Challenges in Construction Over Soft Soil – Case Studies in Malaysia

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Abstract. Construction on soft ground area is a great challenge in the field of geotechnical engineering. Many engineering problems in the form of slope instability, bearing capacity failure or excessive settlement could occur either during or after the construction phase due to low shear strength and high compressibility of this soil. As main technical agencies responsible for implementation of development projects for Government of Malaysia, Public Works Department has vast experience in dealing with this problematic soil over the years. This paper discussed and elaborate on the engineering problems encountered in construction projects that have been carried out by PWD, namely Core Facilities Building of Polytechnic Kota Kinabalu in Sabah and Hospital Tengku Ampuan Rahimah Integration Quarters in Klang, Selangor. Instability of the ground during construction works had caused delay and cost overrun in completion of the project in Selangor, whereas occurrence of continuous post construction settlement had affected the integrity and serviceability of the building in Sabah. The causes of failure and proposed rehabilitation work for both projects also will be discussed in brief.

Keywords: Slope instability, bearing capacity failure, excessive settlement.

1. Introduction
Soft soil typically characterized as a soil with low shear strength, highly compressible and low permeability [1,2]. The shear strength of the soil is reported to be less than 40 kPa and it can be physically moulded by light finger pressure. Generally, construction problems in this deposit are insufficient bearing capacity, excessive post construction settlement and instability on excavation and embankment forming. Theoretically, settlement problem can be defined as a deformation in the soil due to the applied stresses. As a result of settlement, the geometry of load carrying system will be changed, and if the ground water level is high, a part of the fill material will become buoyancy which will influence the total surcharge loading and the stability of the soil [3,4].

Generally, soft soil in Malaysia is considered as quaternary sediments consist of alluvial deposits and organic or peat soils [5]. According to Quarternary Geological Map of Malaysia, soft ground usually found in the coastal plains of the country covers large area of west coast and east coast of Peninsular and East Malaysia [6]. Due to significant proportion of soft ground to the country total land area and major economic activities and social developments are concentrating along the coastal area, construction projects on these problematic deposits are unavoidable. In the past, many failures related to high settlement and deformation to structure such as embankment which resulted from the high compressibility and low shear strength of soft soil have been reported either locally or internationally.

Due to the rapid development experienced by the nation in the last few decades, Public Works Department of Malaysia (PWD) had involved in many highway and building projects on soft soil. As a main technical agency for Government of Malaysia, involvement of PWD in any development project can be during construction or forensic investigation. Since 2010, statistics of geotechnical forensic investigation on problematic projects carried out by JKR is summarized in Table 1. There are 182 cases out of 252 forensic cases (approximately 72%) are related to the issue of ground settlement, the remaining 28% are caused by other factors such as vibration, erosion, foundation failures and so forth.

Therefore, it is clearly shown that the issue of ground settlement is the main engineering problem encountered in construction over soft ground area. A common settlement problem occurred in most of the project is:

- Excessive Settlement – Elastic or immediate settlement, Primary Consolidation Settlement, Secondary Settlement and;
- Differential Settlement – Occur where sudden change in the thickness of fill, e.g. at bridge abutment, or where the compaction of the fill is particularly difficult.

Table 1. Geotechnical forensic cases carried out by PWD

			Year				
Contributing Factors	2010	2011	2012	2013	2014	2015	Total
Vibration				2	1	3	6
Soil erosion				3	2	4	9
Foundation failures		2	1	6	3		12
Retaining structure failures			1	4	2		7
Slope stability			6	3	12	4	25
Ground settlement	1	8	10	63	70	30	182
Water infiltration				4	4	1	9
Collapsible soil			1		1		2
Total	1	10	19	85	95	42	252

2. Case Study 1: Hospital Tengku Ampuan Rahimah Integration Quarters in Klang, Selangor

2.1 Project Background

The construction of integration quarters for Hospital Tengku Ampuan Rahimah in Klang, Selangor was commenced in 2007. This project was implemented through design and builds concept, where the appointed contractor was responsible for the design and construction of the project. It is consist of the construction of three blocks of 13 and 14 storey building within the existing hospital compound. The site is underlain by quaternary alluvial deposit which consists of very soft to soft silty clay with the thickness ranges from 15 to 20m. This layer is followed by a layer of medium stiff to stiff silty clay/ sandy clay, whereas hard stratum is subsequently found at the depth of 18 to 28m.

Based on the site investigation report, 500mm diameter concrete spun pile with design capacity of 850kN has been proposed as foundation system for the buildings. Due to the constraint of the site, jacked – in method was adopted for the installation of the piles in order to minimize the noise and vibration which could affect the existing nearby structures. However, there was no ground treatment work proposed by the design consultant to improve the engineering behavior of soft soil at the site.

2.2 Construction Problems

In this project, engineering problems was encountered during the construction stage. Installation of piles was commenced over soft ground right after site clearing without preparation of proper working platform. Upon completion of piling work, most of the installed piles were found to be deviated from original position after some times. Piles were also found to be severely tilted and damaged at the location of the proposed lift pit and layout of the affected piles is shown in Figure 1.

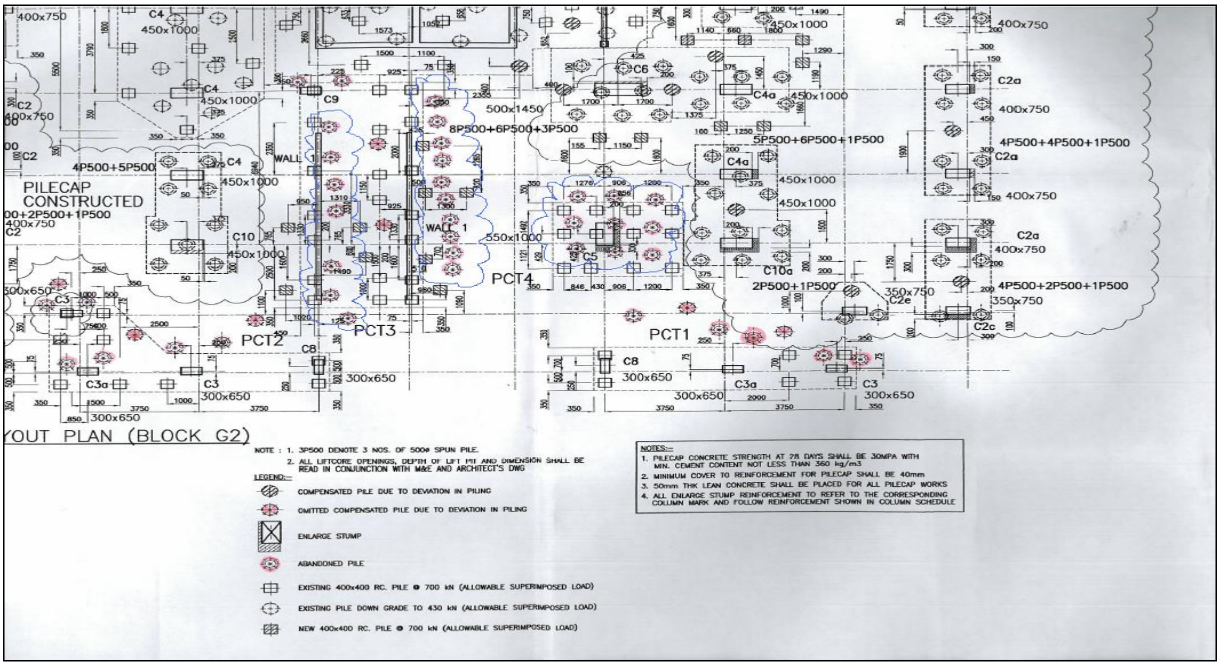

Figure 1. Layout plan of affected piles.

2.3 Causes of Problems

Based on the investigation carried out PWD, there are many possible causes contributed to the deviation of piles. The main cause was due to the displacement of soft ground as results of the moving jacked-in machine and excavation work for lift pits. In order to comply with standard requirement of PWD for pile installation using Jacked – in method, the total weight of the machine used must be approximately three times of the pile design capacity which is equivalent to about 260 metric ton. Such a heavy load that imposed on the surface of the ground had triggered vertical and horizontal displacement of the soil. Due to the existence of thick soft compressible layer at the site, the installed piles were expected to be pushed away by the displaced soil as it was lowly restrained in the horizontal direction.

The construction of lift pit involved an excavation work with approximate depth of 2.5m below ground level. For the purpose of excavation, a 6.0m sheet pile wall had been proposed as a temporary protection. During excavation work, the installed temporary sheet pile wall was found to be tilted as shown in Figure 2. An investigation carried out after the incidents revealed that the failure of temporary protection works was attributed to the shortfall in the design and improper construction practice adopted by the contractor in this particular project. Detailed analysis indicated that at least 9.0m depth of sheet pile wall is required to retain the 2.5m deep of excavation work, instead of 6.0m that was originally proposed.

Figure 2. Sheet piles and piles adjacent to the excavation pit tilted.

Probably due to the cost and time constraints, temporary sheet pile wall was installed at only one side of the excavation area. The excavated earth which was supposed to be transported out of the site was also temporary placed on the crest of the pit as shown in Figure 3. This improper construction practices adopted by the contractor had contributed to the failure of sheet pile wall as the placement of that unsuitable material had induced surcharge load to the ground that caused lateral movement of the unsupported side of the excavated pit.

Figure 3. A large quantity of excavated earth dumped at the crest of excavation pit.

The problem of pile deviation was also expected to be caused by negligent in carry out the setting out survey for the pile position. Movement of the ground as a result of the moving jacked – in machine may shift the pre – pegged pile position. Therefore, without confirmatory check on the pile position prior to installation had caused the piles to be installed at deviated position.

Subsequently, these problems had caused a great delay in completion of the project. It is also incurred huge amount of additional cost to the project because a lot of replacement piles were needed for the tilted or deviated piles.

3 Case Study 2: Core Facilities Building of Polytechnic Kota Kinabalu (PKK), Sabah

3.1 Project Background

Figure 4. Block A and B Polytechnic Kota Kinabalu

Polytechnic Kota Kinabalu is located at Kota Kinabalu Industrial Park (KKIP), Jalan Politeknik, Kota Kinabalu, Sabah. The construction of this project was commenced in 1999 and finally completed in 2003. Topographically, the project site is located on the low lying area which required extensive earthwork in order to achieve the proposed platform. Once completed, the first academic session at the new campus starts its operation on the 1 September 2003. Structural cracks were later detected at one of the main building in the campus, i.e. Core Facilities Building and the Teaching Restaurant. At the point of investigation, the drainage system such as perimeter drains had also experienced serious settlement.

In November 2004, Kumpulan IKRAM (Sabah) Sdn. Bhd. was appointed to conduct a structural assessment and geotechnical audit on the problematic building. The purpose and scope of work include the following:

(a) Physical investigation works include visits, visual inspection and necessary material and structural testing
(b) Monitoring works including defect and crack mapping, monitoring of settlement and movement of the Teaching Restaurant
(c) Proof checking of the structure of the building
(d) Carry out soil investigation works
(e) Carry out geotechnical analysis and ascertained the integrity of the pile foundation
(f) Recommendation of remedial works

The works that was carried out between September to November 2004 are as follows:-

(a) Condition survey and crack mapping
(b) Desk study of construction drawings (non-availability of as-built drawing)
(c) Material testing
(d) Preliminary structural analysis
(e) Field work for site investigation (2 nos. borehole, 4 nos. Macintosh Probe)

3.2 Geotechnical Investigation

The discussion in this section is based on soil investigation data, piling records and analyses conducted by Kumpulan Ikram Sdn. Bhd.

3.2.1 Subsoil Profile

From the boreholes result indicated the presence of fill material at the site with a thickness of about 7.2m. This layer is underlain by 10.6m of very soft to firm clayey sandy silt with some organic matters. A hard weathered siltstone and very poor weak sandstone was encountered at the depth of about 18.0m to 20.0m onward measured from the ground level (Figure 5).

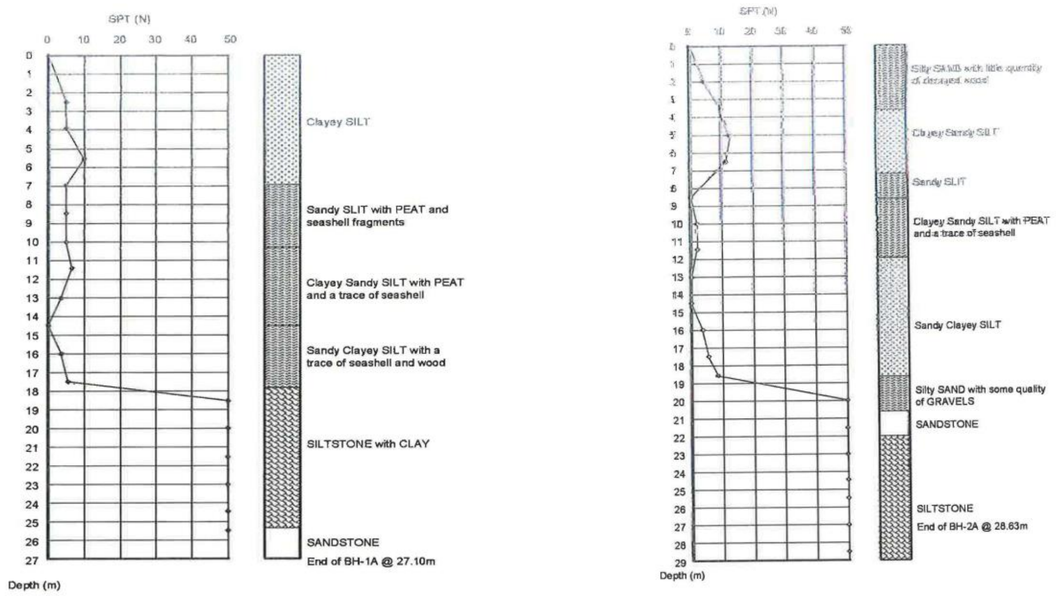

Figure 5. Cross – section of boreholes profile

3.2.2 Settlement Analysis and Monitoring

Back analysis was carried out by the investigation team in order to predict the magnitude and rate of consolidation process at the site. Compressibility parameters obtained from soil investigation work have been in the analysis with the assumption that 7.2m of fill acts as a surcharge load on 10.6m and 11.6m of soft compressible layer, respectively. The results of the analysis are summarized in Table 2 below.

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Table 2. Magnitude and rate of anticipated settlement due to the 7.2m thick of fill material.

BH Location	Thickness of Compressible Layer (m)	Time Required For 90% Consolidation (year)	Predicted Post Settlement after 5 years (mm)
1A	10.6	9.06	243
2A	11.6	13.7	384

Based on the ground settlement monitoring records carried out from September – December 2005, a total ground settlement of about 130mm has been recorded, which equivalent to be about 103mm/ year. Therefore, it was concluded that the ground settlement within the building compound is still active at time of investigation. Depending on the actual thickness of soft compressible layer and height of fill at the site, a targeted 90% degree of consolidation expected to be achieved within 9 – 13 years after completion of the earthwork.

A separate settlement monitoring on columns also recorded a maximum reading of about 52mm settlement within a period of 15 months. The result of column settlement monitoring records had indicated that columns of Core Facilities Building had settled at different rates. Therefore, the major cause of the cracks is expected to be trigger by differential settlement that occurred on the foundation of the building.

3.2.3 Piling Records

Further inspection on the piling records also been conducted by the investigation team in order to ascertain the actual cause of failure. From the summary of the provided piling records, 250mm x 250mm reinforced concrete square piles have used as a foundation for the building. Average pile penetration depth for Block A and B of the Core Facilities Building is approximately 27.0m and 24.0m, respectively. Installation of the piles was carried out using hydraulic hammer with final set criteria was based on the blow count for the last 300mm of penetration. It was recorded that the installation of piles were terminated with blow count for the last 300mm is in the range of 57 - 84 to more than 100 blows. A simple calculation by dividing penetration of 300mm with the recorded total last blow counts indicated that piles may not properly set during installation. Evidently, some piles were proven to be settled trough settlement monitoring on column even though the pile driving records revealed that the piles had achieved set of 12mm/ 10 blows.

3.2.4 Pile Load Test

The proposed working load for 250mm x 250mm reinforced concrete pile used in this project is 600 kN/ pile. A static load test was conducted on the longest pile with penetration depth of about 27.0m in order to verify the design. However, no load test has been conducted on the shorter piles with average penetration depth of about 24.0m, which is mostly found at Block B of that particular building.

Based on the available data, pile capacity analysis was carried out by the investigation team. Taking into consideration of the negative skin friction, the geotechnical capacity for the proposed pile is found to be much lesser compared to the original design. The result of pile capacity analysis is summarized in the Table 3 below.

Table 3. Pile Allowable Bearing Capacity

Allowable Pile Bearing Capacity (kN)	Negative Skin Friction (kN)	Nett Allowable Bearing Capacity (kN)
629	217	412

The finding is in line with the design review carried out on the original design which found that the negative skin friction was not considered in the design. Theoretically, the effect of negative skin friction will induced an additional force on the piles thus reducing its effective capacity. Therefore, the main cause of the problems possibility due to the overloaded piles when subjected to the negative skin friction develops over time as a result of settling ground. This phenomenon has led the occurrence of differential settlement of the pile foundations that causing cracks to the building.

Conclusion

Soil contamination especially by hazardous heavy metals is pointed as a main contributor to environmental problems throughout the world. To ensure that these problems can be reduced and finally be solved, a systematic prevention and remediation methods should be taken. It is evident from this review that S/S remediation methods using various types of binders attempted of addressing these problems. S/S method using OPC are the most frequently studied for the remediation of heavy metals in soil. However, this review have revealed that S/S method using OPC incorporated with other potential additive such as fly ash, bottom ash and lime showed satisfactory results as well as help on reducing the remediation cost. This review also found that the use of recycle material from agricultural waste such as Rice Hush Ash (RHA) capable to improve the quality of soil treatment as well as contributed towards a sustainability remediation method.

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