

Instrumented Trial Embankment on Soft Ground at Tokai, State of Kedah, Malaysia

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ABSTRACT: The geometrical tolerance of railway tracks is generally very stringent, especially at high operating speeds. Hence, when long stretches of the embankment structure supporting the tracks are traversing through soft alluvium deposits, cost effective designs meeting the design performance and construction schedule are required. A cost effective treatment such as PVD with temporary surcharging was designed to meet the stringent performance requirements of differential settlement of not more than 10 mm over a chord length of 10m and a total settlement of not more than 25mm within 6 months after completion. In order to meet the tight construction schedule, basal reinforcement was also used to allow higher embankments to be built without compromising on the embankment stability during construction. Therefore, in order to verify the design philosophy of the ground treatment method adopted, a fully instrumented trial embankment was carried out at Tokai, State of Kedah, Malaysia. This paper presents the consolidation settlement behavior of the trial embankment during construction and waiting period. Back analyses using Finite Element Modeling (FEM) was performed to evaluate the performance of the ground treatment and to verify the subsoil parameters used in the design.

Keywords: Trial Embankment, instrumentation, soft ground, consolidation settlement, excess pore water pressure, lateral displacement

1. INTRODUCTION

The construction of the electrified double track project for northern part of Peninsular Malaysia commenced in year 2007. As most of the embankments supporting the track are founded on soft alluvium deposit, cost effective ground treatment such as PVD with temporary surcharging was widely used to meet the stringent settlement requirements. In order to verify the design philosophy of the ground treatment method adopted, a fully instrumented trial embankment was constructed at Tokai, State of Kedah as shown in Figure 1. This is to study the consolidation settlement behavior, excess pore water pressure response, and lateral displacement at the toe of embankment as indicator of embankment stability during construction filling and rest period. Figure 1 shows an overview of instrumented trial embankment during the surcharging period.

This paper presents the settlement behaviour of the trial embankment. Back analyses using Finite Element Modelling (FEM) was also performed to evaluate the performance of the ground treatment and to verify the subsoil parameters used in the design.

2. SUBSOIL CONDITION

The subsoil condition at trial embankment is relatively homogenous consisting of very soft to soft clay within a depth of 15m.

Underlying is dense silty sand to sand from depth of 15m to 24m depth. Hard layer with SPTN' value of more than 50 was found below 24m. The general subsoil properties including bulk density, compression ratio (CR), re-compression ratio (RR), over consolidation ratio (OCR), pre-consolidation pressure (P_c), undrained shear strength (s_u) and Atterberg limit are plotted in Figure 2. The interpreted subsoil parameters based on the field and laboratory tests are summarized in Table 1.

3. GROUND TREATMENT AND INSTRUMENTATION

The general ground treatment details for trial embankment are summarised in Table 2. The instrumentation scheme includes settlement gauges, extensometers, inclinometers, ground displacement markers, vibrating wire piezometers, standpipe and surface settlement markers. Figures 3 and 4 show the cross section and layout plan of instrumentation scheme. Settlement at centre of embankment was measured by settlement gauges SG2, SG5 and SG8. Whilst, settlements at edge of embankment were measured by settlement gauges SG1, SG3, SG4, SG6, SG7 and SG9. Settlements at various depths were measured by extensometers EXT1, EXT2 and EXT3.



Figure 1 Location and overview of instrumented trial embankment

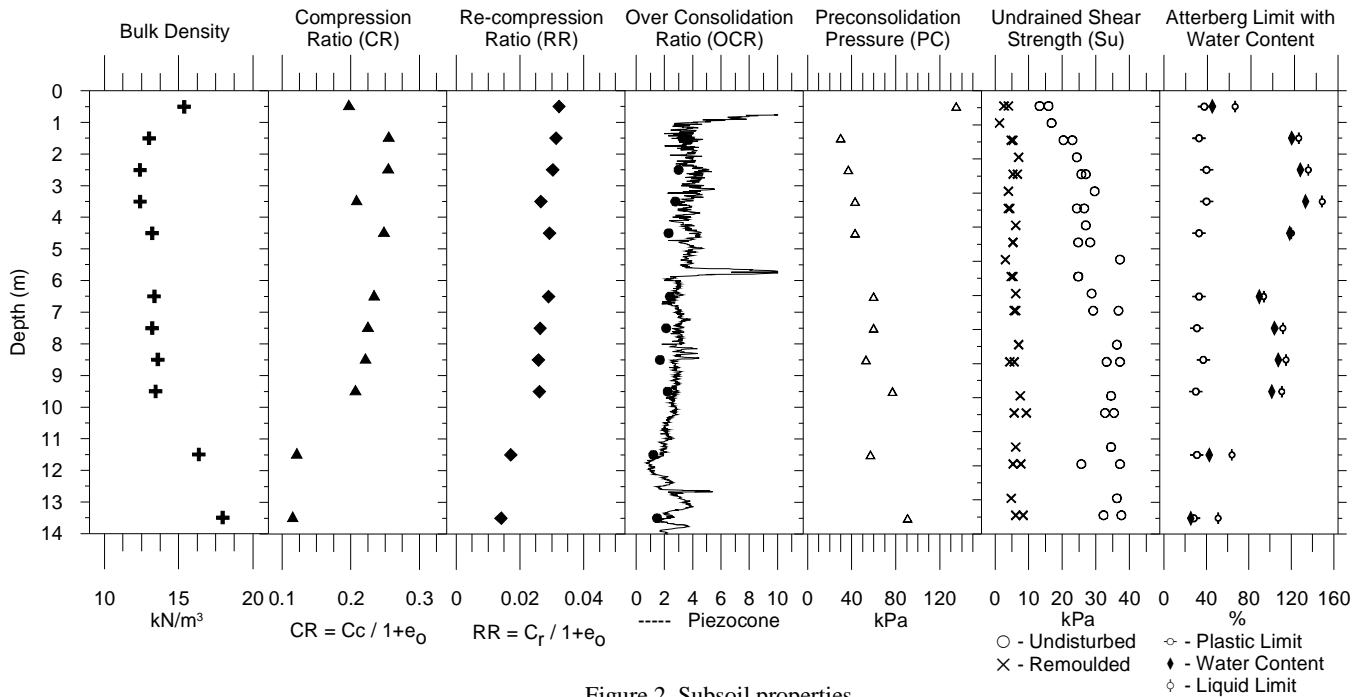


Figure 2 Subsoil properties

Table 1 Interpreted subsoil parameters

Depth	Soil type	SPT'N	γ_{bulk} (kN/m ³)	c' (kPa)	ϕ' (°)	CR	RR	OCR	s_u (kPa)
0m to 5m	CLAY	0 - 1	13	5	21	0.25	0.03	3.0 - 4.4	15 - 25
5m to 10m	CLAY	0 - 1	13	5	21	0.22	0.027	1.7 - 2.7	25 - 35
10m to 15m	CLAY	1 - 4	16.5	5	21	0.12	0.017	1.2	30 - 35
15m to 24m	silty SAND	12 - 21	18	5	30				
24m to 30m	silty SAND	> 50	18						

Table 2 Design Criteria and ground treatment details

Design criteria:	Maximum settlement of 25mm and maximum differential settlement of 10mm for a chord of 10m (1:1000) over 6 months.
Soil replacement:	1m deep
PVD details:	15m long with 1.2m spacing in triangle pattern.
Sand blanket:	500mm thickness
Basal reinforcement:	Geotextile with ultimate tensile strength of 200kN/m
Surcharge:	1.5m thickness
Stages loading*:	1. 3.9m thick fill and rest for 4 months. 2. 5.8m thick fill and rest for 3 months. 3. 7.6m thick fill and rest for 3 months.

* The multistage construction (with higher height) was carried out due to site condition and problems such as delay due to wet monsoon season, no borrow source, etc. The original intent is to construct the trial embankment in single stage loading of up to 5.9m.

4. BACK ANALYSIS BY FEM MODELLING

Back analyses were carried out by using finite element modelling (FEM) software (Plaxis). Soft Soil Model (SSM) was adopted to simulate the behaviour of the soft clay. The SSM is based on the Modified Cam-Clay Model. Stress dependent stiffness (logarithmic compression behaviour) between volumetric strain and mean effective stress is assumed. Distinction between primary loading and unloading-reloading stiffness based on the modified index λ^* (CR/2.3) and κ^* (2RR/2.3) were obtained from 1D-Odometers tests. In addition, SSM can also memorise the pre-consolidation stress with OCR input in the initial stage. Hardening Soil Model (HSM) was utilised to model the underlying silty sand layer and the fill materials.

From a macro point of view, PVD increases the subsoil mass permeability in vertical direction (Lin et al, 2006). Therefore, an equivalent vertical permeability, k_{ve} , approximately represents the

effect of both the vertical permeability of natural subsoil and radial consolidation by PVD was established to simulate the PVD behaviour in the back analyses. Based on the back analyses results, k_{ve} is about 5.8 times more permeable than the vertical permeability of the original subsoil (soft clay). The geometry of FEM and the input parameters are shown in Figure 5 and Table 3 respectively. The back analyses were carried out adopting undrained condition (with generation of excess pore water pressure) with coupled consolidation for each stage of construction.

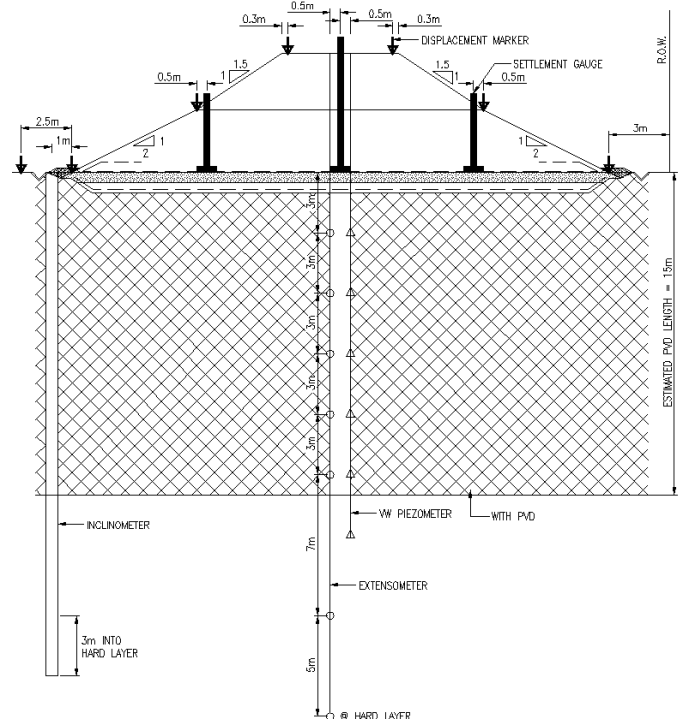


Figure 3 Cross section of instrumentation

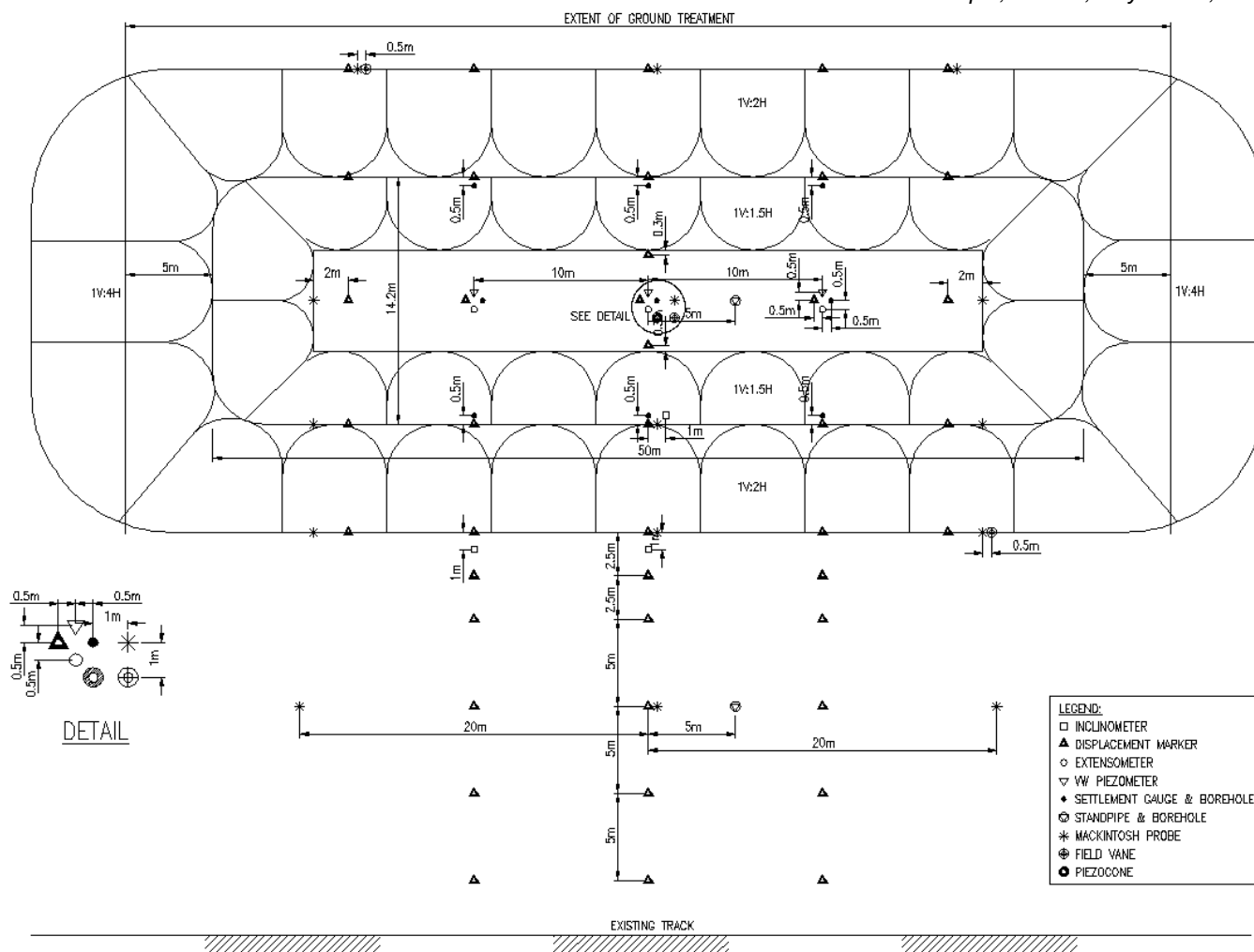


Figure 4 Instrumentation layout plan

5. MEASUREMENT VERSUS CALCULATION

The calculated results of the FEM analyses are compared with the measured data vertical deformation (settlement). Figure 6 shows the settlement profile of the embankment at the centre and the edge versus embankment filling time.

The measured settlements at the end of surcharging period are averagely 1963mm at the centre of the embankment (which is about 26% of the total constructed embankment height) and 1545mm at the edge of the embankment. The calculated settlement at the centre of embankment is 1932mm which is 31mm or 1.6% lower than the measured value. Whilst, the prediction on edge settlement is 1457mm which is 88mm or 5.7% lower than the measured value. In general, the back-calculated settlement profile is fairly close to the measured settlement profile especially during first stage of filling (within 200 days) up to a fill thickness of 3.9m.

Settlements at various depths were obtained from extensometer installed at centre of trial embankment. Figure 7 shows the settlement profile of the embankment at various depths versus embankment filling time and thickness of fill.

The extensometers indicated that average settlements at depth of 1.32m, 1.88m, 3.33m, 4.35m and 6.34m were 2084mm, 1828mm, 1672mm, 1351mm and 1108mm respectively. Generally, the back-calculated settlements in various depths are about 10% to 26% (186mm to 329mm) less than the measured settlement. The measured settlement for the top 6m was close to the surface settlement. The soft clay layer at the depth of first 6m experience largest portion of settlement as expected. Extensometers were also installed at deeper depth to study the settlement profile with depth.

Unfortunately, the extensometers were damage after the first stage of filling. This is likely cause by the large settlement.

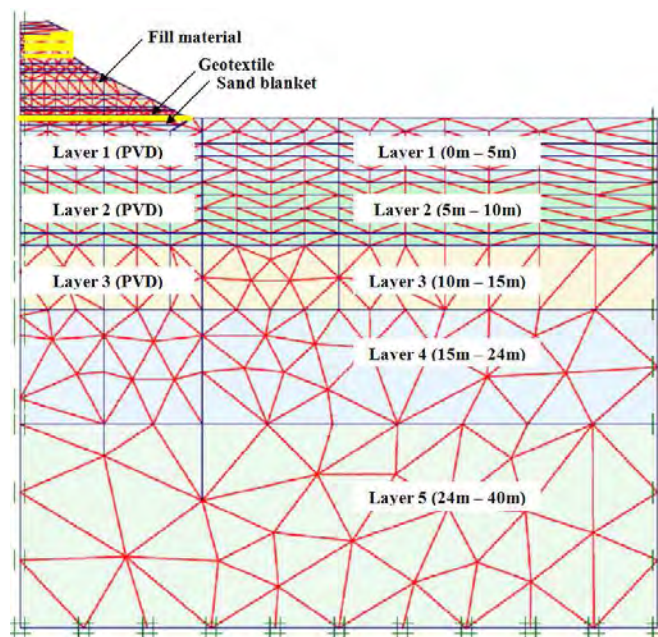


Figure 5 Geometry of FEM

Table 3 FEM input parameters

Material	Soil Model	γ_{sat} (kN/m ³)	k_x (m/s)	k_y (m/s)	λ^*	κ^*	E_{50}, E_{oed}	E_{ur}	c'	ϕ'
Layer 1 (0 - 5)	SSM	13	2.0E-08	1.0E-08	0.109	0.026			5	21
Layer 2 (5 - 10)	SSM	13	2.0E-08	1.0E-08	0.096	0.023			5	21
Layer 3 (10 - 15)	SSM	16.5	2.0E-08	1.0E-08	0.052	0.015			5	21
Layer 4 (15 - 24)	HSM	18	1.0E-06	1.0E-06			34000	102000	5	30
Layer 5 (24 -40)	HSM	18	1.0E-05	1.0E-05			34000	102000	5	30
PVD of Layer 1	SSM	13	2.0E-08	5.8E-08	0.109	0.026			5	21
PVD of Layer 2	SSM	13	2.0E-08	5.8E-08	0.096	0.023			5	21
PVD of Layer 3	SSM	16.5	2.0E-08	5.8E-08	0.052	0.015			5	21
Sand blanket	HSM	19	2.3E-05	2.3E-05			30000	90000	0	30
Fill materials	HSM	19 - 20	1.0E-06	1.0E-06			30000	90000	5	28

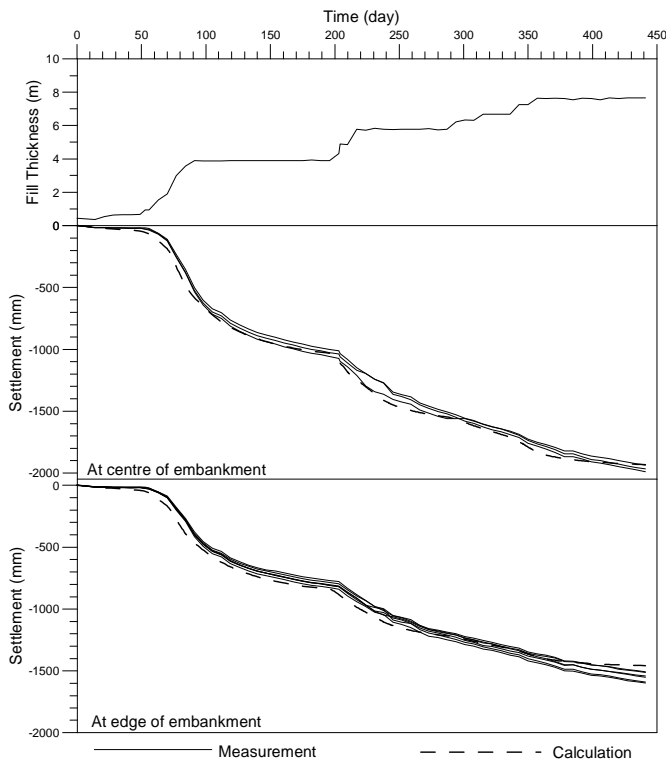


Figure 6 Settlement of embankment

6. CONCLUSIONS

Based on observations of the trial embankment performance and the analyses results, the following conclusions are made:

- The total settlement at the end of surcharge period is about 26% of the constructed embankment height.
- The measured settlement at original ground level was about 1.6% to 5.7% (31mm to 88mm) more than the calculated settlement.
- In general, the settlement was reducing with depth under the embankment. The calculated settlements in various depths were about 10% to 26% (186mm to 329mm) less than the measured settlement.
- In finite element modelling, an equivalent vertical permeability, k_{ve} , approximately represents the effect of both the vertical permeability of natural subsoil and radial consolidation by PVD can be adopted to simulate the PVD behaviour.
- Back analysis by using equivalent vertical permeability method for PVD treatment is about 5.8 times more permeable than the original soil permeability.
- The settlement measured for the first stage filling up to 3.9m has good agreement with the settlement computed using SSM with coupled consolidation and undrained behaviour. However, the settlement measured and computed at the end of surcharging period differ by less than 6%.

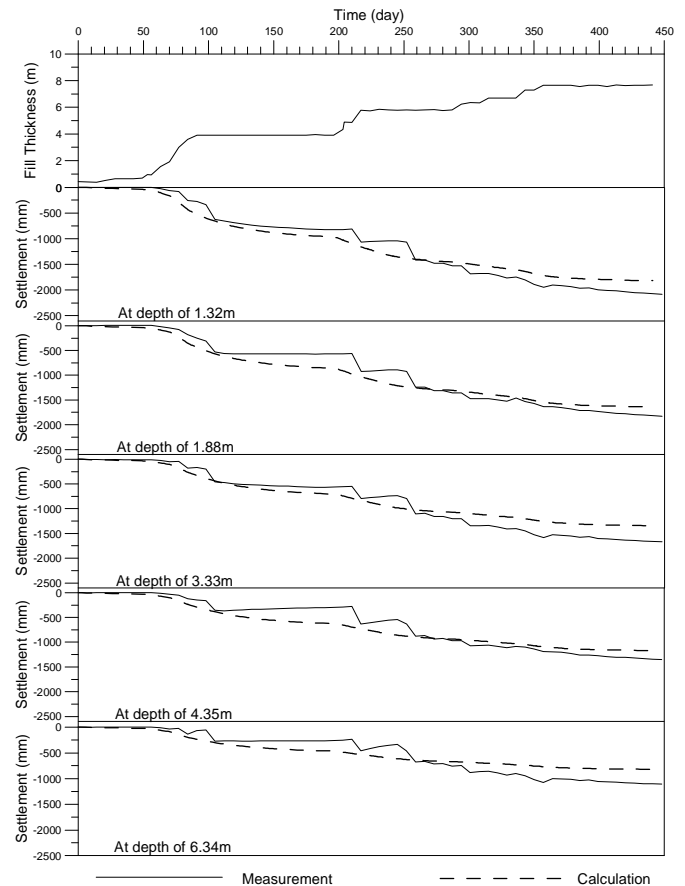


Figure 7 Settlement of embankment at various depths

7. REFERENCES

- [1] D.G.Lin, W.T.Liu and P.C.Lin, Journal of the Southeast Asian Geotechnical Society, December 2006, pg. 157 – 170.