

Construction Control Chart developed from Instrumented Trial Embankment on Soft Ground at Tokai of Kedah, Malaysia

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Abstract

In order to develop and successfully implement a cost effective ground treatment design for railway embankment traversing through soft alluvium deposits for high speed train, a fully instrumented trial embankment was carried out at Tokai, State of Kedah, Malaysia for verification of design. Cost effective ground treatment of prefabricated vertical drain (PVD) with temporary surcharging and geotextile basal reinforcement were widely adopted for the 200km long railway embankment and were designed to meet the stringent performance requirements. From the back analyses using Finite Element Modeling (FEM) of the fully instrumented trial embankment, the performance of the ground treatment is evaluated and verified. Additional FEM analyses were carried out to develop a construction control chart to be used during construction to allow high embankments to be built without compromising on the stability during construction and to meet the tight construction schedule and technical requirements. This paper will present the FEM back analyses results of the fully instrumented trial embankment, the construction control chart developed together with the pre-planned action plan during construction.

Keywords: Instrumented trial embankment, construction control chart, embankment stability, 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 prefabricated vertical drain (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. FEM analyses were carried out to develop a construction control chart to be used during construction to allow high

embankments to be built without compromising on the stability during construction and to meet the tight construction schedule and technical requirements. This paper presents the construction control chart developed together with the pre-planned action plan during construction.



Figure 1: Location and overview of trial embankment.

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 (su) and Atterberg limit are plotted in Figure 2. The interpreted subsoil parameters based on the field and laboratory tests are summarised in Table 1.

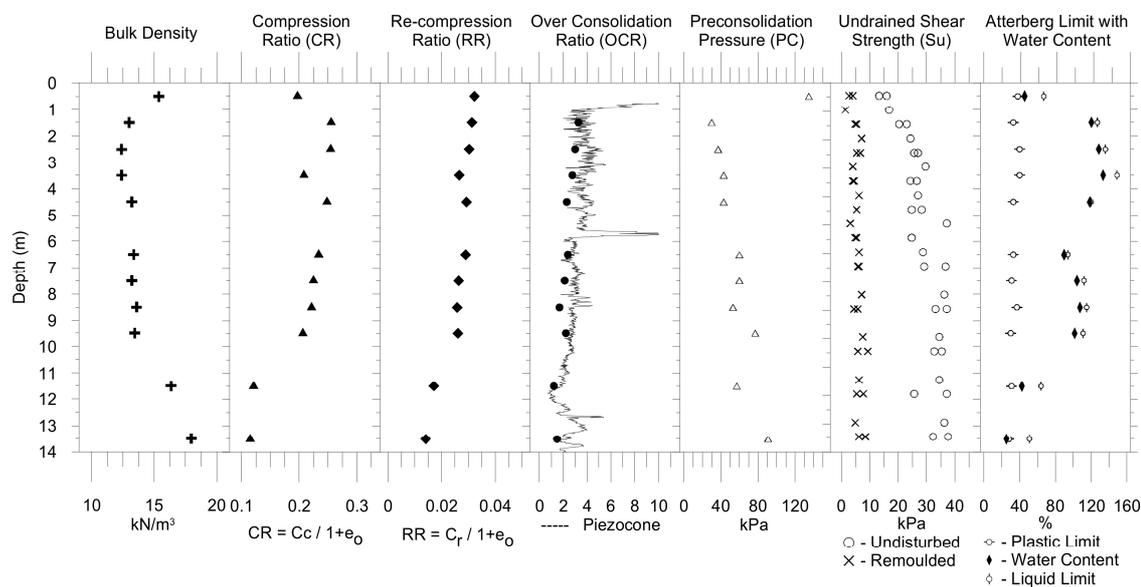


Figure 2: Subsoil properties.

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

Table 1: Interpreted subsoil parameters

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 center 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.

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.

Table 2: Design criteria and ground treatment details

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.

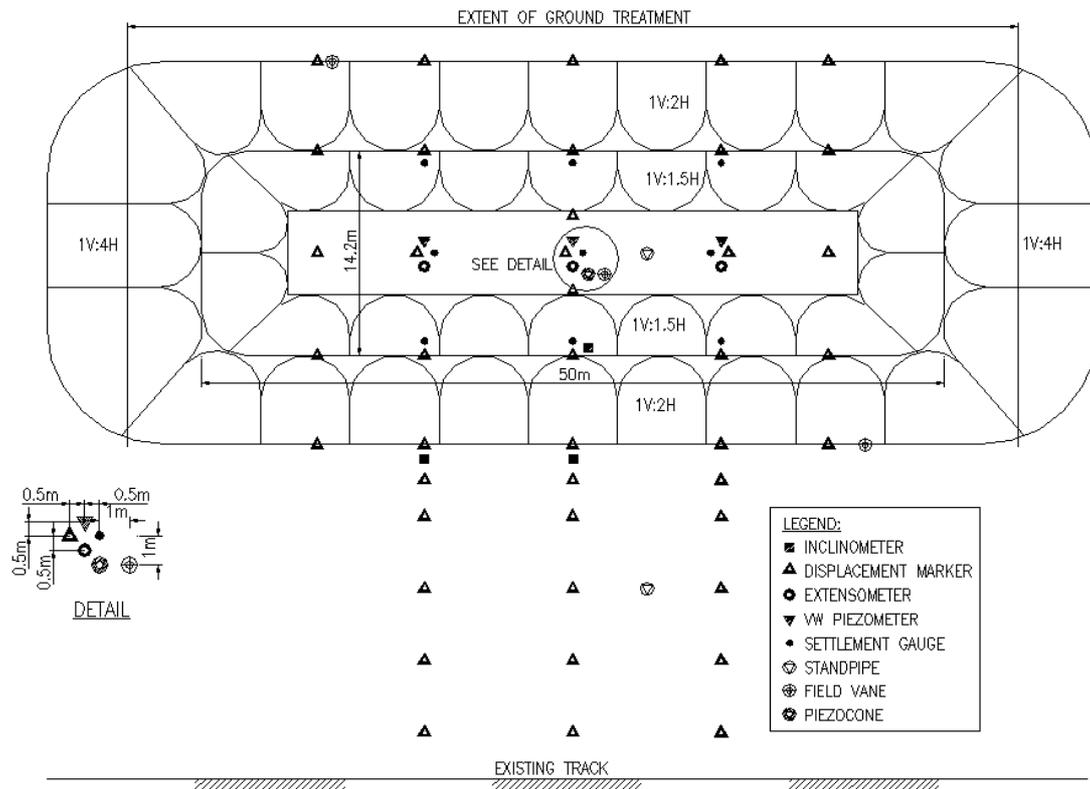


Figure 3: Instrumentation layout plan

The calculated results of the FEM analyses are compared with the measured settlement. **Figure 5** shows the settlement profile of the embankment at the center and the edge versus embankment filling time. The measured settlements at the end of surcharging period are averagely 1963mm and 1545mm at the center and edge of the embankment respectively. This correspondences to 26% and 20% of the total constructed embankment height. The calculated settlement at the center 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.

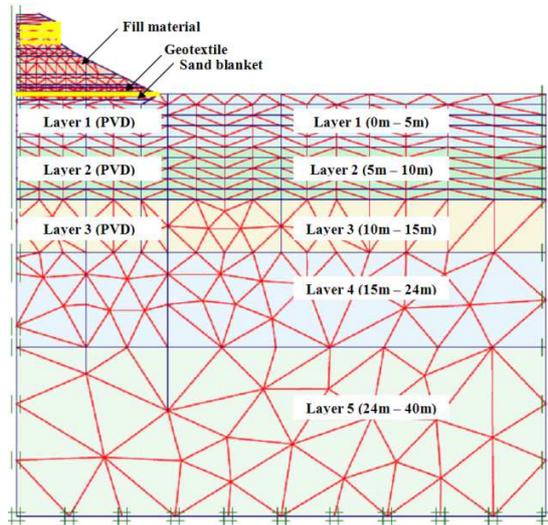


Figure 4: Geometry of FEM

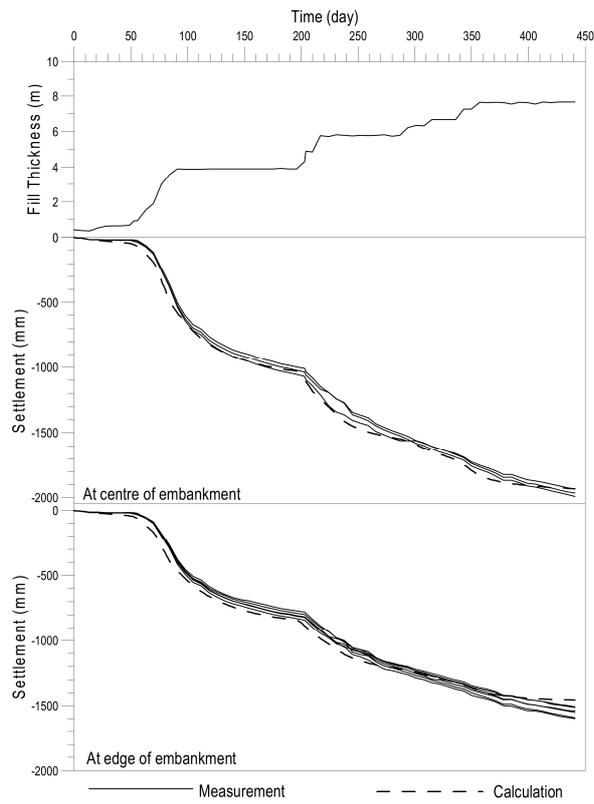


Figure 5: Embankment settlement profile

5 Construction Control Chart

Failures of an embankment constructed over soft clay are closely related to the magnitude and history of the deformations especially lateral deformation of the ground which took place during filling and before failure. Therefore, the information obtained from field instrumentations measurements can be used as early warning system and to ensure the safe construction of embankments. Based on FEM analyses results and actual lateral movement of a series of displacement markers installed at the toe of trial embankment (Figure 6), a construction control chart named “Fill Height (fill thickness) versus Lateral Displacement” (FHL D) plot was developed by the Authors. During construction of the embankment (filling stage), the developed FHL D plot is utilised together with Matsuo stability plot modified by the Authors to suit the project during construction stage to monitor the embankment stability.

The monitoring results of the site when plotted in the original Matsuo stability plot (shown in dashed line in Figure 7), some data indicated increasing in ratio of lateral displacement over settlement under low settlement magnitude (data moving along the X-axis without increase in value along Y-axis). This implies the increase in lateral displacement at constant settlement which is an indirect indication of potential instability of the embankment or the ground treatment of PVD used are not functioning properly to increase the rate of consolidation thus low magnitude of settlement with time. As the proposed embankment is constructed near to existing railway track, the Authors propose to limit the ratio of lateral displacement to settlement as shown in solid line in Figure 7 to ensure the safe construction of embankment and also to act as an early warning system on the performance of the ground treatment.

The FHL D and “Modified” Matsuo stability plots were classified to Green, Yellow Orange and Red Zone respectively to ensure safe construction of embankment and thus to mitigate costly and time consuming remedial works. Whilst, Table 3 shows the actions to be taken at site once the monitoring results reach different colour zone.

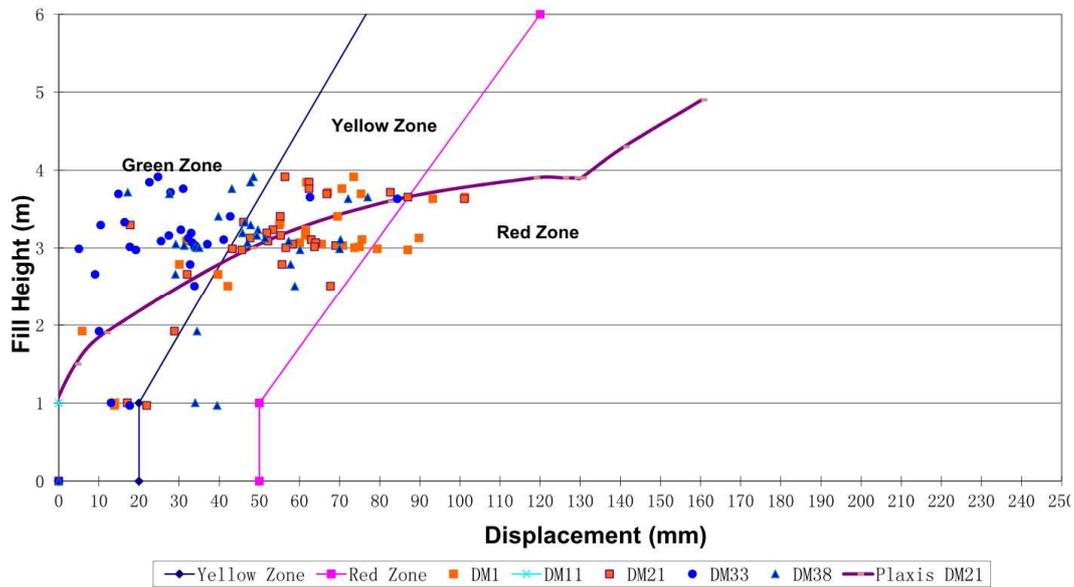


Figure 6: FEM and displacement marker results plotted in FHL D plot

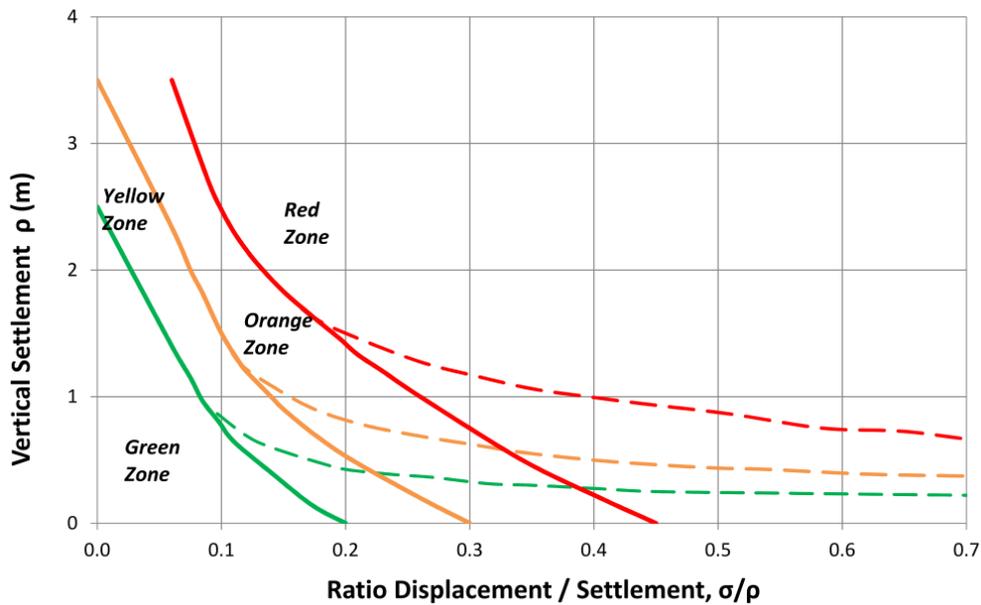


Figure 7: "Modified" Matsuo stability plot

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.

Table 2: Actions required during construction monitoring

6 Conclusions

Based on the actual monitoring and FEM back analyses results, the following conclusions can be drawn:

- 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) The developed FHLD plot can be used together with “Modified” Matsuo stability plot to monitor embankment stability in order to ensure safe construction of embankment and thus to mitigate costly and time consuming remedial works.

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