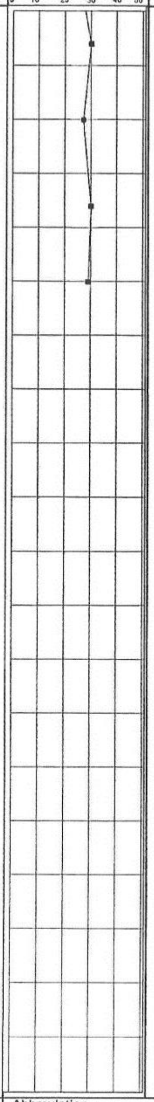
Rig Type : YWE D45
Casing Depth : 37.50m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 3 of 3
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level
Weather : Fine/ Drizzling

Soil Description: Very stiff, dark grey, Clayey Sandy SILT with traces of decayed matter.

END OF BH-1 AT 45.45m

SPT, N-Value Vs Depth



Type	Sample No.	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
N-27	D-27		30	Depth : 40.50-40.95m 4/5/7/7/7/7, Rec=29cm
N-28	D-28		27	Depth : 42.00-42.45m 4/4/4/7/7/8, Rec=45cm
N-29	D-29		30	Depth : 43.50-43.95m 6/4/5/6/6/6, Rec=30cm
N-30	D-30		29	Depth : 45.00-45.45m 5/5/6/6/6/6, Rec=39cm
				Groundwater Level : 21.04.2013 - 0.21m (9:47pm)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG
Operator : Rayhan | Recorded By : Suhaizal
STL GEOTECHNICAL ENGINEERING SDN. BHD.
Checked By : Vera C. | Confirmed By : Roger YONG

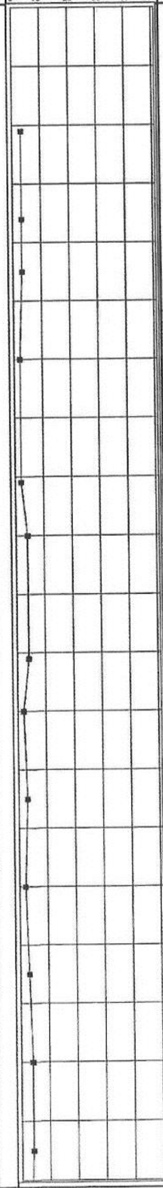
Location : Tawau
Date Started : 16/04/2014
Date Completed : 20/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 48.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 1 of 4
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Cloudy

Coordinates: N.472498; E.913023

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	SPT, N-Value Vs Depth	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
0–1.00	Yellowish to reddish brown, Sandy Clayey SILT. 1.00m								
1.00–4.50	Very loose, dark grey, Silty Clayey SAND. 4.50m		UD	1			C_u=10kN/m^2		Depth : 1.50-2.10m Rec=60cm
			N-1	D-1				3	Depth : 2.10-2.55m 1/0/1/1/0/1, Rec=45cm
			UD	2			C_u=6kN/m^2 C'=4kN/m^2 φ'=16°		Depth : 3.00-3.60m Rec=60cm
			N-2	D-2				3	Depth : 3.60-4.05m 0/1/0/1/1/1, Rec=45cm
			N-3	D-3				3	Depth : 4.50-4.95m 1/0/1/0/1/1, Rec=30cm
4.50–20	Soft to medium stiff, dark grey, Silty CLAY with traces of seashell fragments.		N-4	D-4				2	Depth : 6.00-6.45m 1/1/1/0/1/0, Rec=28cm
			UD	3			C_u=20kN/m^2		Depth : 7.50-8.10m Rec=60cm
			N-5	D-5				2	Depth : 8.10-8.55m 0/1/0/1/0/1, Rec=45cm
			N-6	D-6				4	Depth : 9.00-9.45m 1/1/1/1/1/1, Rec=45cm
			UD	4			C_u=12kN/m^2 C'=4kN/m^2 φ'=15°		Depth : 10.50-11.10m Rec=60cm
			N-7	D-7				4	Depth : 11.10-11.55m 1/0/1/1/1/1, Rec=45cm
			N-8	D-8				2	Depth : 12.00-12.45m 1/1/1/0/1/0, Rec=45cm
			N-9	D-9				3	Depth : 13.50-13.95m 0/1/1/1/0/1, Rec=45cm
			N-10	D-10				2	Depth : 15.00-15.45m 1/1/0/1/0/1, Rec=45cm
			N-11	D-11				3	Depth : 16.50-16.95m 1/1/1/1/0/1, Rec=45cm
			N-12	D-12				4	Depth : 18.00-18.45m 1/0/1/1/1/1, Rec=45cm
			N-13	D-13				4	Depth : 19.50-19.95m 1/1/1/1/1/1, Rec=45cm



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Ricky
Recorded By : Nizam
Checked By : Alex Leong
Confirmed By : Roger YONG

STL GEOTECHNICAL ENGINEERING SDN. BHD.

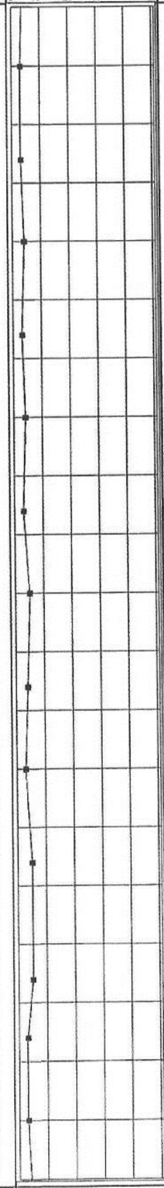
Location : Tawau
Date Started : 16/04/2014
Date Completed : 20/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 48.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 2 of 4
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Cloudy

Coordinates: N.472498; E.913023

Depth (m)	Soil Description	Legend	Type	Sample No.	Piezo.	SPT, N-Value Vs Depth	Shear Strength	SPT (N)	Other Insitu Tests And Remarks
20–40	Soft to medium stiff, dark grey, Silty CLAY with traces of seashell fragments.		N-14	D-14				3	Depth : 21.00-21.45m 1/0/1/0/1/1, Rec=45cm
			N-15	D-15				3	Depth : 22.50-22.95m 0/1/1/1/0/1, Rec=45cm
			N-16	D-16				4	Depth : 24.00-24.45m 1/0/1/1/1/1, Rec=45cm
			N-17	D-17				3	Depth : 25.50-25.95m 1/1/1/0/1/1, Rec=45cm
			N-18	D-18				4	Depth : 27.00-27.45m 1/1/1/1/1/1, Rec=45cm
			N-19	D-19				3	Depth : 28.50-28.95m 1/1/1/0/1/1, Rec=45cm
			N-20	D-20				5	Depth : 30.00-30.45m 1/1/1/1/1/2, Rec=45cm
			N-21	D-21				4	Depth : 31.50-31.95m 1/1/1/1/1/1, Rec=45cm
			N-22	D-22				3	Depth : 33.00-33.45m 1/1/1/1/0/1, Rec=45cm
			N-23	D-23				5	Depth : 34.50-34.95m 1/1/1/1/2/1, Rec=45cm
			UD	5					Depth : 36.00-36.60m Rec=60cm
			N-24	D-24				5	Depth : 36.60-37.05m 1/1/1/1/1/2, Rec=45cm
			N-25	D-25				3	Depth : 37.50-37.95m 1/1/0/1/1/1, Rec=45cm
			N-26	D-26				3	Depth : 39.00-39.45m 1/1/0/1/1/1, Rec=45cm



Project :

Abbreviation
UD-Undisturbed Sample
SPT-Standard Penetration Test
RQD-Rock Quality Designation
D-Disturbed Sample
N-SPT-N Value
VS- Vane Shear Test
C-Core
Rec-Recovery

SUBSURFACE EXPLORATION LOG

Operator : Ricky
Recorded By : Nizam
Checked By : Alex Leong
Confirmed By : Roger YONG

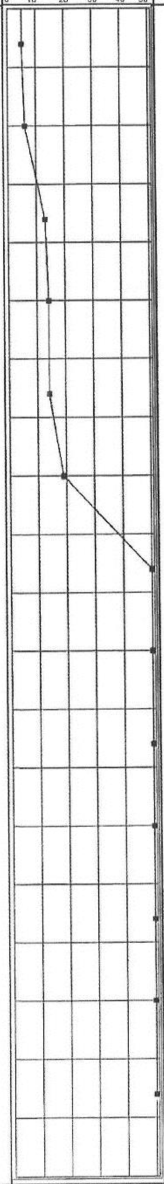
STL GEOTECHNICAL ENGINEERING SDN. BHD.

Location : Tawau
Date Started : 16/04/2014
Date Completed : 20/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 48.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 3 of 4
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Cloudy

Coordinates: N.472498; E.913023



Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
40.00–43.50m	Medium stiff, dark grey, Clayey SILT with traces of seashell fragments.	N-27	D-27	5	Depth : 40.50-40.95m 1/1/1/1/1/2, Rec=45cm
		N-28	D-28	6	Depth : 42.00-42.45m 1/1/1/1/2/2, Rec=40cm
43.50m	Stiff to very stiff, dark grey and black, Sandy SILT.	N-29	D-29	13	Depth : 43.50-43.95m 2/2/3/3/3/4, Rec=45cm
		N-30	D-30	14	Depth : 45.00-45.95m 2/3/3/3/4/4, Rec=45cm
		N-31	D-31	14	Depth : 46.50-46.95m 1/1/3/3/3/5, Rec=45cm
		N-32	D-32	19	Depth : 48.00-48.45m 3/3/4/5/5/5, Rec=45cm
49.50m	Hard, yellowish brown and reddish brown mottled dark grey, Clayey SILT.	N-33	D-33	>50	Depth : 49.50-49.885m 5/8/12/14/17/7(10mm), Rec=26cm
		N-34	D-34	>60	Depth : 51.00-51.35m 6/9/13/15/22(50mm), Rec=20cm
		N-35	D-35	>50	Depth : 52.50-52.85m 8/10/13/18/19(50mm), Rec=10cm
		N-36	D-36	>50	Depth : 54.00-54.35m 10/15/15/18/17(50mm), Rec=19cm
		N-37	D-37	>50	Depth : 55.50-55.84m 13/15/19/21/10(40mm), Rec=18cm
		N-38	D-38	>50	Depth : 57.00-57.275m 15/19/22/28(50mm), Rec=20cm
		N-39	D-39	>50	Depth : 58.50-58.70m 28/29/50(50mm), Rec=13cm

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

Operator : Ricky | Recorded By : Nizam

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong | Confirmed By : Roger YONG

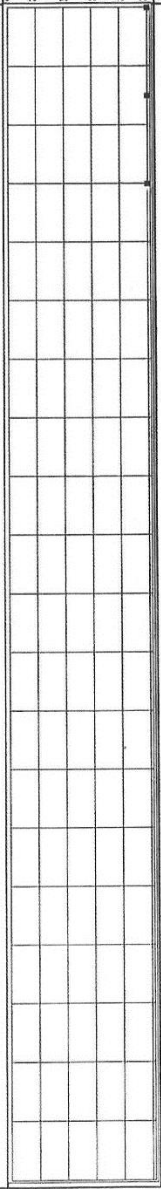
Cont'

Location : Tawau
Date Started : 16/04/2014
Date Completed : 20/04/2014
Type of Boring : Rotary Wash Boring

Rig Type : YWE D45
Casing Depth : 48.00m
Casing Size : NW
Boring Diameter : 76mm

Sheet No. : 4 of 4
Borehole No. : BH- 1
Ground Elev. : Existing Ground Level.
Weather : Fine/Cloudy

Coordinates: N.472498; E.913023



Depth (m)	Soil Description	Type	Sample No.	SPT (N)	Other Insitu Tests And Remarks
60.00–63.19m	Hard, yellowish brown and reddish brown mottled dark grey, Clayey SILT.	N-40	D-40	>50	Depth : 60.00-60.21m 23/36/50(60mm), Rec=14cm
		N-41	D-41	>50	Depth : 61.50-61.69m 29/42/50(40mm), Rec=10cm
	END OF BH-1 At 63.19m	N-42	D-42	>50	Depth : 63.00-63.19m 31/46/50(40mm), Rec=14cm

Groundwater levels below the existing ground level;

16.04.14 - 0.80m (6.30pm)
17.04.14 - 0.90m (6.00pm)
18.04.14 - 1.30m (2.00pm)
18.04.14 - 1.00m (4.30pm)
19.04.14 - 1.20m (7.40am)
19.04.14 - 1.10m (3.00pm)
20.04.14 - 1.30m (7.30am)

Project :

Abbreviation
UD-Undisturbed Sample | D-Disturbed Sample | C-Core
SPT-Standard Penetration Test | N-SPT-N Value | Rec-Recovery
RQD-Rock Quality Designation | VS- Vane Shear Test

SUBSURFACE EXPLORATION LOG

Operator : Ricky | Recorded By : Nizam

STL GEOTECHNICAL ENGINEERING SDN. BHD.

Checked By : Alex Leong | Confirmed By : Roger YONG

Common Problems

- Organic Soils
  - High deformation under load
  - Chemical attacks on embedded structures
- Normally Consolidated Clays
  - Long-term consolidation settlements
  - Heaving and displacement piles

- Expansive Soils
  - Expansion when re-saturated

- Sensitive Clays
  - Excessive settlements

- Loose Sands
  - Compactions and densifications

APPLICATIONS OF ROCKFALL NETTING AND BARRIER IN TAIWAN

Hsiuan Lin[1], TK Wu[2], CH Wu

[1]Peofessional Geotechnical Engineers'Association,
E-mail : hlin0816@gmail.com
[2]Helpfull Machinery Service Ltd.
E-mail : Helpmsco.ms15.hinet.net
3Water Resource Engg & Conservation Dept., Feng Chia University
E-mail : wudickson@hotmail.com

Taiwan is a small island with an area about 36,193 km2. It was formed approximately 4 to 5 million years ago at a complexconvergent boundary between the Philippine Sea Plate and the Eurasian Plate. Since the tectonic boundary remains active, Taiwan experiences 15,000 to 18,000 times of earthquakes each year, of which 800 to 1,000 times are noticed by people. Two third of the Taiwan island is sloping and mountainous area.

The climate of Taiwan lies across the Tropic of Cancer.Typhoons are most likely to strike between July and October each year, with on average about four direct hits Taiwan per year. Intensive rain from typhoons often leads to disastrous mudslides.
With these earthquakes and Typhoons, how to prevent the damages from rockfalls become a challenge issue for geotechnical engineers in Taiwan.

One of the approaches is using the rockfall nettings and barriers. Actively, to prevent rock fragments falling down, and passively, to catch the falling rock fragments.

There were three case studies which one using active rockfall nets and another two the passive rockfall fences introduced and presented in this paper for both design and construction aspects.

Keywords: rockfall, netting, barrier, slope stabilization

1 Introduction

Rockfall Netting and Barrier are used to protect or prevent the rock fall from uphill to downhill.

There are two concepts to prevent or catch the rock fragments falling down as follows:

1.1 Active type:
Using nets to cover the slope closely, lock the nets by rock bolts, the rock fragment cannot move freely and cannot fall from uphill to downhill, so the possible damage can be prevented. Since the nets are lock by rock bolts and close to the surface, the impact to the landscape is little.

1.2 Passive type:

When the potential rockfall source area is large, and the potential disaster spot is relatively concentrated, passive interception may be the best solution. To construct a fence or barrier intercepts the rock fragments before they are falling down.

Of greater present day concern, the industry has now reverted to adopting the PWD-prescribed slope geometries. A great number of slope failures have occurred since; some with very tragic consequences. So the identification of the reasonable science for slope engineering has become an important need to mitigate such catastrophic events.

2 Design Consideration

Information required : The type of the top soil and rock layers, the possible size of the rock fragments, the thickness of the top soil layers, the possible distance of the rock fragments couls move, and the height difference between the top and down hills.

Come out of the solutions: The spacing, length and diameter of the rock bolts required, the details of the wire meshes required; The Length and height of barrier required.

3 Case Studies

There were three case studies which one using active rockfall nets and another two the passive rockfall fences presented and discussed as follows

3.1 *Case One ~ Active Type*

~ Location: ChungHo sloping area, New Taipei City.

~ Design concepts: Using double twisted steel wire mesh to create active protection system. Double twisted steel woven wire mesh is to use the machine in accordance with the way steel wire twisted together with a hexagonal mesh. Hexagonal double twisted steel wire mesh in each direction has a flexible deformable characteristics; twisted way weaving together also ensures that when the local mesh wire breakage accident is not to cause such damage continues to spread and affect the entire network face. Double twisted steel wire mesh with HEA deputy general as steel wire rope, ring network and other common use, in order to compensate for the lack of these large metal mesh. Double twisted steel wire mesh is widely used in various rockfall protection solutions, such as road rocky slope, open pit slope, as active types of protection system.

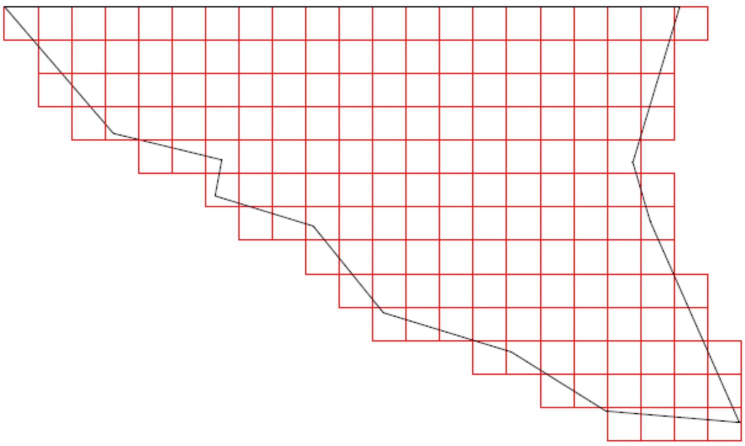
~ Construction details: Two areas were treated in this case:

Area 1 : 1317.6㎡(length:66m, width:39m, roughly in triangular shape)

Wire mesh used : 169 pieces (3m x 3m)

~ Anchors used: 114 pieces (3m) and 93 pieces (4.5m)

~ Layout:

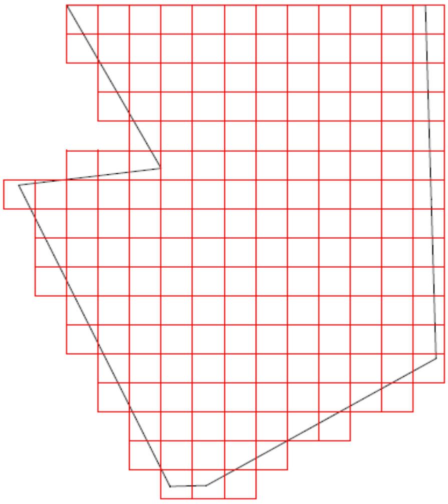


Area 2 : 1424.2㎡(length:51m, width:42m)

Wire mesh used : 181 pieces (3m x 3m)

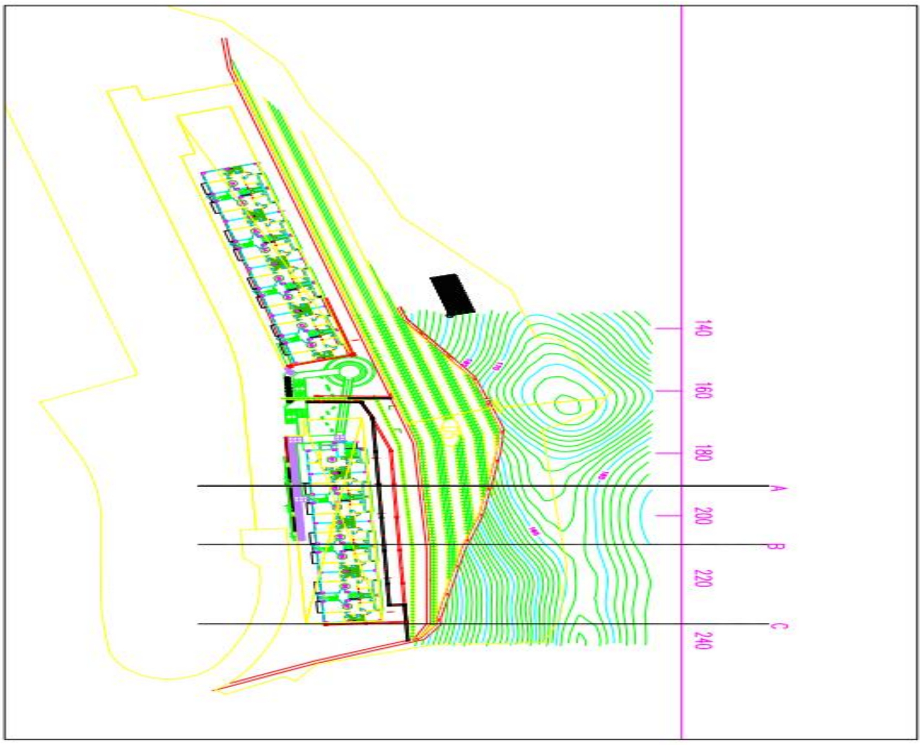
Anchor used: 215 pieces (4.5m)

~ Layout:



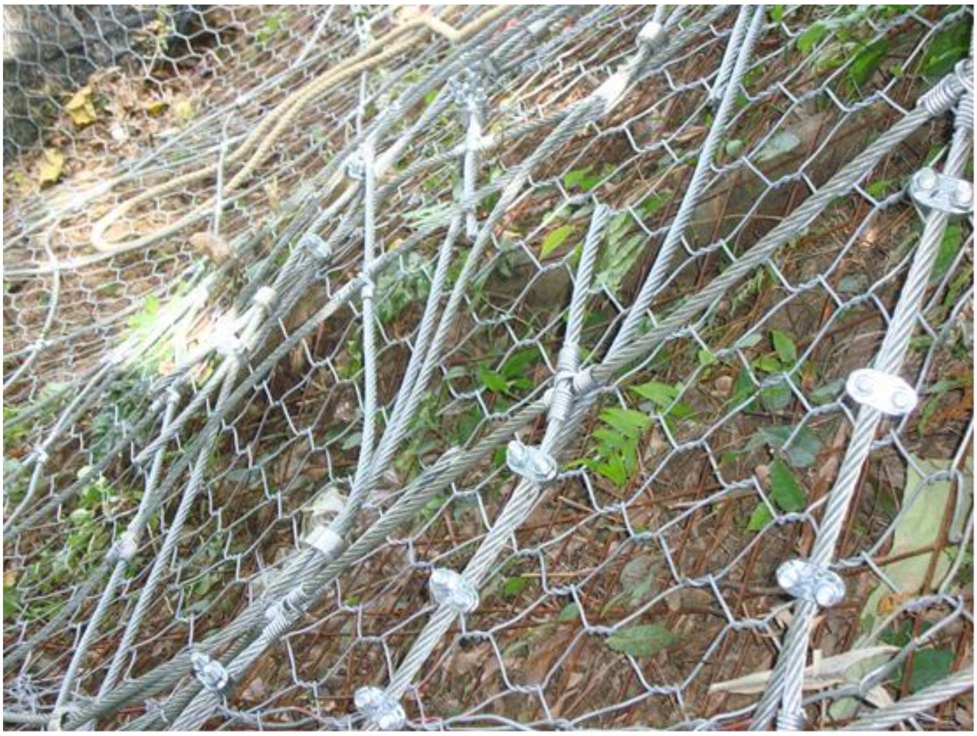
Anchor Pictures:

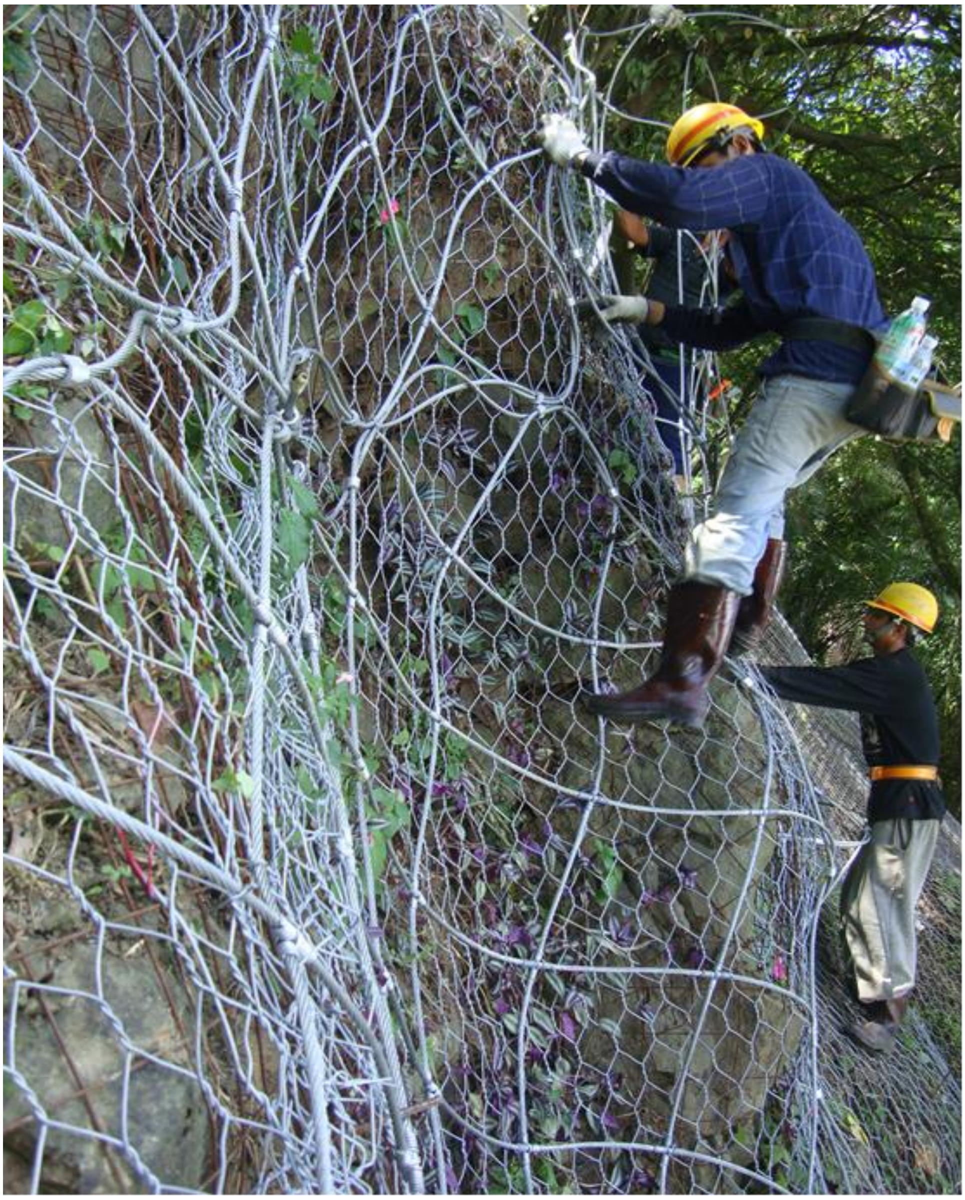
Site contour：



Site picture：







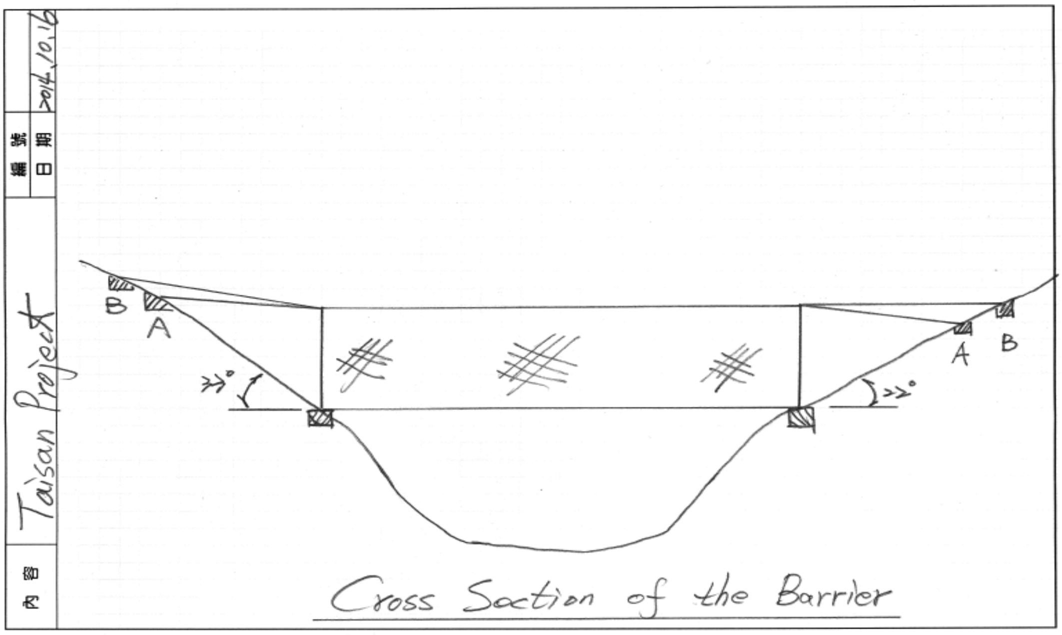
3.2 ***Case Two: ~ Passive Type***

~ Location: TaiSan, New Taipei City

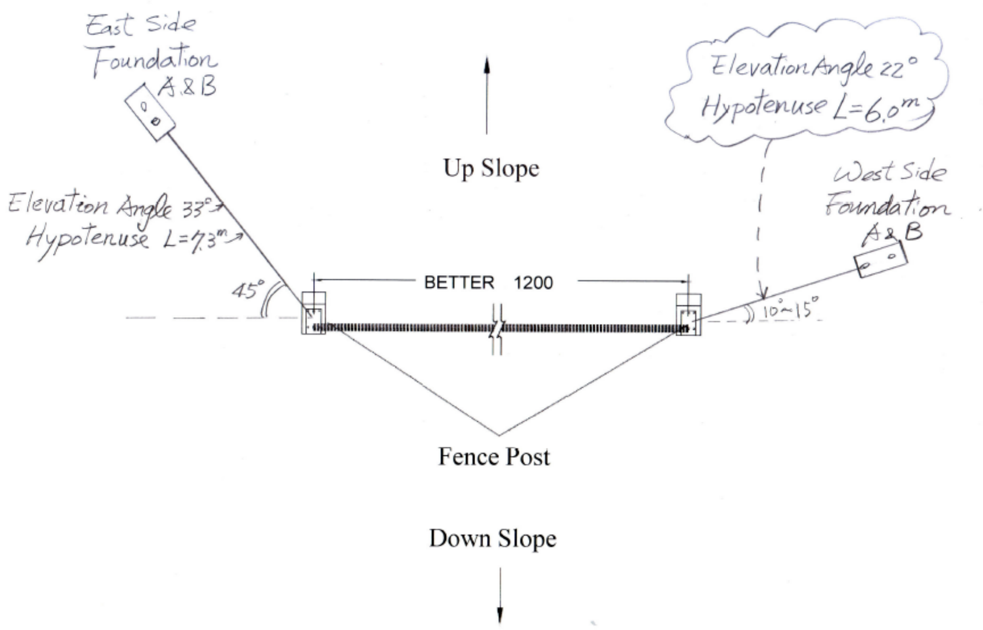
~ Design concepts: stopped stone network consists of columns, interception mesh and pull the anchor system. The metal mesh supported on the motion path rockfall, when the falling rock hit the bar stone online, through the system's own deformation or damage, rockfall dissipate impact energy, will stop falling rocks.

~ Length: 10m, Height: 3m

~ Layout:

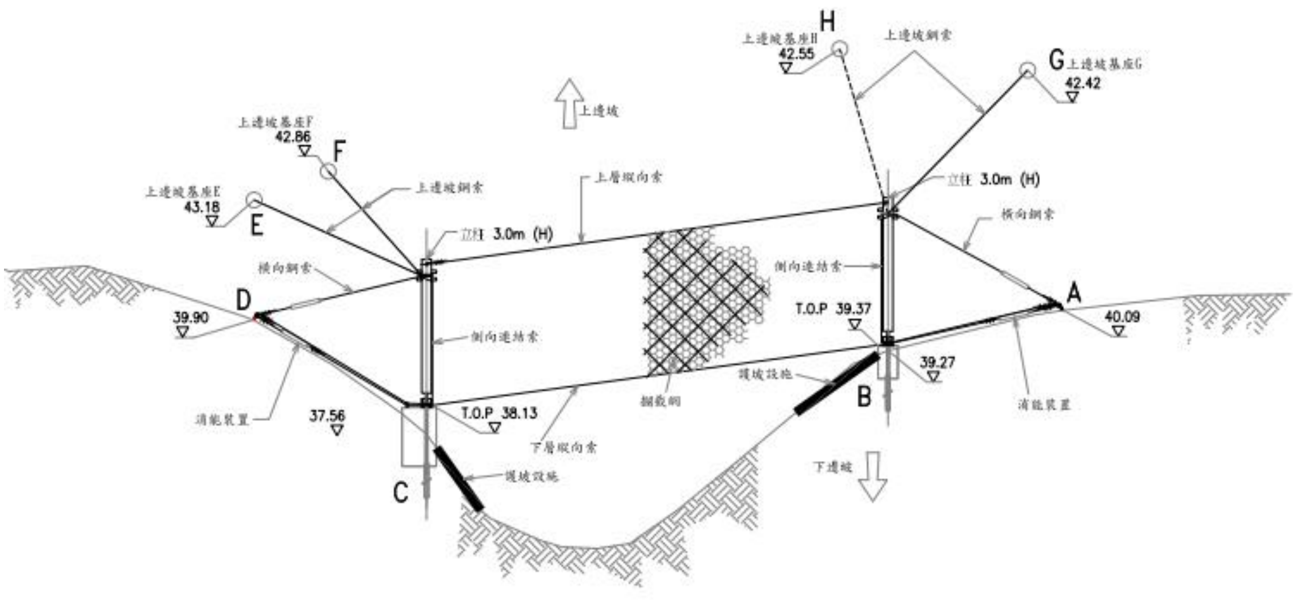


Cross Section of the Barrier



Slope Site Layout (Plan View)

Plan View



剖面圖

~ Pictures:

Site Pictures:

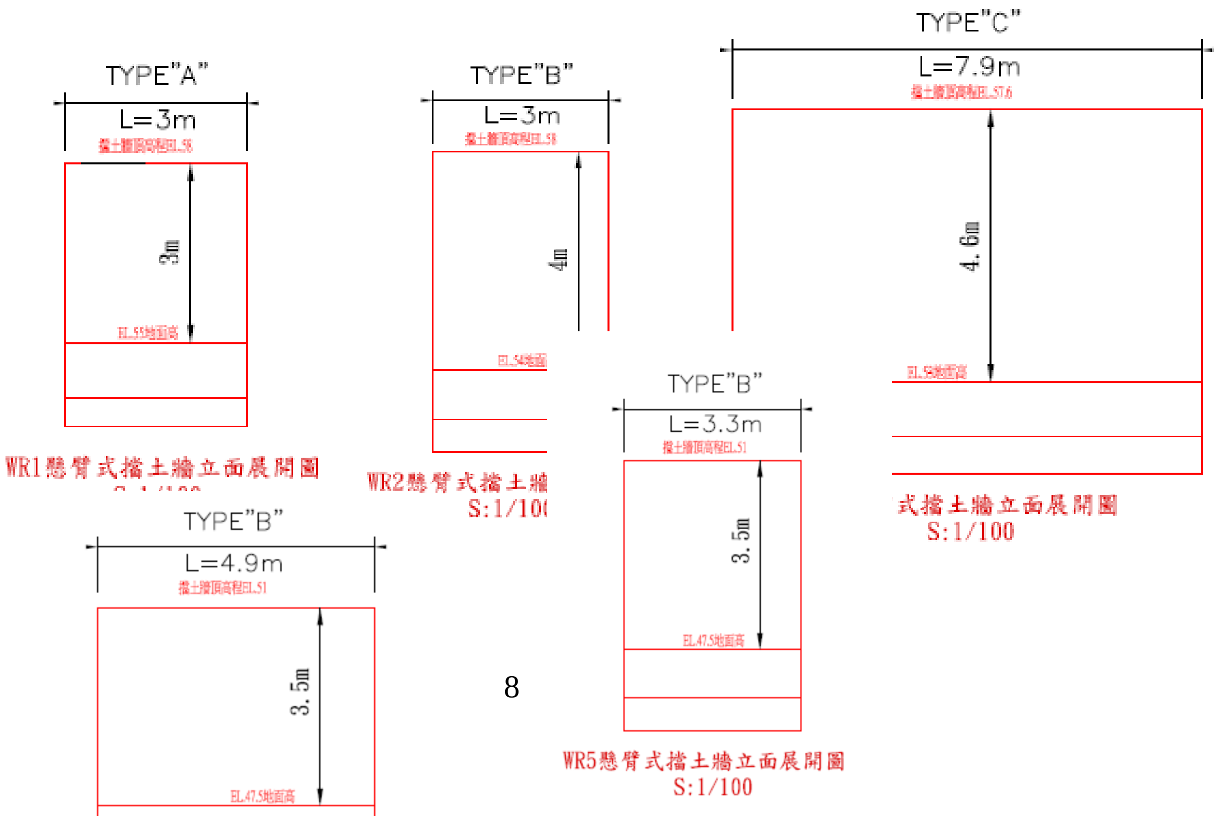
3.3 *Case Three: ~ Passive Type*

~ Location: BaDoZi, Keelung

~ Design concepts: stopped stone network consists of columns, interception mesh and pull the anchor system. The metal mesh supported on the motion path rockfall, when the falling rock hit the bar stone online, through the system's own deformation or damage, rockfall dissipate impact energy, will stop falling rocks.

~ Length: 40m, Height: 2m

~ Layout:



~ Pictures:

Site Pictures:

4 Acknowledgement

Thank you for Mr. Yang Ping-Jin and Maccaferria Asia Co. provided important information for preparing this paper.

Construction of Seawall composed of Sheet Pile Cellular Structure in Reclamation of Land for Hong Kong-Zhuhai-Macao Bridge Cross Boundary Facilities

Ir. Chris W F LAU

China Harbour Engineering Company Limited
19/F, China Harbour Building, 370-374 Kings Road, North Point Hong Kong
E-mail: Chris.lau@chechk.com

The Cross Boundary Facilities of Hong Kong-Zhuhai-Macao Bridge (HKBCF) is established on an artificial island of about 130 hectares reclaimed from the open waters off the northeast of the Hong Kong International Airport. In order to minimize the environmental impacts caused by the dredging and dumping for reclamation, China Harbour Engineering Company Limited, the main contractor of HKBCF, is using a non-dredging method by sinking large diameter circular steel cells through the soft marine mud for reclamation. This is the first time this new construction method is used in Hong Kong. During the construction period, CHEC met some constraints and challenges. 1) Installation and transportation of cellular structures were strictly complied with Airport Height Restriction Requirements due to aircraft operations. 2) The design of barge anchorage and access location were limited by Marine prohibited and restricted areas near the airport and existing marine traffic, e.g., Fire Services Department fire boat access, Sky Pier Fast Ferry, River Trade Vessel from Marine Cargo Terminal, etc. 3) Shallow water conditions which about -4mPD depth of water restricted the draft of working vessels. 4) The cellular structure and stone column were constructed through very soft thick clay and penetrated into dense Alluvium. 5) The underground obstruction or hard stratum may be encountered during installation of cellular structure. 6) Hard layer of Alluvium may cause damage to the sheet piles if there is too much penetration. 7) During installation of the perimeter silt curtains around HKBCF, Dolphin exclusion zone which is 250m around the Project need to be set. This paper is to introduce the application technique for such special task, the use of special equipment and the method adopted to overcome the challenging and constraints. The logistic arrangement, the off-site assembly and the pre-construction works preparation were carried out after contract awarded.

Keywords: HKBCF, non-dredge reclamation, cellular structure

1 Introduction

The Hong Kong–Zhuhai–Macao Bridge (HZMB) is an ongoing construction project package commenced in 2012 and consists of a series of bridges and tunnels that will connect Hong Kong, Macao and Zhuhai, three major cities on the Pearl River Delta in China. The whole project package comprises main bridge, Hong Kong Link Road (HKLR), Cross Boundary Facilities (HKBCF), Tuen Mun-Chek Lap Kok Link (TM-CHKL), Tuen Mun Western Bypass (TMWB) and the Connectivity.

Figure 1. Hong Kong–Zhuhai–Macao Bridge, Hong Kong Boundary Crossing Facilities

The HKBCF is established on an artificial island of about 130 hectares reclaimed from the open waters off the northeast of the Hong Kong International Airport (HKIA). It will provide the boundary crossing facilities for HZMB within Hong Kong territory to tie in with the commissioning of HZMB. Such facilities should provide adequate capacity to handle the cargo as well as passenger traffic that are projected to flow through the HZMB in both directions in the short and long term future.

In accordance with the conclusion of Environmental Impact Assessment report, the Environmental Permit issued by the Environmental Protection Department (EPD) imposed a stringent condition that the disposal of large amount of Marine Deposit generated from Seawall construction is not allowed. China Harbour Engineering Company Limited (CHEC) who was awarded the Construction of this project, react with the heavy challenge of the non-dredged seawall construction method which was never been executed in Hong Kong.

The HKBCF project comprises the following works:

(i) Reclamation of about 130 hectares to provide land for the development of the HKBCF and the required provisioning of the Airport's affected facilities (such as the affected Marine Cargo Terminal), and to cater for the synergy with the Airport (such as extension of the Automated People Mover (APM), a railway, from the Airport to the HKBCF and integration with Tuen Mun – Chek Lap Kok Link;

(ii) The construction works of the HKBCF include cargo & passenger clearing and vehicle inspection facilitates, offices for frontline departments (such as Immigration Department, Customs & Excise Department, etc), road networks, public transport interchange and associated civil, traffic control surveillance system and landscaping works, etc.

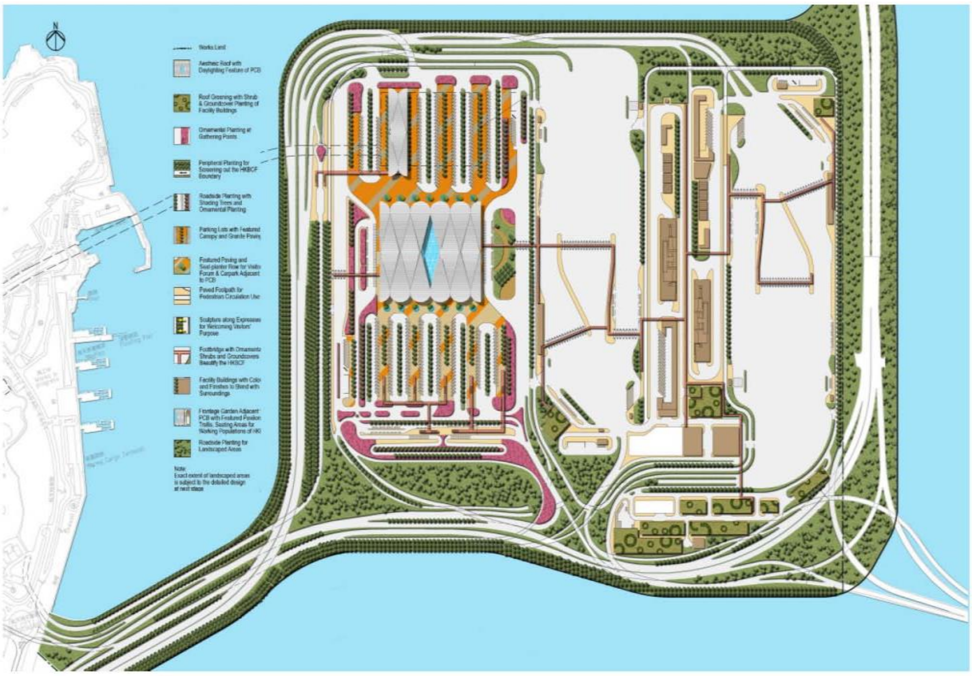


Figure 2. Layout plan of Hong Kong Boundary Crossing Facilities

Conventionally, seawalls are constructed on firm foundations by replacing the soft marine mud in the seabed by core materials composed of sand or rock. This process requires dredging and dumping of a large amount of soft marine mud.

With a view to minimizing the environmental impacts caused by the dredging and dumping for reclamation, a non-dredging reclamation method will be used. This is the first time this new construction method is used in Hong Kong. The seawall of the artificial island will be formed by sinking large diameter circular steel cells through the soft marine mud. The steel cells will then be filled up by inert construction & demolition (C&D) material or sand. The reclamation for the artificial island will also adopt the non-dredge method.

There will basically be no dredging and disposal of marine mud for the HKBCF reclamation. The adoption of the above non-dredge reclamation will greatly reduce the amount of dredging and dumping of marine mud by about 22 Million m^3, and will also reduce the use of about one half of the backfilling material. Furthermore, there will be less impact to the water quality and a large reduction in the construction marine traffic during construction of the reclamation works. This will help to preserve the marine ecology especially the Chinese White Dolphins habitat.

2 Seawall Design

The seawall consists of large diameter circular steel cells, which are made of individual sheet piles with interlocking. By applying the non-dredge method design, the soft marine deposits are left inside the cell.

Stone columns are designed by the Engineer to provide drainage to the very low permeability marine deposit. They are of one meter in diameter and at three meters center to center in a triangular pattern. The stone columns are in general five meters penetrated into alluvium. Cone Penetration Tests (CPT) were executed to determine the interface between marine deposit and alluvium, as well as the stone column toe level, which is based on a cone resistance (qc) of 1.5MPa in general. The geotechnical stability of the sheet pile cells, the seawall slopes and foundations, and settlement performance were evaluated by the Engineer. In addition, the rock fill slope and rock size was checked for stability in case of wave loads and currents.

3 Construction Sequence of Cellular Structure

Since the quality requirement for the straight web sheet piles (SWSP) is high, the competent manufacturers of the SWSPs are a few who are origin from Japan and Europe. With respect to the Contract requirements, the Contractor needs to complete 100,000 tones of cellular structures within 8 months of installation schedule. Pre-contract negotiations and factory inspections were taken place before the contract was awarded. Also the delivery schedule, logistic arrangement and storage yard setting up were well planned in advance to accommodate such large volume of materials. The procurement contract was signed immediately after the main contact was awarded.

Once 200m leading edge of stone column is completed, installation of cellular structure by fabrication in places method is commenced. Meanwhile, special barges and assembly yard are established and equipped.

A fleet for installing fabricated-in-place method typically includes a flat-topped barges equipped with crawler crane and a 65t crane barge for erecting guide frame, storing material, assembling and driving cells.

To facilitate fabricating cell in places, a temporary working platform is utilized to properly align sheet piles during the pitching process and maintain alignment during sheet pile driving. The temporary working platform consists of circular guide frames connected by temporary piles driving to stiff stratum by vibratory method. Each guide frame is fabricated in modular sections for ease of lifting and transport from cell to cell.

Figure 3. Temporary working platform for sheet piles installation

A Differential Global Positioning System (DGPS) is used for horizontal positioning. The position and verticality of the guide frame are checked before the commencement of assembling and pitching.

After guide frame and working platform are set up in the correct cell location, the quarter cells will be installed by prefabricated method. The middle and top platforms will be raised to the mid height and uppermost stoppers locations respectively, once the stoppers are confirmed securely locked at the guide frame, prefabricated quarter cells will be transported to the guide frame using lifting barge. Once the first quarter cell is installed, the guide frame as well as the sheet piles will be rotated 180^{o} to the opposite direction for the installation of next quarter cell. Once the four nos. of quarter cells are installed at guide frame, the four closing piles will be installed by three to four segments depends on the permissible AHR.

The locations of Y-junction piles will be checked and if the orientation is deviated from the design coordinates, the top platform will rotate and adjust the Y-junction pile location. The driving proceeds in one direction from this point on until one reaches the first junction again. Driving direction changes to prevent leaning of the piles in one direction. In the areas where the AHR requirement prevails, sheet piles are required to extend on site while top level is driving to +3.0mPD. This procedure is repeated until founding level is reached. During the driving process, verticality and penetration are closely monitored. A different guide frame for arc unit installation is adopted and similar installation procedure follows. After all sheet piles are driven down to the founding level, temporary spot weld is applied to secure the sheet piles so as to prevent swaying of cellular structures due to wave actions. To overcome the AHR requirement, splicing of individual piles are applied at cells where elevation to reach is constricted.

Figure 4. Installation of Arc Cell

The stability of cells is mainly governed by stiffeners of the cell and interlock forces induced after backfilling. Therefore, temporary piles and guide frames are removed after few meters of Type C (Graded Sand) fill is in place. The deposition of Type C fill is placed starting from the middle of cell and spreading outward so as to avoid any unbalanced loading onto the cellular structures. Underlayer is placed on top to protect Type C fill against wave overtopping. Capping beam is cast before commencing the reclamation behind cellular structure.

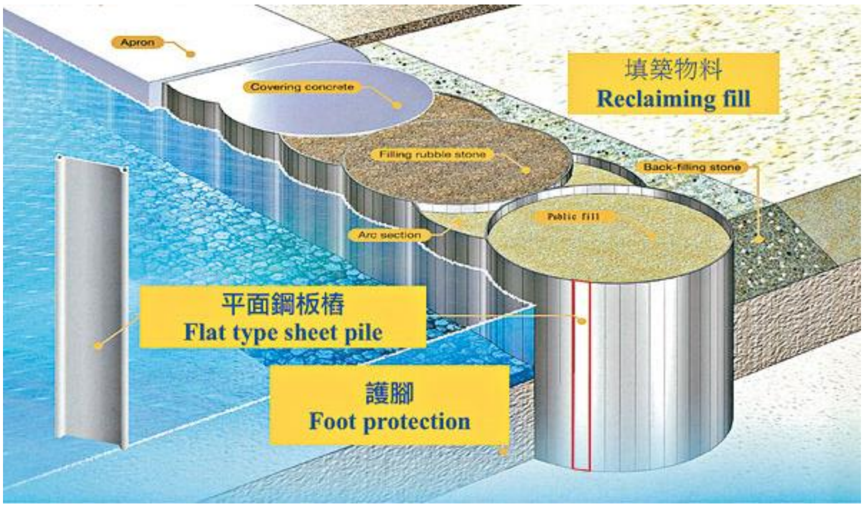


Figure 5. Graphic of Cellular Structure and Reclamation

4 Construction of Remaining Parts of Seawall

Before commencing of stone column installation works, geotextile is placed on seabed covered by stone blanket, which is placed layer by layer with maximum lift of 500mm to prevent local disturbance on the mud. Geotextiles are required as the filters for separating existing marine deposits and reclamation fill material.

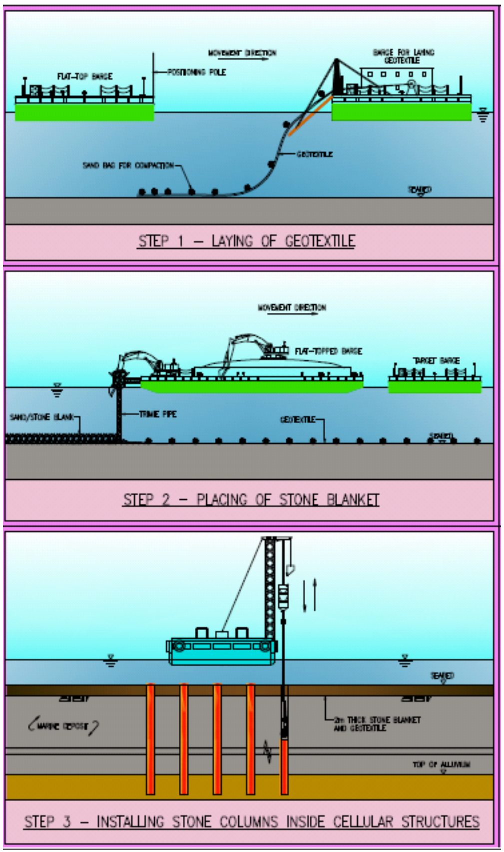


Figure 6. Works before commencing of stone column installation

The stone column work is installed by marine based dry bottom feed system attached onto the leader of piling barges. This system necessitates using air instead of water for bottom jetting to aid penetration and also for side jetting to prevent the vibrolances from getting stuck in the hole during step lifting for the stone compaction phase.

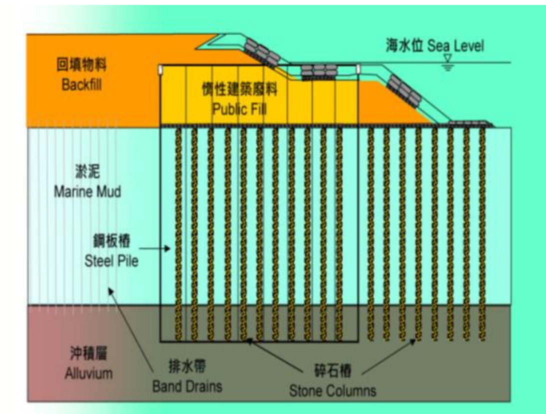


Figure 7. Typical Section of Fully Non-dredged Reclamation Seawall

Fill materials composed of C&D or sand fill form the core of seawall structure rest on the foundation treated with stone columns. Seawall is finally paved with underlays and amours to form the integrated structure.

Figure 8. The cellular structure and arc units are completed and filled up with fill materials and the reclamation fill behind in progress

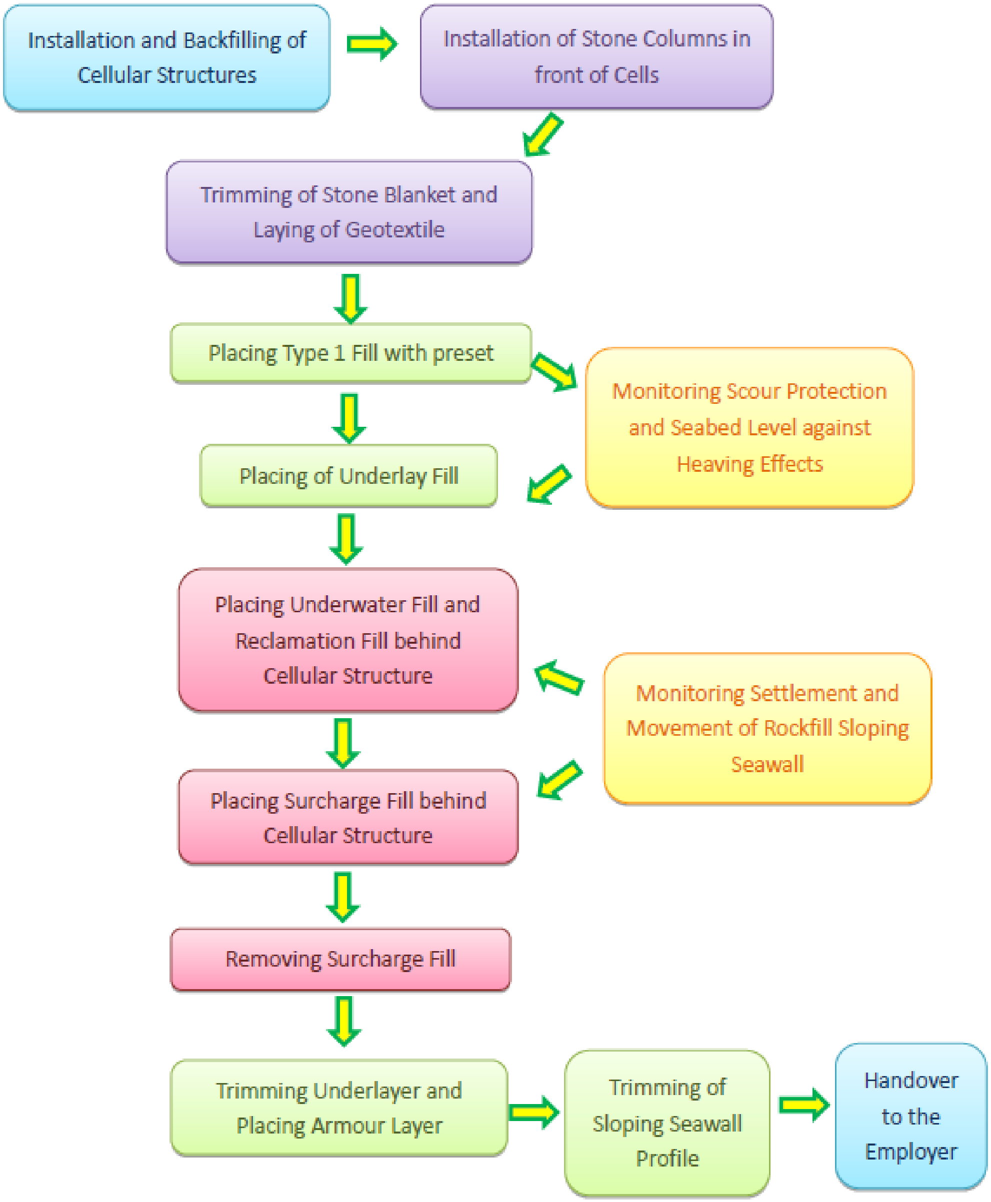


Figure 9. Construction Sequence of Sloping Seawall

5 Constraints and Challenges and the solutions

CHEC met a lot of constraints and challenges during the execution of this project.

5.1 *Considerations on Airport Height Restriction (AHR) Requirement*

Installation and transportation of cellular structures are strictly complied with AHR Requirements due to aircraft operations. It is an opportunity for the Contractor to ask for temporary exemption on official AHR to release such site constraint. However, CHEC cannot rely on such condition in our strategic planning because the available operation window only has 4 to 6 hours a day during the closure of either one runway. CHEC believes that it is very risky, unmanageable and is no guarantee on the timely completion. Therefore, the first objective is to ensure that most of the construction activities are operated with the satisfaction of the official AHR requirement. These construction activities include transportation and installation of cellular structures, installation of stone column and band drain, etc.

An Electronic AHR Monitoring System is procured to provide real-time information of highest altitude and position of major machinery under 24-hour monitoring and alert the supervision team when the equipment is about to exceed the preset warning altitudes.

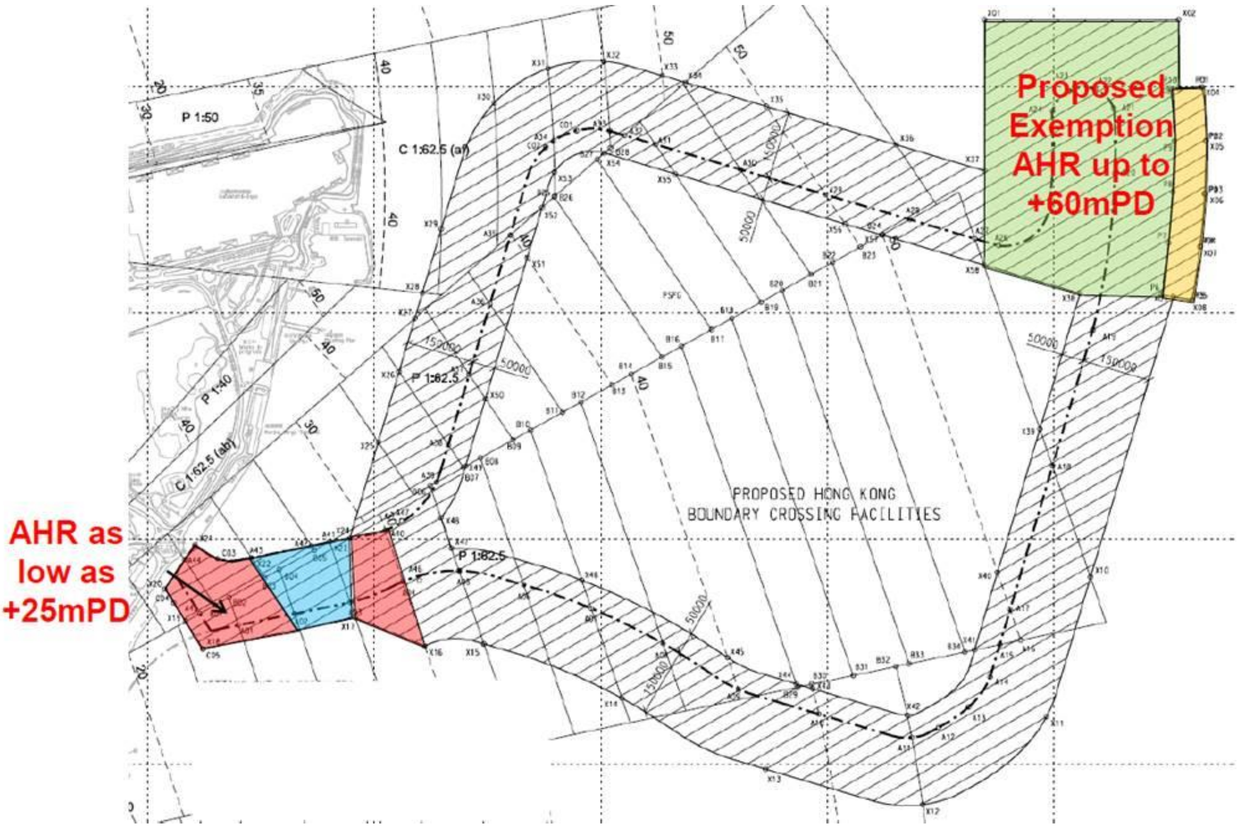


Figure 10. Airport Height Restriction Area

5.2 *Special Barges for Cellular Structure Installation and Stone Column Installation*

The design of barge anchorage and access location are limited by Marine prohibited and restricted areas near the airport and existing marine traffic, e.g., Fire Services Department fire boat access, Sky Pier Fast Ferry, River Trade Vessel from Marine Cargo Terminal (MCT), etc.

Two special barges for main cells and arc units' installation are specially designed and modified by three self-owned flat-topped barges to suit the official AHR requirement. The maximum height of barges together with the cell attached will keep at least one meter clearance below the official AHR level.

The adjustable truss tower on stone column barge is erected to suit for the official AHR levels in different working zones. The special vibrolance adopted in this Contract is also extensible to suit both AHR requirement and the total depth of installation.

Figure 11. Special barge

5.3 *Shallow water conditions*

About -4mPD depth of water restricted the draft of working vessels. Special barges with low draft are allocated to suit shallow water conditions. At critical shallow water locations, activities have to be implemented in high tide intervals.

5.4 *The underground obstruction or hard stratum may be encountered during installation of cellular structure*

During the pre-construction stage, CPT may located any obstruction or hard stratum. Further site investigation works is carried out to identify and record the area and depth of hard stratum by means of DGPS surveying method. Preboring machine is set up on to jack-up barge for drilling through the obstruction in the foot print of cellular structures. If obstruction is found in the course of driving sheet piles, the problematic segment will be lifted up a few meters and temporarily secured onto guide frame to prevent damaging sheet piles during boring through obstruction.

5.5 *The cellular structure and stone column may construct through very stiff clay*

If the CPT results for any particular cellular structure show the presence of very stiff clay which may be reached, high pressure water jet pipes will be pre-installed onto the cellular structure to enhance the penetration into stiff clay by pressurized water jetting method.

5.6 *Hard layer of Alluvium may cause damage to the sheet piles if there is too much penetration*

When the sheet piles are damaged during penetration through the stiff material, replacement of problematic sheet piles are required. The whole cellular structure is secured on the guide frame and the damaged segment is extracted by vibratory hammer. Removing of stiff layer by boring method is carried out and then new segment of sheet piles is reinstated with extra care.

5.7 *Protection of Chinese White Dolphin (CWD)*

CWD habitat could be adversely affected by the development in terms of noise, water quality, and the ecology as a whole. During installation of the perimeter silt curtains around HKBCF, Dolphin exclusion zone which is 250m around the Project is established.

Figure 12. Chinese White Dolphin

Prior to the start of reclamation works, qualified dolphin observer(s) scan the exclusion zone for at least 30 minutes. If dolphin(s) are observed within the zone, works will be pending until they have left the area. If dolphin(s) enter the exclusion zone after construction has commenced, reclamation works will cease until they have left the area.

6 Conclusion

The Challenges of the HKBCF Project are arisen from critical factors, stringent construction period, source of special straight web sheet piles, deployment of special working barges, height restrictions, environmental nuisance abatement and adverse weather and wave impacts. Our project management team utilizes availability of professional expertise in temporary work design, dolphin observations, advanced technology of Electronic AHR Monitoring System, excellent efficiency of materials and plants logistics and teams of diligent and skillful operatives. We learn from experiences, overcome obstacles to complete reclaim the first piece of land to hand over for the commencement of Passenger Building Project in three years time.

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THE SCIENCE FOR SLOPE ENGINEERING

YEE THIEN SENG

Geo.Consult, Petaling Jaya, Malaysia.
E-mail: yeethienseng@hotmail.com

Slopes are perhaps the most visible and simplest appearing form of civil engineering construction. They are associated with earthworks. Yet the understanding necessary for slope engineering proved elusive and remained largely so until this millennium even though as early as 1970, Professor Skempton had concluded, following a study of 5 well documented landslides in the United Kingdom, that for first time slope failures, the resisting shear strengths available in the ground are the fully softened strengths. Fully softened strengths are essentially strengths mobilized with no volume change in the soil and are also referred to as critical state strengths.

Shear strength available in uncemented or very weakly cemented soils to maintain integrity in a slope is derived from interparticle friction. Peak shear strength which includes interlock resistance from dilatancy is degraded by shear straining beyond the peak state. This strength - strain relationship is embodied in an adaptation to the Cam-Clay model. Owing to progressive softening beyond the peak state, intense shearing is confined to a very thin shear band as a plane of slippage.

Physical model tests made in the geotechnical centrifuge facility revealed that exposure of steep homogeneous soil slopes to annual cycles of rainfall results in rapid destruction of suctions in the soil to cause swelling movements in the slope which are only partially recovered with each ensuing dry period. Such slopes failed only after registering large cumulative swelling deformations from repeated cycles of wet and dry exposures without developing significant positive pore water pressures even after prolonged rainfall exposure.

Keywords: shear strength, soil suctions, dilations, slope stability

1 Introduction

Slopes provide the important space-making function to accommodate vital facilities. They form among the simplest engineering constructions. Yet when they lose their integrity, the consequences they bring can be very profound. When such slopes fail and impact upon the facilities adjoining them, the latter's functions get impaired. Buildings and infrastructures are damaged when impacted on by crumbling slopes both from above as well as from below. Lives and economic losses are the consequence of slope instabilities.

In Malaysia, the Public Works Department (PWD) had historically implemented the larger infrastructural civil engineering construction constructions in the country. Naturally, these constructions involved earthworks and slopes; both cuts and filled where hilly terrains had to be traversed and PWD had developed its preferred slope engineering practices comprising standard slope geometry templates to be applied on prescriptive bases with little regard to the properties of the materials in the slope body. Road engineering, then, catered to low design speeds and required relatively small scale earthworks involving largely small slopes; both cut as well as filled. The constructed slopes performed relatively satisfactorily in service. Such prescriptive PWD-design templates for slopes were also adopted for earthworks in the private sector building developments. This had been the practice of virtually every sector in the civil engineering industry, with the exception of earthdam constructions.

Then the commencement of the North-South Expressway (NSE) running the length of Peninsula Malaysia where the multiple lane expressway with high speed road geometrics saw the need for large earthworks whilst traversing hilly terrains. The slopes involved with earthworks to satisfy such road geometrics were considerably larger than in the past. Early sections of the expressway completed just after the mid-1980's quickly exhibited significant slope distresses (Ting et al., 1990). As the result, the expressway concessionaire soon became aware that the practice of employing PWD-prescribed slope geometries was not likely to be entirely satisfactory when adopted indiscriminately. Instead, revised slope design procedures which relied on soil mechanics and material engineering properties of specific relevance to the slopes to be constructed were called for in the endeavour to alleviate integrity problems with the slopes on the NSE project in its later designed sections commencing in 1989. However, not all sections of the NSE embraced the revised procedures.

Of greater present day concern, the industry has now reverted to adopting the PWD-prescribed slope geometries. A great number of slope failures have occurred since; some with very tragic consequences. So the identification of the reasonable science for slope engineering has become an important need to mitigate such catastrophic events.

2 Reserves of Stability in Slope Engineering Practice

Slope engineering routinely seeks a relatively small Factor of Safety; rarely in excess of 1.5, determined using the Limit Equilibrium method of analysis. A Factor of Safety of 1.5 only confers a reserve in stability of just 50 percent against failure; far smaller than those available to other civil engineering practices. Yet, practitioners of slope engineering are not instructed on what slope material strengths ought to be used when conducting the stability analyses. As the consequence, since the ground in almost all slopes in tropical soils contain considerable clay fractions and are deemed cohesive soils, stability analyses for slopes are commonly made using significant cohesion strength values as presented in the majority of available text books on soil mechanics. The geotechnical engineering fraternity routinely employs cohesion strength as in the Extended Mohr-Coulomb generalized equation (Fredlund et al., 1978) for the computation of shear strength, τ:

$$\tau = c' + (\sigma - u_a) \tan \phi' + (u_a - u_w) \tan \phi^b \tag{1}$$

where c', σ, u_a, u_w, ϕ' and ϕ^b are effective cohesion, total normal stress, pore air pressure, pore water pressure, effective angle of friction and angle of friction for matric suction respectively. Eq. (1) is illustrated diagrammatically in Figure 1.

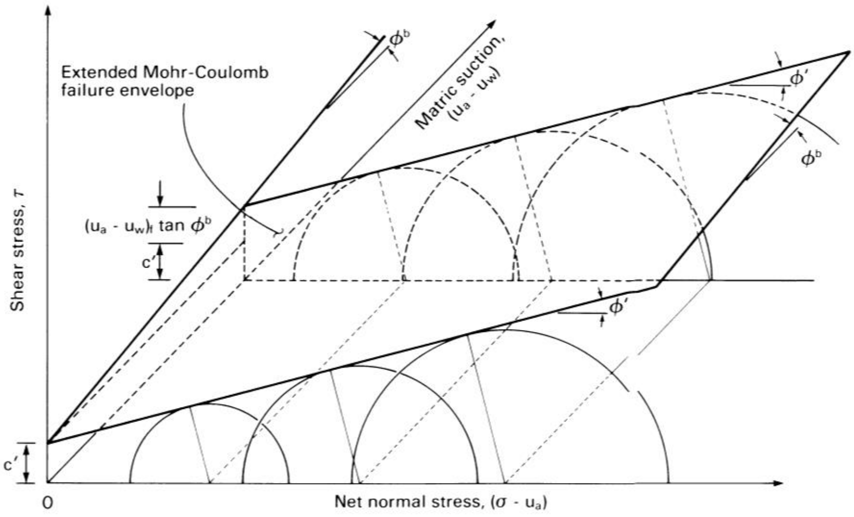

Figure 1. The Extended Mohr-Coulomb (from Fredlund & Rahardjo, 1993).

It ought to be noted that c' is not an effective stress dependent term and hence its contribution to shear strength would not be affected by pore water pressures in the way that $(\sigma - u_a)$ would be. The term c' would confer shear strength to the soil even when there is the complete absence of effective stress.

3 Operational Shear Strengths from Failed Slopes

Skempton (1964) had examined 5 landslides in heavily over-consolidated clays in the United Kingdom. They involved natural slopes as well as cuttings. He noted that the shear strengths operating in those landslides at failure were clearly lower than peak strengths obtained from laboratory tests on representative soil samples collected from the affected locations. They suggested only very small cohesion values were present for the ground water conditions estimated to have prevailed at the time of the landslides. Then when he revisited the same cases (Skempton, 1970), he concluded that the shear strengths that resisted first time failures were the fully softened strengths. Progressive failure in soils had ensured that only the fully softened strengths were present in the slopes during those failures. Reactivated slides, however, mobilize residual strengths along their shear surfaces. Atkinson & Bransby (1978) illustrate why peak strengths could not be mobilised over the entire length of the shear plane during a slope failure.

4 Shear Strength in Modern Soil Mechanics

It is now understood that shear strengths in non-cemented soils are the consequence of friction and effective stresses. This was promoted by Schofield & Wroth (1968). When sheared uniformly under the condition of constant effective stress and no volume change, the shear strength mobilized in the soil is the critical state value. Critical state strengths are synonymous with the fully softened strengths referred to in Skempton (1970). This state prevails to large shear strains before reducing to the residual value. Cohesion strength does not exist. Strengths observed above critical states in laboratory tests are the consequence of dilatancy in soils when sheared at densities greater than that at the critical state for the prevailing effective stress. They occur at relatively small shear strain levels as peak strength values and the strengths would strain-soften to critical states with further deformation and dilation post-peak. Such behaviour is well captured in constitutive soil models adapted from the Cam-Clay model created from the Critical State Soil Mechanics theory of Schofield & Wroth (1968) (Wood, 1990 and Graham, 2014).

5 Suctions or Negative Pore Water Pressures

It is readily observed in Eq. 1 that the effect of positive pore water pressures would be to reduce available shear strength in the ground. When such a situation arises, the resistance necessary to resist a possible collapse in a slope would be compromised.

As slope collapses commonly occurred during wet weathers, it used to be asserted that water retention on the slope surfaces as well as the failure of surface drainage systems induced the failures. These obviously ignored the numerous rice fields established in the form of terraces on steep sided hill slope faces in the tropics. Such rice fields were repeatedly inundated for long periods but yet did not induce collapse in the slopes. This would go to dissuade the simple postulation that the act of surface water retention was the cause of slope failures.

However, in dry weather situations where the ground is unsaturated, negative pore water pressures or suctions prevail in the soil to result in elevated effective stresses and hence increased available shear strengths. Such is the condition in slopes during dry weathers to allow them to remain stable at gradients significantly steeper than the soils' critical state friction angles. But in laboratory tests with steep stable slopes, soil suctions have been observed to reduce to very small values or even developing small positive values extremely rapidly upon exposure of rain to the ground surface (Take & Bolton, 2004). Zhan et al. (2007) provides measurements showing the same behaviour in the field.

This provided the substantiation that soil suctions could not have been the only source of strengths beyond critical state values in steep slopes to allow them to remain stable after the disappearance of negative pore water pressures. These slopes had remained stable for a number of wet exposure sessions before exhibiting instability

6 Cumulative Slope Deformations

Stresses drive strains in soils to manifest as deformations. Stress levels at critical states bring about plastic shear strains most of which are irrecoverable. The amount of plastic shear strains developed depends on the length of time the soil spent at its critical state. In heavily over-consolidated soils, when localized shear stresses exceed peak strengths, shear straining is likely to be concentrated along defined shear bands or slip surfaces which strain-soften as the result of dilation.

Steep freshly constructed slopes also enjoy the effect of soil dilatancy prior to development of post-peak strains to realize shear strengths above critical state values available following the degradation of soil suctions to resist the high prevailing shear stresses developed. Shear strains that are developed and confined at the shear band will drive a small section along the band to peak state at a given instant with the adjoining sections either building up strains towards peak state or having proceeded past peak followed by softening and dilated towards critical states with large shear straining. Non-uniform straining leads to progressive failure in the soil and peak strength cannot occur everywhere along the shear band at the same instant.

Accumulated shear straining and progressive failure in full scale earthworks confine the mobilised peak strength to only a very small area along an entire potential shearing surface leaving the remaining surface to mobilise strengths that correspond to strains before or well after peak. And, by the time the last point on the shear surface attained peak strength the rest of the surface would have strained past the peak state and mobilizing critical state strengths. Atkinson & Bransby (1978) elucidates this phenomenon as illustrated in Figure 2 to assert why critical state strengths are appropriate to ensure the integrity of earthworks structures; especially, given the low Factors of Safety used in such a class of construction.

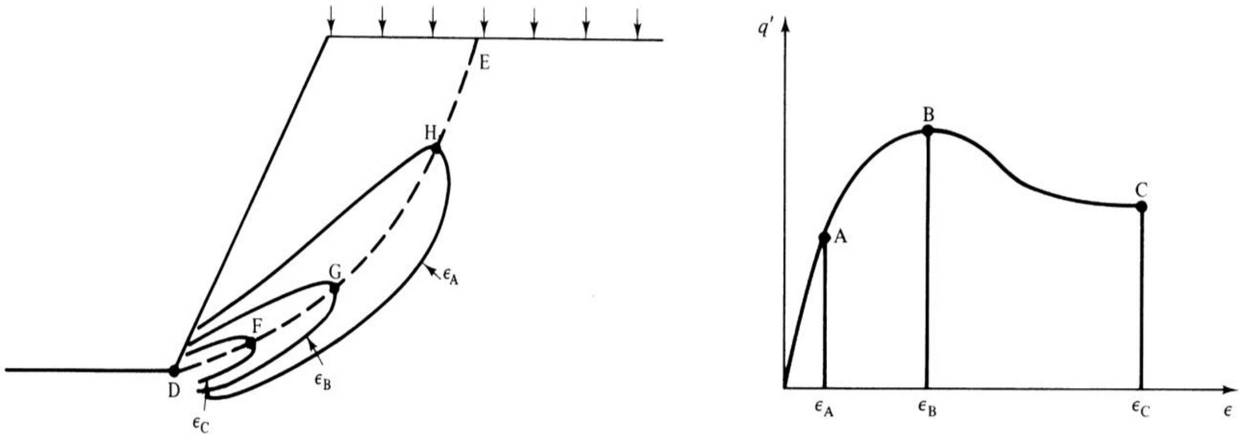

Figure 2. Non-uniformity of straining in a slope leading to progressive failure. (After Atkinson & Bransby, 1978).

When stresses in a slope exceed the critical state strength values for a sustained length of time, the large shear strains that eventually develop together with dilation would degrade the shear strengths available overall to just the critical state strength to resist collapse. This is accompanied by large strains concentrated along the shear band to cumulatively build up to collapse.

Where the shearing process comprise repeated brief periods of overstress owing to exposure to wet weather interspersed with dry periods of no-overstress, each period of overstress creates a finite quantity of largely irreversible plastic shear straining to be accumulated over the numerous episodes of overstress. The overall time required for slope to collapse would be that needed for the total accumulated shear strains along the whole shearing surface to bring about full dilation in the soil thereat to critical states. This phenomenon is responsible for the failure of steep slopes after repeated wet season exposures to manifest as delayed failures and represented in Figure 3. Take and Bolton (2011) contend that as far as they are aware "no first-time failure has ever been reported of a clay slope designed on simple limit-equilibrium principles using the soil's critical state angle of friction together with worst-case pore water pressures."

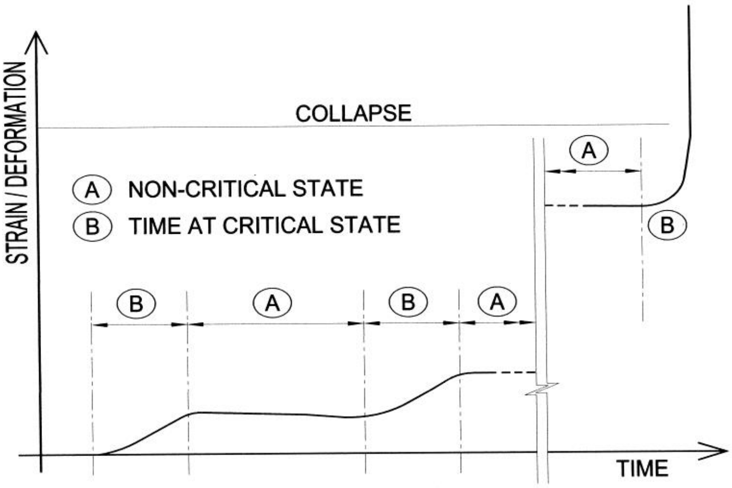

Figure 3. Cumulative slope deformations leading to collapse of a slope.

7 Slopes in Cemented Soils (Weathered Rocks)

Weathered rocks possess particles bonded to each other to leave a form of cemented soils. But weathered rocks also contain the structural discontinuities inherited from their original unweathered states and the discontinuities remain the weakest features in such cemented soils where only frictional resistance is available to resist sliding shear. These discontinuities are either pre-existing shear bands themselves or can concentrate shearing on them to create new shear bands appropriate to the prevailing geometry of a slope.

Naturally occurring discontinuities were formed by geological processes and they exist in sets, each comprising discontinuities with similar geometry; such as inclination and direction of dip. The discontinuity characteristics are best represented on a stereonet plot (Hoek & Bray, 1974). An example of a stereonet plot is shown in Figure 4.

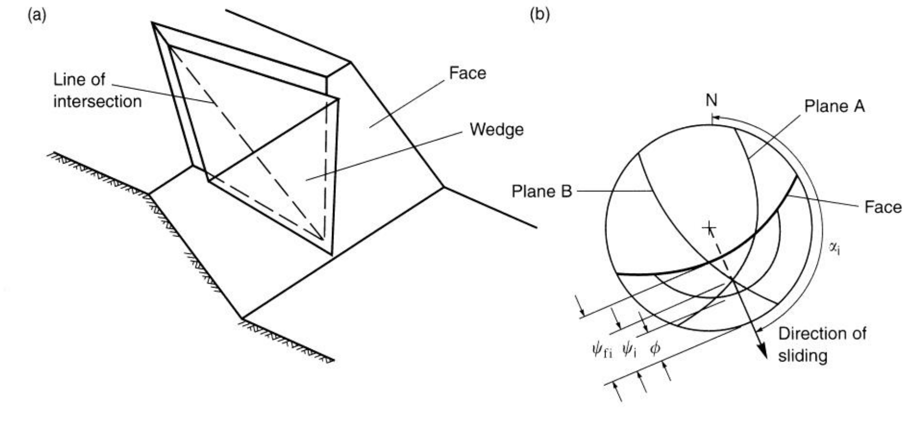

Figure 4. Stereonet plot of a wedge mechanism formed by discontinuity planes A, B and the slope face. (From Hoek & Bray, 1974).

Where shear stresses prevailing in the slope do not exceed the cementation strength soil to rupture interparticulate bonds, the integrity of a slope in cemented soils is dictated by the attitudes of the discontinuities along which sliding are feasible in relation to the geometry of the slope face. The sliding may occur on a single discontinuity plane or it may involve a combination of different planes to generate wedge-shaped surfaces over which sliding takes place. These feasible sliding mechanisms can be revealed in the stereonet plot when the characteristics for the slope face are included on the plot as done in Figure 4.

When the potential for sliding takes place along a discontinuity, resistance is mobilized in shear by the discontinuity material's critical state angle of friction and normal stresses acting on the sliding surface. In the case of a wedge-shaped sliding block formed by a pair of steeply dipping sides, the normal effective contact stresses on the shear surfaces are greatly enhanced like in the mechanical engineer's V-belt power transmission systems for rotating machinery and can generate very large shear resistance against sliding. However, buoyancy from water pressures at the discontinuity faces forming a wedge would produce correspondingly pronounced reduction in normal effective stresses with the attendant effects to interface shear strengths. As such, it would be a prudent necessity to evaluate the propensity for wedge-type failures when water pressures are present.

8 Conclusions

Slope engineering employs a lower Factor of Safety against failure than that in other civil engineering work.

Critical state soil mechanics has been identified as the key scientific framework for slope engineering work.

The shear strengths available for resisting first-time failure in slopes are the critical state or fully softened strengths rather than the peak strengths. This has been established since 1970.

First-time failure in a slope occurs after it has accumulated large enough strains along its shear band to arrive at critical states.

The phenomenon of delayed failure in steep slopes as the result of the need to develop the large strains to critical states is a recent understanding that emerged from laboratory tests. This is entirely consistent with soil behaviour encompassed by critical state soil mechanics as well as the findings of Skempton (1970).

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Geotechnical Challenges on Offshore Wind Farm and Coastal Development in Taiwan

Lien-Kwei Chien[1], Shu-Yi Chiu[2], Chih-Hsiang Hsu[3] , Ruan-Ruey Lee[4], Chia-Chi Wu[5] ,I-Chieh Wang[6]

[1.] *Professor, Department of Harbor and River Engineering, National Taiwan Ocean University*
No. 2 Pei-Ning Road, Keelung 202, Taiwan.
Email: lkchien@mail.ntou.edu.tw
[2.] *Assistant Research, Department of Harbor and River Engineering, National Taiwan Ocean University*
No. 2 Pei-Ning Road, Keelung 202, Taiwan.
Email: sychiu0217@gmail.com
[3.] *Engineer, Dept of Urban Planning , National Cheng Kung University, Taiwan, R.O.C.*
Email: melsel@ceci.com.tw
No.323, Yangguang St., Neihu Dist., Taipei City 114, Taiwan
[4.] *Master, Department of Harbor and River Engineering, National Taiwan Ocean University*
No. 2 Pei-Ning Road, Keelung 202, Taiwan.
Email: b98520043@ntou.edu.tw
[5.] *Master, Department of Harbor and River Engineering, National Taiwan Ocean University*
No. 2 Pei-Ning Road, Keelung 202, Taiwan.
Email: kakhi31109@gmail.com
[6.] *Master, Department of Harbor and River Engineering, National Taiwan Ocean University*
No. 2 Pei-Ning Road, Keelung 202, Taiwan.
Email: null_world@hotmail.com

This paper introduces the coastal risk assessment of planning and management under climate change and geotechnical risks of offshore wind farm development in Taiwan. Global climate change could be induced to sea level rising, extreme rainfall and storm surge. These hazards cause heavy lost on populous area and high-level land use intensity area in western Taiwan coastal area. To promote reasonable use of coastal areas and the improvement of coastal management, the Executive Yuan has announced the "Coast Management Act" this year. The challenge of the circumstances with coastal erosion, flooding, surge flooding and subsidence under climate change on Taiwan coastal areas is need to discuss.

This paper was designed as the first-level or second-level coastal protection zone to prevention the coastal disaster, including the sea intrusion, homeland loss and to protect lives and property of people. This paper not only defined the range for coastal protection areas, but also based on the suggestion of International Strategy for Disaster Reduction (ISDR) proposed the Coastal Vulnerability Index (CVI) and Coastal Vulnerability Level (CVL) fitting Taiwan's coastal environment. Finally, we developed a classification approach and designed criteria as a reference for coastal protection zone planning in the future.

On the other hand, the geological conditions of offshore wind farms are very important environmental risk factors for foundation design and construction. Due to lack of marine engineering equipment and construction experience and limited environmental geological data, foundation design of offshore wind farms and marine construction will face on great geotechnical risks. It could be induced and occurred the self-elevating platform vessel punch through, pile installation difficult, foundation scour damaged, submarine cable erosion etc. The soft ground and spatial distribution of geological sensitive of offshore wind farm should be discussed. This paper, we were discussed and analyze the soft ground of offshore wind farm, environmental geology sensitive of the spatial distribution by GIS, seabed soil liquefaction, the stability and settlement of the foundation construction capacity and marine engineering work safety guidelines. It can be improved to reduce the risk of environmental geology in offshore wind farm and ensure the safety of marine construction in Taiwan. Therefore, how to face the geotechnical challenges on Offshore Wind Farm and Coastal Development in Taiwan, it’s a very important geotechnical engineer issue for sustainable development in the future.

Keywords: Coastal Protection Zone; Coastal Risk; Offshore wind farm; Geotechnical Risk.

1 Coastal development in Taiwan

To maintain natural systems, ensure zero loss of natural coastal, find out countermeasures of climate change, prevention of coastal hazards and environmental damage, protection and restoration of coastal resources, promote the integration of coastal management and the sustainable development of coastal area, the Coastal Management Act in Taiwan was established.

According to the Coastal Management Act with Article 5, the announcement should be published before the central authorities consider ecological environment characteristics and integrity, the influence between foreshore and land, the necessity and feasibility of managing coastal areas. Ministry of the Interior of Taiwan has announced the coastal area on August 4, 2015.

According to Article 9 and Article 16 of the Coastal Management Act, the integrated coastal zones management plan will be established. Coastal conservation plan will be developed for coastal conservation zones, and coastal protection zones can develop the coastal protection program. As for coastal conservation zones, Taiwan's agency performed law of "Coast Management Act" to explain coastal area belong one of coastal erosion, subsidence, flooding, storm surge flooding and other disaster condition. It can designate as Level 1, Level 2 protection area, which is coordinated by the central competent authority formulate Level 1 coastal protection program, and local county authority formulate Level 2 coastal protection program.

1.2 *Coastal protection and management*

1.2.1 *The risk map of coastal protection areas*

The integrated coastal zone management, marine spatial planning and ocean zoning management are all very important strategies for coastal impact under climate change. Chien et al. (2012) was defined the range for Coastal Protection Areas (CPA), and based on the suggestion of assessment disaster risk by International Strategy for Disaster Reduction (ISDR). Risk can be defined as the combination of the hazard and vulnerability. Since 2004, ISDR published by risk defined and the basic formula (as risk = hazard x vulnerability), is being a variety of natural disaster risk research mainly followed the guidelines of natural disaster risks assessment method.

The article focuses on protect lives and property of people under the coastal erosion, storm surge flooding impact in coastal area. According to the ten coastal vulnerability factors of Taiwan's coastal environment (such as Table 1), the Coastal Vulnerability Index (CVI) and Coastal Vulnerability Level (CVL) of Taiwan were proposed.

Table 1. Coastal Vulnerability factors of Taiwan (Chien et al., 2012)

Evaluated factor	Vulnerability evaluation parameter
Physical Factor	1. Population density 2. Fundamental protection facilities
Environmental Factor	1.Coastal morphology 2.Mean wave level(m) 3.Mean tidal range (m) 4.Coastal erosion 5.Coastal geology sensitive area 6. Rate of land subsidence (cm/yr)
Social- Economical	1.Human Development Index 2.Fundamental facilities, harbor, aquaculture, lifelines areas

Based on the current status and protection targets at coast areas, to ensure the sustainable development of coast areas and plan the CPA by disaster risk in an appropriate way, this study developed nine principles of CPA as the designated reference by the basic principles of National Land Planning Act (draft). The flow chart of the designated process of CPA was shown in Figure 1 (Chien et al., 2012).

For CPA as a designated reference, Level 1 and Level 2 of CPA can be designated from these results. Coastal risk analysis is to assess the harmful consequences or expected the losses, which are affected by natural or man-made threat in coastal areas. The level of risk rating can assist the water competent authorities to designate the level 1 and level 2 of CPA, and decide to develop adaptation strategies, the priority of mitigation measures. The study suggests that CPA classification level correspond to the coastal disasters as follows: (1) Level 1: the coast is a high risk area. (2) Level 2: the coast is a medium or low risk area. (Chien et al., 2012)

The designated criteria are including as follows: (1) To define the range of CPA. (2) Exclude the areas with unprotected target. (3) Factors integration of coastal disaster risk. (4) Classification of coast disaster risk factor. (5) Risk map of coastal hazard.

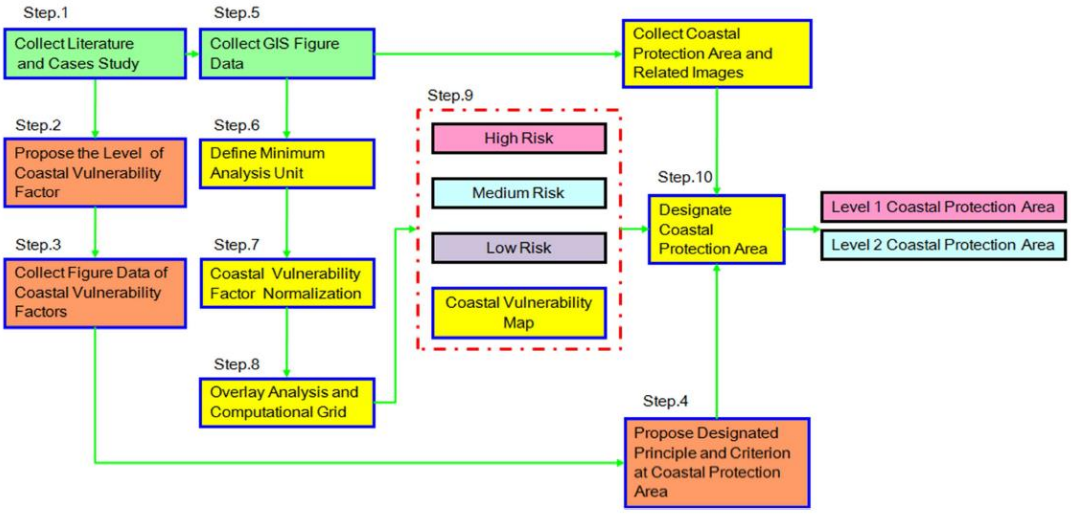


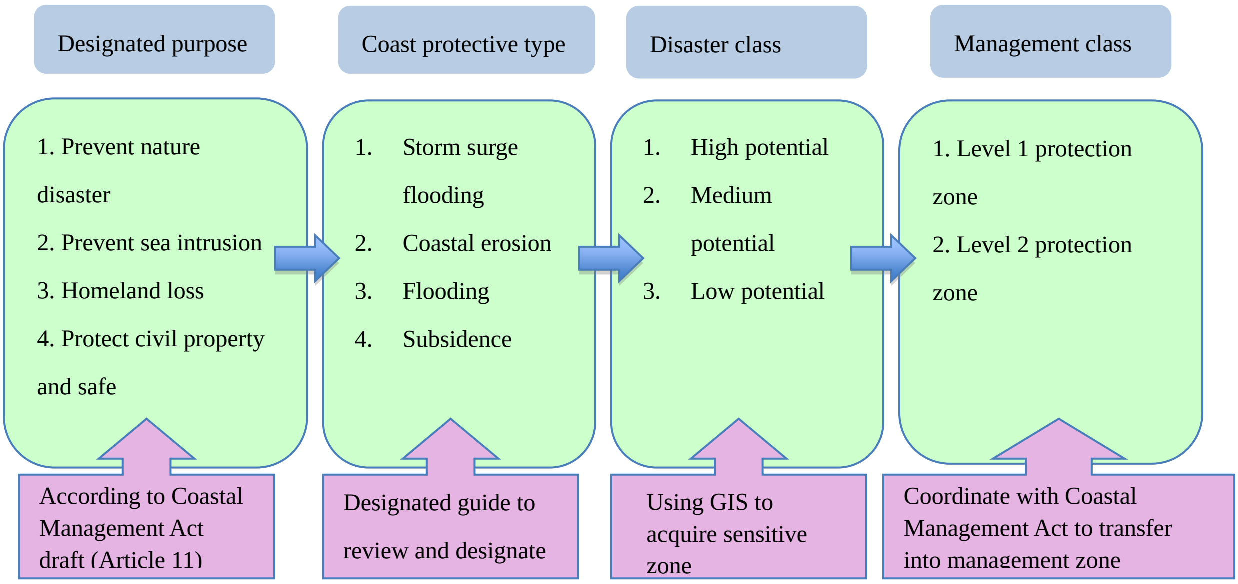
Figure 1. Flow chart of the designated process of coastal protection areas (Chien et al., 2012)

1.2.2 *The designation technology development of coastal protection area*

As so far, the city planning area or urban land development intensity and use patterns within the range of coastal areas, it is not to consider the properties of nature environment of coastal areas. It could easily cause to the adverse environment and ecology of the coastal areas. Hence, the urgent needs to establish the protected management principle to prevent climate change and have to arrange with coastal erosion, flooding, storm surge flooding, subsidence and other potential disasters.

In this study, according to the Coastal Management Act, which has developed four protection zones from high, medium, low potential and then converted to Level 1 and Level 2 of the coastal protection zone. It could be provided for the reference guide of integrated coastal management planning principle in the future. Review the current situation in Taiwan coastal area and to update the image and designation data of the flooding protection zone, subsidence protection zone, storm surge flooding protection zone, and the subsidence protection zone of Taiwan's Coastal Management Act were performed. Chien et al (2012) has tried to classify the coastal disaster from the Coastal Management Act: coastal erosion, flooding, storm surge flooding and land subsidence, referring to a follow-up to this study conducted in Taiwan coastal protection zone of map data updates (as Figure 2).

Figure 2. The designation principle of coastal protection zone (Chien et al., 2012)



Preliminary guidelines of the coastal protection zone were discussed as shown in Table 2, in which the high and medium potential areas are belongs to the severe disaster areas. It needs to protect zones and could convert into Level 1 and Level 2 coastal protection zone. About the low potential area is belongs to lower disaster potential area, and suggested maintaining in current status.

Table 2. Coastal protection designation guidelines and suggestion

Type\potential	High potential	Medium potential	Low potential
Storm surge flooding	Coastal land elevation is less than 50-year return period of storm surge level, and lower than areas below the mean sea level.	Coastal land elevation is less than 50-year return period of storm surge level, and higher than areas below the mean sea level.	Coastal land elevation is more than 50-year return period of storm surge level, and ground level is below 7 meter-area.
Coastal erosion	After investigation identified coastal area belongs to serious erosion, and offshore segment has no buffer zones (beaches) (Note 2).	After investigation identified coastal area to serious erosion, and offshore segment still has buffer zones (beaches) (Note 2).	After setting protection still be potential disaster areas.
Flooding	In the coastal zone, the area of flooding depth(≧ 1 meter) which defined in 24 hours for 50 years accumulated rainfall flooding potential map.	In the coastal zone, flooding depth(≧ 0.5 meter and < 1 meter) which defined in 24 hours for 50 years accumulated rainfall flooding potential map.	In the coastal zone, the area of flooding depth(< 0.5 meter) which defined in 24 hours for 50 years accumulated rainfall flooding potential map.

Subsidence	Water Resources Agency announces serious subsidence range (inclusive) continue subsidence regions, the subsidence rate ≧ 3 cm (Note 3).	Water Resources Agency announces serious subsidence range (Note 4)	Subsidence has occurred but has been slowed down or ground water level is still declining.

Note 1: According to the Water Resources Agency designated the flooding potential map in 2007-2010.
Note 2: The buffer zone refers to under the mean high tide the width of the beach still more than 20m.
Note 3: According to the Water Resources Agency subsidence detection overview map (2011).
Note 4: According to the Water Resources Agency desiganted the severe subsidence area range in 1995.

(iii) Designate process and method of coastal protection zone

The designation method uses GIS overlay analysis, which adopts the coastal lines with same nature disaster characteristics, and graded according to the basis of designation. The 1/25,000 of potential map scale is adopted in this study. It includes the following major steps:

(a) Basic data collection

(b) The principle of coastal protection elaboration

(c) Designated factors by GIS process

(d) Coastal protection zone set painted overlay analysis

(e) Coastal protection zone designation and disaster potential classification

(iv) Designation results of coastal protection zone

Based on four types of coastal protection zones, the designation map are performed as shown in Figure 3 to 6.

(a) Coastal protection zone (coastal erosion): High Potential segments include Hualien coast south coast, Renhua coast of Taitung Chengkung coast, Pingtung Tu family house, Qi mountain, shueili village, Wen Feng, Liu coast, Kaohsiung Linyuan coast etc. as shown in Figure 5. High potential zone is about 132km (6.8%), and the medium potential zone is about 258km (13.3%).

(b) Coastal protection zone (storm surge flooding): High potential storm surge flooding zone is mainly distribute in the southwest coast of Taiwan, including Miaoli, Taichung coast, the Southwest coast, Pingtung coast as shown in Figure 6. High potential zone is about 374km^2 (12.8%), and medium potential zone is about 237km^2 (8.1%).

(c) Coastal protection area (flooding): High potential zone of flooding is mainly distribute in Hsinchu, Miaoli coast, Ilan coast, Chiayi and Tainan coast, Kaohsiung and Pingtung coast as shown in Figure 7. High potential zone is about 282km^2 (9.7%), and medium potential zone is about 383km^2 (13.2%).

(d) Coastal protection zone (subsidence): High potential zone of subsidence is mainly distributed in Changhua, Yunlin, Chiayi, Pingtung area as shown in Figure 8. Yunlin and Changhua area has been the trend of the inland coastal change. High potential zone is about 92.6km^2 (3.1%), the medium potential zone is about 299km^2 (10.3%).

(v) The principle of coastal disaster potential area converts into Level 1 and Level 2 coastal protection zone.

In order to convert the potential data (as coastal erosion, flooding, storm surge flooding, and subsidence etc.) to level 1 and level 2 of coastal protection zone, the designation principles were suggested as follows:

(a) Severe coastal hazard areas or high disaster potential protection as a priority.

(b) Have preservation targets of coast segment as a priority.

(c) The coastal section is defined as the same nature hazard properties.

(d) Designation coastal protection zone is based on the grade of disaster severity as shown in Table 3.

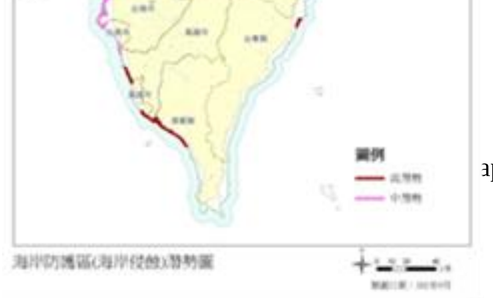


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Figure 5. Designation map of Coastal protection zone (flooding)

Figure 6. Designation map of Coastal protection zone (subsidence)

1.2.3 *Management principle of coastal protection zone*

According to the coastal protection management guide illustrates four principles by Chien et al. (2012), the management targets of protection zone, the protective targets of protection zone, the protection zone management principle, and the supervise principle of protection zone are described as follows:

(i) The management target of protection zone:

As not to affect coastal resources and the environment as the principle, manage the marine disaster risk effective and improve disaster resistance capability and resilience to the preservation of the object, for avoiding or reducing disaster losses of lives and property as well as to ensure that homeland security.

(ii) The protective targets of protection zone:

In response to the affection of climate change and existing coastal disaster (as coastal erosion, flooding, storm surge flooding, subsidence and other potential disasters), and based on the disaster severity (disaster potential or complex disasters), Level 1 and Level 2 of coastal protection zone were established.

(iii) The protection zone management principle:

(a) Management principles: Based on integrated coastal management and sustainable development, and combined with the risk management point of view, the protection classification was adopted for the principles of coastal protect plan.

(b) Coordinate issue: Protection of coastal resources should be a priority. In order to avoid engineering damage or reduce environmental ecology and value of coastal protection zone, in the technical and financial conditions permit, the use and design of coastal protection measures should try to consider the need for coastal protection zone. For land use, except by the central competent authority use, should be low-density use and overlap with land use zoning control.

(c) The management principles of land use in coastal protection zones:

Compliance with one of the following principles, it needs to review land use depending on the actual situation.

i. Significant economic losses

ii. Reduce the difficulty of relief disasters

iii. Reduce the occurrence of secondary disasters

iv. Reduce the effect of construction hazard

(iv) The supervise principle of protection zone:

It should comprehensive consideration of risk reduction, avoid, transfer, undertake and other policies, and adjust the coastal protection plan, restricted behavior, prohibition matters according to the conditions such as the object of preservation and potential environmental disasters flexibly.

(v) Classification of management principle of coastal protection zone:

Based on coastal protection zone management principles, the classification of protection zone corresponds to basic principles. Level 1 coastal protection zone has taken prohibit behavior and compatibility or licensing matters; Level 2 coastal protection zone has taken restricted behavior and compatibility or licensing matters. According to disaster properties to adjust content flexibly.

Table 3. Level 1 and Level 2 of coastal protection zone classification

Type	Level 1 coastal protection zone	Level 2 coastal protection zone
Single disaster	High potential coastal segment	Medium potential coastal segment
Complex disaster	(1) Belongs to severe subsidence regions, and have high or medium potential of complex disaster (2) Not belongs to severe subsidence area, but for the high potential of complex disaster coastal segment	With two kinds of potential disasters (including the above) of the complex disaster coastal segment.

2 Geotechnical Challenges on Offshore Wind Farm in Taiwan

The geological conditions of offshore wind farms are very important environmental risk factors for foundation design and construction. In order to simulate the reaction behavior of the offshore wind turbine supporting structure and foundation under extreme conditions such as storm and earthquakes. In this study, seismic data, drilling data and related soil data of offshore wind farm area were collected and discussed. Based on the geological conditions of Changhua offshore area, the representative soil profiles were provided. On the other hand, by use of the offshore geotechnical investigation, in-situ geotechnical testing and empirical formulas transfer. The requirement of geotechnical parameters for supporting foundation design and construction are suggestion.

On the other hand, for the soft ground and spatial distribution of geological sensitive of offshore wind farm should be discussed. In this study, we will discuss and analyze the soft ground of offshore wind farm, environmental geology sensitive to the spatial distribution, seabed soil liquefaction, the stability and settlement of the foundation construction capacity and marine engineering work safety guidelines. It can be improved to reduce the risk of environmental geology in offshore wind farm and ensure the safety of marine construction in Taiwan. It can provide information to model and simulation different condition for supporting foundation design and construction. (Chien et al., 2015)

2.1 *Offshore wind development in Taiwan*

In Taiwan, the government authorities had oriented the policy of offshore wind power development, and published support schemes in offshore wind development (Wind power offshore system demonstration and incentives schemes). Taiwan’s wind energy potential is excellent, there some literatures indicated evidence are shown in Figure 7 of wind resources were about 1.2GW in the shallow water area (depth form -5 to -20m), and about 5GW in deep ocean area (depth from -20 to -50m).(Chien, et. al, 2013)

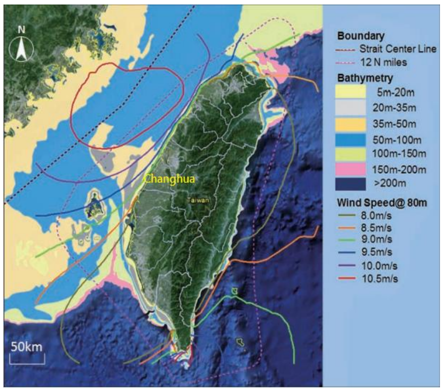

Figure 7. Taiwan offshore wind potential depth distribution and wind speed distribution. (Lin et al., 2014)

For promoting offshore wind farm, the government promulgated “The Offshore Wind Power Demonstration Incentives Rules”, that all project object is as follow:

- The demonstration of offshore wind farm before 2015 to subsidize 3 demonstration wind farm projects and total 6 demonstration devices.
- Demonstration devices: 2 offshore wind power systems of single capacity above 3 MW.

Taiwan is short of installing offshore wind farm experience. Europe predominate the key technology we needed about construction, turbine, blade, supporting structure, foundation, and marine construction. We will be limited by other countries when we develop offshore wind, and localize industrial difficult.

The supporting structure and foundation costs are approximately 25~30% on offshore wind construction, the safety and stability are very important. To reduce the geological induced risk, this study cautious think out design parameter under extreme conditions of offshore supporting structure and foundation.

2.2 *Spatial distribution of soil of offshore wind farm*

A case study of Chang-Bin coastal area was adopted. This study considered the definition of soft soil, such as SPT-N values, soft soil thickness, etc. Using kriging method to estimate the distribution of offshore wind farms soft soil, and using ArcGIS to display spatial distribution form 20m to 90m below sea level by interval equal to 5 m, the soil spatial distribution are shown in Figure 8. The soil type in two wind farm is the depth form 20m to 35m is belongs to sand, depth form 40m is 80m is belongs to alternations of clay and silt, and depth large than 80m is belongs to sand.

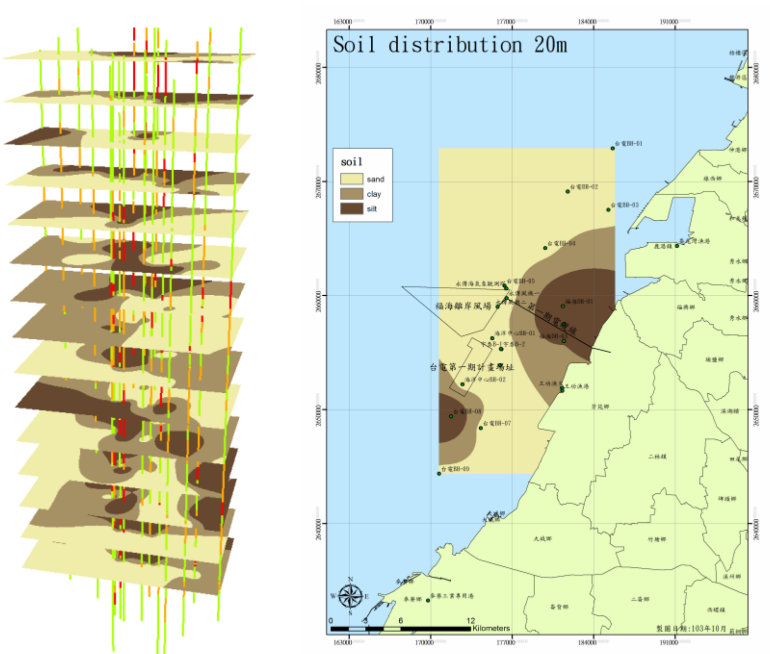

Figure 8. (a) Each depth of parallel seabed section of Chang-Bin coastal area (b) The soil spatial distribution below 20 m of sea level

Soft geology is one of most important effect of risk assessment of supported foundation design, the stability of submarine cables and marine construction engineering. If the wind turbine's foundation is located above the soft soil layer, it may cause differences settlement and failure. Therefore, to understand the distribution of soft soil is an important issue. In this study, the offshore wind farm sites of soft soil determination method, due to the borehole data collected in offshore wind farms, with standard penetration test N (SPT-N) value is the most complete record, Based on related geotechnical engineering studies, the soft soil could be defined by SPT-N value when SPT-N <10 for sand, and SPT-N < 4 for clay. So, with SPT-N value as a reference to plot the soft soil distribution, combined with the thickness of soft sand and the thickness of soft clay conditions. (Chien et al., 2015)

2.2 *Soil Risk Assessment*

Review of geological disasters in Taiwan and DNV (2013) for the design guideline of offshore wind structures, the geology disaster of offshore wind farm disaster is considering as Table 4. The geology sensitivity factors of offshore wind farm are included as the soft ground, soil liquefaction, slope stability etc. Among them, the jack up vessel footings poured through damage is more possible to occur in this study sites because of soft soil.

Table 4. Geological disaster factors of offshore wind farm (DNV, 2013).

Risk of Geological	Objects	Impacts
Soft layers	Marine Vessels	Platform pile run through the soil layers
	Foundations	Differences settlement induce pile toppled down
Scour	Foundations	Reduce lateral support force of foundation
Slope Stability	Cables、Pipeline	Affect pipeline stability
Soil Liquefaction	Foundations	Reduce bearing capacity
	Cables、Pipelines	Induce pipeline damage

In this study, the soft soil conditions can be divided into five levels, given the risk class for the soft soil, if a factor of higher classes on behalf of a factor in the higher risk of the wind farm. The risk class was graded as follows in the Table 5. (Chien et al., 2015)

Soft sand and soft clay are grading by standards SPT-N value. The thickness of soft soil class is based on equal intervals method. According to the risk assessment classification of Table 5, the score of each soft soil factor was calculated and summed. When the higher scores represent higher potential of hazard here, it also said that when an earthquake, wave loading or other environmental condition, softly soil can cause the installation of cables or supported foundations have a higher risk. The results of soil risk assessment could be shown in Figure 9. (Chien et al., 2015)

Table 5. The risk factors and class of soft soil.

Soil Risk Assessment						
		Safe←		Risk Class		→Danger
Risk factors \ Risk Class		Class 1	Class 2	Class 3	Class 4	Class 5
Soft Soil	SPT-N(Sand)	N>50 Very dense	30<N<50 Dense	10<N<30 Medium	4<N<10 Loose	N<4 Very loose
	SPT-N(Clay)	N>15 Very stiff	8<N<15 Stiff	4<N<8 Medium	2<N<4 Soft	N<2 Very soft
	The thickness of soft soil	<1.0m	1.0-1.5m	1.5-2.0m	2.0-2.5m	>2.5m

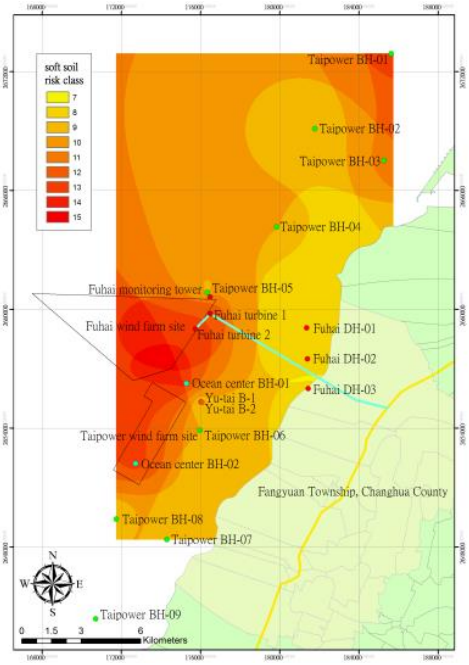

Figure 9. The results of risk assessment of soft soil for offshore wind farm site.

Form the analysis of soil risk assessment, it can find that soft soil in the wind farm zoning obtained a high risk score. On behalf of the wind farm within the zoning covers a lot of soft in shallow layer, the installation of cable has a higher risk, so the design of cable should be considering the risk of soft soil (Chien et al., 2015).

3 Geotechnical challenges on offshore wind farm and coastal area

3.1 *Possible impact of climate and environmental change*

(i) The normalization of the extreme disaster cases

Under the climate change, the extreme disaster cases may be normalized and it will induce in extreme cases of severity disasters.

(ii) Far exceeded expectations of complex disaster

Large-scale of slope collapse, landslide, reservoir silt and flood control operation, driftwood, river siltation, barrier lake, bridge safety, cut off of roads, the dike embankment erosion, subsidence area flooding, siltation, and other secondary disaster etc., the complex disaster induced damage more than expected.

(iii) Over than the existing protection capacity

Existing anti-disaster plans, protection standards and operational mechanisms prevention and relief cannot suitable for the complex large-scale disasters such as Typhoon Morakot.

3.2 *Response countermeasure of disaster in the future*

(i) Ensure the ability of preventing flooding, strengthen non-engineering measures

(a) Facing the climate anomalies and frequent extreme hydrological events, should be restored and to ensure the existing water conservancy facilities have ability of preventing flooding.

(b) When rehabilitate the hydraulic structures in the area of potential complex disasters, should consider the impact of complex disasters, supplemented by non-structural disaster prevention measures to reduce disaster losses.

(ii) Enhance the self-prevention ability of complex disasters

(a) Consider the complex disasters, promote independent community of preventing disaster and draw the disaster prevention map, implement the evacuated practice.

(b) Encourage private volunteers, organizations, company to assist investment in prevention and relief work, to enhance the country's overall disaster prevention and energy.

(c) Advocacy the conception of preventing complex disaster by various aspects, strengthening the awareness of self-prevention.

3.3 *The window of Chance*

(i) Mitigation and relief of disaster.

(ii) Prevent disaster is an interdisciplinary disaster futurology.

(iii) The importance of disaster mitigation and preparedness.

(iv) Mitigate disaster can create sustainable development, and needs to coordinate with environment.

(v) Prevention and mitigation work is the basic requirement which the engineers face the environment in the future, and the ultimate goal is sustainable development.

Acknowledgements

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A CASE STUDY ON THE GEOTECHNICAL CHALLENGES INVOLVED IN HIGH-RISE RESIDENTIAL DEVELOPMENT ADJACENT TO STEEP HILLSIDES IN WANGSA MAJU, KULA LUMPAR

VIC PUN[1] , SL CHIU[2] and STEVEN WILLIAMSON[3]

[1]*AECOM Asia Co. Ltd.*
9/F., Grand Central Plaza, Tower 2, 138 Shatin Rural Committee Road, Shatin, Hong Kong
E-mail: vic.pun@aecom.com
[2]*AECOM Asia Co. Ltd.*
9/F., Grand Central Plaza, Tower 2, 138 Shatin Rural Committee Road, Shatin, Hong Kong
sl.chiu@aecom.com
[3]*AECOM Asia Co. Ltd.*
9/F., Grand Central Plaza, Tower 2, 138 Shatin Rural Committee Road, Shatin, Hong Kong
steven.williamson@aecom.com

In cities with hilly terrain such as Kuala Lumpur and Hong Kong, increasing demand for residential development land necessitates consideration of sites adjacent to steep hillsides. Such sites may present a number of geotechnical challenges to overcome such as potential landslide hazards from upslope terrain/slope failure, excavation and support of large temporary and permanent retaining structures and drainage. This paper presents a case study for the investigation, assessment and design of solutions to such challenges for a residential development located adjacent to steep hillside terrain in Wangsa Maju, Kuala Lumpur. The issues discussed include remote assessment of natural terrain hazards using conventional air photographs and airborne LiDAR survey, ground investigation, construction of engineering geological models, robust design of significant retaining structures to give sufficient development area and foundation considerations.

Keywords: Kuala Lumpur, steep hillside, landslide hazards,

1. Project Background

1.1. Company background

AECOM was created to design, build, finance and operate the world's infrastructure. Whether we serve clients at one phase of the project lifecycle or throughout it, our role is to apply creative vision, technical expertise, interdisciplinary insight, and local experience to address complex challenges in new and better ways. We help our clients deliver critical resources and services, improve the places where people live and work, and sustain a world in which we can all flourish. Our markets include Buildings & Places, Civil & Infrastructure, Industrial, National Governments, Oil, Gas & Chemical and Power. Our core services include Architecture and Landscape Architecture, Building and Equipment Maintenance, Civil and Building Engineering, Construction Management, Cost Consulting, Environmental Planning and Remediation, Facilities Management, Program Management, and Urban Planning and Design.

AECOM is a US based company and was ranked at 343 in Fortune 500 Ranking and was named as 2015 Fortune World's Most Admired Companies. AECOM Asia Co. Ltd possesses the planning, engineering, design and program management capabilities to serve many industries across the region and beyond. As a global leader, we are the No.1 International Design Firm in Asia, according to an Engineering News-Record 2011 ranking. With more than 9,000 employees in around 35 offices across Asia, we are uniquely equipped to offer our clients a truly integrated suite of services that address complex project challenges, and deliver local service excellence that reflects our global knowledge and expertise. We are designers, architects, engineers, planners, economists, scientists, project managers - working together to shape our future cities, communities and environments.

In this project, our Malaysia branch accompanying Hong Kong branch to provide engineering services to the development project including civil, geotechnical and structural design.

1.2. Project background

The Mitrajaya Wangsamaju development consists of three highrise condominium towers housing over 600 residential units. with the first 8 levels being used as multi storey carpark and communal area. The development is located adjacent to the famous Wangsawalk and cuts into a hillslope. AECOM Perunding Sdn. Bhd. have been appointed by Mitrajaya Homes Sdn. Bhd. to undertake structural, geotechnical and civil engineering for the development with geotechnical engineering services undertaken by AECOM's Hong Kong office.

Figure 1 - Architectural Layout for the Proposed Development

The proposed structure will be located on a cut platform at 100m PD. The structure itself will be independent of the retaining wall. The existing hillslope comprises of a man made cut slope to the south of the site with the rest being natural hillslope with dense vegetation.

The site is located at Lot 28144, P.T. 6630, Jalan J7, Wangsa Maju Mukim Setapak, Kuala Lumpur Wilayah Persekutuan. The total area of the site is around 3.168 hectares. The following are located adjacent to the project site;

- Jalan 58/26, a main road with moderate traffic, is located approximately 3m from the southern site boundary.
- Wangsawalk Mall across the road from Jalan 58/26.
- The Telekom Exchange building with boundary is approximately 100m from the western site boundary.
- Sri Rampai Putra LRT station and Desa Putra Condominium approximately 150m from the eastern side boundary.

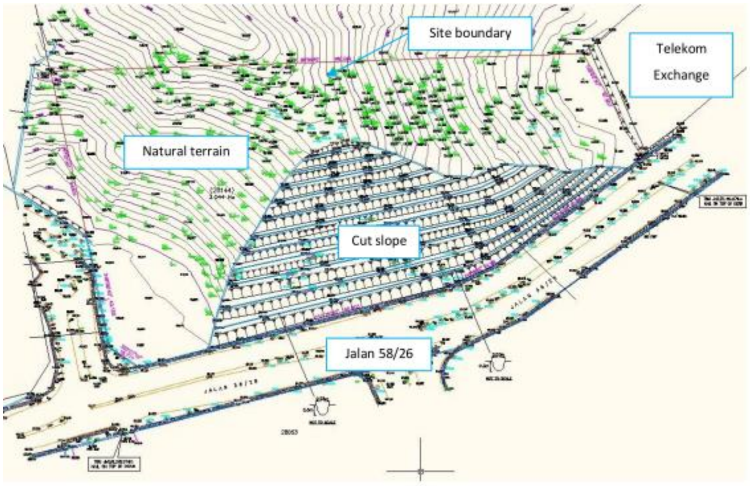

Figure 2 - Site Location

The site is situated along the southern portion of an existing natural hillslope. The hillslope is over 80m high with a base height of RL+96m and a peak height of over RL+176m. The peak is located outside the project site. The slope is quite shallow, around 25° to 40° and completely obscured by vegetation. The western side of this hill has been cut to locate the existing Telekom Exchange building. Between the natural hillslope, almost centred on the site is a man-made cut slope. This cut slope faces Jalan 58/26, approximately 200m in length and 80m in height. Intermediate berms were formed such that the slope condition can be inspected.

Figure 3 - Front View of the Development

1.3. Site geology

The site consists of predominantly in-situ terrain with no superficial deposit observed. Published geological information indicates that the geology of the site lies in the metamorphic terrain of the Dinding Schist rock formation, Permo-Ordivician in age. These are the oldest rock units found in the Kuala Lumpur area. The formation comprises of metasedimentary rocks, predominantly quartz-mica Schists with minor intercalations of Phyllite. The Schists are fine to medium grained and light grey to greenish grey in colour, while the Phyllite is dark grey. Both rocks are well foliated.

1.3.1. Structural geology

The site comprises of non-uniform foldings, due to regional anticlinal and synclinal structures. The foliation of the metamorphosed rocks generally strikes Southeast and invariably dipping moderately to the southwest (average dip is 33°). There are four sets of discontinuity present at the project site, two dominant joint sets and two minor joint sets. One of the dominant sets is consists of sub-vertical joints that strike north-east, the other dips generally to South-Southwest and strikes East-Southeast. The minor joint sets strike North-Northwest and Southwest, both steeply dipping towards subvertical. The joint spacing range from 0.02m to 1.00m wide. The joints are generally tight and occasionally sealed by quartz. The joint surfaces are generally smooth. However the Northwest striking joint surfaces are polished and slickenside. This suggests that they are shear fractures related to nearby fault or shear zones. The unweathered rock mass of the schist is generally medium strong to very strong. The decomposed rock and residual soil generally consists of very stiff or dense to very hard or very dense sandy silts with gravels.

1.3.2. Ground water

The upslope catchment of the site is small and the geomorphological setting of the upslope terrain causes preferential flow of groundwater toward Southwest and West down the valley. Seepage has not been observed on the existing cut slope. According to the existing groundwater monitoring records, the groundwater table is generally between 14m to 28m below the ground surface, which is in below the proposed formation level of +100mPD. However, a perched water table may exist a few meters below the ground surface.

2. Past Experience in Hong Kong

In this project, we share our global experience in site formation design at hilly areas, and compile the design with local practice in Malaysia. The experience sharing has enhanced to provide a practical design solution in particular the natural terrain review for the 80m high hillside. In this section, two recent projects will demonstrate similar site conditions where engineers attempt to obtain buildable areas by cutting into hilly site in congested big cities in South East Asia.

2.1. Residential Development at 21, 23 & 25 Borrett Road, Hong Kong

Similar to the project in Wangsamaju, there is a natural slope laid behind the proposed development site at Borrett Road. Natural terrain was assessed and site formation design was carried out to cut into the originally natural hill. The natural terrain hazard assessment identified several potential hazards such as debris flow and boulders fall that would likely occur; hence, a check dam with temporary soil nail is designed for the potential debris flow and in-situ boulder stabilization was carried out after detailed boulder survey. Site formation design, including socketted H-pile, reinforced concrete wall and rock cut slope were proposed to form platform for superstructure development after cutting.

Figure 4 - Site Layout Plan at Borrett Road

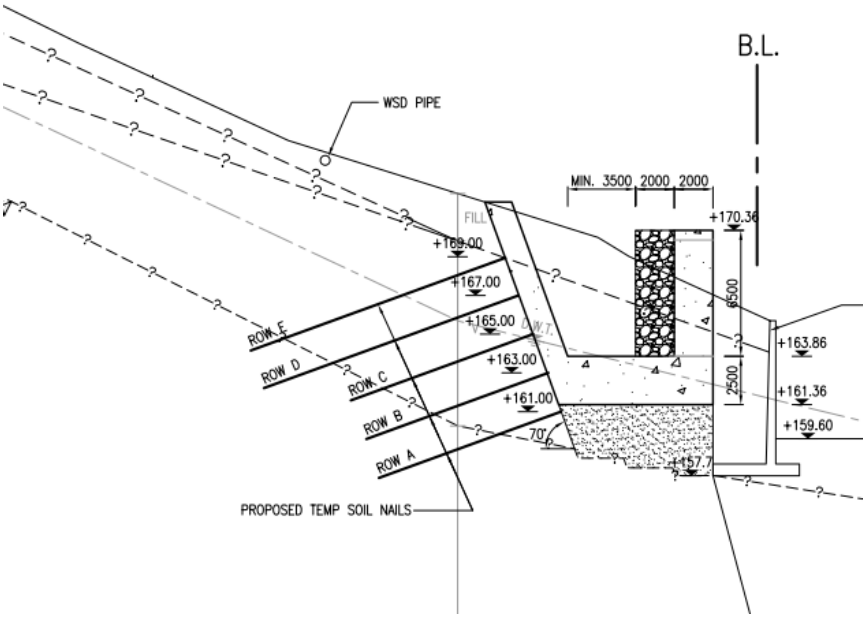

Figure 5 - Check Dam Construction Details

2.2. Development at Wai Lung Ave., Macau

The proposed development at Macau was originally a hilly slope with elevation difference of more than 50m. The purpose of the site formation works is to cut into the existing slope to cater for the future residential building blocks. Since the rockhead was generally located 6m below the existing ground, reinforcement concrete wall was proposed to retain the soil on top of the rockhead with 70 degree to 85 degree rock cut slope underneath. Rock joint mapping assessment with necessary remedial works, including rock dowel and buttress, were proposed for the rock cut slope.

Figure 6 - As-built Condition at Wai Lung Site

3. Engineering Design

3.1. Project site investigation

In order to understand the site properties, site investigation was carried out for the development. 18 numbers of drillholes and 4 numbers of trial pits were proceeded in 2011. The following information and design parameters were established base on the detailed site investigation works;

- Site geology & geomorphology profile;
- Geological mapping;
- Rockhead contour;
- Design soil parameters included shear strength parameters, bulk and dry density, and moisture content;
- Soil and rock permeability;
- N value of the soils
- Rock strength and rock bearing capacity
- Rock discontinuity surveys
- Groundwater level
- Soil aggressivity assessment included resistivity (ohm-cm), pH value, soluble sulphate (ppm) and chloride iron.

3.2. Natural Terrain Hazard Study

According to the Geological Assessment Report for a Cut Slope, for E-Geo Consultant SDN. BHD., no significant mass-movement processes were observed on the slope however, some localised, small-scale landslips were previously reported which occurred on the natural hillslopes within the east and west of the study area. The landslips are believed to be largely attributed to the substantial infiltration in the residual soils due to the uphill sub-catchments on both slopes. No information on the existence or location of boulders is available.

A cut slope is present on the southern flank of the elongated sub-rounded hill. The cut slope is approximately 190m long with a maximum height of around 80m from road level. The cut slope faces south towards Jalan 58/26. It is unknown whether the natural hillside has been further disturbed by human processes.

3.2.1. ***Geomorphology***

The study area is an area of natural terrain hillslope which exists to the north of Jalan 58/26 upslope of the proposed development. The study area is on the southern flank of an elongated sub-rounded hill, with a cut slope dominating the southern portion of the hillslope.

The eastern portion of the study area comprises of relatively homogenous natural hillslope terrain ranging between 30° and 35° in topographic gradient. The lower portion of the hillslope exhibits two benches which are form an area of steep terrain (45° to 50°) between them. Toward the cut slope within the centre of the study area a series of topographic benches exist on the upper hillslope. The eastern portion of the study area is also punctuated by a series of streamcourses which are likely to be ephemeral.

The western portion of the study area comprises a steep upper hillslope with a convex break in slope forming a shallow mid and toe slope. A number of streamcourses are present transecting the hillside, forming minor depressions. The contours imply that the streamcourse immediately adjacent to the cut slope is relatively deeply incised in comparison to those across the rest of the study area.

A slope angle plan is presented in Figure 7 and a geomorphological plan in Figure 8. Both plans are based on limited contour data and therefore may not be accurate. A number of potential landslide initiation locations are considered to exist based on slope angle and geomorphology. Through lower hillslope within the east of the study area the steeper topographic areas could be the result of anthropogenic activity.

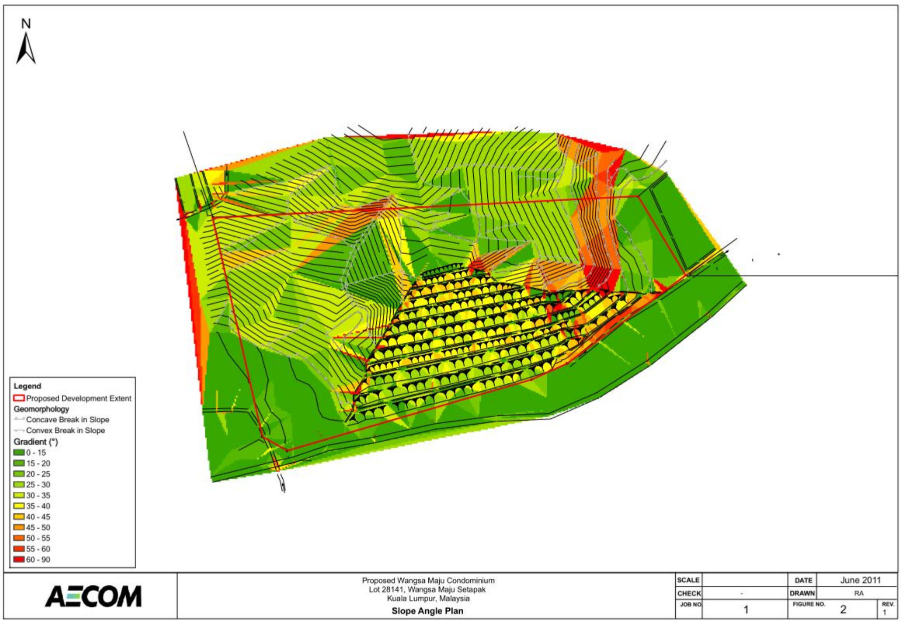

Figure 7 - Slope Angle Plan

In general, streamcourse channels are poorly defined and will tend not to confine a landslide to generate high mobility or channelised debris flows, with the exception of the incised streamcourse channel within the western portion of the study area.

Figure 8 - Geomorphological Plan

The distance between the upslope and toe of the study area is also short and steep, and although some possible depositional/colluvial areas are defined by concave breaks in slope, the potential for entrainment is considered low. Therefore, landslides which occur within the study area are likely to reach the toe of the study area.

3.2.2. ***Natural Terrain Assessment***

A number of localised, small-scale landslips were previously reported which occurred on the natural hillslopes within the east and west of the study area. The landslips are believed to be largely attributed to the substantial infiltration in the residual soils due to the uphill sub-catchments on both slopes and therefore may occur in similar locations across the study area. Overall the primary failure mode is likely to be dominated by open hillslope failure within broad depressions/drainage lines.

Within the eastern portion of the study area where there is a possibility of the rock head being close to the ground surface, forming an area of steeper terrain, there is the possibility of rock outcrop being present. The slope stability analysis presented in the Geological Assessment Report for a Cut Slope, for E-Geo Consultant SDN. BHD., suggests that there is a potential for wedge failures to occur within proposed cut slopes. However, the desk study information suggests that at surface the rock mass is completely weathered or a residual soil, and therefore only small scale sprawling is likely from rock outcrops. No obvious boulder fall or rock fall hazard was identified.

There is no previous evidence of deep seated failures within the study area, and no information within the previous reports suggests the potential presence of tensions cracks or slope bulging. However, the dense vegetation across the site may have limited the visibility of such features. There is no significant debris lobe identified at the toe area, therefore, the potential for deep seated failure is considered to be low.

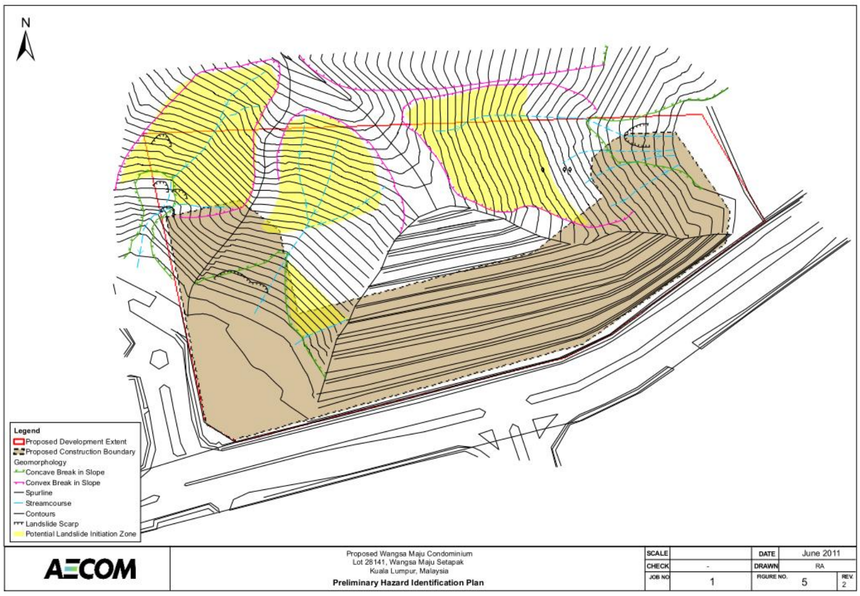

Figure 9 - Preliminary Hazard Identification Plan

However, localized stabilization will be required in areas with gradient greater than 35° in order to increase the safety limits to meet the requirements stipulated in Garis Panduan Perancangan Pembangunan di Kawasan Bukit dan Cerun Bagi Wilayah Persekutuan Kuala Lumpur, 2010 (GPWPKL2010), DBKL. In these areas, where possible the slopes will be trimmed down to 35° otherwise, soil nails will be used.

3.3. Slope Works/Retaining Structures

The site formation design aims to facilitate the excavation down to final formation level. The design shall ensure that any potential slope instability caused by the development will be addressed by the proposed geotechnical proposals. Open-cut excavation will be carried out after construction of the retaining walls along the line of the cut.

As described in previous section, the majority of the slope within the natural terrain area is Class III or better with gradients less than 35 degrees. The slope within the natural terrain area is deemed safe as less than 10% fall under Class IV.

Slope Class	Percentage within the site boundary
Class I: < 15 degree	11.97%
Class II: between 15 and 25 degrees	10.58%
Class III: between 25 and 35 degrees	68.97%
Class IV: > 35 degrees	8.48%

Table 1 – Slope Classification

The soil parameters, based on the findings of the existing site investigation works, are adopted in the current design proposal. Garis Panduan Perancangan Pembangunan di Kawasan Bukit dan Cerun Bagi Wilayah Persekutuan Kuala Lumpur stipulates a minimum factor of safety of 1.3 and 1.5 for natural slope and man-made slope respectively. The stability analysis has been undertaken using Morgenstern-Price Method of the software SLOPE/W (GEOStudio 2004).

Soil Type/ Rock	□(kN/m3)	c' (kPa)	□ (°)
Fill	18	-	28
Residual Soil	18	3	30
Completely/highly decomposed Rock	18	5	35
Moderately decomposed Rock	19	10	42

Table 2 Summary of geotechnical parameters

Three cases were assessed to check if these limits are met;

- Area with the largest difference in height.
- Area with the maximum slope gradient (60° degrees).
- Area with slope gradient of 35°.

Case	Factor of safety obtained from analyses	Minimum factor of safety required
1.Area with the largest difference in height	0.646	1.5
2.Area with the maximum slope gradient (60° degrees)	0.727	1.5
3.Area with slope gradient of 35°	1.529	1.5

Table 3 Summary of the factor of safety obtained from slope stability analysis of the existing ground (unreinforced)

From the analyses, it was found that slope stabilisation is required for Cases 1 and 2. Case 3 does not require any stabilisation. Based on these findings, any slope greater than 35° will be trimmed back where possible or stabilised using soil nail.

Case	Factor of safety obtained from analyses	Minimum factor of safety required
1.Area with the largest difference in height with soil nail	1.522	1.5
2.Area with the maximum slope gradient (60° degrees with soil nail)	2.124	1.5

Table 4 Summary of the factor of safety obtained from slope stability analysis of the stabilized ground

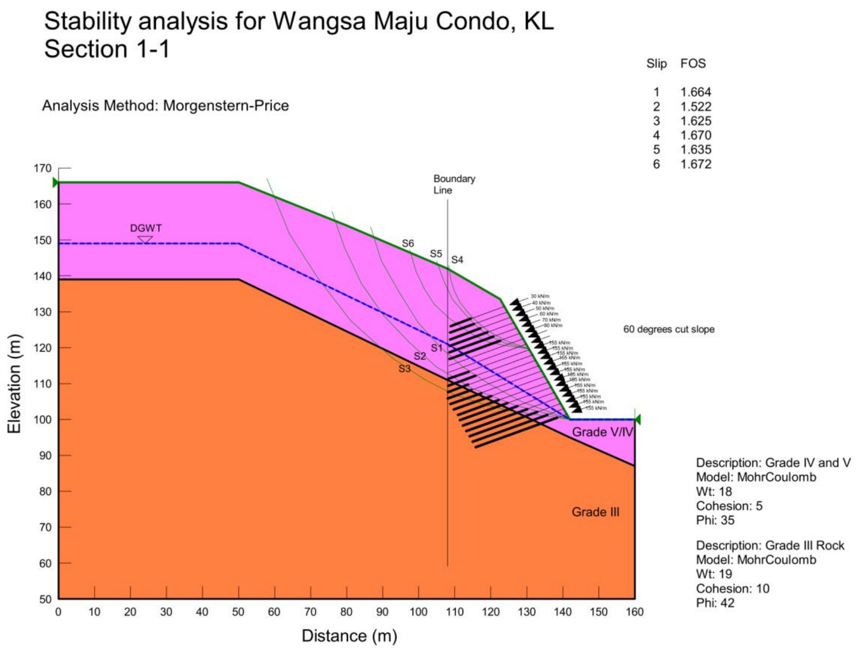

Figure 10 - SlopeW Result for critical Section

Critical sections were assessed to determine the global slope stability before and after the proposed works. Factor of safety of the existing slope before and after the proposed development obtained from the analyses were greater than the min FOS of 1.3 and 1.5. It can be concluded that the proposed works does not have any detrimental effect on the remaining slope and the slope will be stable.

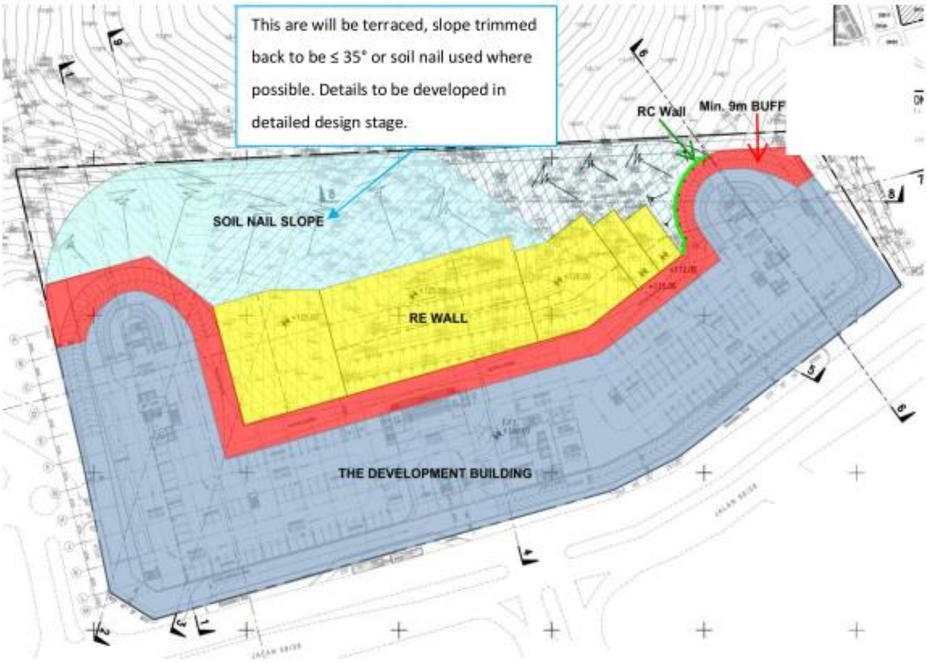

Figure 11 - Layout Plan showing Proposed Site Formation Works

The structure sits on a level platform requiring the existing slope to be cut, 25m at its deepest. Various options were studied for retaining the earth along this cut slope, including contiguous bored pile wall (CBP wall) with prestressed ground anchors, double CBP wall, soil nail wall and reinforced earth wall (RE Wall). Taking on board the comments received from the various authorities from the initial Development Order submission, the project team collectively decided to proceed with a RE wall along the main cut length supplemented with soil nail and conventional reinforced concrete wall (RC Wall) where there's space constraints. RE wall is a robust solution that would require minimal maintenance and has the longest design life amongst all the options considered. It will also give the best visual comfort for the residents, i.e there would not be a 25m high vertical retaining wall just outside the building.

3.4. Technical Considerations

The purpose of this geotechnical design is to provide a platform for further development by cutting the heavily vegetated slope approximately 50m in height with a natural terrain laid on the crest of the site boundary. During the preparation of the engineering design, the design engineers carried out desk study on the previous information. This is always challenging when there is limited information for a detailed design. Previous landslide records, topographical survey and arial photos are not usual practice in Malaysia. Hence, fundamental approaches, including visual site inspection and review on the Geomorphological plan, had been carried out to interpret the local geological condition in the natural terrain assessment. No adjacent site investigation works were carried out as the site was located in rural area; hence, the geological profiles and selection of design parameters are mostly based on the project site investigation records.

Actual site condition may be different from the original design assumptions. Therefore, regular site inspection was carried out during construction stage to verify the design assumptions. In case there were deviations observed, timely engineering review on the current design was carried out to ensure that the validity of the engineering design.

4. Conclusion Remark

Land demand is always a typical concern in urban cities, and developers tend to search for feasible land by applying heavy site formation works. In the Wangsamaju project, the original slope was cut to provide a building platform for a highrise development. Geotechnical and geological experts carried out feasible design scheme by application of practical techniques in natural terrain assessment and site formation design. The mixture between global solution solving experience and local expertise fit well into the project and provide a cost-effective design scheme for the development.

Acknowledgments

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Detection and Monitoring of Deep-seated Landslides Using Multi-scale Remote Sensing Techniques

Meei-Ling Lin[1], Kuo-Lung Wang[2] and Te-Wei Chen[3]

[1]*Department of Civil Engineering, National Taiwan University, No. 1, Sec. 4, Rooservelt Road, Taipei, Taiwan*
linml@ntu.edu.tw
[2]*Department of Civil Engineering, National Chinan University, Nantou, Taiwan*
klwang@ncnu.edu.tw
[3]*Department of Civil Engineering, National Taiwan University, No. 1, Sec. 4, Rooservelt Road, Taipei, Taiwan*
acura0308@gmail.com

The deep-seated landslide often causes severe damages to lives and properties due to the movement of massive volume. Detection and monitoring of the deep-seated landslides are important issues for protection of affected residents and drafting of mitigation measures. Due to the rapid developments and large area sensing ability, the multi-scale remote sensing techniques can be integrated to provide coverage of information on regional as well as local topography variations. The regional evolvement of the geomorphology of the deep-seated landslides thus can be identified and monitored. In this study a methodological approach for identifying the deep-seated landslides is introduced, which adopts the LiDAR (Light Detection and Ranging) data, aerial photos and field investigation. An example in the Namasha Areas in Kaohsiung City, Taiwan severely hit by Typhoon Morakot, 2009 is illustrated. The identification of deep-seated landslides was performed based on the LiDAR high-resolution topographic information. The linear structures were mapped based on the shading maps in different azimuth to show good details of the structures and the scarps of the landslides were thus identified. Validation of the results was made using both aerial photos and field investigations. For monitoring of local landslide, the ground-based LiDAR and close-range photogrammetry could be used. With the temporal 3-Dimensional slope and retaining structure images reconstruction, deformations in 3-D can be established. Ground-based LiDAR measurements were conducted from 2007 to 2009 at the Lushan site in central Taiwan, and the deformation of the overall slope was identified, including typhoon Sinlaku event in 2008. The time-series of close range photogrammetry measurements were also conducted by tracing coded targets placed on 3-D retaining structures. With the projection of 3-D control points, the rotation and displacement of retaining structures were determined. The ground based LiDAR provides overall surface landslide information and the close range photogrammetry provides local deformation. The landslide behavior can be analyzed by combining ground based LiDAR and close range photogrammetry. In addition, the InSAR technique using satellite images can be used to monitor the ground deformation of the north slope of Lushan area. Such techniques provide useful tools for monitoring long-term deformation tendency of deep-seated landslide.

Keywords: deep-seated landslide, Identification and monitoring, LiDAR, ground-based LiDAR, close range photogrammetry, InSAR

1 Introduction

The deep-seated landslide often causes severe damages to lives and properties due to the movement of massive debris volume. Detection and monitoring of the deep-seated landslides are important issues for protection of affected residents and drafting of mitigation measures. Due to the rapid developments and large area sensing ability, the multi-scale remote sensing techniques can be integrated to provide coverage of information on regional as well as local topography variations. In this research, we used LiDAR (Light Detection and Ranging) data and aerial photo to identify the deep-seated landslides on the regional area scale. For monitoring of the deep-seated landslide movement and topographic variation, we used ground base LiDAR to monitor the deep-seated landslide in Lushan area to understand the ground surface movement of the whole slope. The close range analysis can be used to monitor the relative movement of the retaining wall situated inside the Lushan deep-seated landslide and the results can be integrated with the LiDAR data to provide movement and behavior of the landslide. For long-term deformation monitor, we used time series SAR (Synthetic Aperture Radar) satellite images to execute the PS-InSAR (Persistent Scatterers SAR Interferometry) and SBAS-InSAR (Small Baseline Subset InSAR) analysis to monitor the Lushan deep-seated landslide.

2 Identification of the deep-seated landslides using aerial photo and LiDAR data

2.1 *Identification of Regional Landslide Scars Distribution*

After a rainfall event causing severe landslide hazard, it is often needed to investigate the regional distribution of landslides. For a regional investigation, a typical practice would be to use the aerial photos or satellite images taken after the event, and the exposed ground in the aerial photo would be identified as the landslide scars. One such example of the distribution of the landslide scars caused by typhoon Morakot in 2009 in the Namasha district, Kaoshiung City in southern Taiwan was identified using the aerial photos as shown in Figure 1. In Figure 1 we can observe many landslide scars are of small area and most of them are shallow landslides. Although some of the scars might be associated with the deep-seated landslide, or involved large area, it was difficult to determine whether the scar corresponded to the deep-seated landslides from the mapped results directly. Some previous researches suggested that the landslides with associated area larger than 10ha were described as deep-seated landslides (Chigira, 2011). For identified landslide scars with area larger than 10 ha in Namasha study area was marked in green color as shown in Figure 1. The distribution of the large area of shallow landslide provided helpful information for identifying the current events of the deep-seated landslide. However, in many cases only small part of the ground exposure in the deep-seated landslide could be identified in the aerial photo due to the translational motion of the landslide. To confirm the deep-seated landslides in the site, a field investigation would be required and which would become a huge effort when involving a regional scale. For the regional investigation, the morphology features of the deep-seated landslide identified using remote sensing data would be more feasible. Typically the deep-seated landslide has a translational movement and displayed significant topographic features that can be used for identification of the deep-seated landslide. The LiDAR data was used to help finding the topographic characteristics of deep-seated landslide in the Namasha district.

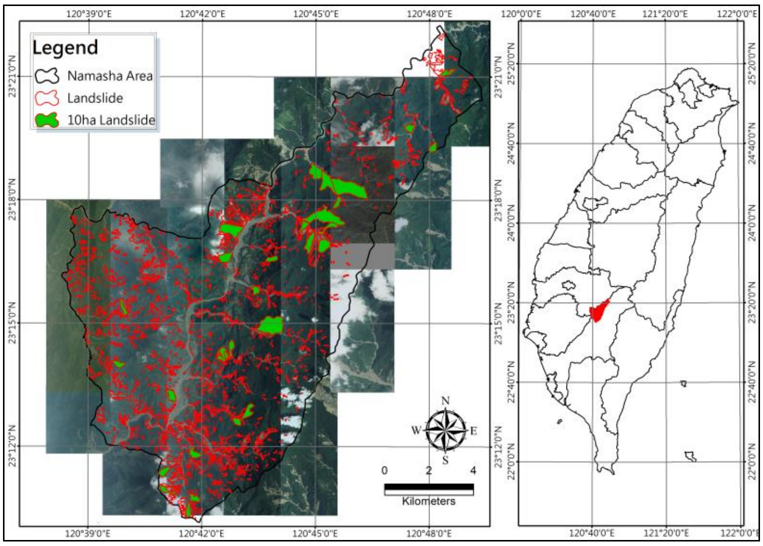

Figure 1. Distribution of identified landslide scars of Namasha district using aerial photos

2.2 *Identification of deep-seated landslide with LiDAR data*

The methodology for identifying a deep-seated landslide with rotational translation was based on the geomorphologic characteristics and related scarps according to Varnes (1978) as shown in Figure 2. From Figure 2, the topographic characteristics of such a deep-seated landslide include: (1) crown with cracks, (2) main scarp or head scarp, (3) related slide blocks, (4) minor scarp, (5) main body, (6) transverse tension cracks and (7) bulging toe area. Most of these features when well exposed can be identified from aerial photos; however, differences in elevation of scarps or tension cracks that are not well exposed are difficult to pinpoint.

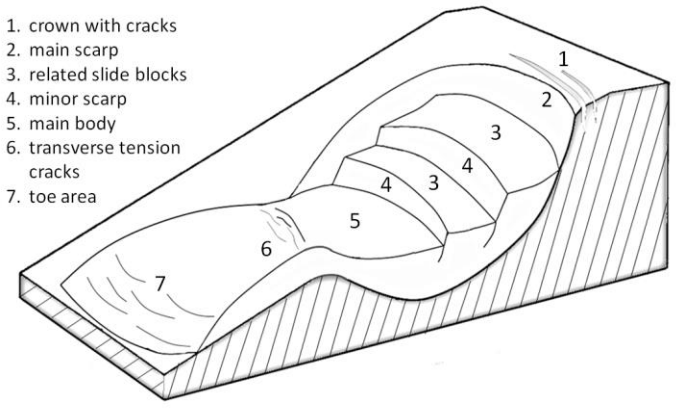

Figure 2. The geomorphologic characteristics of a rotational deep-seated landslide (modified from Varnes(1978))

Due to the rapid development of the remote sensing technique, by using the remote sensing images combined with techniques for finding the topographic features would be a good method for the regional identification of the deep-seated landslides. By LiDAR technique, the laser energy can penetrate the tree crown and reach the real ground elevation. The development of LiDAR technique provides high resolution terrain which can reveal details of the topographic variations for identification of the geo-morphological characteristics. Figure 3 illustrates an example of 2 m resolution DEM (digital elevation model) shading map of the downstream area of Nachilan River, Namasha district from LiDAR data taken after typhoon Morakot by the Soil and Water Conservation Bureau (SWCB) in 2010. For finding the deep-seated landslides, we can use the LiDAR shading map to identify the linear structures that are consistent with the scarps of the deep-seated landslide first. Figure 4 illustrates the linear structure results of KSDF007 (Kaohsiung Debris Flow torrent No.007) debris flow torrent area. Figure 4(a) was the shading map with azimuth angle of 45°, by rotating the shading map to eight different azimuth angles, we could find an azimuth angle that reveals the best details of linear structure. The identified results of linear structure were as shown in Figure 4(b), in which the red lines were the results of linear structure that also corresponded to scarps of the slopes. Procedures for identification of the deep-seated landslides start with using the shading map derived from LiDAR data to locate the linear structures, which are considered as scarps of landslide area, and then the slope map is derived to identify the topographic characteristics of the deep-seated landslide such as crown with cracks, landslide body, bulging toe, and corresponding scarps. Figure 5 was the identified deep-seated landslide and its features in the Maya area, Namasha district. From the figure, some small landslides were observed in the slope area. The erosion gullies and side cracks were well-developed and could be easily recognized. There are many scars parallel to each other in the crown area. These characteristics are consistent with the deep-seated landslide descriptions by Varnes (1978), thus the red scars (linear structures) of slope were used as the scarps of the identified deep-seated landslide.

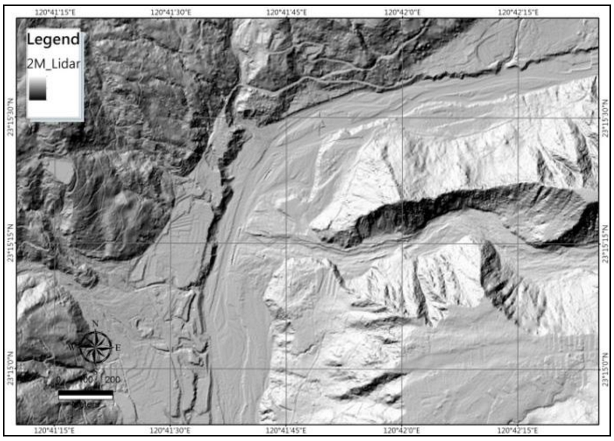

Figure 3. An example of shading map from 2 m resolution LiDAR DEM of the downstream area of Nachilan River, Namasha district.

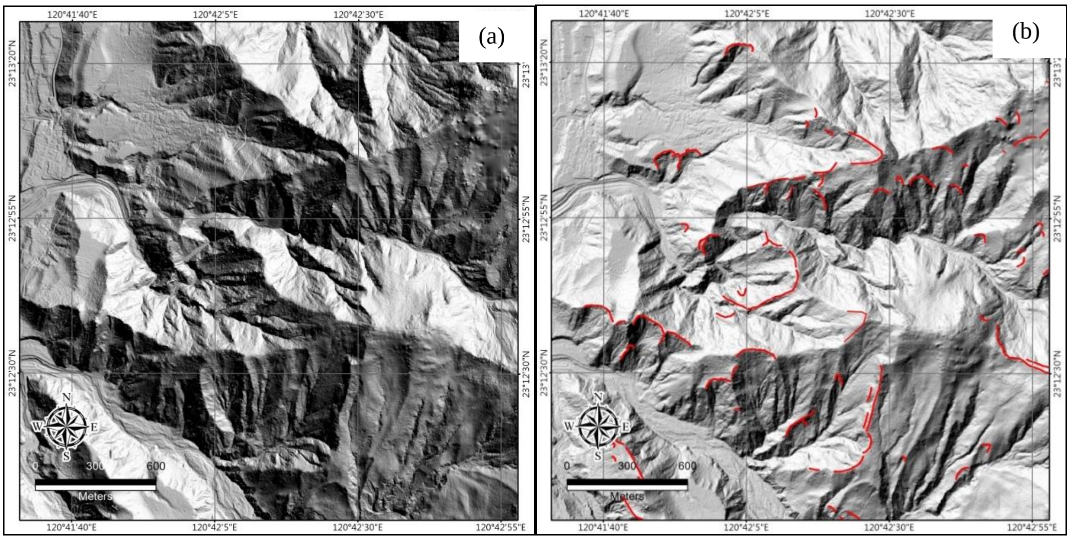

Figure 4. Results of identified scars in KSDF007 debris flow torrent area: (a) shading map with an azimuth angle of 45°; (b) identified scars in the best azimuth angle shading map.

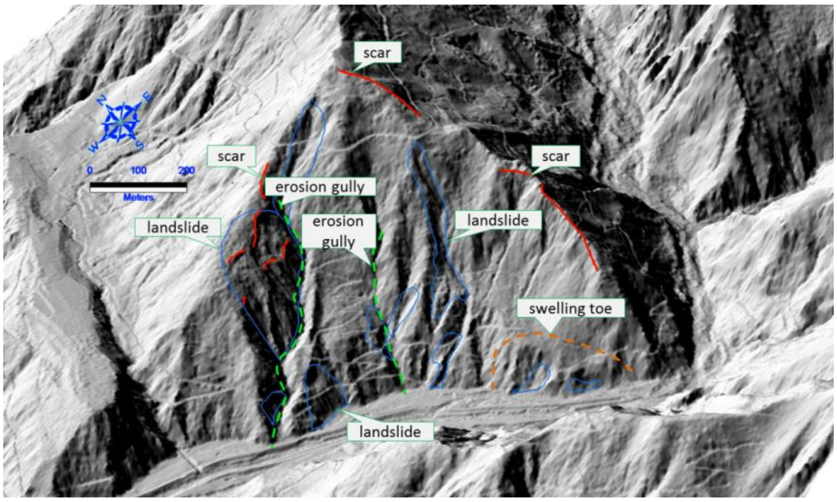

Figure 5. An example of the slope map of the deep-seated landslide in the Maya area in Namasha district

2.3 *Identification of regional deep-seated landslides*

For the identification of deep-seated landslides in the basin area or the regional area, we start with the identification of landslide scars from aerial photos and landslide scars (linear structures) from LiDAR data as plotted in Figure 6(a) for KSDF069 debris flow torrent basin. Figure 6(b) shows the shallow landslides identified by aerial photos in comparison with the deep-seated landslides mapped by LiDAR data. It could be observed that identified results of scars/linear structures by using LiDAR data are not quite consistent with the identified landslide scars from the aerial photo. The mapped deep-seated landslides in Figure 6(b) were validated by field investigation, and good consistency was found. Some of the smaller landslides could not be identified through LiDAR data and techniques, but most of the large landslides are well identified. The prior events of deep-seated landslide and/or deep-seated landslides with geomorphologic evidences could not be identified from aerial photo directly; however, these are identified by the LiDAR information as illustrated in Figure 5. In Figure 6(b), most landslides identified in aerial photos are smaller and often included in the mapped area of deep-seated landslides. The total area of landslides mapped by aerial photo is 63 ha, and approximately 74% is included in the mapped deep-seated landslides. The deep-seated landslide identification method by using LiDAR data is feasible and can be used for the regional area. On the other hand, the aerial photo was not able to provide much information for the deep-seated landslides as shown in Figure 6(b).

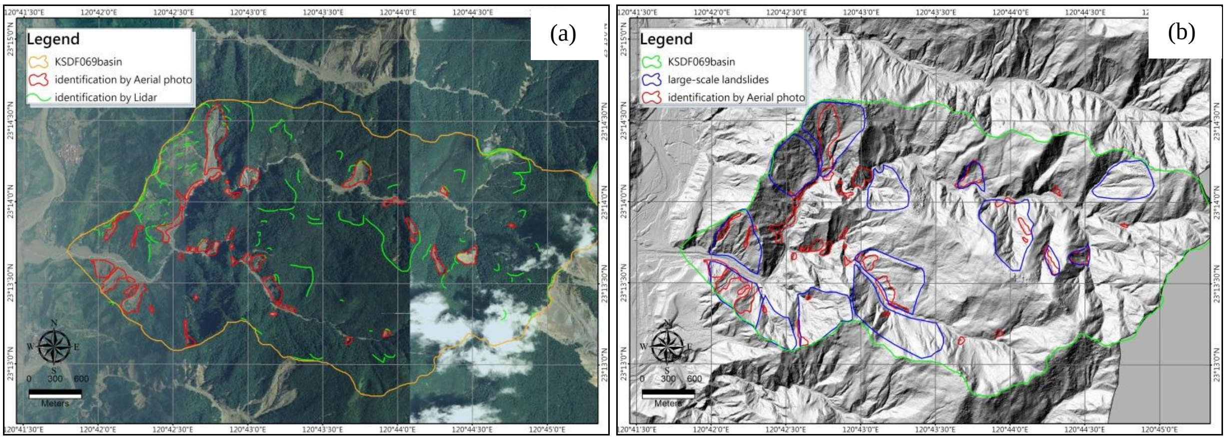

Figure 6. Comparisons of landslides mapped using aerial photos and Lidar information in KSDF069 debris flow torrent basin: (a) aerial photo with mapped landslide and scars by Lidar, (b) Lidar shading map with landslides from aerial photo and mapped deep-seated landslide.

3 Multi-Scale Remote Sensing Techniques for Monitoring Deep-Seated Landslides

3.1 *Monitoring of deep-seated landslide using ground based LiDAR*

In the previous session with the regional identification of deep-seated landslides results, the distribution of the deep-seated landslides as well as the shallow landslides was mapped. For understanding how active the deep-seated landslide is, the ground based LiDAR and close range photogrammetry can be used to monitor the landslide activity.

The ground based LiDAR was used to monitor Lushan deep-seated landslide located at the north side of the convergence of Talowan River and Mahaipu River, Nantou County in Central Taiwan. The slope situated from northwest to southeast and tilted to the west. The digital elevation of Lushan area is as shown in Figure 7. The major geological formation of this area is Lushan formation (CGS, 2002). Lushan formation is the youngest and widely spread formation of the central mountain (Ho, 1975) composed of plate with some folds in the Lushan deep-seated landslide area.

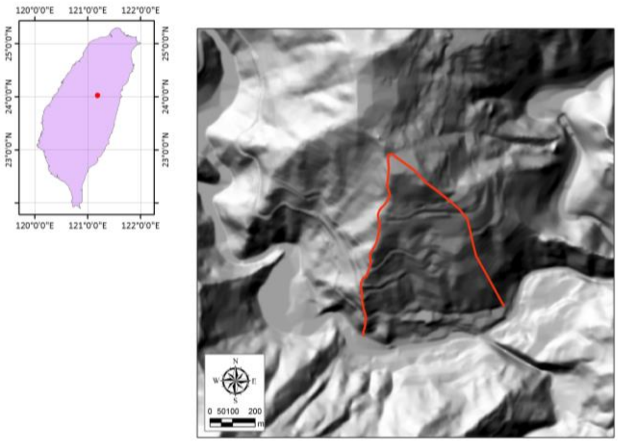

Figure 7. The location and digital elevation model of Lushan landslide area.

The ground based LiDAR for monitoring landslide has been used for its ability of extracting accurate topographic data on flexible time schedule (Proieti et al., 2009). The ground based LiDAR of landslide deformation detection is thus widely used (McClarty, 2009; Jones, 2006). We used two ground based LiDAR instruments to scan the Lushan deep-seated landslide, which are Dibit 3D Laser Geoscanner and Trimble Mensi GS200. The overall landslide deformation detection is based on Dibit 3D Laser Geoscanner. The scanned point clouds are projected to local coordinate system with 4 high accuracy GPS (Global Positioning System) stations set up when performing laser scanning as shown in Figure 8(a). The overall scanning was executed on 2007/11/14, 2008/11/06 and 2009/11/06. The toe area where most human activities situated was scanned with Trimble Mensi GS200 with denser point cloud as shown in Figure 8(b). The toe scanning was executed more often than the above mentioned dates because of the dense distribution of buildings and facilities. The hotel building shown in Figure 8(b) fell into the Talowan River during typhoon Sinlaku in 2008, and from Figure 8(b) we could see that part of the embankment in front of the building was damaged, which could be the main reason to cause scouring and damage to the foundation of the hotel building.

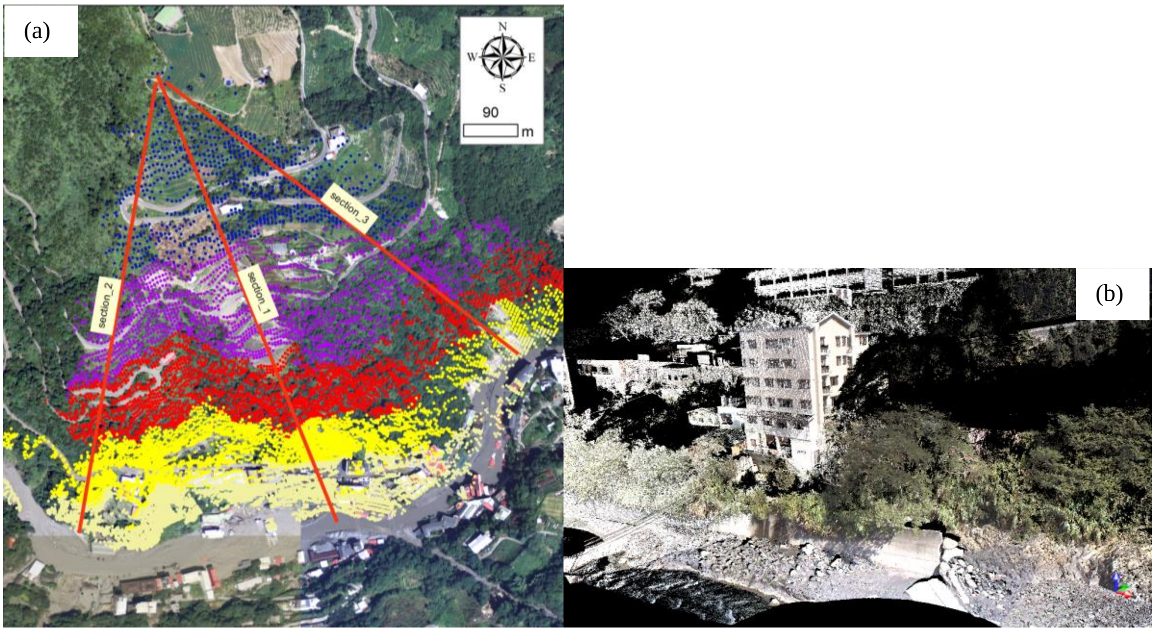

Figure 8. The point clouds of scanned results using (a) Dibit 3D Laser Geoscanner and (b) Trimble Mensi GS200

Variations of the profile section 1 in Figure 8(a) are shown in Figure 9. The DEM base line of the profile in Figure 9 was derived from aerial photos taken in 2007, and LiDAR data were acquired using Dibit 3D Laser Geoscanner on 2007 /11 /14, 2008 /11 /06 and 2009 /11 /06 and geocoded with GPS. The variations of the profile of section 1 show reasonable consistency between LiDAR data and DEM. The variations of LiDAR data from 2007 to 2009 suggested some subsidence near the crown and slight bulging in the lower part of the profile. In Figure 9(b), the variances between different time series pair of LiDAR are shown across the horizontal direction of the profile. The variations of LiDAR data from 2007 to 2008 showed the topographic variations caused by typhoon Sinlaku, which indicated the reactivation or movement of the landslide. The variations of LiDAR data from 2008 to 2009 showed the topographic variations caused by typhoon Morakot, and not much of changes were found. In Figure 9(b) the subsidence near the crown is consistent with that of the profile in Figure 9(a), but the bulging of lower slope is not as significant. The lower part could be affected by human activities.

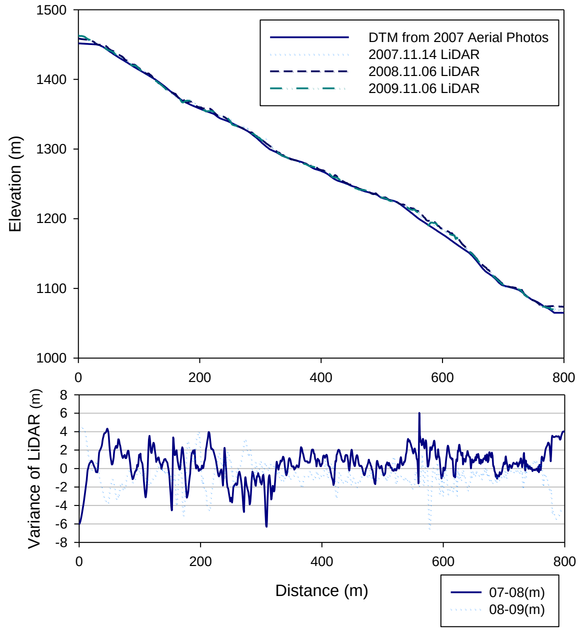

Figure 9. The variations of profile elevation acquired from LiDAR data

To monitor the variations of a small scale landslide located in the main Lushan landslide area, the ground-based LiDAR using Trimble Mensi GS200 was conducted. The aerial photo and selected sections of the small scale landslide is as shown in Figure 10. The landslide located close to the middle toe section of Lushan deep-seated landslide near the road. The red lines in Figure 10 are the analysis lines and were divided into two directions: longitudinal and lateral, which were approximately in north-south and west-east direction. The variations of elevation in longitudinal and lateral directions are as shown in Figure 11(a) and 11(b). In Figure 11(a), the longitudinal sections show elevation decrease/subsidence in landslide scarp area and elevation increase/bulge in deposition area except section lon_3. The deposition area was not significant in Figure 11, which might due to that the LiDAR scanning was performed two months after the event, and the deposition debris caused by landslide was cleaned up shortly after the event. In Figure 11(b), the elevation variations in the lateral direction also displayed decrease in a more or less circular shape except for the section lat_1 where part of upper slope near center still remained on the slope as shown in Figure 10.

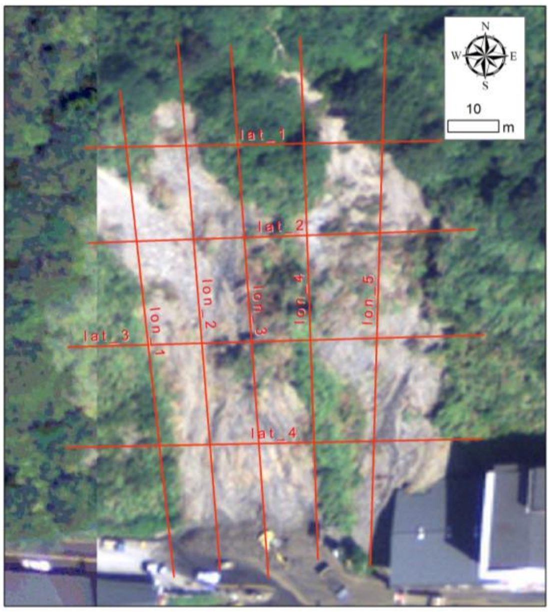

Figure 10. Aerial photo and study sections of the small scale landslide in Lushan area

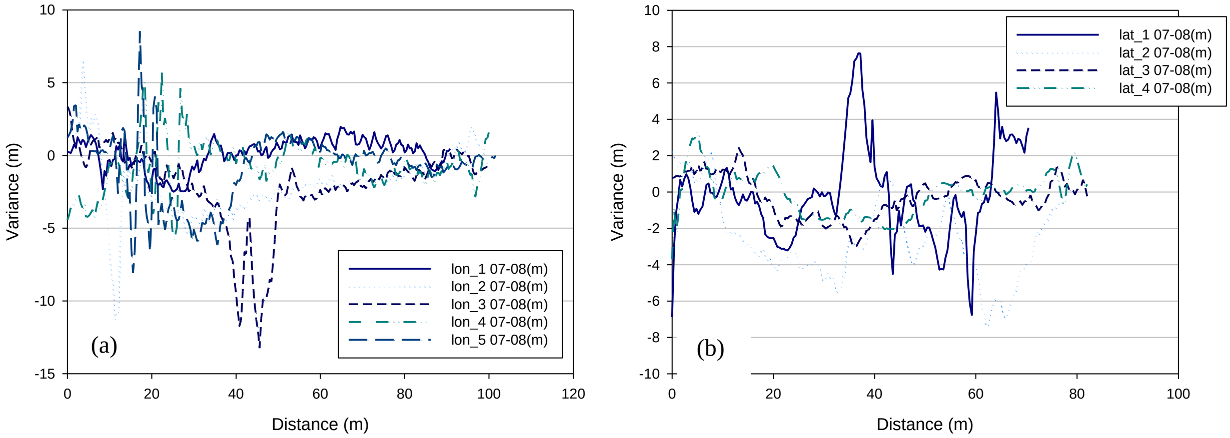

Figure 11. The variations of elevation acquired from LiDAR data (a) in south-north direction (longitudinal direction) (b) in west-east direction (lateral direction)

3.2 *Monitoring of retaining structure for deep-seated landslide deformation using close range photogrammetry*

The movements of structures located inside the deep-seated landslide Lushan were affected by the landslide, and monitoring of the movements would provide further information of the landslide activity. The close range photogrammetry measurements trace the coded targets placed on 3-Dimensional retaining structures. With the projection of 3-D control points, the rotation and displacement of retaining structures were determined. The time-series close range photogrammetry was performed for monitoring the relative displacements and deformations of the retaining structures located inside the landslide area. Figure 12(a) shows the selected sites of the retaining structures which are mainly located at the boundary of identified deep-seated landslide area except site A, and deformations of the retaining structures were monitored. The measurement of deformations is based on the 3-D data of local coordinates determined using close range photogrammetry. The monitored results are as shown in Figure 12(b) as the relative displacements compared to the reference point and base line. The measured time lines are since January, 2008 except site S1, for which measurement started from October, 2008. Two significant rainfall events were recorded during the monitoring period, which were typhoon Sinlaku in September, 2008 and typhoon Morakot in August, 2009. Significant changes in local coordinates and relative displacements were observed after typhoon Sinlaku as shown in Figure 12(b). For most of the sites, a significant increase of relative displacements was found immediately after both events and with the similar trends except at site D. In general the displacements caused by typhoon Sinlaku were more significant than those of typhoon Morakot due to larger rainfall in the Lushan area. A field investigation at site D conducted after typhoon Sinlaku found that site D located near the scar and displayed overall movement similar with the development of scar. This suggested that the development of the scar at site D was severe, which caused rearrangement of retaining structure panels and movements in similar direction, and thus lead to a lower relative displacement as monitored by 3-D positions shown in Figure 12(b).

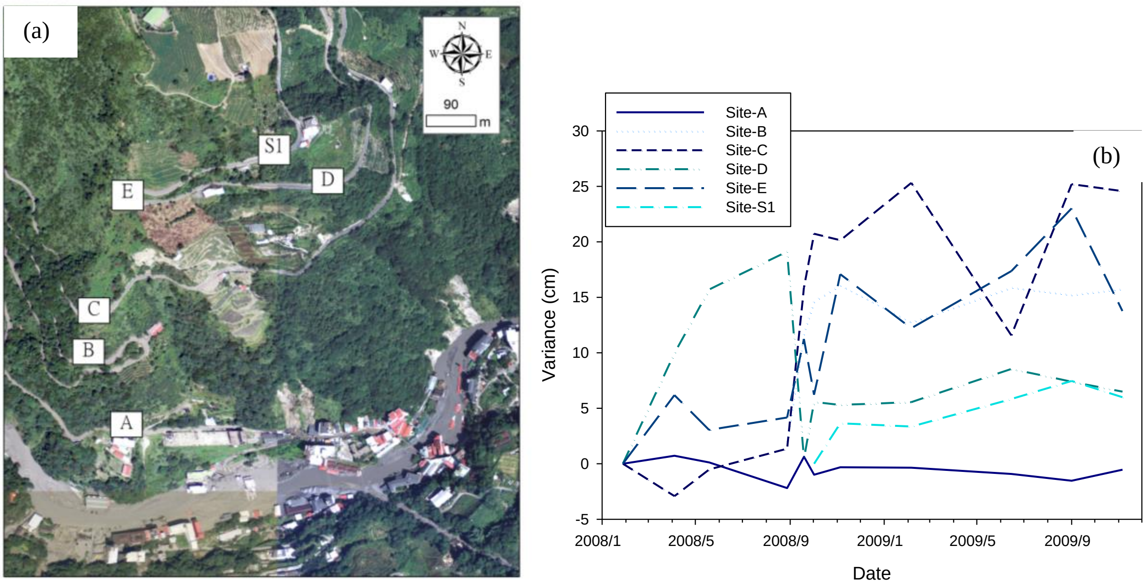

Figure 12. Close range photogrammetry for monitoring the retaining structures located inside the Lushan deep-seated landslide, (a) Positions of monitored retaining structures; (b) Relative displacements of retaining structures

The resulting displacements at retaining structure site D were shown in Figure 13. The moving direction of retaining structure at site D shown in Figure 13(a) was in a consistent direction and increased consistently. The relative displacements of retaining structure site D was shown in Figure 13(b) and the displacement increased significantly up till typhoon Sinlaku. The monitored displacement after typhoon Sinlaku increased slowly and had the same tendency till typhoon Morakot. Typhoon Morakot induced less rainfall in Lushan area than typhoon Sinlaku did, thus the displacement did not increase significantly. In addition, the landslide might be under an overall movement with the retaining structure displaced as a whole, and caused the relative displacement to decrease after typhoon Morakot.
The overall displacements and motion direction of all the sites were consistent with the landslide activity and the projected motion direction of the Lushan deep-seated landslide. Thus the proper setting of close range photogrammetry measurements of the retaining structures located in the landslide proved to be useful for providing information of the landslide activity and displacement, and the measured results could be integrated with LiDAR monitoring data to provide information of the landslide behavior and activity.

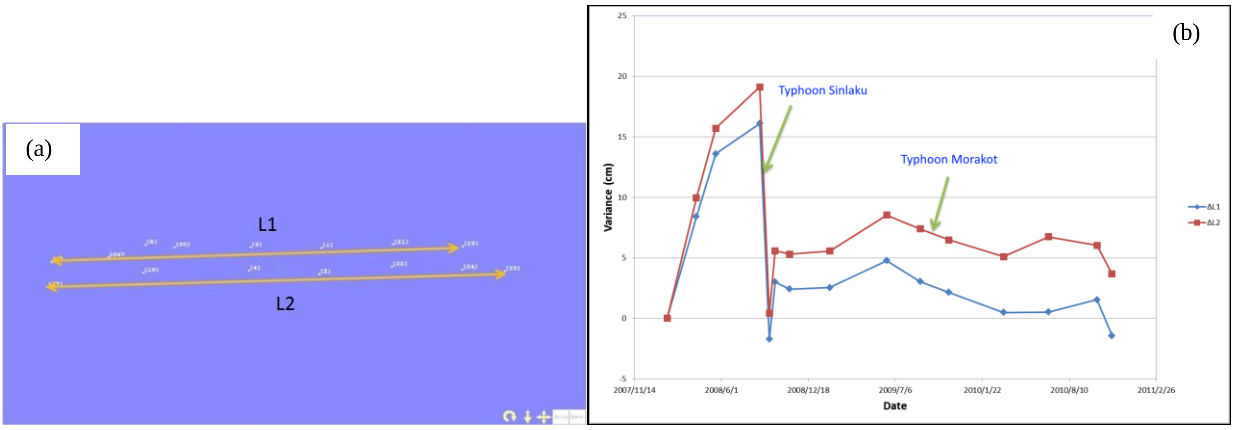

Figure 13. Results of close range photogrammetry at retaining structure site D, (a) motion direction and surveyed lines of retaining structure site D; (b) relative displacements of retaining structure site D.

4 Monitoring Deep-Seated Landslide Using InSAR Technique

For monitoring the long-term deformation tendency of Lushan deep-seated landslide, we used the InSAR technique. The SAR image signal and the DInSAR (Differential InSAR) technique were used to evaluate the displacement between SAR satellite and ground surface, and the deformation could be inferred to monitor the ground surface and natural disaster (Didier et al., 1998). The surface deformation derived by only one DInSAR analysis could have some error (Wang et al., 2007a, 2007b, 2005). However, we could use time series SAR images to conduct the DInSAR analysis, and the information would include terrain variations, changes of ground surface characteristic, movements of ground surface and atmospheric effects. The phase changes of terrain information can be modified by high resolution digital elevation model (DEM) and small base line (Hsieh & Shih, 1999). The error caused by atmospheric effect could be modified by using long time and many images. By reducing the possible error, we could get the ground surface movement and changes of elevation (Lu et al., 2012; Greif and Vlcko, 2012). SAR measures the distance between satellite and ground surface by sending and receiving radar signals. Measurement of ground topography using SAR is as illustrated in Figure 14. Figure 14 represents two locations of antenna sensing the surface and the antennas are separated by a baseline B. If the viewing geometry is controllable or known with sufficient accuracy, then the topography h can be derived from the phase measurement of the two sensing radar waves. The topography h can be obtained by geometry of satellite and observation points (Wang et al., 2014).

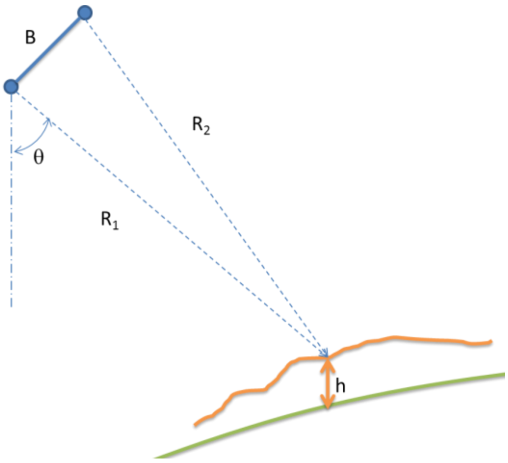

Figure 14. Illustration of phase generated from two set of SAR data.

For monitoring the Lushan deep-seated landslide, we used SAR images of ALOS PALSAR satellite to conduct PS-InSAR (Persistent Scatterer Interferometric Synthetic Aperture Radar) analysis. Using one SAR image as the main image and others are sub-images; the elevation changes were analyzed in observed time series between main and sub SAR images, and the results were as shown in Figure 15(a). From the figure we could find that the elevation increased in the toe area of Lushan deep-seated landslide, and the subsidence was found in the upper slope area. The second method is the SBAS-InSAR (Small BAseline Subset Interferometric Synthetic Aperture Radar). We used three SAR images and checked one by one to analyze which could eliminate the error. Figure 15(b) is the analysis results of SBAS-InSAR method. The same tendency of ground variations was found as the results of PS-InSAR analysis with upheave of the toe of the Lushan deep-seated landslide and subsidence in the upper slope area. In addition, the total station was used to monitor the Lushan deep-seated landslide, and the results of the total station were consistent with both the PS-InSAR and SBAS-InSAR analysis. The InSAR technique is good for long term monitoring of the activities of deep-seated landslide, and can be applied for both local scale and regional scale.

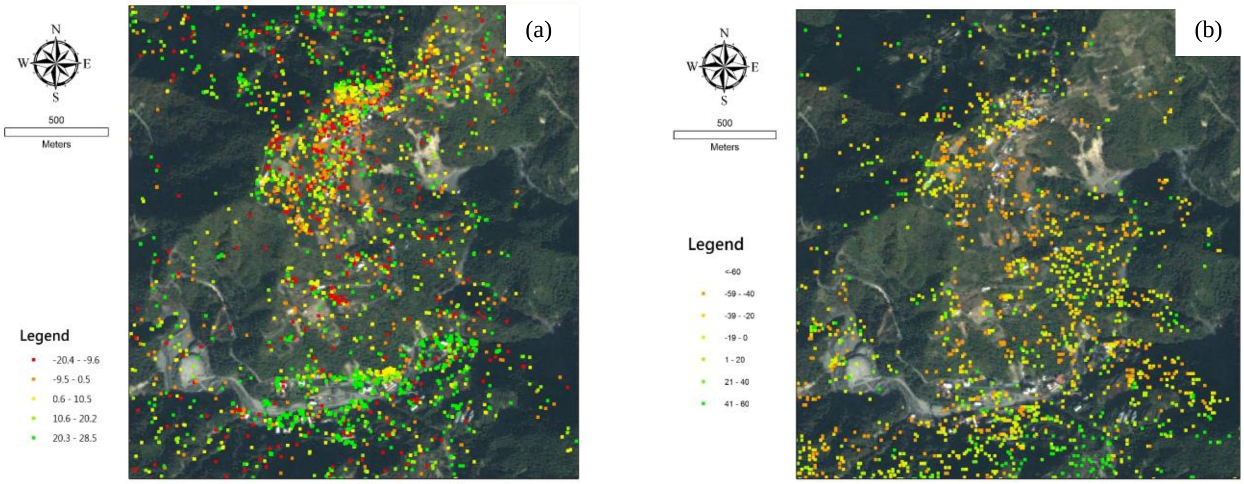

Figure 15. Monitoring results of InSAR analysis of the Lushan deep-seated landslide using: (a) PS-InSAR technique, and (b) SBAS-InSAR technique

5 Conclusions

Due to the rapid developments and large area sensing ability, the multi-scale remote sensing techniques can be integrated to provide coverage of information on regional as well as local topography variations, and the regional evolvement of the geomorphology of the deep-seated landslides thus can be identified and monitored. A methodology of application of the LiDAR (Light Detection and Ranging) data for identification of the regional deep-seated landslides in the Namasha area in Kaohsiung City, Taiwan is introduced in this study. The aerial photos and field investigation provides additional information and validation of the results. Results of the identified deep-seated landslides were conducted based on the LiDAR high-resolution topographic features proved to be feasible and reliable. The techniques of using ground-based LiDAR measurements were applied for monitoring of the Lushan deep-seated landslide in central Taiwan from 2007 to 2009, and the deformation of the overall slope was identified. The monitoring period included typhoon Sinlaku event in

2008 and typhoon Morakot in 2009, and the activity of the landslide was well observed. The time-series of close range photogrammetry measurements were conducted by tracing coded targets placed on 3-D retaining structures located inside the Lushan Deep-seated landslides. The ground based LiDAR provides overall surface landslide information and the close range photogrammetry provides local deformation. Consistent results were obtained and by combining ground based LiDAR and close range photogrammetry, the landslide behavior can be well monitored. The SAR images were used by application of the PS-InSAR and SBAS-InSAR analyses to monitor the terrain variations of the Lushan deep-seated landslide, and both InSAR analysis results produced same tendency of ground movement in comparison with the total station monitoring results. Such technique proved to be feasible for long term monitoring of activity and evolvement of deep-seated landslide on local as well as regional scale. The deep-seated landslide often causes severe damages to lives and properties due to the movement of massive debris volume. Detection and monitoring of the deep-seated landslides are important issues for protection of affected residents and drafting of mitigation measures. Applications of the remote sensing techniques could provide detail topographic variations within short time and cover a large area. The methodologies are available and proved to be feasible and helpful for both identification and monitoring of the deep-seated landslide on local and regional scales.

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