Cost Effective Geotechnical Solutions For Roads And Factories Over Soft Ground

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ABSTRACT: Geotechnical solutions for roads and factories over soft marine or alluvium deposits are varied. In the case of roads, the approach to bridges or the transition between rigid bridge abutment and the settling fill behind the abutment is a challenge to engineers in exploring cost effective solutions to ensure smooth riding comfort and reduce maintenance. Similarly, the engineering challenge also exists at the approach to drainage culverts across a road. This paper presents some of the geotechnical solutions that are commonly used in Malaysia to treat the subsoil for road embankment construction. The advantages and disadvantages of these methods are also briefly discussed.

A safe and cost effective geotechnical solution for the foundation treatment of a palm oil mill is also presented in this paper. Value engineering has applied in this project with the use of the local tree trunks during site clearing as friction piles for the foundations and the platform. Significant savings in terms of construction time and cost have also been achieved.

1 INTRODUCTION

Road design and construction over soft ground especially over very soft and soft marine deposits are interesting engineering challenges to engineers especially at the approaches to bridges and culverts. Many geotechnical options are available for engineers' consideration. Of course, the one that uses the local materials and resources that are cheaper and easier to construct would no doubt be the choice. This concept is also common to foundations for buildings and factories.

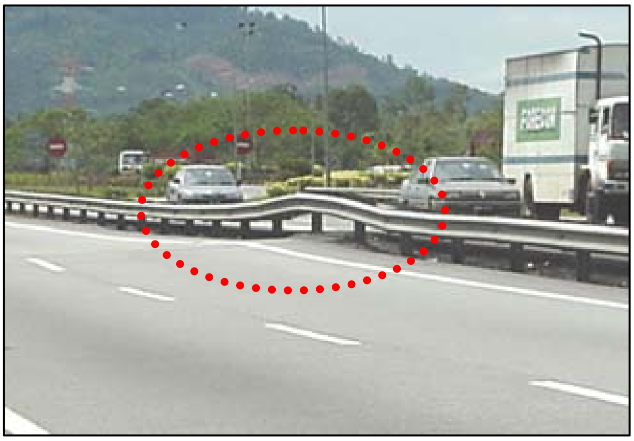

Figure 1 : Hump over piled culvert

The approaches to bridges and culverts over soft deposits often suffer differential settlements as shown in Figures 1 and 2. The reason for this phenomenon is not difficult to apprehend. The bridge abutment is often supported by piles. The piles are driven or installed through the soft overburden into the hard stratum.

Plate 2 : Hump at Bridge Approach

These piles rarely settle compared to the approaches which are settling due to the imposed embankment load onto the compressible soft deposits. The settlement is due to the consolidation of the subsoil when the excess pore pressure induced by the embankment dissipates with time and creeping (secondary compression) of the subsoil. Consequently constant topping up of the uneven surface at the approaches are needed to ensure smooth riding surface and prevent accidents. The thicker the compressible layer the longer the time for consolidation. Similar phenomenon also occurs for approaches to culverts if culverts are piled into the hard stratum.

Buildings constructed over compressible marine deposits also suffer the same problem when the buildings are supported on piles installed into the hard stratum. Fig. 3 shows the differential between the building and settling platform.

Figure 3 : Settling platform detached from building

2 PROBLEMS OF SOFT GROUND

Soft Ground

Very soft and soft deposits of river alluvium and marine deposits are common in Southeast Asia as shown in Fig. 4. The river alluvium and marine deposits normally consist of clay, silty clay and occasionally with intermittent of sand lenses especially near a major river mouth and delta. The marine deposits in Malaysia are encountered along the coast of the Peninsular, where they are up to 20km in width. (Raj & Muhinder, 1990).

Subsurface Investigation (SI)

The use of piezocone and insitu vane shear test is particularly useful in determining the direct undrained shear strength of the soft marine clayey deposits. This is in addition to collecting undisturbed samples from conventional boreholes for unconfined compression and consolidation tests. The use of piezocone is useful to detect presence of sand lenses and indirect determination of undrained shear strength. The detection of sand lenses is particularly important for the assessment of ground treatment. The selection of surcharge alone or surcharge with prefabricated vertical drains to accelerate consolidation depending on this information for economical design. For example, when intermittent layers of sand lenses within the clayey marine deposits, vertical drains are often not necessary.

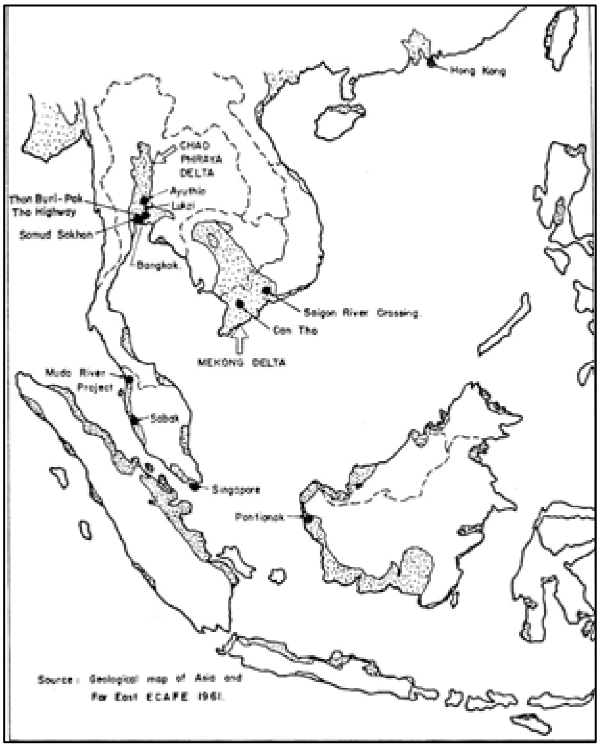

Figure 4 : Distribution of Recent Clays in Southeast Asia (after Cox, 1970)

The spacing of vertical drains is also sensitive to the information and permeability or consolidation properties of the clay. The spacing of vertical drain is very sensitive to the cost. Hence, SI needs to provide reliable subsoil data for design. The details on subsoil subject can be obtained from the papers by Gue & Tan (2000), Gue (1999) and Tan (1999).

3 SOLUTIONS FOR SOFT GROUND

GEOTECHNICAL SOLUTIONS FOR ROADS

Embankment Design

Embankment design of roads needs to satisfy two important requirements among others; the stability and settlement.

The short term stability for embankment over soft clay is always more critical than long term simply because the subsoil consolidates with time under loading and the strength increases. In design, it is very important to check for the stability of the embankment with consideration for different potential failure surfaces namely circular and non-circular.

It is also necessary to evaluate both the magnitude and rate of settlement of the subsoil supporting the embankment when designing the embankment so that the settlement in the long term will not influence the serviceability and safety of the embankment. The details of the embankment design can be obtained from papers by Tan & Gue (2000).

Design considerations include numerous issues such as those outlined by Tan & Gue (2000). The height or thickness of embankment is often dictated by the flood level. As the height of embankment is most critical over marine deposits, hence decision on height after consideration of settlement of the subsoil is critical to the cost and time of the project. When the height exceeds the maximum one stage construction (loading), multistage construction will be required. The crude estimate of the maximum height of embankment can be obtained as follow :

$$H_{max} = \frac{5s_u}{F_s \gamma_f}$$

where

H_{max} = Estimated Maximum Height of Fill (Single Stage Construction)

s_u = Undrained Shear Strength of the subsoil.

F_s = Short Term Factor of Safety (usually 1.2).

γ_f = Unit weight of compacted fill (usually about 18 to 20 kN/m^3)

Of course more detailed analyses are required when more refined soil layers and properties are obtained. In the detailed analyses, both circular and non-circular slope stability analyses should be carried out. Very often, the non-circular failure is more critical than circular slip failure for layered soil especially with very soft subsoil at top few meters.

Long term stability of embankment is usually not an issue for embankment over soft marine deposits because the subsoil would gain strength with time after the excess pore water pressure in the subsoil dissipates during consolidation.

When the analyses based on subsoil and thickness of embankment indicate multistage construction is required, the construction of the embankment usually take substantially longer time especially when the cohesive subsoil does not have sand lenses. If time permits with early planning, multistage construction could be reduced by geometry change in the embankment as described by Tan & Gue (2000). However, geometry change requires wide road reserve due to flatter slope and stabilizing berms. Prefabricated vertical drains could also be installed to reduce the time required for consolidation.

Other techniques such as piled embankment, stone columns, vacuum preloading with prefabricated vertical drains could be considered. However, the technique would increase the cost of the embankment. Piled embankment in particular using local wood piles for shallow subsoil could be competitive.

The details on the design and construction control for embankment over soft clay are also described in the above reference.

Ground Treatment Methods

In order to identify suitable ground treatment to be adopted, the design engineer needs to carry out both technical and cost analyses. Some of the embankment construction methods commonly used in Malaysia are as follows :

(a) Modification of Embankment Geometry
(b) Excavation and Replacement of Soft Soils
(c) Surcharging (with or without vertical drains)
(d) Staged Construction
(e) Lightweight Fills using Expanded Polystyrene (EPS)
(f) Geosynthetics Reinforcement
(g) Stone Columns
(h) Piled Embankment

Modification of embankment geometry through reduction of slope angle or construction of counterweight berms can be cost effective option if there is sufficient cut earth or abundant suitable materials nearby. Although excavation and replacement of soft soil (either partial or total) is an old method but still viable and popular where the very soft compressible is not very deep. The experience on highway construction in West Malaysia indicates that the excavation and replacement depth of up to a maximum depth of 4.5m in soft clay is still viable in terms of cost and practicability. The excavation should extend up to the toe of the embankment and beyond to increase the stability of the embankment.

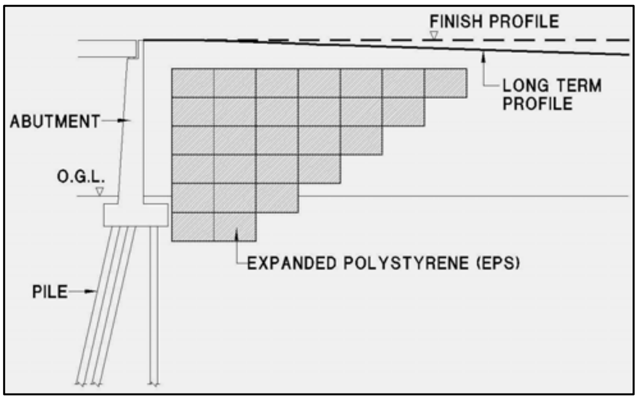

Figure 5 : Use of EPS at Bridge Abutment

Surcharging is to subject the ground to higher pressure than that during the service life in order to achieve a higher initial rate of settlement thus reducing long term settlements. Usually surcharging method is used to control both total and differential settlement at the approaches to abutments of a bridge/flyoever and culvert beneath the embankment. Vertical prefabricated band-shaped drains (commonly called Vertical Drains) can be used together with surcharging to reduce the waiting time or rest period for consolidation. The spacing of vertical drains has significant influence on the cost. For example, 1m c/c spacing vertical drains will cost 300% more than 2m c/c spacing vertical drains. In view of the cost sensitive nature, it is very important to acquire sufficient information of the subsoil so that a cost effective design can be carried out. If the subsoil is very soft and bearing capacity is the major concern then staged construction is required.

Lightweight fills using Expanded Polystyrene (EPS) can be an option for bridge approach embankment to smoothen the differential settlement between rigid structure (bridge) as shown in Figure 5. The most critical consideration in designing embankment using EPS is floatation (uplift forces) under flood condition because of its low density.

Geosynthetics in the form of geogrid or geotextile are sometime used to improve the stability of the embankment over soft soils by placing it at the base of the embankment. Geosynthetics could facilitate and improve the stability of the embankment but the magnitude of consolidation settlement generally remains the same.

Stone columns are occasionally used to strengthen thus increase the stability of the embankment. The two case histories of failure of embankment supported by stone columns investigated by the Authors indicate that the design of stone columns using Priebe's Method (1995) alone is not adequate to ensure safety. All other modes of failure shall be checked and they are bulging failure, general shear failure and sliding failure. If not careful "mushroom" effects will appear in the long term for the low embankment supported by stone columns. The "mushroom" effects is the small area of embankment fill directly above stone column will protrude up like hump compared with the area between the stone columns. This is due to instability of the arch region in the fill above the stone columns and excessive settlement (consolidation and secondary settlement) of the subsoil between the stone columns under embankment loading.

Some general solutions to this problems are to use granular (gravels) materials with high angle of friction as fill materials above the closely spaced stone columns to ensure soil arching of the fill between stone columns or to place high strength geosynthetics on top of the stone columns before placing the fill. It is generally recommended to limit the spacing of the stone columns to less than 2m c/c to prevent "mushroom" effects. Figure 6 shows the "mushroom" effects at the road median which has not been regulated.

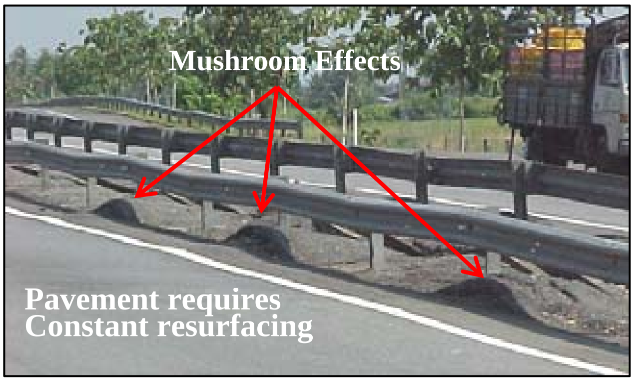

Figure 6 : Mushroom Effects (Defects)

Piled embankment is sometimes used especially when time is a major constraint and in some cases it could be more cost effective than other ground treatment methods. Piled embankment with transition piles is also used to provide a smooth transition (reduce differential settlement) at bridge approaches and the bridge as shown in Figure 7.

Many case histories in Malaysia have shown that using isolated pile caps with or without geosynthetics had caused "mushroom" effects and therefore piled embankment with reinforced concrete slab is preferred. It is very important to construct the slab of the piled embankment lower than the original ground level to ensure the soft subsoil is not subjected to the loads from the fill embankment. When the subsoil is subjected to loads from the fill, the subsoil would consolidate and induce negative skin friction to the piles.

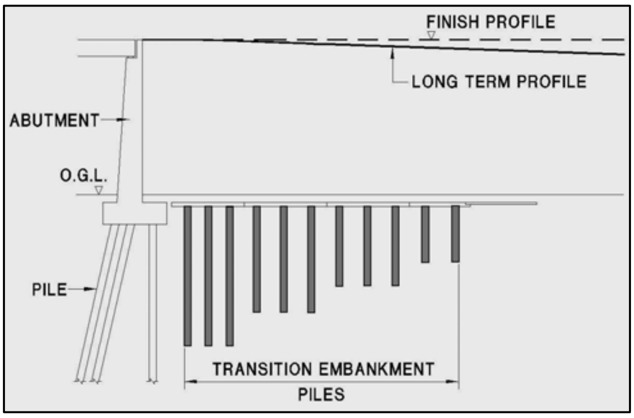

Figure 7 : Piled Embankment with Transition Piles

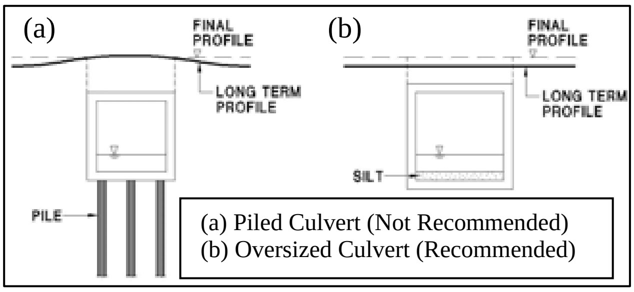

Figure 8 : Culvert Foundation Design

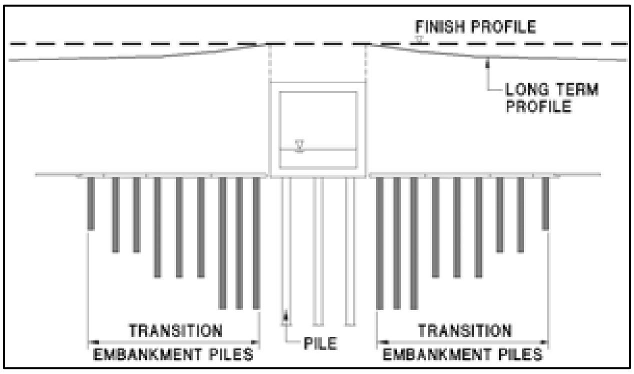

Figure 9 : Culvert with Transition Embankment Piles

Consideration for Approaches to a Culvert

Very often, the culverts are designed and constructed with piles foundation as shown in Figure 8a to ensure that the area of flow of the drain through the embankment remain unchanged with time. The consequences of having rigid support (piles) as shown induces differential settlement between the rigid piled culvert and the unpiled embankment.

The possible geotechnical solutions to eliminate the differential settlement are described by Gue (2000). It includes :-

- Provide a larger culvert to allow for long term settlement (Figure 8b)
- Provide a transition piled embankment at the approaches to a culvert (Figure 9). This option is often more costly.

GEOTECHNICAL SOLUTIONS FOR FACTORIES (A CASE HISTORY)

The project in this case study is a 120 Ton/hr palm oil mill constructed over the sand filled platform of about 83,000m^2 on soft compressible swampy ground. The location of the project site is about 50km away from the river mount of Sg. Guntung of Riau province of Sumatra, Indonesia. The total project cost for the earthworks, civil works, building works and ancillary works excluding the mechanical and electrical costs are about RM60 millions. This mill is strategically important as it will serve to process the palm oil fruits from part of the surrounding 80,000 hectares oil palm plantation. As such, it is a great challenge to complete the mill in relatively short contract duration with difficult logistic conditions. However, value engineering has been carefully applied to this project and results in significant reduction in terms of construction costs and time.

Subsoil & Geomorphology Conditions

The site is generally underlain by recent alluvial soils, which are very weak in strength and highly compressible. Organic peat of about 1m thick are found in the topsoil. Following the top layer of peats is 34m thick very soft compressible clay and subsequently 12m thick medium stiff clay overlying the medium dense fine clayey sand at lower stratum. Figure 10 shows the schematic subsoil strata of this project site.

The geomorphology of the site is featured with typical extensive flood plain and high groundwater table. Due to nature of the overall ground condition of the region, canals become a convenient way for transportation of goods and passengers. With the recent rapid development of oil palm plantation at the area, more canals have been constructed for transporting the fruits and irrigation purpose. Due to the need of proper drainage and irrigation for the palm oil plantation, the water level in the canal system is then controlled by gated structures.

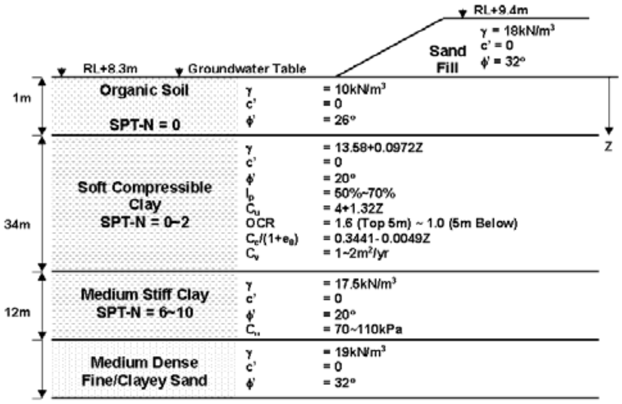

Figure 10 : Subsoil Condition of Project Site

Ground Treatment for Platform

Despite the water level in the canal system is controlled, there is a concern on the extreme flood condition in the vast canal system. Therefore, in the conventional design, a platform above the expected flood level was proposed on the very soft and highly compressible subsoil. It was a great challenge to construct the filled platform with provision for long-term settlement. It required a thicker fill and longer duration to reach the required platform using staged construction method to prevent bearing capacity failure. The subsoil is too soft for a single stage construction.

In the proposed alternative design, a thinner platform of 1.1m was proposed to avoid instability and long-term settlement. In case of extreme flood event, provision of bund construction around the mill compound has been allowed to protect the mill. With the naturally available straight and long tree trunks during the site cleaning for the oil palm plantation project, wood piles of appropriate size and length were selected and installed in square grid pattern for supporting the 1.1m thick sand fill as shown in Figure 11. Woven geotextile fabrics were added over the grid of wood piles to spread the fill loading uniformly for better stability and reduce differential settlement. This is shown in Figure 12. Figure 13 shows a partially completed mill structure. The buoyancy of the wood-piles in grids and the stiffening effect of the soft subsoil by pile installation have also helped in reducing the platform settlement.

Foundations of Heavy Equipment

With the expected settlement of subsoil, negative skin friction would develope on the originally designed end bearing piles and are expected to be very high and required expensive slip coating to the piles. In the alternative design, similar floating concrete pile system is used to support heavy equipment, such as the crane system for FFB Reception Bay, Incinerators, Chimneys, Boilers and other processing stations. Figure 14 shows the floating concrete pile foundation. This floating pile system results in much shorter pile length of 36m as compared to the original design using end bearing piles of 50m penetration length. Most of the structural columns carrying light load are supported by single length hardwood piles.

Figure 11 : Hardwood Blanket Piling

Figure 12 : Hardwood Piled Foundations for Platform & Structures

Figure 13 : Partially Completed Mill Structure

Figure 14 : Floating Piles for Structures

Figure 15 : Completed Tank Structures

Bulk Storage Structures

There are seven numbers of heavy steel tank structures for the storage of processing water and processed palm oil. The total weight of the tank structure is about 3500Ton including maximum storage capacity of 3000Ton for water or crude palm oil. The steel tanks are seated on 0.5m sand bed coated with bitumen strips in order to have uniform seating between the coned-down tank base and the reinforced concrete (RC) raft with thickness optimized to 500mm. This is rather thin as compared to the similar type of tank structures on floating piles. Figure 15 shows the completed tank structures and the tank raft. A total number of 137 of 350mm diameter hollow circular prestressed concrete (PC) spun piles with characteristic concrete strength of 60MPa have been designed and installed to support the tank through the RC raft.

Figure 16 : Piled Raft Foundation for Storage Tank

Figure 16 shows the installation of the tank foundation piles. To avoid the bowl shaped deflection profile of the raft as a result of the interaction effect of large floating piles group, the floating piles are designed with varying lengths to control the deflection profile of the raft as part of the design optimization for the raft. The central portion of the raft is supported with longer piles, in which the supporting stiffness is relatively higher than that of the short piles at outer rim of the raft. Figure 17 shows the schematic diagram of the pile foundation for tank structures. Detailed documentation on the performance of the tank foundation can refer to the technical paper by Liew S.S., Gue, S.S. & Tan, Y.C. (2002).

Retaining System for Wharf Structures

As the oil palm fruits are transported through canal, there is a need to construct a wharf structure for receiving the oil palm fruits. Because of the very weak subsoil, it is practically difficult to design a 3.6m high retaining wall facing the canal. An innovative concept in the retaining wall design for the FFB crane bay was used. The design concept used the sheetpiles in a successive “T” arrangement to act as a container for soil containment and, at the same time, to act as the primary supports for the wharf deck. Figure 18 shows the schematic diagram of the design. Only 12m long FSP IIIA sheetpile section has been used. This penetration length would not be possible to have adequate wall stability in the conventional retaining wall design in this type of soil condition. Figure 19 shows the steel frame erection of the crane system.

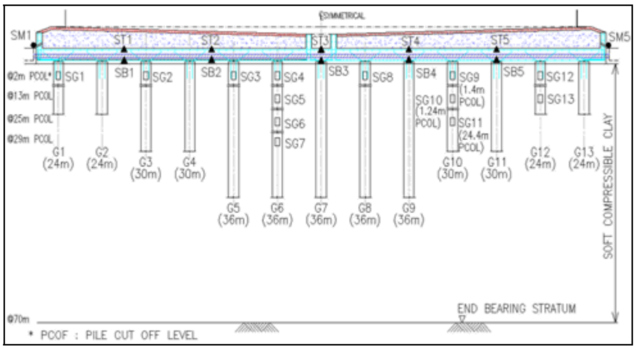

Figure 17 : Piled Raft Foundation for Storage Tank

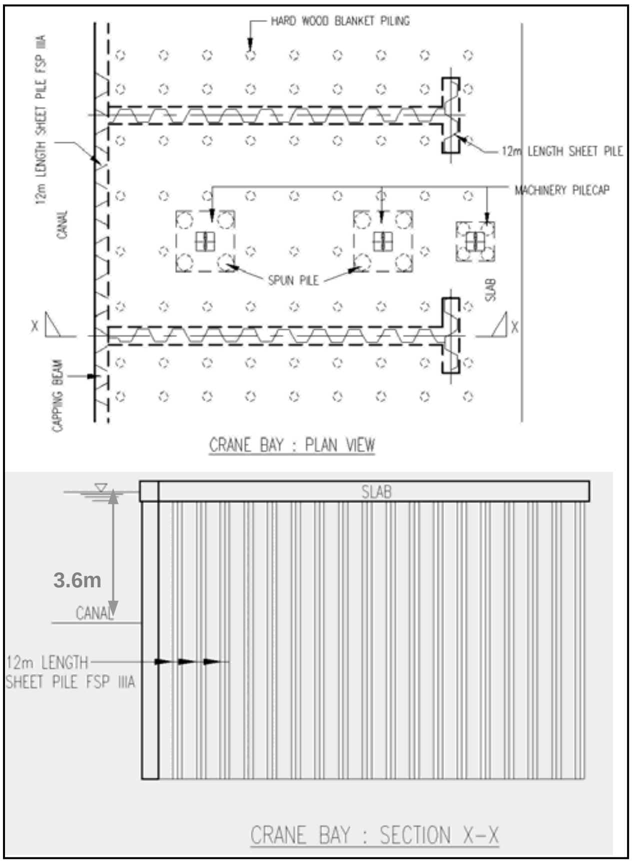

Figure 18 : Schematic Diagram of Crane Bay

Figure 19 Erection of Steel Frame of FFB Crane Bay

Performance from Instrumentation Results

Instrumentation and load tests have been implemented to validate the actual performance against the design expectation. The monitoring results show very convincing and satisfactory outcome. The maximum settlement on the monitored structural columns and stumps, floor slab and sand fill platform is less than 30mm at the time of handing over. The maximum settlement of the storage tank with full water storage is also only about 18mm, which is well within the tolerance of 75mm. Figure 20 shows the instrumentation results of the tank structure during the water test. The view of the completed mill is shown in Figure 21.

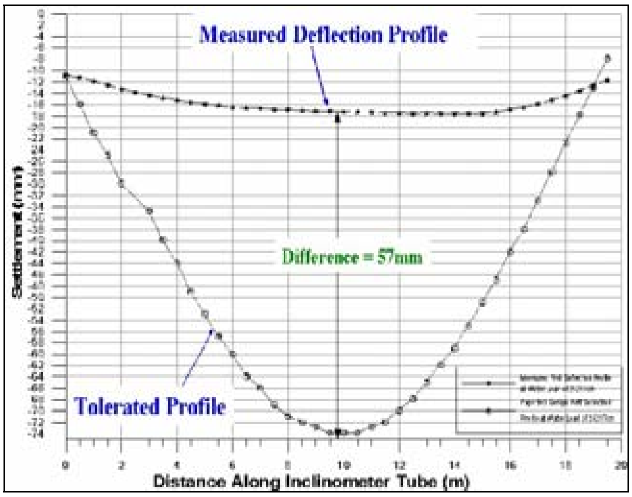

Figure 20 : Instrumentation Result of Tank Structure

Figure 21 : Overview of Completed Mill Structures

Achievements in Value Engineering

The proposed alternative geotechnical designs have satisfied the four design criteria demanded by the turnkey contractor. There are remarkably cost savings in the geotechnical design and the construction time. The objective to utilise the local resources rather than transporting from outside has been well satisfied as the water transportation is not as effective as land transport. The uses of less sand fill, optimized thinner tank raft, successive 'T' sheet piles as wharf structure, local wood-piles for platform construction and floating piles system of shorter length have cut down significant amount of the construction materials and time. In the original design, the total cost of earthwork and foundation are about 75% of the total civil and structure costs. The alternative design has a cost saving of more than 30% on the total costs and significant time saving. The performance of the proposed system has been verified by instrumentation and the alternative foundations performed better than expected. From the instrumentation results, it appears that further design optimization is possible.

4 CONCLUSION & RECOMMENDATION

a. It has been shown that geotechnical design can be innovative to provide cost effective solutions for roads and factories.
b. Floating or friction pile system is a very cost effective solution for projects over soft ground. However, the floating pile system shall be designed with appropriate settlement tolerance.
c. An inclusion of transition between the rigid bridge and the settling embankment provides smooth riding comfort. Oversize culverts without end bearing piles are economical and also provide smooth riding comfort.

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