Design and Settlement Monitoring of Embankment on Soft Ground in Southwest Sabah

S.C.Ng[1] and C.J.Wong[1]
[1]*CJ Consulting Engineers Sdn. Bhd., Kota Kinabalu, Malaysia*
E-mail: cjperunding@gmail.com

ABSTRACT: Ground treatment for road work has become popular in Sabah in the recent years due to the rapid development of highways with stringent requirement in the long-term settlement and stability. This paper presents the geotechnical parameters and the settlement monitoring results of the proposed highway which is situated at Dongongon-Papar Spur, Southwest of Sabah. The area of interest is about 4km of road which is split into two single bound dual carriageways, one involves minor widening of the existing road embankment and another one is the construction of a new road embankment in the paddy field with soft and compressible subsoil layers ranging between 10m to 17m. The proposed fill embankment is about 2.2m. Temporary surcharge with prefabricated vertical drain (PVD) was predominantly adopted to expedite the consolidation settlement. Besides that, other ground treatments such as basal reinforcement, excavate and replace, counterweight berm and staged construction were also adopted. Based on the settlement analysis during the design stage, the expected settlement ranged between 1.2m and 2.0m. Based on the monitoring results, settlement of up to 1.9m was recorded using deep settlement gauges during construction.

KEYWORDS: Ground treatment, Embankment, Soft ground, Geotechnical engineering, Sabah

1. INTRODUCTION

Rapid urbanisation in Sabah the recent years has led to the increase in traffic volume and demand. Most of the existing intercity roads were single carriageway and built with JKR R3 standards with design speed limit of 70kmph. As such, the upgrading works for existing rural roads and construction of new highways connecting major town districts and cities throughout the state is deemed necessary. This paper presents the geotechnical parameters, adopted ground treatments and the settlement monitoring results of the new single bound fill embankment (Figure 1) of a 4km dual carriageway road, which one bound involves minor widening of the existing road embankment and another with the construction of a new road embankment in paddy field area.

Figure 1: Location of Site in West-Coast Sabah (Google Earth, 2018)

The road was designed for 90kmph operating speed limit. With fill embankment being constructed on highly compressible soft ground and low bearing capacity, problems on long-term settlement and stability are unavoidable. Hence, geotechnical engineering input is important for the construction of the embankment with adequate factor of safety and to ensure that the completed highway can provide good ride quality. Several adopted ground treatments are introduced in this paper and the post construction requirements specified by the design criteria are discussed in the next section.

2. DESIGN CRITERIA

The need of statement for this highway project is made reference to JKR Standard Specification of Road Works. According to the design criteria, the minimum Factor of Safety (FOS) in short term and long-term stability for the fill embankment is 1.2 and 1.3 respectively.

In addition, notable performance characteristics of the embankments are:

i. Differential Settlement - Allowable settlement for five (5) years post construction

(a) Within 50m from structures < 100mm

(b) Within 100m remote from structures <150mm

ii. Total Settlement – Allowable settlement for road < 250mm for five (5) years post construction

3. SUBSOIL AND INTERPRETED PARAMETERS

3.1 Geology

The proposed site is underlain by Quaternary Alluvium deposits of Quaternary to Recent age and Crocker Formation of Middle Eocene to Lower Miocene age. Crocker Formation consists of mainly interbedded sandstone and siltstone with shale units. Whereas, the Quaternary Alluvium is mainly derived of unconsolidated alluvial sediments with mixtures of gravel, sand, silt and clay. Furthermore, the proposed site is situated very close to the shoreline (Figure 2) with superficial alluvial deposits consisting of decayed wood and seashell fragments.

Figure 2: Quaternary Age Sediments and Crocker Formation at West-Coast Sabah (Geological Map of Sabah, 2015)

3.2 Subsoil Condition

Based on the subsurface investigation (SI) and laboratory test results, it is generally observed that the proposed site is underlain by primarily coastal, riverine alluvium soils and mainly consist of sandy SILT and sandy CLAY with occasionally shell fragments. There are also some noticeable organic materials such as dark and fibrous peat that are found in the collected samples from the subsoil with high natural moisture content up to 292% and organic content up to 68% in soil which is tally with the general geology of the site. Figure 3 shows the tabulated moisture content and organic content.

The distinct presence of compressible layers with SPT 'N' less than 4 is evident ranging between 9mbgl to 17mbgl. A slightly stiffer soil with SPT 'N' up to 15 can be identified up to depth of 22mbgl. Figure 4 illustrates the subsoil profile interpolated from five (5) boreholes drilled during subsurface investigation works. Hard stratum is encountered from 24.0mbgl to 25.0mbgl depth onwards.

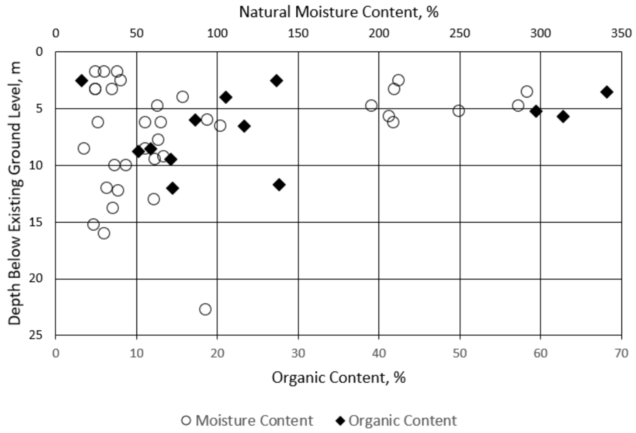

Figure 3: Moisture Content & Organic Content

Based on the SI done on the existing road embankment, which was constructed more than 30 years ago, the top subsoil consists of up to 4m thick of fill material before the compressible soft soil to depth about 10mbgl. As the earlier SI was carried out at the shoulder of the existing road embankment with the fill height of about 2m from the surrounding, about 2m of fill material below the surrounding ground level is believed to be the settlement that have taken place over the long period of consolidation.

3.3 Groundwater Level

The groundwater level is measured after the borehole is drilled by monitoring the water level every morning and evening before and after cessation of works. Based on the information provided, the groundwater table was mostly high or full (i.e.:BH1 and BH4) which is expected as the location within the paddy field area. Summary of the recorded groundwater level is tabulated in Table 1.

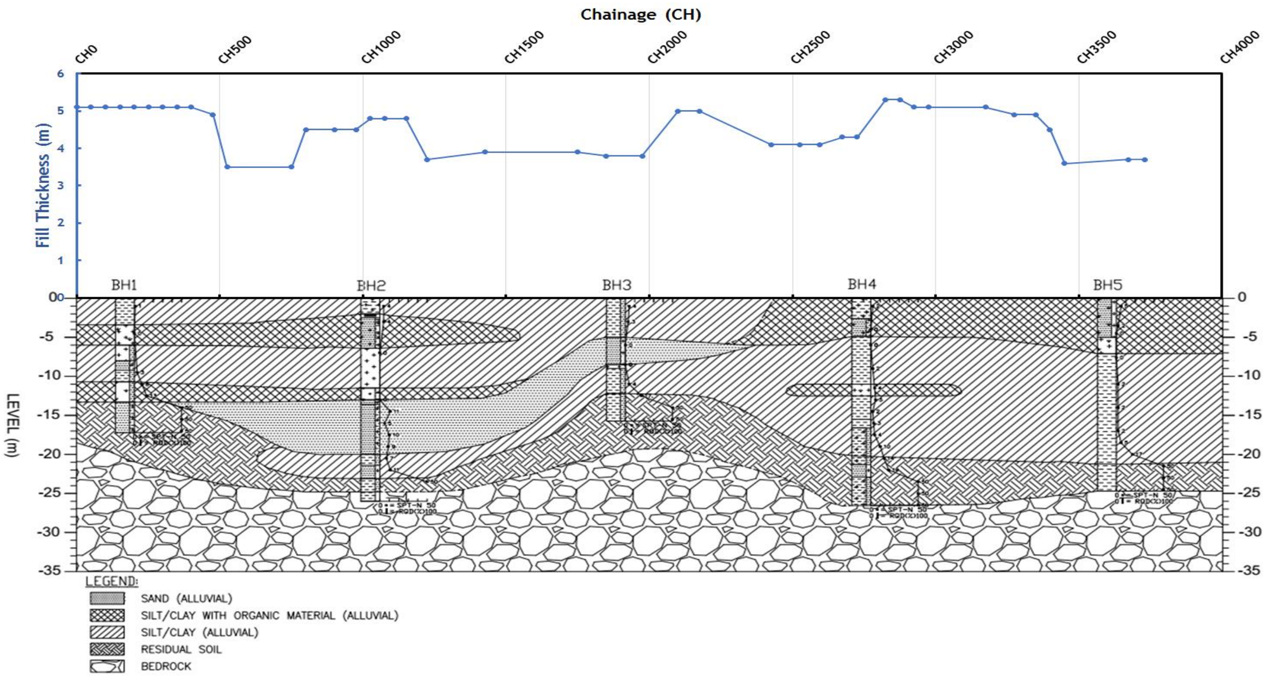

Figure 4: Subsoil Profile (bottom) interpolated from subsurface investigations and designed Fill Thickness including temporary surcharge (top) of the road embankments from CH0 until CH4000

Table 1 Summary of Groundwater Levels

BH	GWL (m)	Remarks
BH1	Full	Flat/Swampy
BH2	1.00	Flat/Filled
BH3	1.40	Flat
BH4	Full	Flat/Swampy
BH5	0.50	Flat/Swampy

3.4 Summary of Interpreted Parameters

As the main geotechnical issues are the long term settlement and the stability of the road embankment on soft ground, consolidation parameters and strength parameters were acquired for the analysis and design. One-dimensional Consolidation Tests (Oedometer Test) were conducted to obtain the consolidation parameters such as unit weight, compression ratio (CR), recompression ratio (RR), over-consolidation ratio (OCR) and coefficient of consolidation in vertical direction (Cv).

As fine-grained soils have low permeability, undrained shear strength (Su) of the underlying subsoil is used for stability analysis. The parameters are derived from Field Vane Shear Test (VS), Unconsolidated Undrained (UU) Triaxial Test and Mackintosh Probe (MP). The summarised interpreted parameters can be viewed at Figure 5 and Table 2 respectively. The undrained shear strength generally ranges between 10kPa to 20kPa down to about 10mbgl. Therefore, extensive combination of various type of ground treatment was adopted to enhance the stability of the fill embankment.

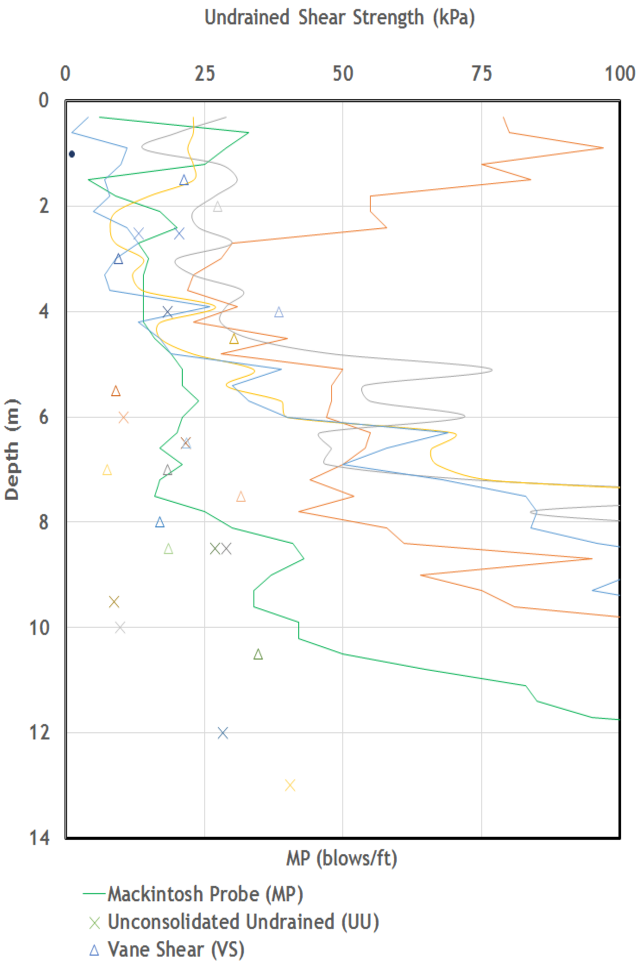

Figure 5: Undrained Shear Strength of five (5) boreholes using MP, VS and UU

Table 2 Summary of Interpreted Parameters

Depth (m)	Unit Weight (kN/m^3)	CR ($\times 10^{-1}$)	RR ($\times 10^{-2}$)	OCR	Cv
0 to 5	11	3.5	4.2	2.0	2.0m^2/year (BH1 to BH4)
5 to 7	11	2.5	3.5	1.4	
7 to 8	16	2.5	3.5	1.4	
8 to 9	16	1.5	3.0	1.4	
9 to10	16	0.8	1.5	1.4	1.5m^2/year (BH5)
10 to 12	19	0.8	1.5	1.4	
12 to 14	19	0.8	1.5	1.2	

4. GROUND TREATMENTS

4.1 Remove and Replace

Remove and Replace (R&R) allows improvement of the subsoil with minimal cost by enhancing the bearing capacity and removing the top subsoil which typically contribute most to the total settlement. The assigned depth of E&R is limited to 1.0m in view of the high water table.

4.2 Basal Reinforcement

High strength geotextile as basal reinforcement was proposed at most part of the main alignment. Basal reinforcement with tensile strength up to 600 kN/m were laid before the commencement of filling works.

4.3 Temporary Surcharge with Prefabricated Vertical Drain (PVD)

Due to low permeability of the subsoil, temporary surcharge with prefabricated vertical drain were introduced to accelerate the consolidation process during the construction period. PVD were installed in triangular grid with the spacing range from 1.1m to 1.4m. The total thickness of the surcharge, in the range of 1m to 3m, consists of the estimated settlement as the earth compensation and additional 1m of temporary surcharge. At the end of the stipulated staged construction rest period, the excess surcharge will be removed.

4.4 Counterweight Berm

Counterweight berm was also introduced to some location as an additional stabilizing force to provide additional stability to the fill embankments.

4.5 Staged Construction

When both basal reinforcement and other methods are insufficient to achieve the desired factor of safety, staged construction was adopted. This method requires a sequence of staged filling work and rest period at the intermediate fill level to allow the subsoil to gain strength through consolidation process prior to progressive filling up and resting to the intended platform level repeatedly until final design level is attained.

Staged construction is a method that does not involve significant increase of material cost but time as it requires relatively long resting time at multi-intermediate filling layers and the decision to proceed next stage of filling depends on the review of the monitoring results. Therefore, this is an effective method when there is limited budget for pre-treatment before filling and time is less concerned comparatively.

5. MONITORING

As the completion of the ground treatment relies on the performance of the proposed method, instrumentation and settlement monitoring program including deep settlement gauges and settlement markers over the platform, piezometers at the centre of the fill, inclinometers along the toe of the embankment for critical subsoil movement were installed on the treated embankment to monitor the performance of the ground treatment. Typical detail of the instrument locations can be viewed at Figure 6.

Such monitoring scheme is also crucial to prevent premature filling or overfilling that may lead to irrevocable failure. This may reduce potentially expensive remedial costs during construction as anomalies detected at early stage could be solved at lower cost. Hence it is very important to allow sufficient provision for instrumentation and adequate monitoring frequency during the construction period.

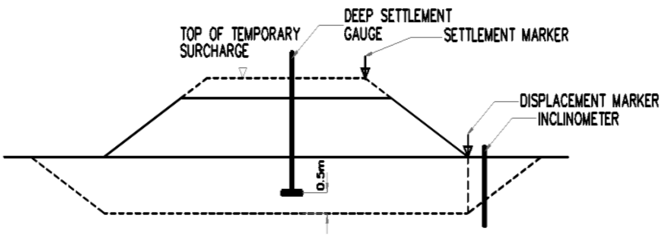

Figure 6: Typical Detail of Geotechnical Instrumentation

To reduce the risk of failure during the construction of fill embankment, the instrumentation readings were monitored weekly on a regular basis as every fill placement took place, in which controlled filling rate of 500mm/week was specified. Where the magnitude and rate of lateral deformation and settlement is concerned, should the ratio of monitored lateral deformation against settlement (δ/ρ) exceeds 0.2, the design engineer shall be notified immediately.

6. SETTLEMENT MONITORING RESULTS

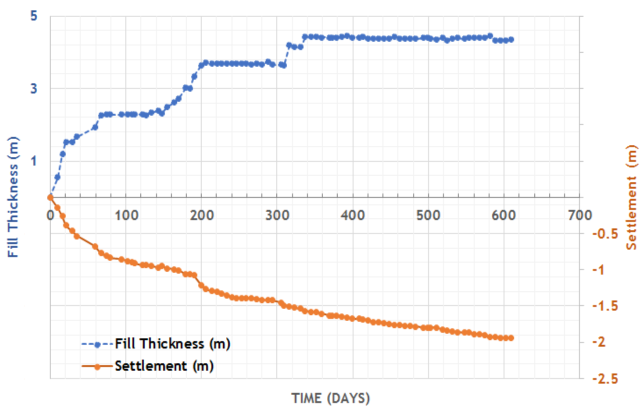

Figure 7: Fill Thickness and Settlement Measurement during construction at CH2975

With reference to Figure 7, the graph shows the settlement process (selected from CH2975) of a deep settlement gauge installed under the embankment as fill placement is gradually added. This location has the deepest soft soil deposit at 17m below ground. The embankment had maximum fill height of 4.5m (including the temporary surcharge) and settlement of about 1.9m has taken place. From the fill thickness graph, it shows the process of the controlled filling rate and also the staged construction that allows the consolidation to take place prior to reaching the designed fill thickness.

Figure 8 shows the actual cumulative settlement recorded at site with reference to the design total fill thickness. From the plot, the settlement behaviour generally can be categorised into three (3) zones, CH0 to CH1200, CH1200 to CH2000 and CH2000 onwards.

The settlement from CH0 to CH1200 is about 1m. Based on BH1 and BH2, the compressible layer in this are shows the thickness of the compressible layer is about 13m. However, it is observed there are areas where the measured settlement is much less. These are probably the localised areas with existing houses and workshops with filled up platforms, which has occupied the areas for long period, prior to the construction of road, allowing consolidation to take place during that period.

From CH1200 to CH2000, the measured settlement is generally around 0.5m. This area, which BH3 was made reference to, has similar thickness of soft material as BH1 and BH2. However, it consists of thick layer of Sandy material which probably explain the actual low settlement magnitude. Besides that, the fill thickness at this part of the alignment is relatively less compare to the other area.

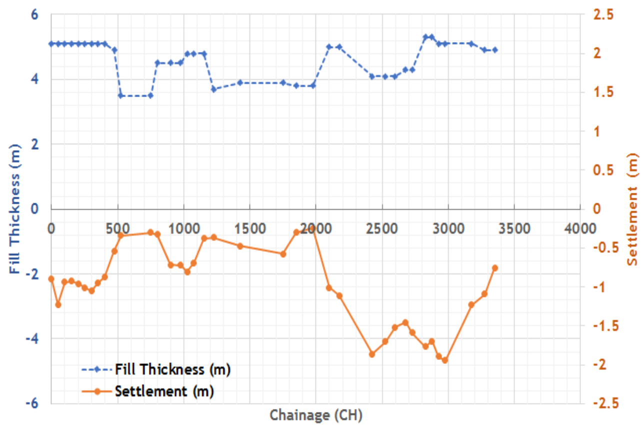

Figure 8: Fill Thickness and Settlement Recorded During Construction from CH0 until CH4000

With reference to BH4 and BH5, from CH2000 onwards, the thickness of the compressible soft layer is about 17m. The subsoil material observed from these two (2) SI boreholes is relatively softer and consists of high organic contents. Therefore, that justified the high settlement magnitude of up to 1.9m at this location compare to the other chainages.

The areas treated with temporary surcharge and PVD were targeting minimum 95% degree of consolidation. The removal of temporary surcharge is determined from interpretation of Asaoka plot based on settlement monitoring results.

7. DISCUSSION AND CONCLUSIONS

During the construction of the fill embankment, there was not much of issue on the stability and the excessive lateral deformation reported from site. Therefore, it is believed that the adopted undrained shear strength was on the very safe side. This is probably due to the confidence level on test results with high variance and its consistency along the alignment. It is learnt that field vane shear test which is commonly being carried out at soft ground with clayey material is not suitable at this kind of subsoil profile which is highly inconsistent with the silt and sand layers. Apart from that, we would normally expect some disturbances from the Vane Shear Test in borehole and Unconsolidated Undrained (UU) Triaxial Test. In the future, it is probably more reliable to use Cone Penetration Test (CPTU). CPTU gives a more detailed subsoil profiling and shear strength estimation. CPTU was not a very popular soil test method back then during the design stage due to limited local demand.

A comparison of the ground treatment methods employed at site is summarized on Table 3.

Table 3 Pros and Cons of Adopted Ground Treatments

Ground Treatment Type	Pros	Cons
Remove and Replace	Economical	Only applicable to shallow depth
Basal Reinforcement	Economical	Not applicable for high fill embankment without improving the subsoil properties
Temporary Surcharge with PVD	Accelerate consolidation process	Expensive due to limited availability of sand as drainage blanket
Counterweight Berm	Enhance stability	Space consuming
Staged Construction	Cost effective	Time consuming

An interesting finding in this study is the comparison of the settlement between the existing road embankment constructed in the past and presently treated embankment. For the treated embankment, the maximum recorded actual cumulative settlement using ground treatments was 1.9m. In comparison to the subsurface investigation result obtained from the existing embankment, the amount of fill settled into the ground in the past construction also accumulated up to 2m. This illustrates the proposed ground treatments could attain similar outcome which is concurrent with the conventional method of fill placement but with a reduced waiting time.

Weekly settlement results monitored during construction found that there was a huge variation between the magnitudes of settlement within the road alignment. The recorded settlement varied between 0.3m and 2.0m. The difference could be due to the design fill thickness, the history of the area (previously occupied by houses and workshops with fill up platform), the thickness of the compressible layer and the variation of the consolidation parameters within the area.

8. REFERENCES

Brand, E., W. and Brenner, R., P. eds. (1981) Soft Clay Engineering, Elsevier, Vol. 20

Gao, X., Liu, C.Y. and Shi M.L., (2004) "Key Problems in Embankment Widening of Expressway on Soft Ground", Journal of Highway and Transportation Research and Development, pp008.

Serridge, C.J., and Synac, O., (2007) "Ground improvement solutions for motorway widening schemes and new highway embankment construction over soft ground", Proceedings of the Institution of Civil Engineers – Ground Improvement, pp219-228.

Smith, I. (2014) Smith’s elements of soil mechanics, John Wiley & Sons, 7th edition

Tan, Y. C., (2016) "Design and Construction of Road Embankment on Soft Ground", Sabah Road Day.

Tan, Y. C., (2005) "Embankment over Soft Clay – Design and Construction Control", 2-day course on Geotechnical Engineering 2005, The Institution of Engineers, Malaysia.

Terzaghi, K., and Peck, R, B.. (2013) Soil Mechanics in Engineering Practice, Read Books Ltd.

Ting, W.H., Chan, S.F., Ooi, T.A, Yee, Y.W., (2007) "Achievements in Geotechnical Engineering Practice in Malaysia", Development, Advancement and Achievement of Geotechnical Engineering in Southeast Asia 40th Anniversary Commemorative Volume of the Southeast Asian Geotechnical Society, pp135-146.

Yee, T. S., (2007) "Soft Ground Engineering for Embankments on the North-South Expressway", Development, Advancement and Achievement of Geotechnical Engineering in Southeast Asia 40th Anniversary Commemorative Volume of the Southeast Asian Geotechnical Society, pp213-222.