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EFFECTS OF COMPRESSIBILITY AND PERMEABILITY OF PEATY SOILS ON THE DESIGN AND CONSTRUCTION OF INFRASTRUCTURE

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SUMMARY

In practice, it is near impossible to obtain undisturbed samples of fibrous peat for laboratory testing in order to derive engineering design parameters, as its water and organic contents can be high as 1,200% and 60%, respectively. This forms the challenge that civil and geotechnical engineers have to face in the design of infrastructure on peaty soils. 2 case studies on the design and construction challenges in Sarawak peaty soils are presented. Through these case studies, it is hoped that the effects of construction on challenging peaty soils can be duly recognised so that care and due diligence are taken during both design and construction stages of any infrastructure project so as to minimise potential failures.

Keywords*: peaty soils, prefabricated vertical drain, hydraulic sand-fill, shaft construction, anisotropy*

CASE STUDY 1: DEEP PEAT REPLACEMENT & PVD ON THICK, SOFT CLAY

INTRODUCTION TO GEOLOGY OF SITE

A 13.5km single-carriageway road was to be constructed in Sibu. The geology of Sibu is characterized by the Quaternary sediments, which consist mainly of clay, silt, sand and peat (Lam, 1998). Peat is a type of fibrous material which contains high organic content, usually in excess of 35%. Peat soils are mostly found on the coastal lowland area and poorly drained valleys. Water content of peat may be as high as 2000% (expressed as percentage of dry weight) (Chen et al., 1989) with high compressibility once drained, thus presenting a challenging engineering problem in Sarawak. If water is drained from the peat swamp, some 75% to 90% reduction of its volume may occur. This will result in excessive settlement when a road embankment is constructed on it.

SITE INVESTIGATION WORKS

Figure 1 shows the anticipated sub-surface soil profiles. It is observed that peat up to 10m deep with underlying soft soil of maximum thickness of 30m can be found at the later road chainages.

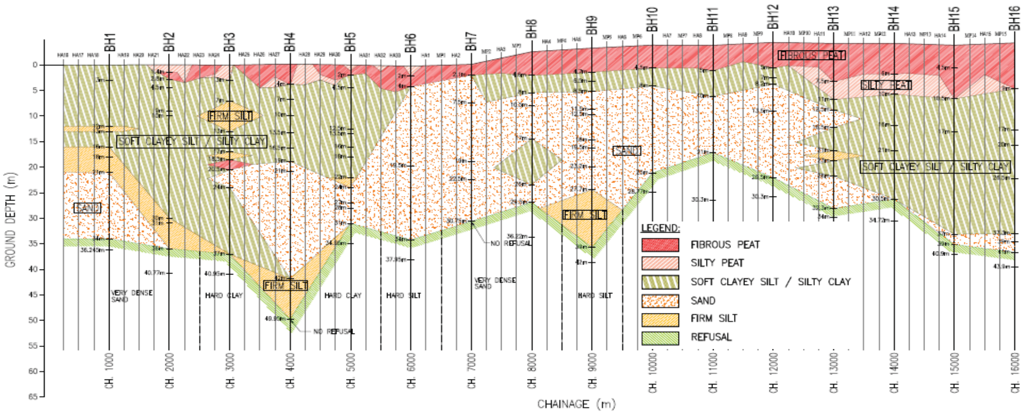
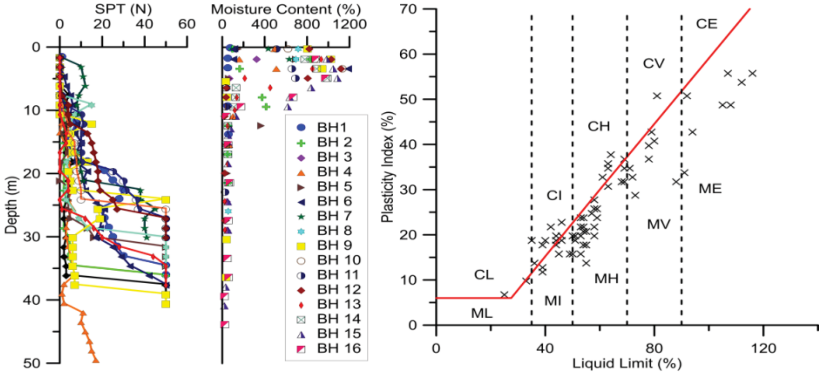


Figure 1: Interpreted sub-surface soil profiles at project site.

SOIL CHARACTERISATION

Figure 2(a) shows that generally, most boreholes show the presence of soft soil layers with low SPT N blow counts for the first 8m depth, except for BHs 6 and 7 where sand is encountered at a depth of 4m and 2m, respectively. BHs 2, 3, 14 and 16 show soft clay layers of up to 30m depth. Figure 2(b) generally confirms that fibrous peat with natural moisture content in excess of 300% can be found as top layers in most. The A-line plot as shown in Figure 2(c) shows that the soft soils (excluding peat samples) are generally more silty with a wide range of consistency.



(a) (b) (c)

Figure 2: (a) Distribution of SPT N values, (b) moisture content and (c) plasticity chart for soft soil samples tested.

DESIGN CRITERIA AND ESTIMATED SETTLEMENTS

The design criteria states that total settlement of the road embankment should be less than 300mm in 3 years while differential settlement of less than 200mm is desired over 25m in 3 years. Such criteria could not be readily satisfied due to the estimated large post-construction consolidation settlement of the deep clays. As such, some form of ground improvement techniques are required to treat the peat and soft clays.

PROPOSED GROUND IMPROVEMENT SCHEME

It was proposed that underlying peat be replaced with sand-fill as the maximum depth of 10m was not widespread. The main advantage of peat replacement is to reduce the detrimental differential post-construction settlement and to allow the installation of pre-fabricated vertical drains (PVD) to treat the underlying thick soft soil layers whose untreated post-construction consolidation settlement is estimated to be in excess of 1m at certain locations.

CONSTRUCTION OF ROAD EMBANKMENT USING HYDRAULIC SAND-FILLING METHOD

Peat excavation & hydraulic sand-filling works

Firstly, peat excavation was performed using long-arm excavators as shown in Figure 3(a). The excavation started from the centre of the proposed road alignment moving backwards towards the edge of the embankment, in the transverse direction. The excavated peat was subsequently used for the construction of side bunds and the excess materials were spread over the remaining of the road reserve area. A 610-mm diameter mild steel pipeline transporting hydraulic sand-fill was laid from Batang Igan to the project site as shown in Figure 3(b).

Figure 3. (a) (left) Fibrous peat excavation using long-arm excavators and (b) (right) Hydraulic sand-filling works in progress.

Construction cases

For areas to be installed with PVD, two stages of sand-filling works were proposed. In the first stage, the excavated pit was filled up to the existing ground level and PVD installed. The second stage of works involved filling the ground to the required Finished Road Level (FRL) plus a minimum 0.5m high surcharge. The surcharge was subsequently removed and road embankment trimmed to the required formation level after 6 months of treatment. For areas where no surcharge and PVDs were required, the sand-filling works was carried out to the required formation level in one single stage.

Slope stability analyses

Slope stability analyses were carried out on embankments seated on the hydraulic sand-fill. The estimated factors of safety (FOS) provided by the design are all within allowable limits of 1.3 and 1.2 for short-term undrained and long-term drained analyses, respectively.

Ground improvement and field monitoring work

For field monitoring, Asoaka method was implemented to estimate the performance of PVD in treating the soft soils. Table 1 shows the comparison of calculated settlements with the representative measured settlements for various settlement plates.

Table 1: Selected results used for comparison of calculated and measured settlements.

Borehole	Settlement details			
	Calc 90% settlement	Settlement Plate	Measured settlement (mm)	Asoaka 90% settlement (mm)
BH2 (CH2000)	1425.7	S6@ch2150 S7@ch2360	954@623days 1249@665days	899.0 1165.0
BH3 (CH3000)	837.3	S8@ch2800 S9@ch3140	545@561days 1073@576days	532.0 990.0

Completion of works

Figure 4 shows the tar-sealed road pavement successfully completed after 1.5 years.

Figure 4: (a) (left) Just completed road and (b) (right) successful turfing of road shoulders.

CASE STUDY 2: EFFECT ON DEEP SHAFT EXCAVATION IN ORGANIC SOILS

INTRODUCTION

The Kuching Wastewater Management System (KWMS) Phase 1 was implemented to channel household grey and black water via a full-gravity underground network of sewer pipelines to a centralised wastewater treatment plant. Therefore, deep primary shafts with depths of between 10m and 25m were constructed to enable the launch and reception of micro-tunnelling boring machines (MTBM). The construction of shafts in the Tuang Formation posed great challenges especially in sandy and organic soils as appreciable ground water drawdown could be resulted, followed by the detrimental effects of ground settlements.

GEOLOGY OF AREA

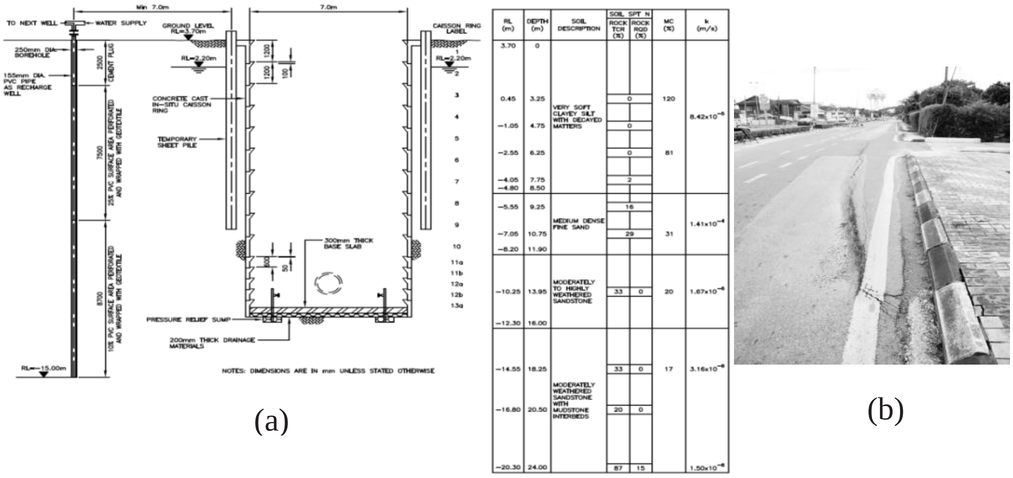
The geology of the area is characterised by Quaternary deltaic deposits consisting layers of peat, clay, silt and sand overlying the older Tuang Formation of Kuching. At low-lying areas such as where the current project site was located, sediments were deposited due to receding sea level in the ancient times. The sediments remained trapped at foothills and plant matters started to accumulate to form horizontal beds of clays or silts with organic matters. Over long periods of time, the surface organic deposits rose and finally remained above the flood level. The underlying Tuang Formation rock has been described as ‘erratic’ by Ong & Choo (2011, 2012) in view of its highly sheared and weathered rock mass.

DETAILS OF DEEP SHAFT

Figure 5(a) shows the details of the proposed 7 m diameter, 16 m deep shaft. Advancing cast in-situ circular concrete caisson rings (each measuring 1.3 m in height, with 100 mm overlap) were then installed to provide structural support to the surrounding soils so that excavation inside the shaft could be carried out. The steel reinforcement used was nominal since the hoop stresses were designed to be taken entirely by the concrete.

EFFECT OF LEAKAGE AT UNDERLYING FRACTURED ROCK

At one of the many challenging excavation sites, when the shaft that was being excavated reached the moderately to highly weathered sandstone at depth of about 13.3 m, major leakages occurred and hence, the deep excavation works had to be suspended. Consequently and inevitably, ground water drawdown of about 5 m occurred, triggering settlement of 125 mm to nearby infrastructure as shown in Figure 5(b), mainly due to the relatively high permeability of the 8.5 m upper soft, peaty soils with SPT N = 0.



(a)

(b)

Figure 5: (a) Typical deep shaft construction with recharge well and (b) settlement caused by water drawdown.

GROUND WATER RESPONSES

The quantity and rate of the ground water that seeped into the leaking shaft could be estimated on site by simply calculating upwards from the base of the shaft the number of caisson rings flooded in the shaft after it was successfully pumped dry.

Table 2: Calculated seepage rates based on site measurements.

Elapsed days	No. of hours without pumping (hr)	No. of caisson rings filled with water		Total volume of water (m^3)	Seepage rate (m^3/hr)
		Full ring	Half ring		
Day 404	12	4	0	184.8	15.4
Day 405	11.5	3	0	138.6	12.0
Day 406	11	2.5	1	138.6	12.6
Day 407	9.5	2	2	138.6	14.6
Day 408	9	2.5	3	184.8	20.5
Day 409	20.5	4	3	254.0	12.4
Day 410	14.5	4	3	254.0	17.5
Day 413	15.5	1.5	3	138.6	8.9
Day 414	16.5	1.5	3	138.6	8.4
Average seepage rate =					13.6

The amount of water that rose in the shaft overnight (no pumping activity) would then give a reliable estimate of seepage rate into the shaft. Table 2 shows the seepage rates measured over 9 occasions. The average measured seepage was 13.6 m^3/hr, which was comparable to the estimated ground water seepage rate of 17.4 m^3/hr based on the finite element seepage analyses conducted during the design stage (see Figure 6).

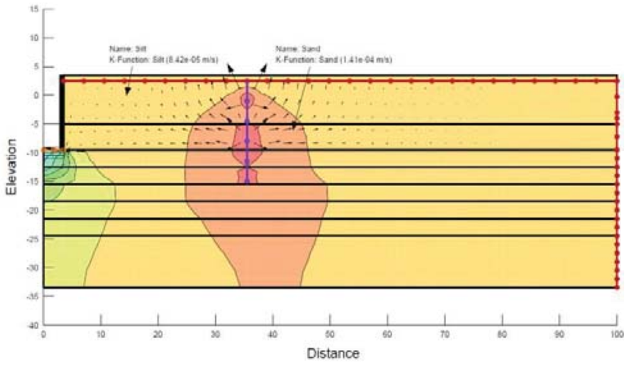


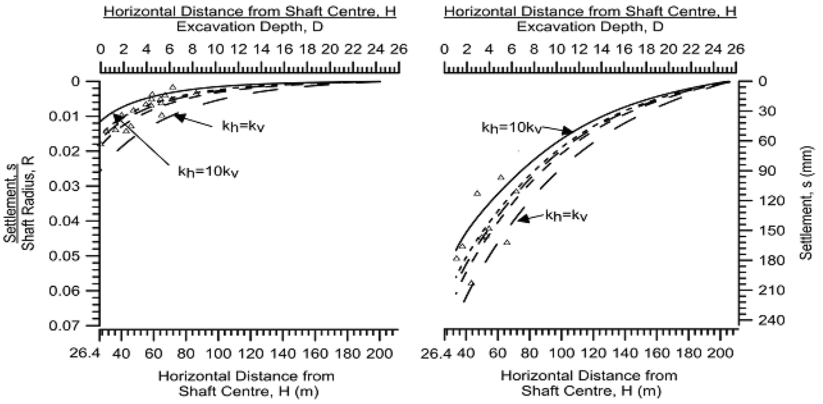
Figure 6: Typical transient seepage analysis showing total pressure head contours

GROUND TREATMENT WORKS

155mm diameter recharging wells were installed to try to recharge the depressed ground water table at site. Field monitoring showed that ground settlements of less than 7.5 mm were observed when the excavation works resumed when the recharging was carried out simultaneously. It took a further 17 days to complete the remaining excavation works, which consisted merely a further excavation of 1.8 m and casting of the base slab to complete the works.

GROUND RESPONSES

Finite element analysis was modelled using 2D transient analysis. Figure 7 shows the predicted and measured ground surface settlement profiles at various stages of the excavation. It is found that the ground settlement magnitudes and profiles are sensitive towards the ratio of k_h:k_v of the top peaty soil layer, where k_h is the horizontal soil permeability and k_v the horizontal. In general, the predicted and measured values show good agreement. Based on Figure 7, the predicted ground surface settlement profile using k_h:k_v ratios of 1, 3 , 5 and 10 consistently fall within the range of measured settlement values in both magnitudes and profiles. Similar range of anisotropy magnitudes in organic soil permeability had also been reported by Mesri et al. (1997), Younger et al. (1997) and Sobhan et al. (2007). This could be due to the greater effect of horizontal permeability than vertical within the soft silt layer with organic materials. Therefore, this implies that for any deep excavation works carried out in such soil condition, water seepage can be considerable in the horizontal direction.



(a) (b)

Figure 7: Predicted and measured settlement profiles when excavation depths approach (a) 9.7 m and (b) 13.3 m.

CONCLUSION

Two cases studies on the effects of compressibility and permeability of peaty soils on the design and construction of infrastructure have been discussed. The geotechnical challenges highlighted in this paper are not exhaustive. As Sarawak is located on the third largest island in the world, Borneo, with its generous coastline bordering the South China Sea as well as having the longest river in Malaysia, its geology is comparatively much younger than its Peninsular counterpart due to the presence of trapped peaty soils at foothills and river basins as well as thick, soft sediments found along its long coastlines, wide floodplains and thick deltas. In the field of geotechnical engineering, developing fundamental understanding of soil properties and behaviour based on field observational method via instrumentation and monitoring program is also part of the learning process, alongside good engineering designs and practical construction methodologies.

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