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

Embankment essai instrumenté sur un sol mou à Tokai, État de Kedah, en Malaisie

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ABSTRACT: The geometrical tolerance of railway tracks at high operating speed is generally very stringent. Hence, when long stretches of the railway embankment traversing through soft alluvium deposits, cost effective designs meeting the design performance and construction schedule are required. A cost effective treatment such as prefabricated vertical drain (PVD) with temporary surcharging was designed to meet the stringent performance requirements. In addition, basal reinforcement was adopted to allow higher embankments to be built without compromising on the embankment stability during construction and to meet the tight construction schedule. Therefore, a fully instrumented trial embankment was carried out at Tokai, State of Kedah, Malaysia to verify the design philosophy of the ground treatment method adopted. This paper presents the consolidation settlement behavior and excess pore water pressure responses of the trial embankment during construction and surcharge 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.

RÉSUMÉ : La tolérance géométrique des voies ferrées à grande vitesse de fonctionnement élevée est généralement très strictes. Ainsi, lorsque de longues étendues de la voie ferrée traversant remblai par des dépôts d'alluvions souples, efficaces coûtent conceptions répondant à la performance de la conception et du calendrier de construction sont nécessaires. Un traitement rentable telles que vidange verticaux préfabriqués (PVD) avec surcharge temporaire a été conçu pour répondre aux exigences de performance rigoureuses. En outre, le renforcement de base a été adopté pour permettre aux plus digues pour se construire sans compromettre la stabilité de remblai lors de la construction afin de respecter le calendrier de construction serré. Par conséquent, un remblai d'essai entièrement instrumenté a été effectuée à Tokai, État de Kedah, en Malaisie afin de vérifier la philosophie de conception de la méthode de traitement des sols adopté. Cet article présente le comportement tassement de consolidation et de l'excès de pression d'eau interstitielle des réponses du remblai d'essai pendant la construction et la période d'attente. Retour à l'aide des analyses de modélisation par éléments finis (FEM) a été réalisée afin d'évaluer la performance du traitement des sols et de vérifier les paramètres du sous-sol utilisés dans la conception

KEYWORDS: Instrumented trial embankment, soft ground, consolidation settlement .

1 INTRODUCTION

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

This paper presents the settlement behaviour and excess pore water pressure response 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 adopted in the design.

2 SUBSOIL CONDITION

The subsoil is relatively homogenous consisting of very soft to soft CLAY (15m thick) overlying dense silty sand to sand from depth of 15m to 24m. Hard layer with SPT'N' 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 (Pc), 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 as shown in Figure 3. 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. The multistage construction with higher height of up to 7.6m was carried out due to site condition and problems such as delay in view of 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 under loading condition and coupled consolidation process for each stage of construction. Stress dependent stiffness (logarithmic compression behaviour) between volumetric strain and mean effective stress is assumed in SSM. 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 Oedometers tests. In addition, SSM is able to memorise the pre-consolidation stress with OCR input in the initial stage. Whilst, 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 is shown in Figure 4.

5 MEASUREMENT VERSUS CALCULATION

5.1 *Settlement*

The calculated results of the FEM analyses are compared with the measured settlement. Figure 5 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 and 1545mm at the centre and edge of the embankment respectively. This correspondences to 26% and 20% of the total constructed embankment height. The calculated settlement at the centre of embankment is 1932mm which is 31mm or 1.6% 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.

Figure 1. Location and overview of trial embankment.

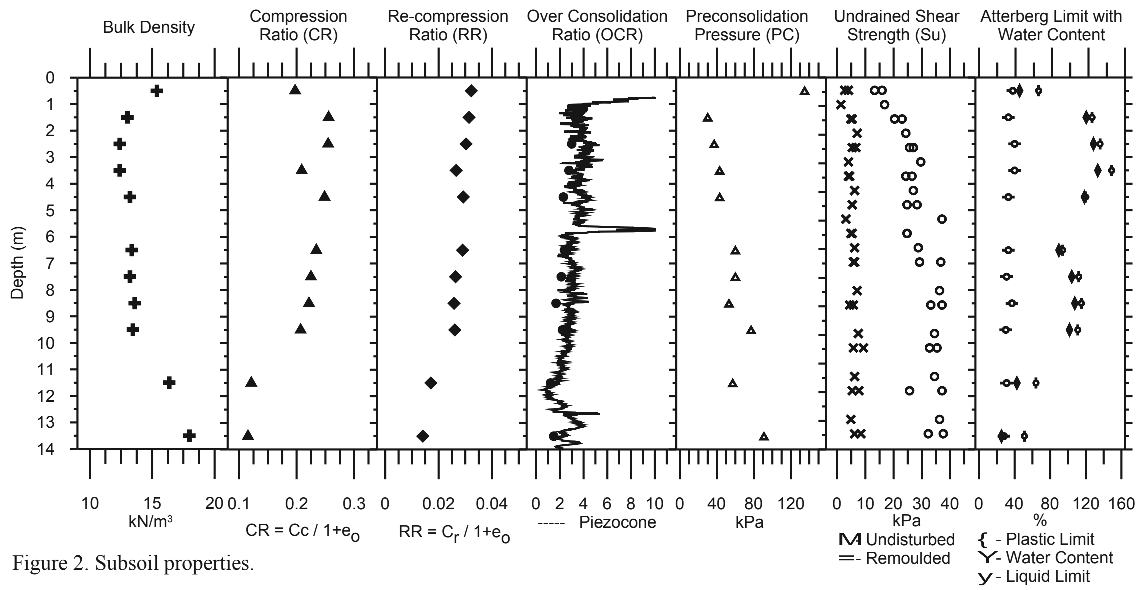

Figure 2. Subsoil properties.

Table 1. Interpreted subsoil parameters.

Depth	Soil type	SPT'N	γbulk (kN/m3)	c' (kPa)	ϕ' (°)	CR	RR	OCR	su (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 t o15m	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						

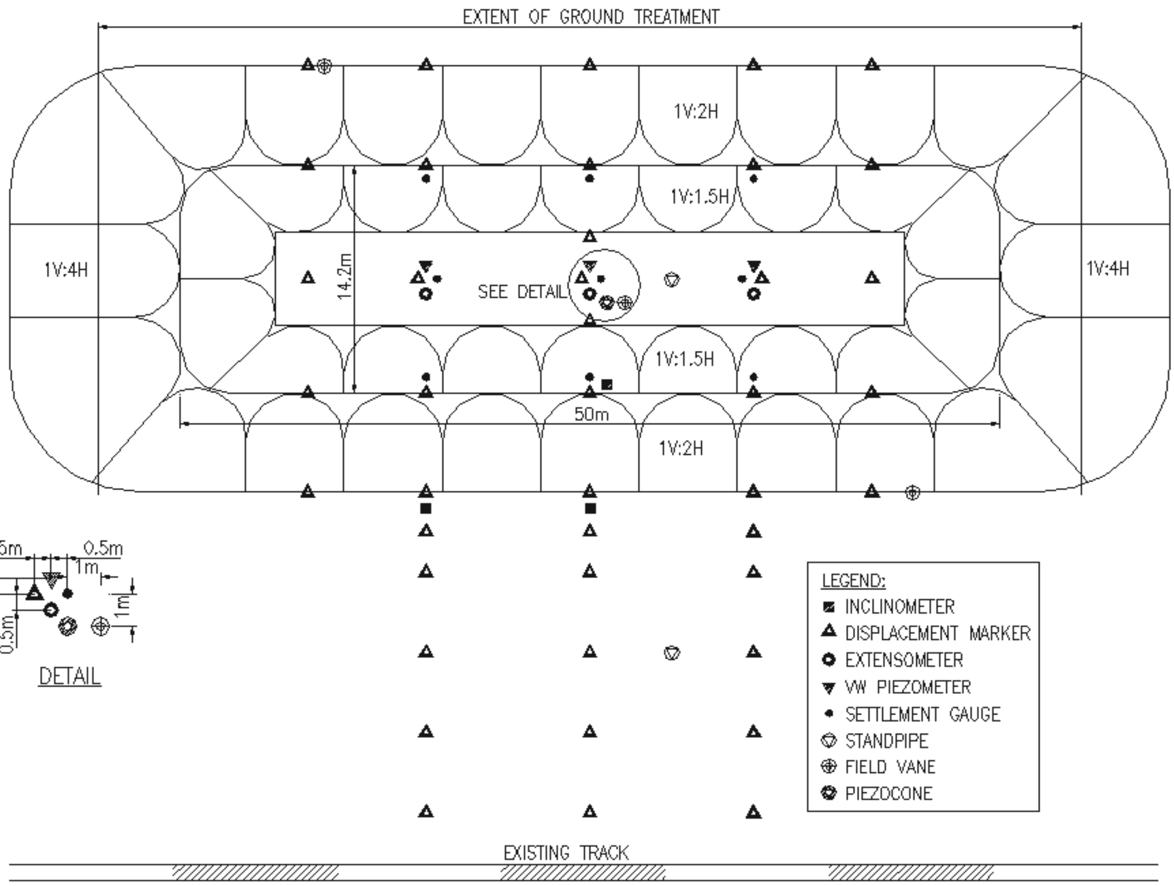

Figure 3. Instrumented layout plan.

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.

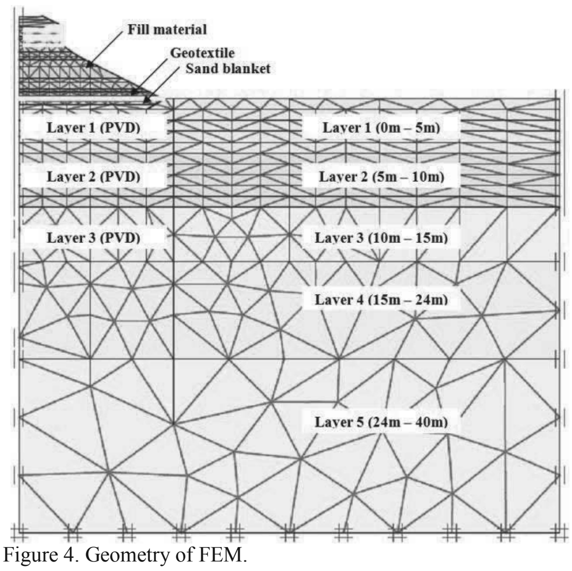

Figure 4. Geometry of FEM.

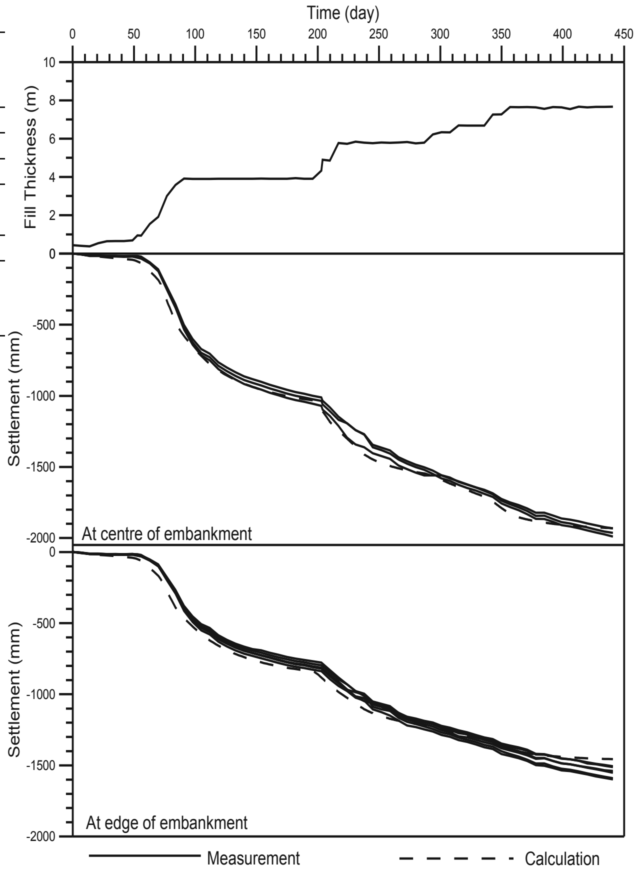

Figure 5. Settlement of embankment.

5.2 *Excess Pore Water Pressure*

The calculated results are compared with the measured excess pore water pressure at varies depths. Excess pore pressures were monitored using vibrating wire (VW) piezometers installed at centre of trial embankment. Figure 6 shows the excess pore water pressure profiles at depths of 2m, 3m, 4m, 8m and 10m versus embankment filling time. Generally, the measured pore water pressure increased during filling and dissipated during surcharge period. At 1st stage of filling (up to 3.9m), the VW piezometers indicated that the excess pore pressure at depth of 2m, 3m, 4m, 8m and 10m were 21kPa, 27kPa, 32kPa, 35kPa and 31kPa respectively. The measured excess pore pressure at depth of 2m is about 6kPa less than calculated result. However, the measured excess pore pressures at 3m depth and below are less than the calculated result with various pressure of 7kPa to 22kPa. The calculated result over predicted the excess pore pressure by more than 50% for depth at 4m and below. At 2nd stage of filling (up to 5.8m), the difference between measured and calculated results were less than 5kPa for depth of 4m and below. However, the calculated result over predicted the excess pore water pressure by more than 50% for depth of 3m and above.

VW piezometer results were corrected based on the measured settlement from extensometer at various depths. This is because the VW piezometers embedded into subsoil will settle together with subsoil during consolidation process. Some of the extensometers were damaged at 3rd stage of filling works. Therefore, the VW piezometer results at depth of 8m and 10m were not presented for 3rd stage filling.

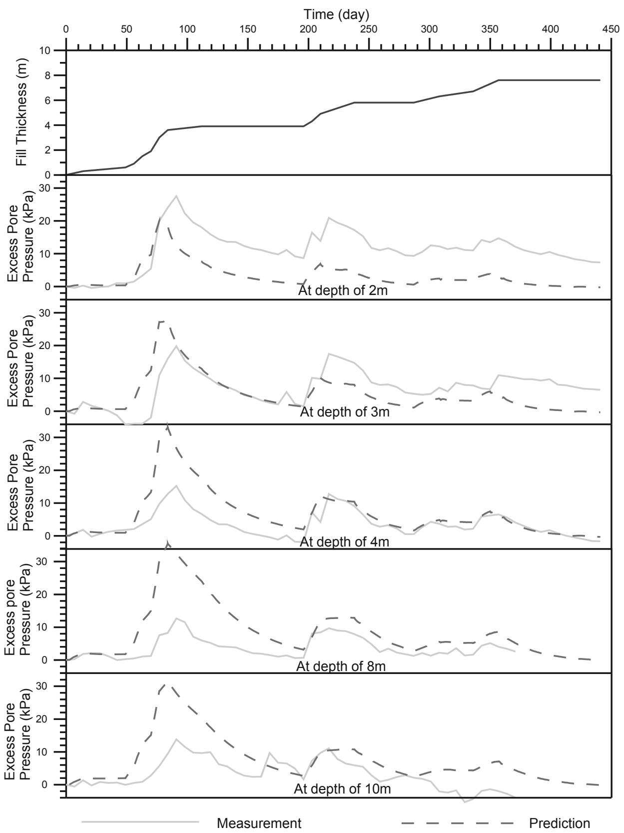

Figure 6. Measured excess pore pressure of embankment at depth of 2m, 3m, 4m, 8m and 10m.

5.3 *Lateral Displacement*

The measured lateral displacements of the embankment and subsoil compared with the predicted values at the end of surcharging period are presented in Figure 7. As refer to Figure 3, the lateral displacement of trial embankment were monitored by three inclinometers with two inclinometers located at the toe of embankment and one inclinometer located at the slope of embankment. The maximum measured lateral displacement at the toe of embankment is 172mm at depth of 2.5m below ground. The calculated values were over predicted by 79% (134mm). For the lateral displacement measured at the slope, the maximum measured lateral displacement is 258mm at depth of 3.2m below ground. The calculated displacement was over predicted by 62% (162mm).

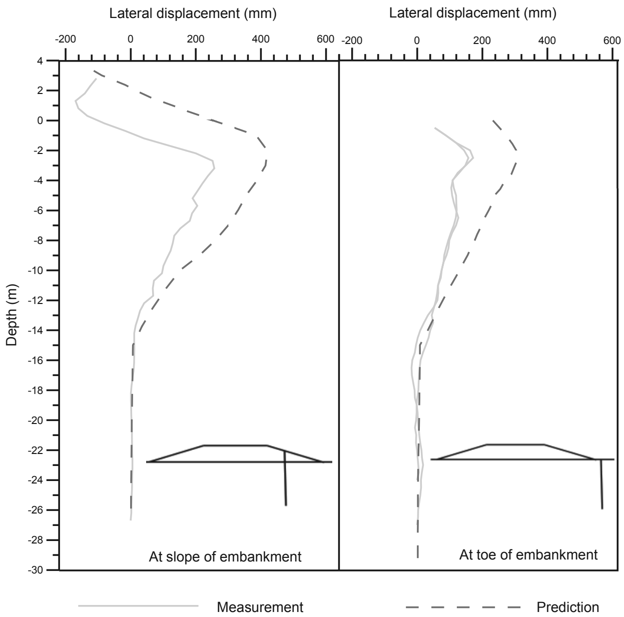

Figure 7. Measured lateral displacement of embankment.

6 CONCLUSIONS

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

a) The total settlement at the end of surcharge period is about 26% of the constructed embankment height.
b) The measured settlements at original ground level were about 1.6% to 5.7% (31mm to 88mm) more than the calculated settlement.
c) 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.
d) Back analyses using equivalent vertical permeability method for PVD treatment is about 5.8 times more permeable than the original subsoil permeability.
e) The settlement measured for the first stage filling up to 3.9m has good agreement with the settlement computed using FEM. The settlements measured and computed at the end of surcharging period only differ by about 6%.

7 REFERENCES

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