Ground Treatment Design for 200km Electrified Double Tracks Railway Project at Northern Peninsular Malaysia

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ABSTRACT: The construction of the electrified double tracks railway project at the Northern Peninsular Malaysia commenced in year 2007. As the railway tracks transverse from north to south going through different geological formations, the subsoils encountered vary from soft alluvium deposit to dense residual soil. The geometrical tolerance of railway tracks is stringent, especially for train with high operating speeds of 180km/hour. Hence, various ground treatment designs meeting the performance requirements and construction schedule are required especially when long stretches of the embankment supporting the tracks are traversing through very soft, low permeability and highly compressible subsoil layer (alluvium deposits) with thickness varying from 15m to 20m. Ground treatment techniques such as excavate & replace (E&R), prefabricated vertical drain (PVD), temporary surcharge, geoxtextile basal reinforcement, stone columns and piled embankment were designed to meet the stringent performance requirements. The performance requirements include differential settlement of not more than10 mm over a chord length of 10m and settlement of not more than 25mm within 6 months after completion. It is also vital to check the dynamic effect due to repetitive axle load of high speed train to prevent excessive subgrade deformation and failures. The adopted design methodology such as settlement analyses, stability analyses, ground treatment selection and dynamic effect analyses will be presented. This paper also highlights the usage of piled embankment with different pile lengths as transition area to provide smooth profile between bridge abutment (rigid structure supported by piles installed to hard stratum) and embankment which is relatively more flexible.

Keywords: high speed railway, soft ground, ground treatment, embankment, construction control

1 INTRODUCTION

Malaysian Government decided to extend the electrified double tracks railway from Center (Ipoh) to Northern Region (Padang Besar) of Peninsular Malaysia where the tracks from Kuala Lumpur to Ipoh are near completion. The electrified double tracks railway generally follows the alignment of the existing railway line from Ipoh to Padang Besar for a distance of 350km as shown in Fig. 1. The Authors are involved in the ground treatment design for 200km stretch of the electrified double tracks from Padang Rengas to Alor Setar. The designed speeds for passenger train and freight train is 180km/hour and 90km/hour respectively. Whilst, the axle loads are 20 tonne and 16 tonne for passenger train and freight train respectively.

As the railway tracks transverse a distance of 200km from north to south going through different geological formations, the subsoils vary from soft alluvium deposits to dense residual soils. In addition, the geometrical tolerance of railway tracks is stringent especially for train with high operating speeds compared to normal expressway. Hence, various ground treatment designs meeting the performance requirements and construction schedule are required especially when long stretches of the embankment supporting the tracks are traversing through very soft to soft alluvium deposits with thickness of 15m to 20m. This paper presents the design methodology to address settlement, stability, dynamic effect, selection and design of various ground treatment techniques to suit different the subsoil conditions.

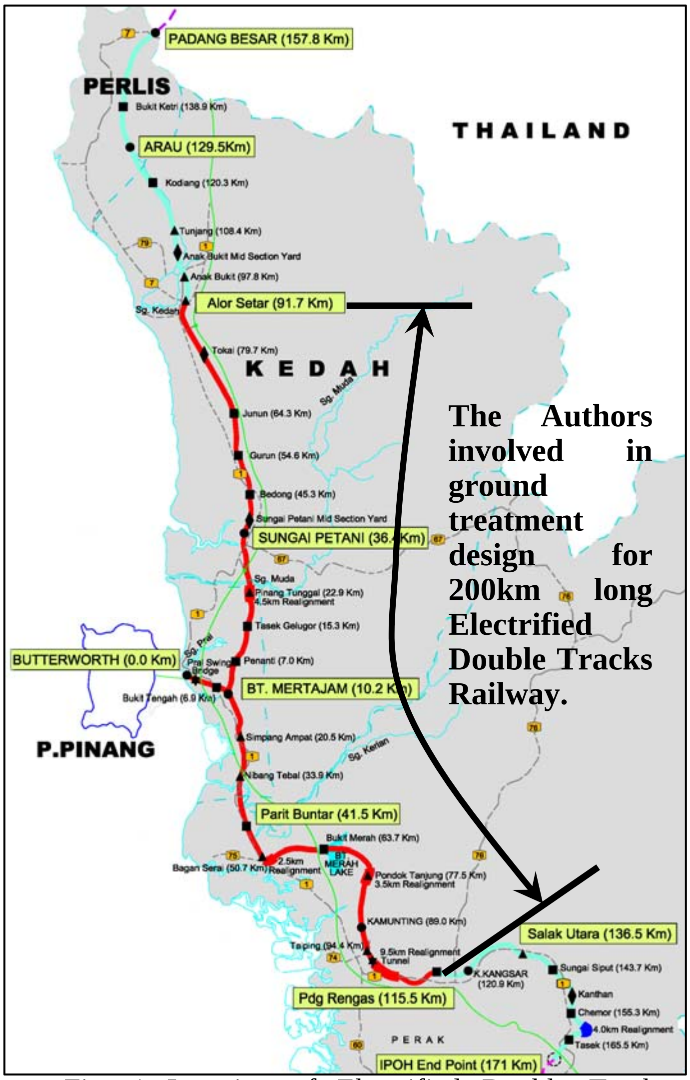

Fig. 1 Location of Electrified Double Tracks Railway

As the proposed railway tracks are to be built within the current Right of Way (ROW), which is just adjacent to the existing live railway track, the construction of the embankment has to be carried out with care to ensure the safety of trains using the existing live track. In view of this, assessment on the existing track condition was carried out as a risk management measures prior to commencement of the construction works thus allowing the contractor to take necessary precaution measures based on the risk level. In addition, displacement markers that are relatively cost effective compared to inclinometer and easier to monitor, were utilized to monitor lateral movements of the existing live tracks and embankments under construction. In addition, the checking of embankment stability as part of the observational approach during construction using modified Matsuo's method (1977) as construction control measures to prevent slip failure, will be elaborated in this paper.

2 GENERAL GEOLOGY AND SUBSOIL CONDITION

2.1 *General Geology*

Based on Geological Map of Peninsular Malaysia (Edition 8) published by Jabatan Mineral and Geosains Malaysia in 1985, about 50% of the electrified double tracks alignment transverses through soft alluvium as shown in Fig. 2 and 3.

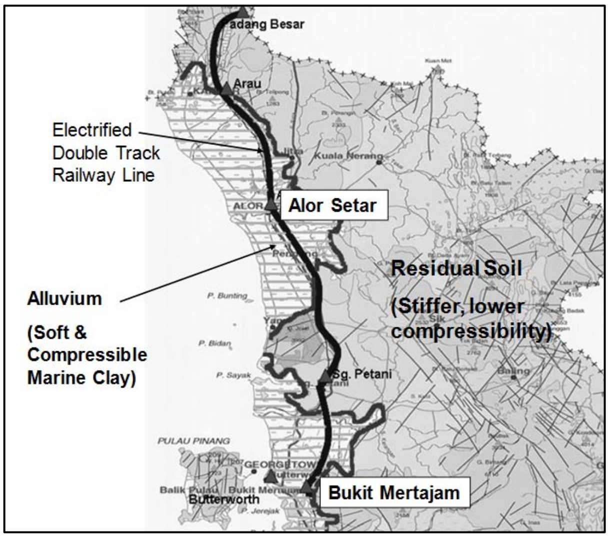

Fig. 2 General Geology for Electrified Double Tracks Railway from Bukit Mertajam to Alor Setar

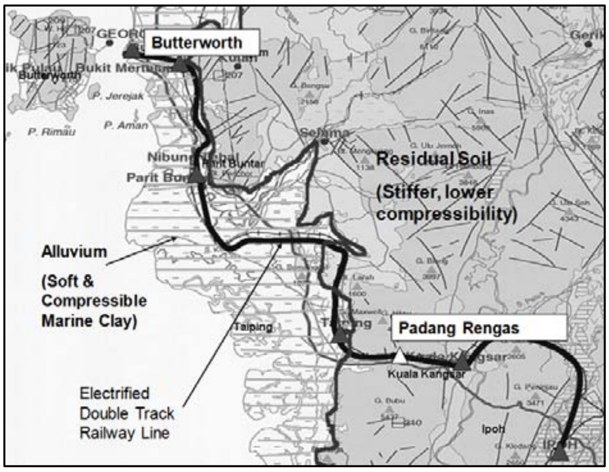

Fig. 3 General Geology for Electrified Double Tracks Railway from Butterworth to Padang Rengas

2.2 *Subsoil Condition*

Two series of subsurface investigation (SI) works namely preliminary and detailed SI were carried out in year 2003 and 2007 respectively. Table 1 summarises the number of field tests [e.g. boreholes, piezocone (CPTu), field penetrating vane shear tests (FVS) and Mackintosh Probe (MP) tests] carried out along the electrified double tracks.

Based on the available subsurface investigation and laboratory test results, the subsoil conditions along the alignment of the proposed electrified double tracks are summarized in Table 2. Fig. 4 shows part of borelogs profile for the subsoil along the alignment.

Table 1 Summary on Field Tests.

Field Test	Total number of Tests	Number of Tests per km
Borehole	213	1.1
CPTu*	139	1.4
FVS*	406	4
MP	5061	25
MP (during construction)	25m c/c spacing	40
	Average	71.5

Note: * - Only for Soft clay area

Table 2 Summary on Subsoil Condition.

Location	Subsoil Condition
Bukit Mertajam to Tasik Gelugor	Sand and sandy Silt (Residual soil). Very Soft to Soft clay was encountered near to Tasek Gelugor.
Tasek Gelugor to Pinang Tunggal	Very Soft to Soft clay
Pinang Tunggal to Sungai Petani	Sandy Silt (Residual soils). Very Soft to Soft clay was encountered near Pinang Tunggal.
Sungai Petani to Terusan Dulang Kechil	Sandy Silt (Residual soils) with localized soft clay at Gurun area
Terusan Dulang Kechil to Junun to Alor Setar	Very Soft to Soft clay
Butterworth to Bukit Mertajam	Sandy/Silty Clay with localized residual soils at Bukit Mertajam area.
Bukit Mertajam to Simpang Empat	Sand and sandy Silt (Residual soil).
Simpang Empat to Parit Buntar	Very Soft to Soft clay
Parit Buntar to Bagan Serai to Bukit Merah	Very Soft to Soft clay
Bukit Merah to Pondok Tanjung	Sandy/Silty Clay. Very Soft to Soft clay was encountered near Pondok Tanjung.
Pondok Tanjung to Kamunting to Padang Rengas	Sandy Silt (Residual soils) with localized soft clay

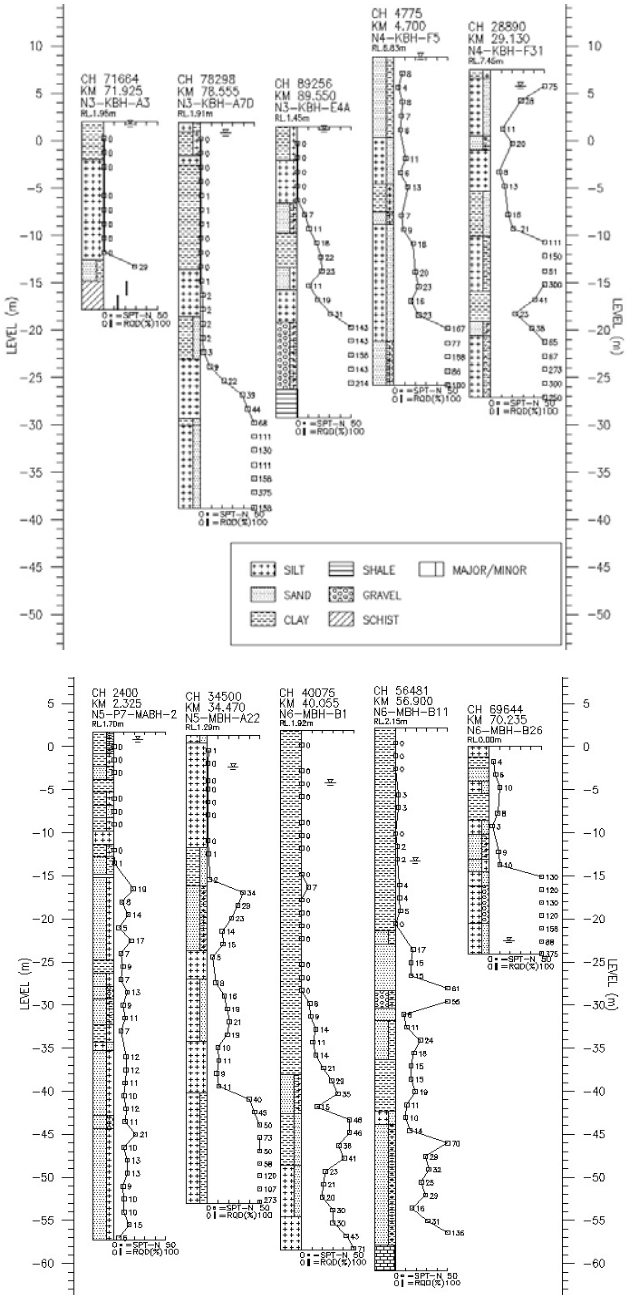

Fig. 4 Typical Borelogs Profile of the Subsoil

3 DESIGN CRITERIA

Design of railway embankment should satisfy both stability against failure and settlement requirements. When there is settlement, invariably there will be some differential settlement which could cause serviceability problems, distresses and damages to rail tracks during operation. Uncontrolled differential settlement will also pose risk to the safety of train. In addition, if soft ground is excessively stressed, it may cause instability (e.g. slip failure and bearing capacity failure of embankment). Hence, settlements (both total and differential) and stability against failure are the two main areas of concern in railway embankment design.

As the designed speeds for passenger train and freight train is 180km/hour and 90km/hour respectively, the allowable settlement for the tracks (during service stage) is summarized as below based on design criteria set by the Malaysian Government:

a) Total settlement of less than 25mm over 6 months after Certificate of Practical Completion (CPC), or
b) Differential settlement of not more than 10mm over 10m chord, which is equivalent to angular distortion of 1:1000.

However, another important aspect to address in railway embankment design is dynamic stress effect from the train with high axle loads and speed. The repetitive dynamic stress will lead to excessive subgrade deformation and failures if the resilient modulus of the subgrade is insufficient.

4 DESIGN METHODOLOGY

The design methodology of the ground treatment for electrified double tracks is discussed in the following sections

4.1 *Interpretation of Subsurface Investigation (SI) Results*

In view of the proposed electrified double tracks alignment transverses through varied subsoil condition, it is vital to categorize and zone the subsoil condition to facilitate the interpretation of physical soil properties, shear strength (drained and undrained) and compressibility parameters as shown in Fig. 5 to 8.

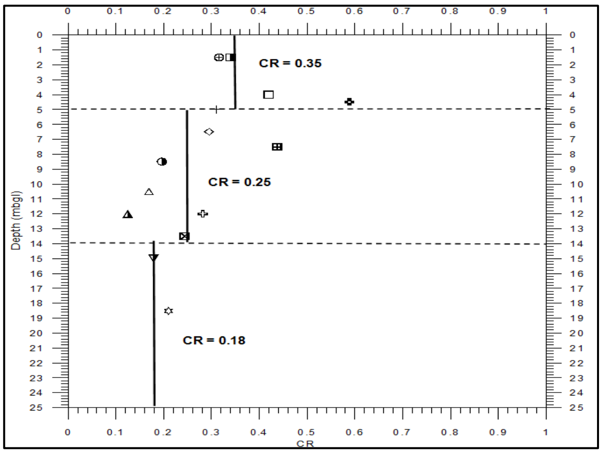

Fig. 5 Typical Compressibility Parameters – Compression Ratio

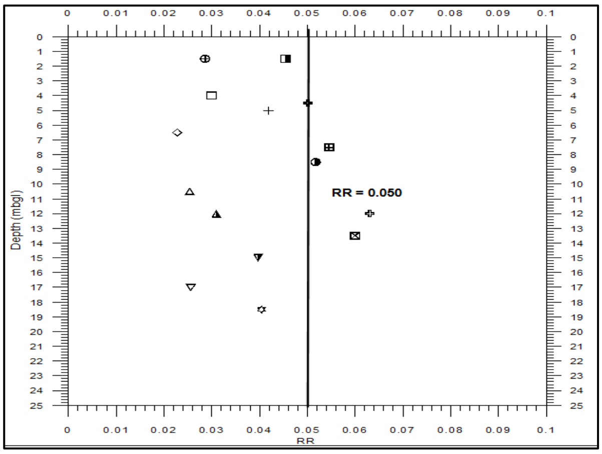

Fig. 6 Typical Compressibility Parameters – Recompression Ratio

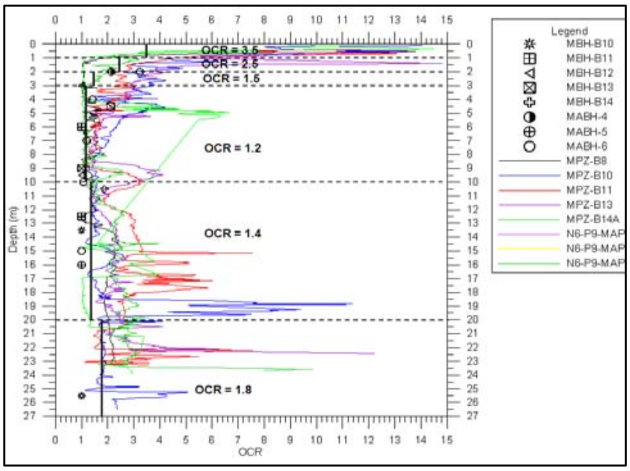

Fig. 7 Typical Compressibility Parameters – Over Consolidation Ratio

As shown in Figs. 5 to 8, some of subsoil parameters are still relatively wide range even after categorization and zoning. Further refinement into smaller zoning for each stretch of embankment was carried out to select representative parameters for each small stretch and possible localized weak subsoil. Therefore, it is vital to exercise good engineering judgments in selecting designed parameters with guidance of published correlations and past experiences. In addition, the designers shall be clear on the usage and limitations of different field and laboratory tests.

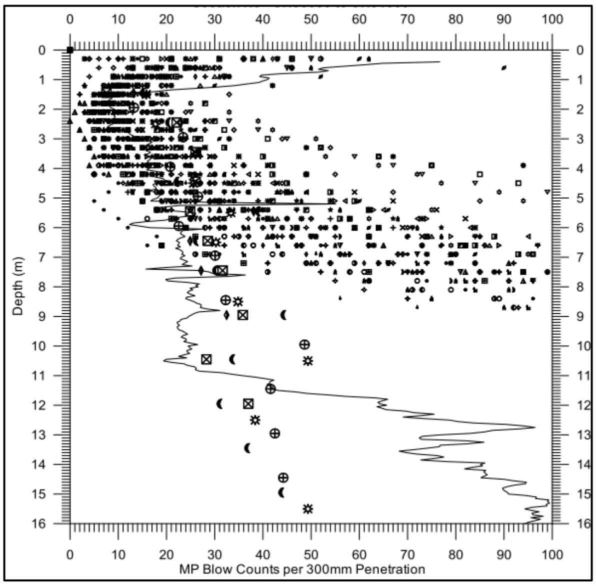

Fig. 8 Typical Undrained Shear Strength (including indirect values from MP tests)

4.2 *Determination of Embankment Height*

Fig. 9 shows a typical section of the electrified double tracks. Some engineers will wonder which height [“A” (up to rail level) or “B” (up to subgrade level)] to be used in settlement analyses. The Authors opine that Height “A” shall be used to calculate the load in the settlement analyses as sub-ballast and ballast are permanent loads acting on top of the embankment.

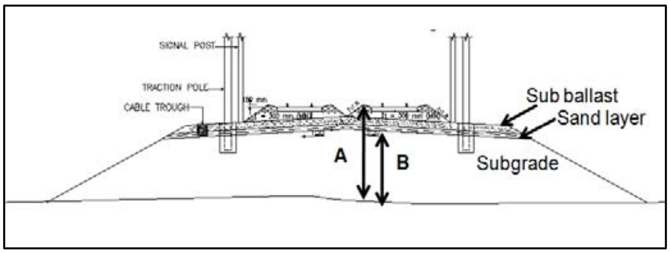

Fig. 9 Embankment Height

4.3 *Settlement Analyses*

Construction of embankments will cause settlement to take place in the subsoil during and after filling. This phenomenon is more obvious for embankment constructed over soft clay due to consolidation process. Therefore, it is necessary to evaluate the magnitude and rate of settlement of the subsoil supporting the embankments so that the settlements in the long term are within the specified limits and shall not affect the serviceability of the railway tracks on top of the embankments.

It is important to estimate the magnitude of settlements that occur during construction and waiting period so that the total actual thickness of the fill at site can be designed to ensure stability. An iterative process is required in the estimation of the settlement because the extra fills (more load) are required to compensate for settlement that will lead to further settlement of the subsoil and also to ensure the post construction settlements are less than the fixed allowable settlement limits. Fig. 10 illustrates the important of iterative exercise to achieve the designed platform level.

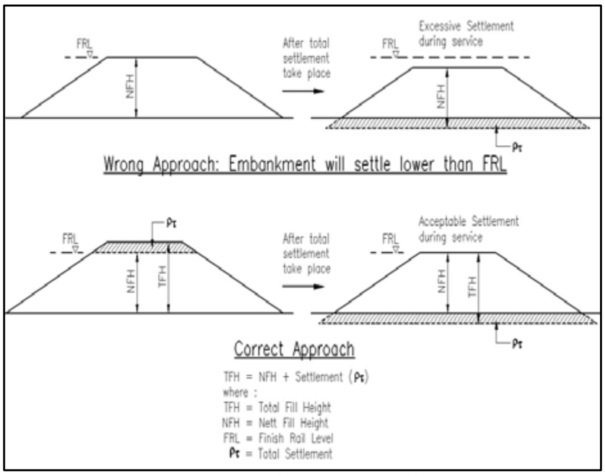

Fig. 10 Concept on Settlement Analyses

Nonetheless, train load shall be excluded in the settlement analyses as it is not a permanent load. With consideration of train load in settlement analyses will lead to overestimate of settlement and thus end up with unnecessary and costly ground treatment.

4.4 *Stability Analyses*

The stability of the embankment were analysed to determine the safe fill slope gradients, total fill heights and the required ground treatments during construction. Generally, the stability of the embankment is assessed using a limit equilibrium analysis. It is very important to check for the stability of the embankment with consideration for different potential failure mechanism namely circular (Modified Bishop Method) and non-circular (Modified Janbu Method) as shown in Fig. 11. This is because circular failure surfaces may not yield the lowest factor of safety (FOS), particularly for embankments on thin clay layers or where discrete weaker layers occur, where translational failure generally dominates.

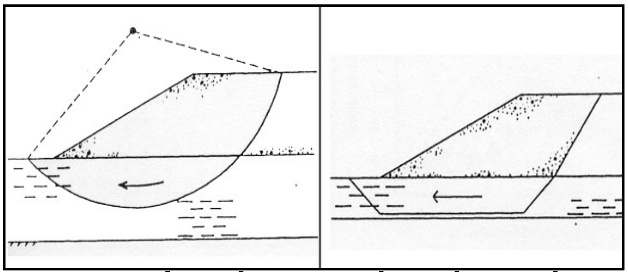

Fig. 11 Circular and Non-Circular Failure Surfaces

The following stages were taken into consideration in the stability analyses:

a) Construction stage – Short term stability of the railway embankment constructed over soft ground, which is generally the most critical, is analysed based on undrained shear strength (s_u) of the subsoil prior to the commencement of construction works (Total Stress Strength Parameters). For staged construction, gained in strength (Δs_u) is considered based on calculation and further verification at site after each stage of rest period)
b) Construction stage – Short term stability of the railway embankment constructed over sandy layer is assessed using drained parameters (Effective Stress Strength Parameters).
c) Serviceability stage – Long term stability of the railway embankment are assessed using undrained shear strength with consideration of gained in strength to stimulate the stability of the embankment immediately after removal of surcharge.
d) Serviceability stage – Long term stability of the railway embankment is assessed using drained condition with effective stress parameters to simulate the long term stability of the railway embankment under constant axle load in serviceability stage.

The adopted factor of safety (FOS) for each stage is tabulated in Table 3. Whilst, surcharge loads of 10kPa during construction and static train load of 38.3kPa during service were applied on top of the embankment as shown in Fig. 12 for stability analyses.

Table 3 FOS adopted in Stability Analyses.

Stage	FOS
Construction	1.2
Serviceability	1.4

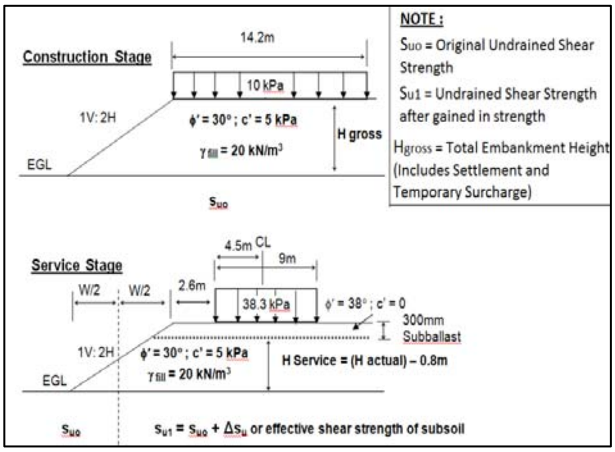

Fig. 12 Stability Analyses

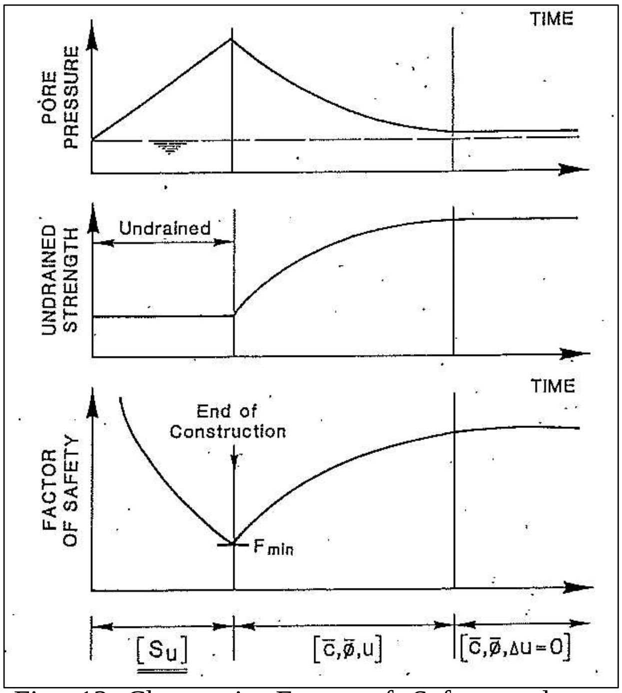

Fig. 13 Change in Factor of Safety under an embankment built rapidly on soft clay (Bishop & Bjerrum, 1960)

As shown in Fig. 13, the stability of the embankment is most critical when the embankment height is the highest during construction (short term) and the subsoil will gain in strength with time when the excess pore pressure dissipates. Therefore, lower FOS of 1.2 was adopted in stability analyses for construction stage (short term).

It is important to note that FOS of 1.2 adopted for construction stage is adequate as moderately conservative parameters are selected for analyses and further verification at site with field tests, and using observation method via instrumentation during construction to prevent failure. If higher FOS is used, there will a need for unnecessary and costly ground treatments. It is more important to carry out proper planning and interpretation of SI, analyses and design rather than using higher FOS to cover weaknesses in design methodologies.

4.5 *Dynamic Effect Analyses*

Other than stability analyses (static effect), dynamic effect analyses were also carried out to determine the safe configuration of the railway embankment in order to prevent excessive subgrade deformation and failures due to repetitive axle load.

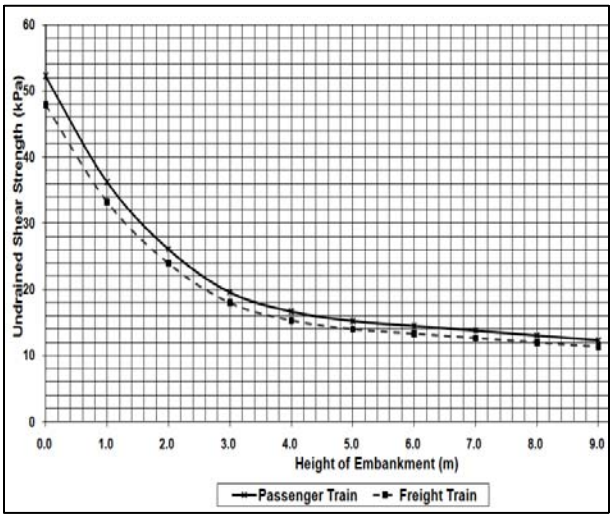

Fig. 14 Undrained Shear Strength Required for Dynamic Stress Effect

Response of tracks structure overlying embankment subgrade is characterised by frequency response. Large dynamic amplification occurs when the excitation loads have frequency components close to resonant frequency of tracks structure. Therefore, the static stress from analysis needs to be augmented by a dynamic amplification factor (DAF). However, theoretical analysis of such problem is complex and difficult to analyse. Hence, empirical formula based on speed, probability factor and tracks conditions are adopted to determine the DAF.

Based on vertical stress distribution profile published by Sondhi (2003) and the computed DAF, the minimum required undrained shear strength of subsoil to prevent excessive subgrade deformation is presented in Fig. 14. Fig. 14 reveals that for low railway embankment (less than 2m), dynamic effect dominates.

5 GROUND TREATMENT DESIGN

At the areas where the strength and stiffness of the existing subsoil is not adequate to receive the fill embankment or to fulfil the specified stability, settlement criteria and dynamic effect; ground treatment techniques are designed to improve the existing subsoil or to support the weight of the fill materials. The design of the ground treatment works shall comply with the FOS and the specified settlement criteria. The compliance includes following criteria:

a) The strength of the subgrade to support embankment, tracks structure, train static and dynamic loadings shall achieve the FOS specified against failure.

b) To fulfill the specified settlement criteria.

Different ground treatment techniques are adopted solely or in combination to satisfy the design's requirements based on the existing subsoil conditions (e.g. strength, thickness of soft soil stratum), height of embankment, train loading (static and dynamic), availability of local materials, and ease of construction, cost and duration of construction. The following sections of this paper discuss some of the ground treatment techniques adopted in this project.

5.1 *Excavation & Replacement of Soft Soil*

Excavation & replacement (E&R) is carried out when the subsoil which form part of the embankment foundation is unsuitable (e.g. organic) or does not have the required engineering properties (e.g. strength or stiffness). This method is old but still viable and effective. Very soft compressible cohesive soils are excavated out and replaced with engineered materials (e.g. compacted sand or compacted suitable fill) that will provide a stronger and less compressible foundation.

The experiences on highway construction in West Malaysia indicate that excavation and replacement depth of up to a maximum 4.5m is viable in terms of cost and practicability. However, if the water level is high, high permeability of subsoil, too near a river, the viable depth of E&R reduces. As the proposed embankment is to be built within the current ROW, which is near to the existing live tracks, the designed depth of E&R is limited to 2m. In addition, temporary sheet piles are installed as shown in Fig. 15 to prevent excessive movement of the existing live tracks during E&R works.

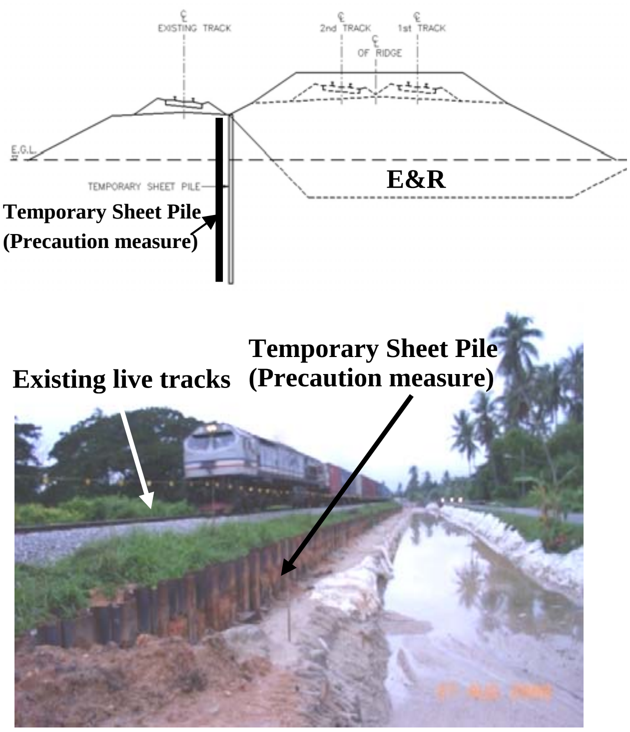

Fig. 15 Typical Cross Section and Photo showing Temporary Sheet Pile for E&R.

If the soft material is much deeper than the practical excavation depth, only partial E&R is carried out up to a depth of 2m despite of thicker layer of very soft to soft clay (e.g. up to 15m to 20m thick). Hence, the effect on stability and long term settlement of the remaining soft subsoil needs be considered in the design and to adopt in combination with another type of ground treatment (e.g. prefabricated vertical drain with temporary surcharge).

There is always some arguments that the top few meters of very soft to soft clay shall not be replaced as the undrained shear strength are relatively higher in view of hard crust. However, the Authors opine that with the removal of the top few meters of very soft to soft clay will result in significant reduce in settlement as shown in Fig. 16. Fig. 16 also demonstrates that by removed the top 0.5m to 2m very soft to soft clay, the subsoil settlement is reduced by 27% and 60% respectively compared to no E&R. Another reason is the strength of thin top crust is not reliable and will be disturbed and weaken during construction due to movement of construction machineries and soaking.

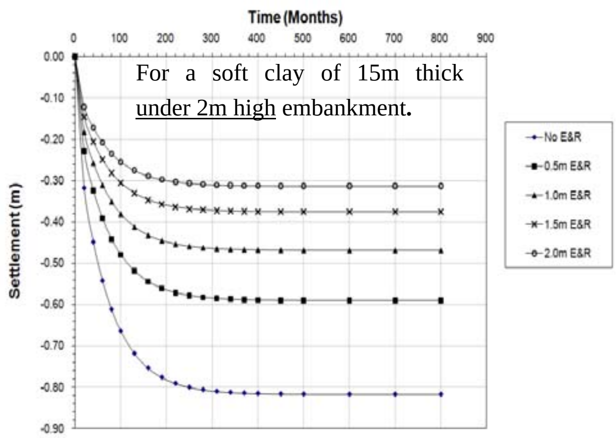

Fig. 16 Effect of E&R on Magnitude of Consolidation Settlement

The main disadvantage of the E&R method is the amount of soft soil that needs to be disposed. Nonetheless, the excavated soft soils can be utilized as temporary/permanent counterweight berm (as weight) to enhance the stability of the railway embankment.

In addition, it is recommended to carry out visual inspection of the site through trial pits and MP at about 25m interval during construction stage to map up the localised softer area prior to the E&R works. This will allow the engineers have a better understanding on the subsoil condition, detection of any localised weak zones and carry out necessary adjustment on the depth of E&R.

5.2 *Surcharging*

In view of the stringent requirements on allowable long term settlements (both total and differential settlement), it is prudent to surcharge the railway embankment especially at soft clay area. Surcharging is to subject the ground to higher pressure than that during the service life to accelerate consolidation settlement and thus reducing long term settlements. The magnitude (thickness of surcharge material) and duration of the surcharging will be controlled by the magnitude of total settlement, permeability of the subsoil and available construction period. Fig. 17 shows the concept of surcharging. Usually, surcharging is used together with prefabricated vertical drain (PVD) installed into the low permeability soft compressible layer.

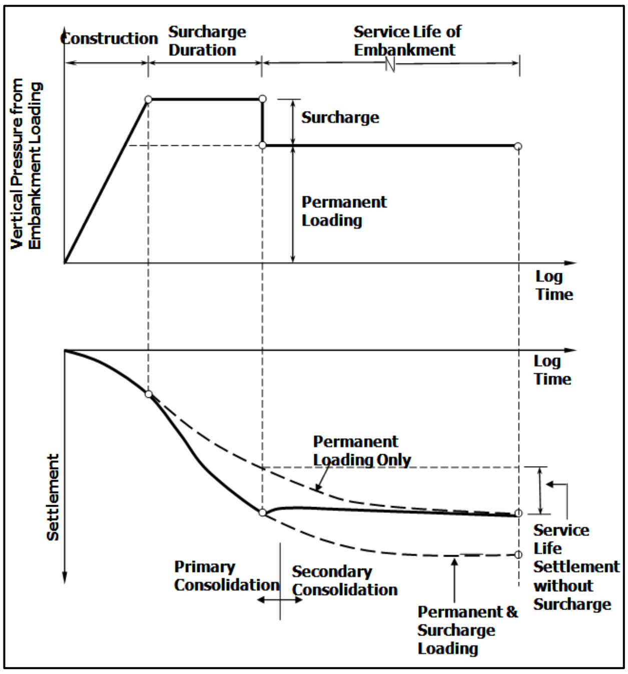

Fig. 17 Surcharging Concept

During construction, the fill materials above the final rail level consist of two portions to incorporate both settlement and surcharge as illustrated in Fig. 18. As mentioned in earlier section, an iterative process is required in the estimation of settlements. The consolidation settlements normally will take years to take place without PVD. As time is an essence, surcharge is required to accelerate the settlements.

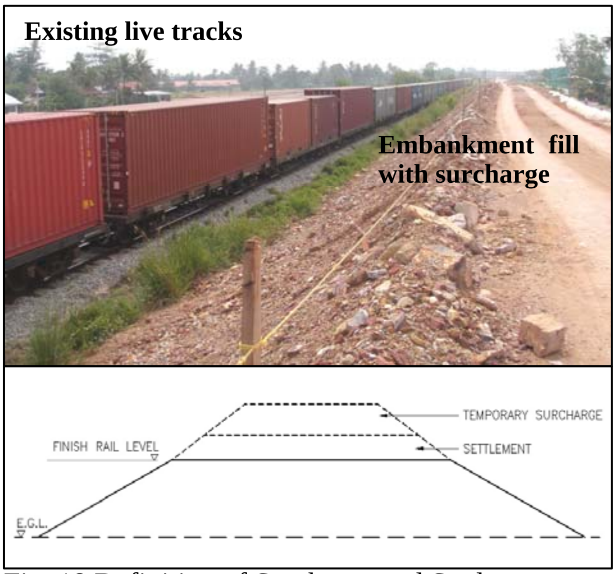

Fig. 18 Definition of Surcharge and Settlement

It is also necessary to surcharge the embankment constructed over residual soil to cater for serviceability limit requirements of the railway tracks. The effect of surcharge on the settlements of embankments founded on residual soil definitely will not be significant compared to embankment constructed over soft clay. However, the Authors opine that surcharging will help to reduce the long term settlement and thus minimise long term maintenance. Therefore, the Authors recommend surcharging all railway embankments either constructed over residual soil or soft clay to minimise post construction settlements.

5.3 *Prefabricated Vertical Drain (PVD)*

Prefabricated vertical drains (PVD) were installed at 0.9m to 1.2m spacing in triangular pattern into very soft to soft clay layer to expedite the consolidation settlement. The design of PVD was carried out based on Barron's method and taking into the consideration the effects of smearing and the variation of vertical and radial permeability. The important design parameters adopted in the PVD design for this project are summarized in Table 4.

Table 4 Adopted Parameters in PVD Design

Parameter	Value
Ratio of d_s/d_e	4
Ratio of k_h/k_s	2

Notations:
d_s - Diameter of idealized disturbed zone
d_e - Equivalent diameter of PVD
k_h - Radial permeability coefficient for undisturbed zone
k_s - Radial permeability coefficient for disturbed zone

It is important to note that the effectiveness of PVD as ground treatment to expedite consolidation settlement will increase significantly if combine with temporary surcharge. The surcharge period ranges from 3 to 5 months with surcharge thickness of 1m to 1.5m was successfully implemented for this project. The key factors to success are correct selection of soil parameters, proper design methodology and correct selection of PVD materials.

Table 5 Minimum Mechanical Properties of Geotextile Filter.

Property	Testing	Minimum Value
Grab strength	ASTM D4632	350N
Puncture strength	ASTM D4833	100N
Burst strength	ASTM D3786	900kN/m^2
Trapezoid tear	ASTM D4533	100N

The mechanical characteristics of PVD, particularly the tensile strength of the core and filter, are important because of the stresses to which PVD are subjected to during installation. The maximum tensile force develops when the mandrel accelerates at the start of the penetration or after slowing down because of passing through an obstacle or a resisting soil layer (Kremer et al 1982). Therefore, the longitudinal tensile strength of any drain components should be at least 0.5kN to minimize risk of PVD damage (tear), which may lead to malfunction and clogging of PVD and thus prolonging the surcharge period. In addition, Table 5 shows the adopted minimum values of the physical properties of geotextile filters in drainage and filtration application to survive construction operation. The adopted minimum values are as per recommendation of Christopher & Holtz, 1985.

Another important aspect in PVD construction is discharge outlet, which is always overlooked by the engineers. If the discharge outlet is clogged, the excess pore water pressure will not be able to discharge effectively. Therefore, following are some good construction practices proposed by the Authors and implemented at the electrified double tracks railway project to improve PVD efficiency with minimal cost:

a) To install PVD at horizontal direction with spacing of not more than 5m c/c. This is to use cost effective PVD as modified "horizontal" subsoil drains to assist the sand blanket layer to discharge water
b) To provide crusher run at the end of sand layer as shown in Fig. 19. This is to ensure there is clear outlet for the water coming out from the subsoil through vertical drains to be effectively discharge out from the embankment. A clearly visible crusher run layer will also prevent contractor from accidentally block it and for easy inspection by supervising engineer.

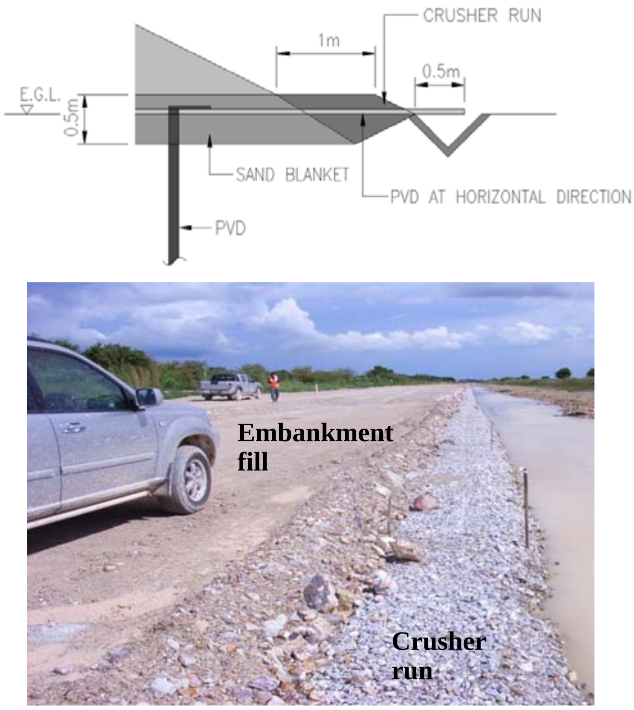

Fig. 19 Details of Discharge Outlet for Sand Blanket Connecting All PVD

The installation of PVD was carried out by using static or hydraulic rig. The machine was generally fitted with a structural frame (drain mast) and a mandrel that designed to the required depth as shown in Fig 20. The structural frame is as high as the designed PVD length. In view of this, the installation of PVD cannot be carried under headroom constraint in areas such as under existing high tension cable and road over bridge (ROB) without sufficient clearance. In this areas of constraints, conventional sand drains were adopted as a replacement to PVD. The installation of sand drains was carried out by using borehole drilling machines.

Fig 20 Typical PVD Machine working beside the Live Track

Combination of PVD and temporary surcharge are a technically suitable and cost effective ground treatment technique to remove long term consolidation settlement in very soft to soft clay. Nevertheless, as the proposed electrified double tracks railway are constructed adjacent to existing live track, the live track will be subjected to some settlement during the construction period especially during temporary surcharging. Therefore, necessary maintenance works shall be carried out to ensure the serviceability of the adjacent live track.

5.4 *Geotextile Basal Reinforcement*

Installation of PVD will not increase the subsoil shear strength. The subsoil will only experience gain in strength upon dissipation of excess pore pressure caused by the embankment load during construction (filling) and surcharged period. As the soft compressible subsoil has low undrained shear strength, staged construction is normally adopted to construct the embankments. However, in order to meet the tight construction schedule, geotextile basal reinforcement is used to allow higher embankments to be built without compromising the embankment stability during construction. Fig. 21 shows the typical section of geotextile basal reinforcement used at site.

5.5 *Stone Columns*

Stone columns were utilised as ground treatment once the combination of E&R, PVD, temporary surcharge and geotextile basal reinforcement are found not viable. The presence of stone columns creates a composite material of lower compressibility and higher shear strength than the in-situ very soft to soft clay. Therefore, stone columns were adopted to support high embankments. In addition, stone column also act as "giant PVD" to accelerate consolidation settlement and thus shorten the construction period.

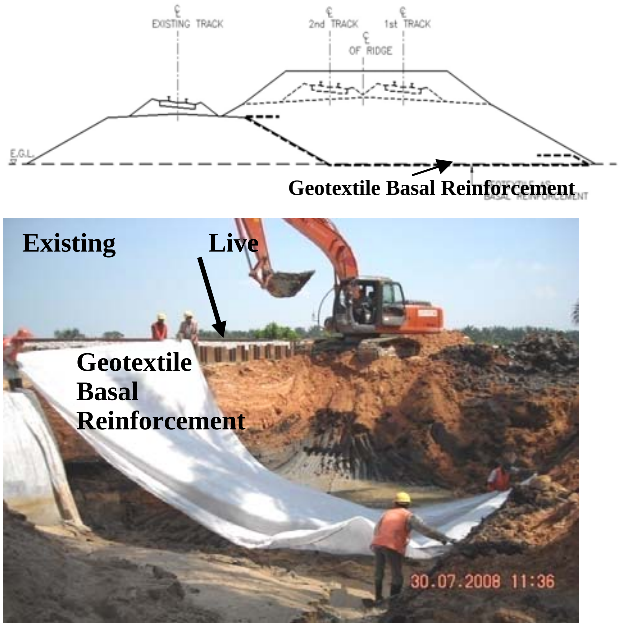

Fig.21 Typical Cross Section and photo showing Geotextile Basal Reinforcement

Following are several limitation of stone columns:

a) Commonly not recommended for subsoil with undrained shear strength of less than 10kPa in view of low confinement stress in the subsoil. Special care shall be exercised in design and construction if stone columns are to be used for the subsoil with very low shear strength

b) Not suitable for subsoil with high organic contents
c) Commonly not recommended for embankment height of less than 2.5m. Sufficient embankment height is required to provide soil arching within the embankment fill to distribute more load to the stone columns instead of loading the soft soils between them. This is to prevent long term "mushroom" effect problems (uneven settlements that looks like mushrooms) on the embankment surface. However, thicker crusher run layer with high angle of friction (ϕ') or high stiffness geogrid can be used to overcome this weakness.

Fig. 22 shows the installation of stone columns adjacent to existing live tracks.

Fig. 22 Installation of Stone Columns adjacent to Existing Live Track.

5.6 *Piled Embankment*

At areas of very soft clay where other ground treatments are not suitable to support the railway embankment, piled raft are used as ground treatment and settlement reducer. Piled embankments are designed to provide the required embankment stability and to achieve the specified tracks settlement criteria. Hence, lower global safety factor such as 1.5 is adopted for pile capacity. Whilst, the piled slab supporting the embankments were designed generally in accordance with BS 5400 Part 4 using lower partial safety factors.

5.7 *Piled Embankment as Transition Zone*

Significant differential settlements at bridge approach are still common along highways and railways in Malaysia. Bridge abutment over soft deposits is normally supported by piles. The piles for the abutment are usually installed to a firm/hard layer. The long term settlement of the abutment is hence negligible. However, the embankment adjacent to the abutment would still have some settlement with time. Consequently, this will create a significant differential settlement between bridge abutment and flexible embankment as shown in Fig. 23. This will pose high risk to the train in view of the high travelling speed. Hence, piled embankments with different pile lengths as transition area is utilised to provide smooth profile between bridge abutment (rigid structure with pile to set) and embankment. Fig. 24 illustrates the innovative solution to mitigate the differential settlement.

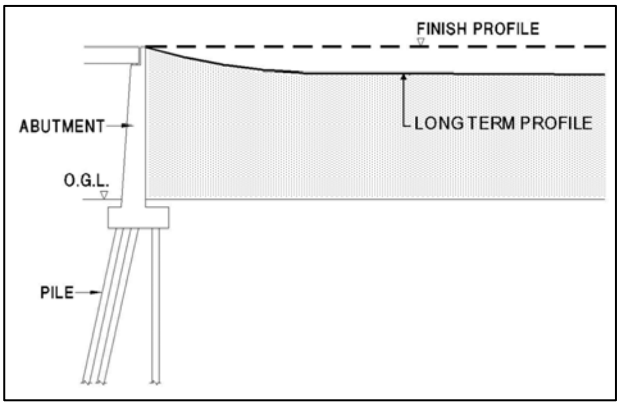

Fig. 23 Settlement Profile at Bridge Approach

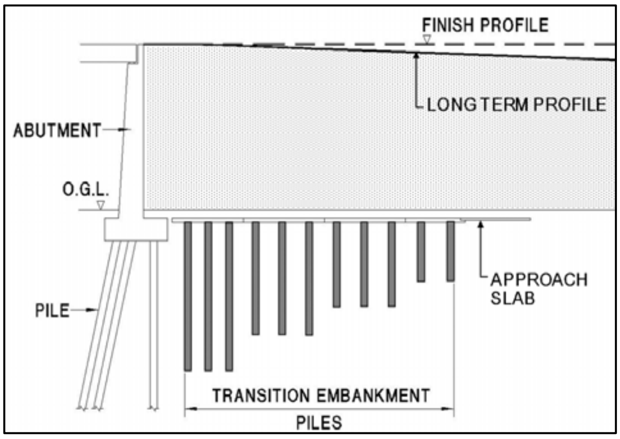

Fig. 24 Transition Pile at Bridge Approach

5.8 *Ground Treatment for Culvert*

Very often, culverts are wrongly designed and constructed as shown in Fig. 25 to ensure that the area of flow of the drain through the embankment remain unchanged with time. This is achieved by using piles to provide a rigid platform. The consequence of having rigid platform as shown induces differential settlement between the rigid piled culvert and the flexible embankment.

In order to overcome this problem, the ground treatment and foundation for culverts shall be the same as the embankment. This mean that section with culvert needs to complete the ground treatment (i.e PVD, surcharge etc) prior to construction of the culvert. As such, the differential settlement can be mitigated.

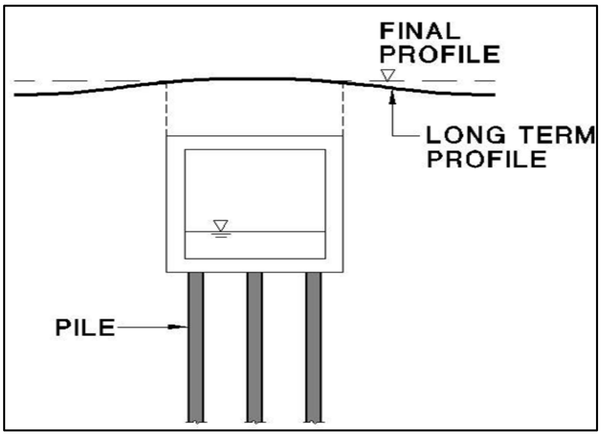

Fig. 25 Culvert Founded on Pile Foundation (not recommended)

6 CONDITION ACCESSMENT SURVEY OF EXISTING LIVE RAILWAY TRACK

As the proposed railway tracks is to be built within the current ROW, which is near to the existing live track, the construction of the railway embankment needs to be carried out with care to ensure the safety of the existing live track. Hence, assessment of the existing tracks condition was carried out as a risk management measure prior to the commencement of construction works. This allows the contractor to take necessary precautionary actions if the existing track is not in a safe condition.

Condition assessment of existing track embankment was carried out based on the following parameters:-

a) Embankment condition – Slope gradient, Embankment geometry (Height), Erosion condition, Localised slip, Voids of embankment and Existing retaining walls with distress.
b) Drainage condition – Existing drainage condition, Existing ponds/canals and Vegetation.

Based on the assessment, the existing tracks was classified to four (4) risk categories namely Low Risk, Moderate Risk, Significant Risk and High Risk. A sample of the risk classification is shown in Fig 26.

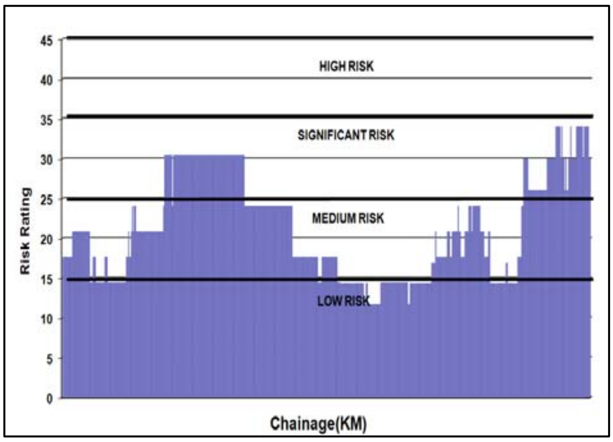

Fig. 26 Sample of Risk Classification.

7 EMBANKMENT STABILITY CHECK DURING CONSTRUCTION

Many literatures reported that failures of an embankment constructed over soft clay are closely related to the magnitude and history of the deformations which took place before failure. Therefore the information obtained from field instrumentations measurements can be used to ensure the safe construction of embankments.

Displacement markers that are relatively cost effective compared to inclinometer, were extensively utilised to monitor the lateral movements of the constructed embankments. With reference to the lateral movements and settlements (recorded from settlement gauge), the stability of the constructed embankment is monitored based on "modified" Matsuo stability plot as shown in Fig. 27.

During construction, Fill height (fill thickness) versus Lateral displacement (FHLD) plot as shown in Fig. 28 was developed by the Authors as supplementary to the "modified" Matsuo's Method (1997). The FHLD plot was developed based on actual monitoring results of fully instrumented trial embankment constructed in Tokai, Kedah, Malaysia (Tan et al., 2010) and finite element method (FEM) analysis using computer programme "Plaxis".

Both "Modified" Matsuo and FHLD plots were classified to Green, Yellow Orange and Red Zone respectively. Table 6 shows the actions to be taken at site once the monitoring results reach certain colour zone.

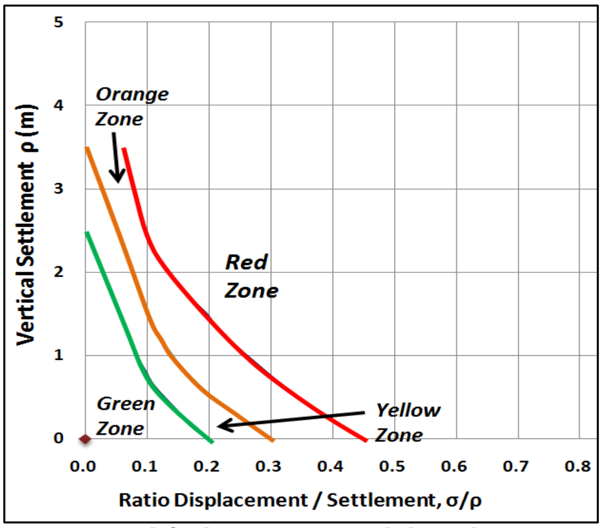

Fig. 27 "Modified" Matsuo's Stability Plot

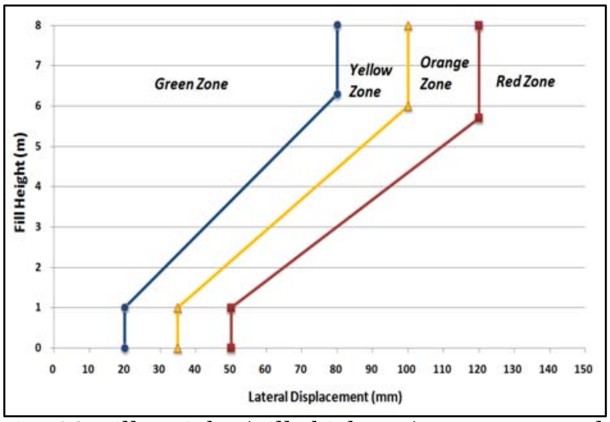

Fig. 28 Fill Height (Fill thickness) versus Lateral Displacement Plot

Table 6 Actions Required During Construction Monitoring

Zone	Action
Green	Embankment filling can continue.
Yellow	Supervising Engineer to inform design office and embankment filling can continue. For area with PVD, the embankment filling rate reduced to 0.5m/week.
Orange	Supervising Engineer to inform design office immediately. Embankment filling work only can proceed with permission from the design office
Red	Supervising Engineer to stop the embankment filling immediately and inform design office. Design office to review instrumentation data and advise on next course of action.

8 CONCLUSIONS

The basic key ingredients for a successful ground treatment to achieve the performance requirements (stability and settlement) for design and construction of high speed railway embankment are summarized as below:

a) Awareness of the project requirements in terms of serviceability criteria (total settlement and differential settlement criteria, dynamic effect, etc.), costs (construction cost and maintenance cost), site constraint and construction time (construction time, service period).
b) Knowledge on the site and subsoil conditions through proper desk study, gathering of geological information and well planned and supervised subsurface investigation (SI) and laboratory testing to acquire the necessary reliable parameters for geotechnical designs.
c) Proper understanding on the subsoil behaviour, concepts of each ground treatment technique and its limitations.
d) Proper geotechnical design to address both stability of the embankment and control of deformation.
e) Careful and proper monitoring on the performance of the embankment during and after construction through instrumentation scheme.

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REFERENCES

Kremer, R., DE Jager, W.Maagdenberg, A. Meyvogel. I. and Oostveen, J. 1982. Quality Standards for Vertical Drain. *Proceedings, Second International Conference on Geotextiles*, Volume II. Las Vegas, Neveda, pp. 319- 324

Matsuo, M. & Kawamura, K. 1997. Diagtram for Construction Control of Embankment on Soft Ground. *Soils and Foundations*, Vol.22, No. 4, 45-56.

S. Sondhi Jogesh, Ganeswara Rao Dasari & Tan, Siew Ann. 2003. *Design Issues and Sub-grade Assessment for The Rawang-Ipoh High Speed Tracks*

Tan, Y.C., Ooi, L.H.; Yeow, Andrew; Lee, P.T. & Koo, K.S. (2010), "Instrumented Trial Embankment on Soft Ground at Tokai, State of Kedah, Malaysia", *The 17th Southeast Asian Geotechnical Conference*, Taipei, Taiwan, 10 to 13 May 2010

Tan, Y.C. and Gue, S.S. 2000. *Embankment over Soft Clay – Design and Construction Control*. Seminar on Geotechnical Engineering, 22 & 23 September 2000, Penang.

Tan, Y.C. 1994. *Analysis of Trial Embankments at the Muar Flat Site, Malaysia*. Master Thesis, Asian Institute of Technology, Bangkok, Thailand.