Geotechnical Solutions for High Speed Track Embankment – A Brief Overview

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ABSTRACT: The design and construction of high speed track embankment over very soft soils have always been a challenging task for geotechnical engineers. This paper presents a brief overview of the geotechnical solutions that are commonly used in Malaysia to treat the subsoil for embankment construction. The importance of the subsurface investigation to acquire the necessary information for design and construction as well as some typical defects and solutions are also discussed.

1 INTRODUCTION

The design and construction of high speed track embankment over very soft soils has always been a challenging task for geotechnical engineers. There are many different types of ground improvement techniques that can be used for construction of the embankment on soft soils. The design and choice of construction method in this formation are not only governed by direct costs, but also duration of completion, long term maintenance costs, and cost benefits.

This paper presents a brief overview of the various commonly used techniques for construction of embankment on soft soils. The importance of the subsurface investigation to acquire the necessary information for design and construction as well as some typical defects and solutions are also discussed

3 SUBSURFACE INVESTIGATION

When planning of the subsurface investigation (S.I.), the Engineer shall always remember that majority of the unforeseen costs associated with contruction on soft soils are geotechnical in nature. Additional costs are often attributed to inadequate planning of S.I. and improper interpretation of the factual information.

Site reconnaissance is required to confirm and obtain additional information from the site. Site reconnaissance allows the engineer to compare the surface features and topography of the site with data and information obtained from desk study. One important aspect of site reconnaissance is the study on the vegetation to search to tell-tale signs of localised very soft areas where additional subsurface investigation should be carried out.

The basic information required for planning and preliminary design of the embankment includes :

- Site Topography;
- Geology and Landuse;
- Soil Stratigraphy;
- Soil Strength;
- Soil Compressibility;
- Groundwater Levels.

The commonly used field and laboraty tests in Malaysia are :

(A) Field Tests :
- Light Dymanic Penetrometer (JKR or Mackintosh Probes)
- Standard Penetration Test (SPT)
- Field Vane Shear Test
- Piezocone (CPTU)
- Pressuremeter Test

(B) Laboratory Tests :
- Unconfined Compression Test
- Triaxial Test (UU, CIU and CID with pore pressure measurement.)
- Consolidation Test
- Compaction Test (for fill materials)

For safe and cost effective design of embankment on clayey subsoil, it is very important to detect intermediate sand layers between the clayey subsoil using either piezocone (CPTU) with pore pressure measurement and continuous sampling in borehole. The existence of the intermediate sand layers will reduce the drainage path and increase the rate of consolidation thus reduce significantly the waiting time to achieve the required settlement, and in certain case even the use of vertical drains can be omitted.

Additional soil properties may be needed depending on the construction methods to be adopted. The planning and interpretation of the site investigation and interpretation will not be covered in this paper. Details of the subject can be obtained from papers by Gue & Tan (2000), Gue (1999) and Tan (1999).

All engineers are strongly advised to provide site supervision of the S.I. by staff under his/her direct control to ensure tests are carried out according to the specifications with proper equipment, accessories and method. Otherwise, they would be taking great risks of getting wrong or improper data. Site supervision is also a legislation requirement as stated in Uniform Building By-Laws, 1984 and Street, Drainage and Building Act, 1974 (Act 133).

4 DESIGN CONCEPT

Before carrying out an embankment design and selection of the most appropriate construction methods, the following issues should be considered:

- Boundary of the embankment;
- Influence of the embankment on adjacent structures, services, slopes and drainage;
- Earliest construction start date and completion date;
- Tolerance on total and differential settlements of the proposed embankment.
- Rate at which embankment fill material can be placed;
- Availability of fill from other parts of the site;
- Availability of alternative materials;
- Cost analysis and implication of the ground treatment proposed.
- Future maintenance (frequency and cost)

It is very important to check for the stability of the embankment with consideration for different potential failure surfaces namely circular and non-circular as shown in Figure 1.

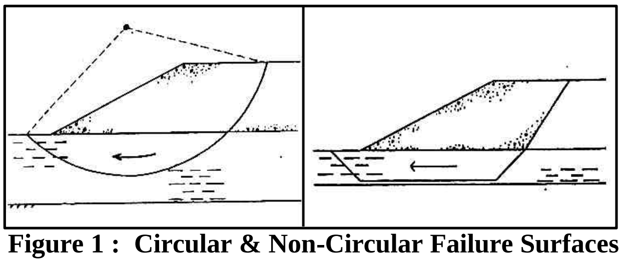


Figure 1 : Circular & Non-Circular Failure Surfaces

The factor of safety to be used in the stability analysis will depend on the following factors :

- Method of analysis
- Reliability of the design method
- Reliability of the design soil parameters
- Consequences of failure in terms of human life and economic loss.

British Standard BS6031:1981 gives no specific values or method for soil strength determination for use in embankment design. It only refers to a range of factor of safety between 1.3 and 1.4 for cut slopes. Generally in practice, the factor of safety on shear strength (FOS) from total stress or undrained strength analyses used in temporary stage is usually taken as between 1.2 to 1.3. FOS of 1.4 and 1.5 are normally adopted in effective stress analyses of embankment for permanent stage using moderately conservative soil parameters.

4.1 Settlement Analysis

In addition to various stability analyses for embankment designs, settlement prediction is also very important especially for high speed track. Settlement of the subsoil supporting the embankment will take place during and after filling. It is 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.

In carrying out stability analyses, it is necessary to estimate the magnitude of settlement which occurs during construction so that the thickness of the fill can be designed to ensure stability. An iterative process is required in the estimation of settlement because the extra fill (more load) required to compensate for settlement will lead to further settlement.

When a load of finite dimensions is rapidly applied on a compressible subsoil, the resulting settlements can be conveniently divided into three stages :

(A) Initial Settlement (also called immediate or undrained or shear settlement), ρ_i
(B) Primary Consolidation Settlement, ρ_c
(C) Secondary Compression, ρ_s

The details of the embankment design, can be obtained from papers by Tan & Gue (2000).

5 GROUND TREATMENT METHODS

The engineer will only able to identify the suitable ground treatment to be adopted after carrying 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 (Total or Partial)
(c) Surcharging
(d) Staged Construction
(e) Vertical Drains (with surcharging or/and staged construction)
(f) Lightweight Fills using Expanded Polystyrene (EPS)
(g) Geosynthetics Reinforcement
(h) Stone Columns
(i) Piled Embankment

5.1 Modification of Embankment Geometry

Reduction of slope angle or construction of counterweight berms improves the stability of the embankment but this method has a disadvantage of greater land-take and volume of fill materials are needed.

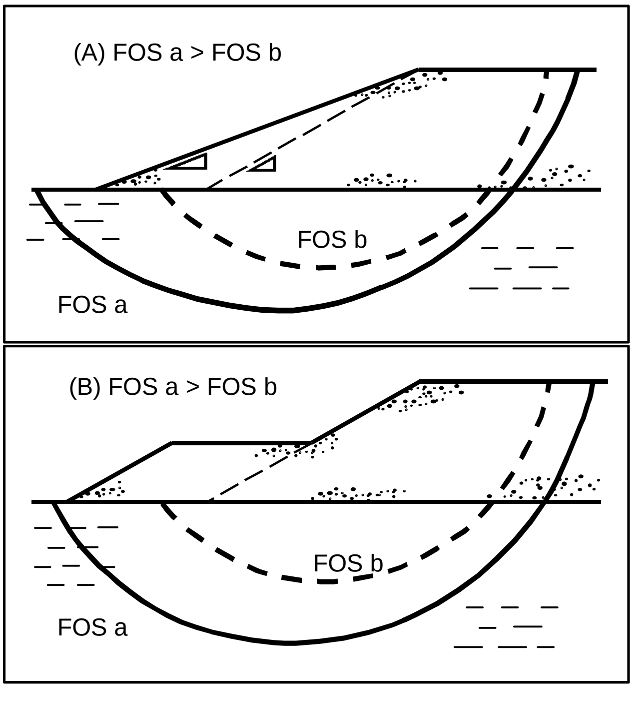


Figure 2 : (A) Reduction in Slope Angle (B) Using Berms

5.2 Excavation and Replacement of Soft Soils (Total or Partial)

This old method is still viable where the very soft compressible cohesive soils are excavated out and replaced with better materials (e.g. compacted sand or suitable fill) that provide a stronger and less compressible foundation. The experience on highway construction in West Malaysia indicates that the excavation and replacement depth up to a maximum depth of 4.5m is viable in terms of cost and practicability. Usually the excavation should extend to at least to the toe of the embankment and beyond to increase the stability of the embankment.

This method will be more difficult if the groundwater level is high. If pumping of water is not practical, then underwater replacement materials (granular materials) should be used. These materials shall be of a grading that it is effectively self-compacting. The main disadvantage of the method is the amount of soft soil (unsuitable materials) which needs to be disposed. During excavation, the stability of the temporary slope must also be check to prevent slip failure even before the good materials can be placed. This method also requires high quality prediction of bearing capacity and settlement.

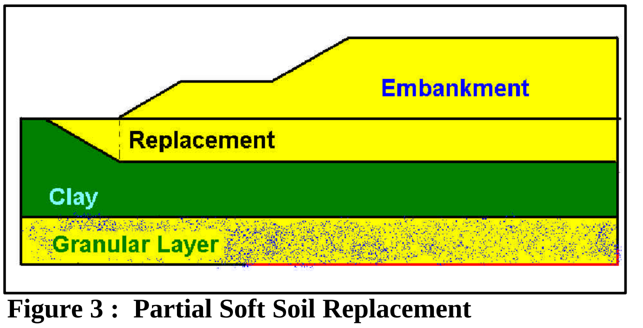


Figure 3 : Partial Soft Soil Replacement

5.3 Surcharging

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 these methods are used to control both total settlement and differential settlement at the abutments to bridge / flyover and where culverts are crossing beneath the embankment. Some of the disadvantages of surcharging are :-

- require waiting period for consolidation before the temporary surcharge materials can be removed
- extra fill materials to be used and later excavated.

This method is only applicable to compressible subsoil with reasonably high permeability (if vertical drains are not used) or height of embankment is low.

5.4 Staged Construction

Staged construction is the method by which the embankment can be constructed on the soft soil such that the rate of filling is governed by the increase in soil strength due to consolidation. Usually vertical drains are used together to increase the consolidation process.

The use of the staged construction method requires close liaison and communication between the design engineer, contractor and supervising engineer. Instruments like settlement markers, displacement markers, piezometers, etc. need to be placed to monitor the performance of the embankment during construction to prevent failure. In more sensitive cases, confirmation of gain in strength is needed before the application of the next stage of loading to ensure safety of embankment. Similar to surcharging method, staged construction is usually effective only for compressible soils with high permeability (if vertical drains are not used).

5.5 Vertical Drains

Vertical prefabricated band-shaped drains are installed through soft clay soils to accelerate the speed of consolidation of the subsoil by reducing the drainage path lengths and utilizing the naturally higher horizontal permeability of clay deposits.

Prefabricated drains using corrugated polymeric materials (polyethylene and polypropylene) for the core, and woven or non-woven fabric or fibre for the filter. They are about 100mm wide, about 4mm thick and are installed using a closed-end mandrel and usually to a depth no more than 30m in very soft soil or terminate shorter in stronger materials (SPT'N' $\approx$ 7 to 10). Sometimes, pre-boring is required to penetrate some surface crust or artificial obstructions at the surface.

Vertical drains will only be effective when using in conjunction with another technique, such as surcharging and staged construction and the design is governed by the time allowed in the construction programme for consolidation to occur.

The vertical drains should have sufficient capacity to enable the water to discharge to layers above and below the consolidating layer. Granular materials are laid above the ground surface as platform for the movement of the plant and also as drainage layer. The drainage layer must be free from blockage so that water from the vertical drains can be discharged effectively. Pre-fabricated drains are usually cut off about 150mm above the initial drainage layer prior to placing further drainage material. Hence the drains have to be properly embedded inside the drainage layer by manual labour.

We also wish highlight that 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.

5.6 Lightweight Fills using EPS

Lightweight fills using Expanded Polystyrene (EPS) will reduce the weight of the embankment significantly thus increasing the stability of the embankment and reduce settlement in long term. Usually EPS is used in bridge approach embankment to smoothen the differential settlement between rigid structure (bridge) and the abutment as shown in Figure 4. The choice of the grade of EPS will generally depend on the required strength and stiffness. The most critical condition in designing embankment using EPS is flotation (uplift forces) under flood condition because of its the low density.

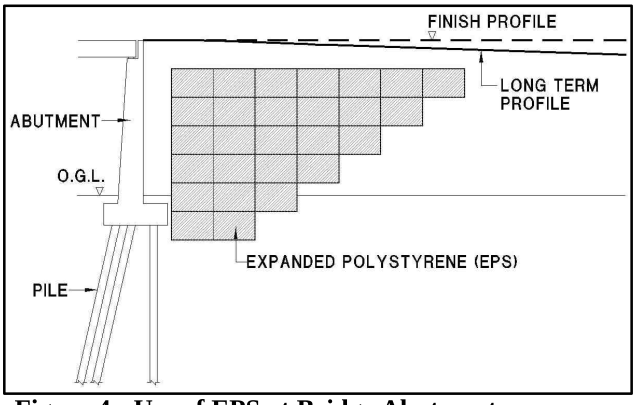


Figure 4 : Use of EPS at Bridge Abutment

EPS is supplied in blocks that can be easily handled by two men. The first layer of blocks should be placed on a bliding layer of sand of at least 50mm thick. Successive horizontal layers of blocks shall be placed in a bond pattern to avoid continuous vertical joints and all blocks are connected by dowels. The top of the EPS is usually covered with high density polyethylene (HDPE) sheeting and reinforced concrete slab to protect from UV light, hydrocarbons and solvents that can cause damage to the EPS. Other precaution include protection from burrowing animals/insects.

5.7 Geosynthetics Reinforcement

Geosynthetics in the form of geogrid or geotextile are sometime used to improve the stability of the embankment over soft soils. Usually the geosynthethics are placed at the base of the embankment. The function of the geosynthetics reinforcement is to reduce the forces causing failure (lateral stresses and outward movement of the soil) and increase the forces resisting failure (tensile strength of the geosynthetics). For design of geosynthetics reinforced embankment, reference shall be made to BS8006 : 1995 "Code of Practice for Strengthened/ reinforced soils and other fills".

The important parameters for design are strength, stiffness, creep, long term behaviour, permeability, resistance to chemicals and UV light resistance. Attention shall be paid to ensure that jointing and overlap details of the geosynthetics are adhered to. Care shall be taken as to the handling and use of plant on geosynthetics as this may affect the properties assumed in design.

5.8 Stone Columns

Stone columns are used to strengthen thus increase the stability of the embankment and to reduce settlement (stiffening). Stone columns also accelerate the rate of consolidation of the subsoil. Stone column as the name imply is replacing the very poor soils are replaced with granular materials (gravels) in grid pattern forming granular columns.

There are two basic techniques for forming stone columns, vibro-replacement (in clayey soils) and vibro-displacement (in sandy soils).

When designing stone columns the following mode of failure shall be checked :

- Bulging failure
- General shear failure
- Sliding failure

The two case histories of embankment failures supported by stone columns investigated by the Authors indicate that the design of stone columns using computer software (Priebe's Method, 1995) alone is not adequate to ensure safety. Further checking of the three failure modes stated above especially general shear failure in very soft cohesive soil is necessary to prevent failure.

If stone columns are used to reinforce the subsoil for embankment construction, it is also very important to prevent "mushroom" effects in long term in which the fill with stone column immediately beneath it will protrude up like hump compared with the fill between the stone columns. This is due to instability of the arch region in the fill above the stone columns. Some general solutions are to use granular (gravels) materials with high angle of friction as fill materials above the closely spaced stone columns to have proper 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 the "mushroom" effects.

5.9 Piled Embankment

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.

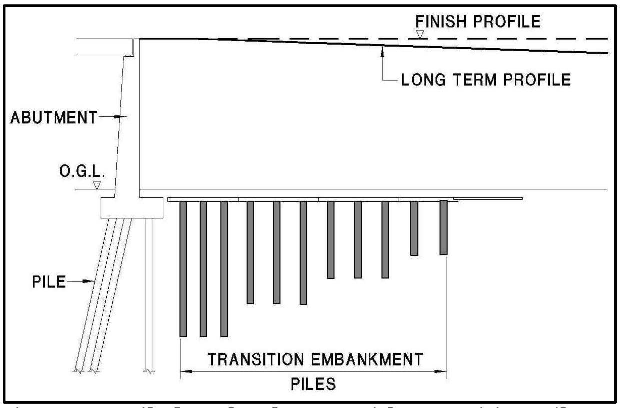


Figure 5 : Piled Embankment with Transition Piles

Piled embankment with transition piles is also used to provide a smooth transition (reduce differential settlement) between bridge abutment and the bridge as shown in Figure 5.

The weight of the fill and any load on top of it is transferred to the piles using a reinforced concrete slab or using high-strength geosynthetics reinforcement between isolated pile caps. Many case histories in Malaysia have shown that using isolated pile caps with geosynthetics had caused “mushroom” effects and therefore piled embankment with r.c. slab is recommended. Figure 6 shows an example of cost saving on the piled embankment by using granular fill at the slopes of the embankment but it is important to check and limit the safe height of the embankment where the fill is not supported by piles will not fail either through bearing capacity failure or slip failure. The advantage of using gravels at the slope is to prevent tension cracks due to differential settlement between piled and unpiled sections.

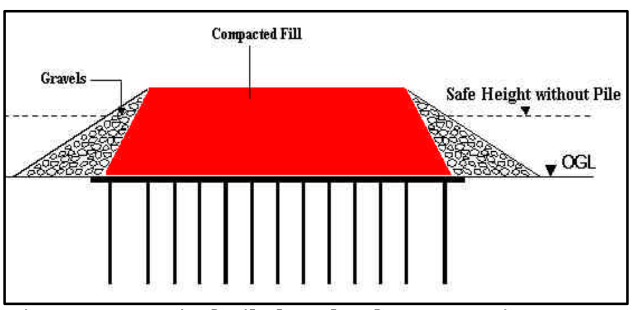
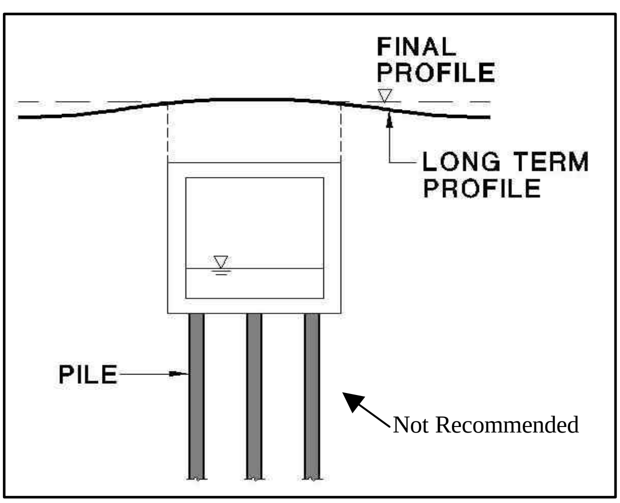


Figure 6 : Typical Piled Embankment Section



It is very important to construct the slab of the piled embankment lower than the original ground level so that there is no filling at the piled embankment area to cause long settlement of the subsoil that would induce negative skin friction (down drag) to the piles.

Figure 7 : Piled Culvert (Not Recommended)

6 CONSIDERATION FOR APPROACHES TO A CULVERT

Very often, the culverts are design and constructed as shown in Figure 7 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 consequences of having rigid platform as shown induces differential settlement between the rigid piled culvert and the unpiled embankment.

The possible geotechnical solutions to eliminate the differential settlement are (Gue, 2000) :-

- Provide a larger culvert to allow for long term settlement. (Figure 8)
- Provide a transition piled embankment to the approaches to a culvert.

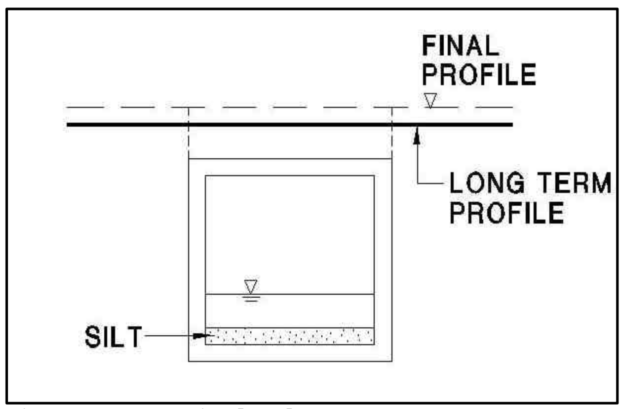


Figure 8 : Oversized Culvert

The first option as shown in Figure 8 allows the culvert to settle evenly together with the embankment hence the size available for flow will reduce with time as the culvert settles and a section of the culvert will be silted up as shown. The net flow area after taking into consideration of settlement and siltation should have a size not smaller than that required for the volume of flow designed.

7 CONCLUSION

There are many construction methods that can be adopted for the high speed track embankment and they are :

(a) Modification of Embankment Geometry
(b) Excavation and Replacement of Soft Soils (Total or Partial)
(c) Surcharging
(d) Staged Construction
(e) Vertical Drains (with surcharging or/and staged construction)
(f) Lightweight Fills using Expanded Polystyrene (EPS)
(g) Geosynthetics Reinforcement
(h) Stone Columns
(i) Piled Embankment

Each method has its advantages and disadvantages. Therefore to ensure a successful construction of high speed track embankment over very soft soils, the following criteria shall be fulfilled :

- Awareness of the project requirements in terms of serviceability criteria (deformation tolerances, differential settlement, bearing capacity, etc.), costs (construction cost and maintenance cost), site constraint and time (construction time, service period).
- Knowledge on the site and subsoil conditions through proper desk study, gathering of geological information and well planned and supervised subsurface investigation and laboratory testing to acquire the necessary reliable parameters for geotechnical designs.
- Proper geotechnical design to address both stability of the embankment and control of deformation.
- Full time proper supervision of the construction works by qualified personnel / engineer.
- Careful and proper monitoring on the performance of the embankment during and after construction through instrumentation scheme to prevent failure (Tan & Liew, 2000)
- Proper construction control to prevent uncontrolled filling, stocking piling of fill materials causing overloading of the embankment, proper compaction, etc.

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