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Settlement and stability of bridge approach embankments on soft clays – Two case histories

Stabilité et tassements de remblais d'approche de pont construit sur argiles molles – Deux cas historiques

Sri Srithar
Golder Associates Pty Ltd, Melbourne, Victoria, Australia

ABSTRACT: Design and construction of bridge approach embankments on soft clays are generally challenging. Stability of the embankment and settlements due to the load imposed by the embankment are two of the key issues that need to be considered. Space constraints on a project site and time constraints on the delivery of a project will pose additional challenges on these issues. This paper presents two case histories of design and construction bridge approach embankments. The first case history involves construction of a 6 m high approach embankment over 14 m of soft to firm clays for the Phu My bridge in District 2, Ho Chi Minh City, Vietnam. Wick drains and surcharging was used to accelerate the settlements at this site. Staged embankment construction, relying on strength increase in soft clays, was adopted to satisfy stability considerations. The second case history involves construction of a 10 m high approach embankment over 6 m of soft to firm clays for the Western Highway duplication bridge across Mount Emu creek in Trawalla, Victoria, Australia. Surcharging was used to accelerate settlement at this site. Heavy duty basal geogrid reinforcement was used at both sites to improve the stability. Differences between the predicted and measured settlements and the likely reasons are also discussed in the paper.

RÉSUMÉ : La conception et la construction d'approche de ponts construits sur argile molles présentent géneralement des problèmes. Les deux points principaux qui doivent être pris en compte sont la stabilité des remblais ainsi que les tassements induis par ceux-ci. Des difficultés supplementaires apparaissent aussi à cause des contraintes d'espace sur le chantier et celles liées aux temps de livraison de l'ouvrage. Cet article présente deux cas historiques de conception et de construction pour des remblais d'approche de ponts. Le premier exemple est la construction d'un remblais d'approche de 6 mètres de haut construit sur une epaisseur de 14 mètres d'argile molle à ferme pour le pont Phu My situé dans le District 2 à Ho Chi Minh au Vietnam. Des drains verticaux ainsi qu'un remblais de surcharge ont été utilisés pour accélérer les tassements sur ce site. La construction du remblais par étapes, se reposant sur l'augmentation de la resistance au cisaillement des argiles molles, fut adoptée pour satisfaire les considerations liées à la stabilité du remblais. Le second cas historique considère la construction d'un remblais d'approche de 10 mètres de haut reposant sur plus de 6 mètres d'argile molle à ferme pour la duplication du pont de la Western Highway enjambant le ruisseau du Mount Emu à Trawalla dans l'état du Victoria en Australie. La technique de surcharge à été utilisé pour accélérer les tassements sur ce site. Des geogrilles furent aussi utilisées à la base du remblais pour améliorer la stabilité de celui-ci. Les différences entre les tassements calculés lors de la conception et ceux mesurés durant la construction ainsi que les probables causes de ces différences sont aussi présentées dans cet article.

KEYWORDS: Soft clay, embankment, stability, settlement, case history.

1 INTRODUCTION

Design of approach embankments for the bridges over creeks and rivers are often challenging as the banks of the creeks and rivers, where the approach embankments will be constructed, often consist of soft alluvial clay deposits. The soft clays are also mostly normally consolidated or only slightly over consolidated. Stability of the embankment and settlements due to the load imposed by the embankment are two of the key issues that need to be considered in the design. The settlements and potential lateral ground movements over the short term and long term will need to be considered. Space constraints on a project site and time constraints on the delivery of a project will pose additional challenges on these issues.

This paper presents two case histories of design and construction bridge approach embankments. The first case history involves construction of a 6 m high approach embankment over 14 m of soft to firm clays for the Phu My bridge over the Saigon River in District 2, Ho Chi Minh City, Vietnam. Wick drains and surcharging was used to accelerate the settlements at this site. Staged embankment construction, relying on strength increase in soft clays, was adopted to satisfy stability considerations.

The second case history involves construction of a 10 m high approach embankment over 6 m of soft to firm clays for the Western Highway duplication bridge across Mt Emu creek in Victoria, Australia. Surcharging was used to accelerate settlement at this site. Heavy duty basal geo-reinforcement was used at both sites to improve the stability.

2 PHU MY BRIDGE

The Phu My Bridge is a 705 m long cable stayed bridge across the Saigon River connecting Districts 2 and 7. The approach viaduct structure on the District 7 side is about 760 m and that on the District 2 side is about 640 m. The approximate location of the bridge is shown in Figure 1.

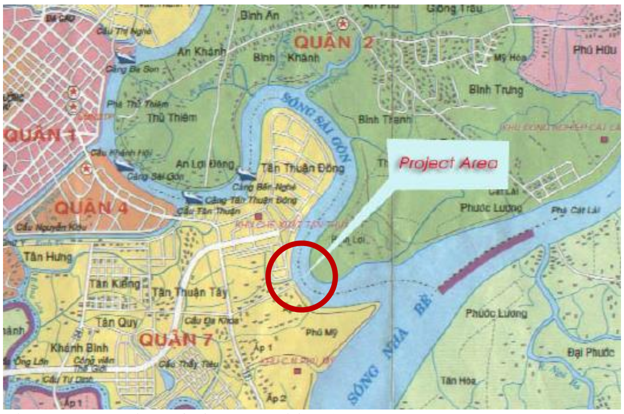

Figure 1. Location of Phu My Bridge (Source: TEDIS, 2003).

The District 2 side has a 6 m high approach embankment and the District 7 side, which was in a built up area has minimal approach embankment.

2.1 *Subsurface conditions*

A summary of the subsurface material units below the original ground surface in the area of the approach embankment in District 2 is presented in Table 1. The relevant material parameters are also presented in Table 1. The groundwater level was close to the existing ground surface.

Table 1. Subsurface material units and parameters – District 2 approach

Material unit	*Unit 1a*	*Unit 1c*	*Unit 2a*
Description	Very soft to soft clay (CH)	Loose to medium dense silty sand (SM), with clay layers	Stiff to very stiff clay (CH)
Depth range (m)	0 - 14	14 - 20	20 - 25
Unit weight (kN/m^3)	15	19	19
Undrained shear strength (kPa)	10 + 1.5 z*	N/A	60 - 130
Eff. friction angle (deg)	25	28	25
Eff. cohesion (kPa)	1	1	10
Liquid limit (%)	80 - 100	N/A	50 - 60
Plasticity index (%)	55	N/A	35
Compression index	0.90^	N/A	0.13

* z is the depth below original ground surface
^ based on consolidation tests on samples from shallow depths

The results of a typical cone penetration test in the area are shown in Figure 2.

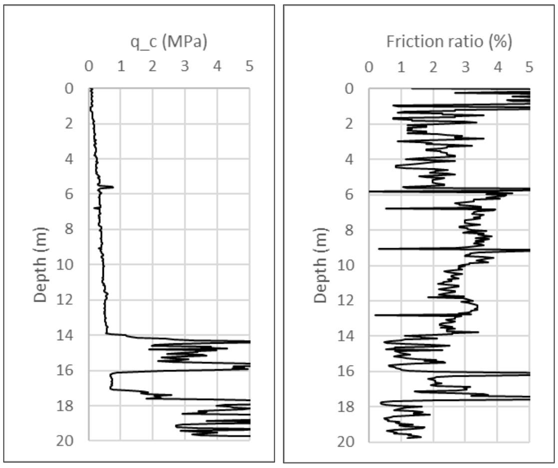

Figure 2. Results of a typical cone penetration test.

The pore pressure dissipation tests during the cone penetration tests indicate a coefficient of horizontal consolidation, C_h, ranging from about 20 m^2/year to about 100 m^2/year in the Unit 1a materials. The laboratory consolidation tests indicate a coefficient of vertical consolidation, C_v, ranging from 0.5 m^2/year to 2.5 m^2/year. Generally, the coefficient of vertical consolidation in the field is expected to be much higher those observed in the laboratory (Leroueil, 1988, Ozcoban et al., 2007). It is considered that a C_v of 10 m^2/year and drainage path length of about 5 m are reasonable allowing the presence of thin sandy layers within the very soft to soft clay unit (Unit 1a).

2.2 *Approach embankment design*

2.2.1 *Embankment stability*

The maximum height of the approach embankment was about 6 m. The side batters of the embankment were at a slope of 2H:1V for about 3 m high with a mid-level bench of about 20 m wide. The embankment was constructed in stages relying on the strength gains in very soft to soft clays between stages, similar to the approach discussed in Srithar and Ervin (2000). The embankment was subjected to a 1.5 m high surcharge with the provision of wick drains to accelerate the strength gains. A minimum factor of safety of 1.3 was targeted during temporary construction stages and 1.5 was targeted for long term conditions. Geogrid reinforcement with ultimate strength of 100 kN/m was also provided at the base of the embankment to meet the target factors of safety.

Figure 3 presents the plan and section showing the embankment construction stages and the surcharge.

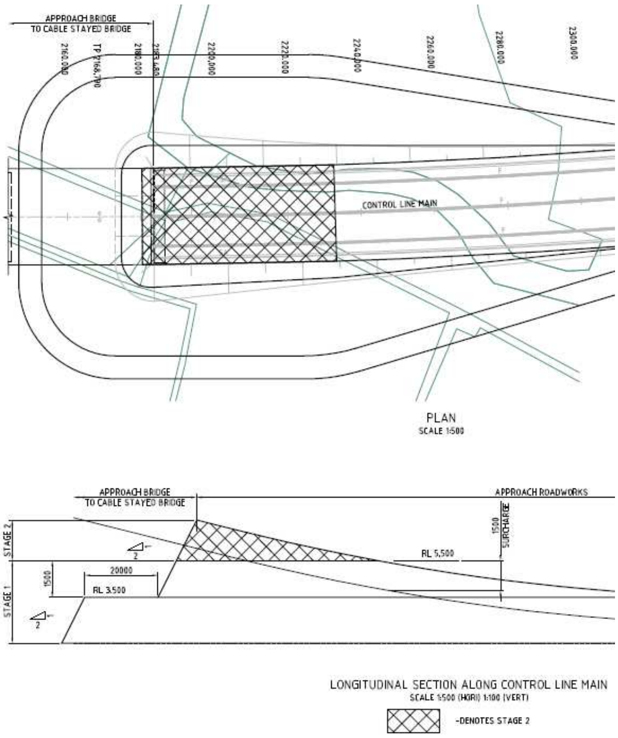

Figure 3. Plan and section showing embankment construction stages.

2.2.1 *Wick drains*

At the design stage, the available time between the construction stages of the approach embankment was indicated to be about 3 months. The total time available for surcharging and removal potential consolidation settlement due to embankment construction was indicated to be about 6 months. To meet these construction time limits, wick drains were provided to accelerate the consolidation in Unit 1 a.

The design of required wick drain spacing was based on the methodology described in Yeung (1997). A C_h of 20 m^2/year, a smeared zone around wick drains of two equivalent diameters of the wick drain and a permeability of the smeared zone of 1/5 of the surrounding soil were assumed for the design. Wick drain spacings varying between 1.25 m and 2 m in a triangular pattern were adopted for various zones depending on the degree of consolidation that needed to be achieved within the available time frames. Figure 4 presents a plan showing the zones of different wick drain spacings adopted.

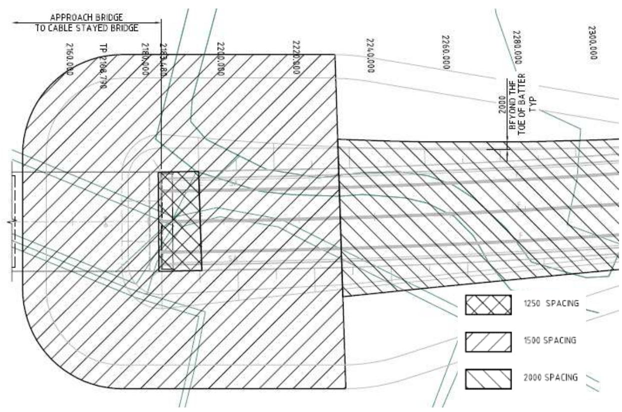

Figure 4. Plan showing zones of different wick drain spacings.

Based on the subsurface conditions and material parameters discussed in Section 2.1 and assuming that the Unit 1a clays are normally consolidated a maximum primary consolidation settlement of 2.2 m was calculated for a 6 m high embankment.

2.3 *Monitoring instruments and results*

The approach embankment was instrumented with settlement plates, settlement profiler, magnetic extensometer, vibrating wire piezometers and surface settlement markers to assess the settlement performance. An inclinometer was also installed in the abutment area to confirm that most of the horizontal movements in the area have occurred prior to the installation of abutment pile footings. Figure 5 shows the layout of monitoring instruments, excluding the surface settlement markers.

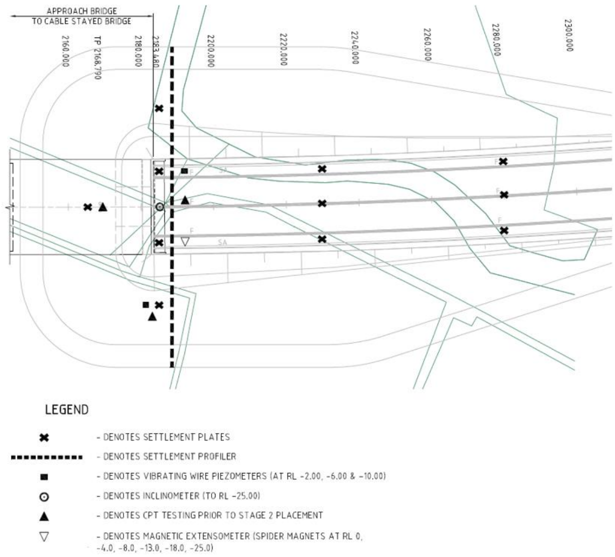

Figure 5. Plan showing monitoring instrument locations.

The measured settlements at one of the settlement plates at the highest embankment fill height is shown in Figure 6. It should be noted that a working platform of about 2.5 m thick was constructed at this location before the placement of the settlement plate. Maximum measured settlement was about 1.17 m after about 3 months of consolidation since the completion of embankment construction. An assessment of the degree of consolidation based on the measured settlements using the Asaoka (1978) method indicates that about 95% consolidation has been achieved under the 1.5 m high surcharge. The magnetic extensometer measurements, which are not presented here, indicate that 99% of the settlements were from Unit 1a materials.

The measured settlement along the settlement profiler on four selected dates within the last 4 four months of monitoring is shown in Figure 7. The lateral movements measured in the inclinometer on the same selected dates are shown in Figure 8.

The vibrating wire piezometers did not show any appreciable increase in the pore pressures indicating that the wick drains were very effective. However, it is noted that the pore pressures were not considered for the assessment of degree of consolidation.

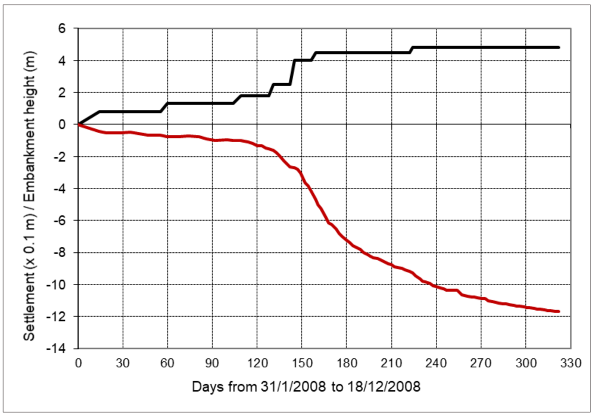

Figure 6. Measured settlement in a settlement plate.

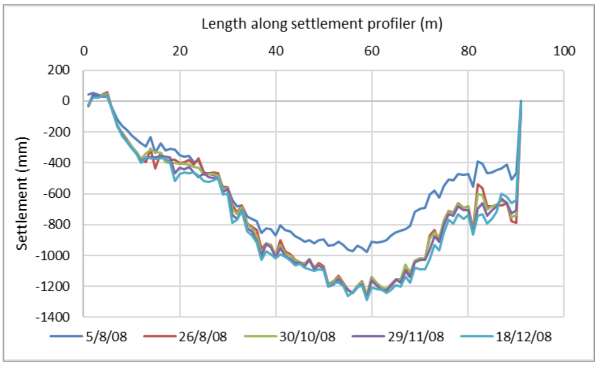

Figure 7. Measured settlement along settlement profiler.

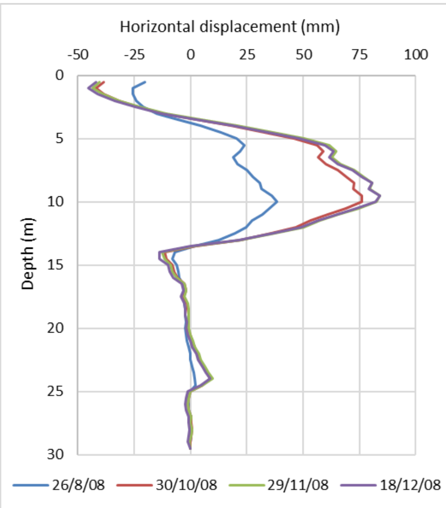

Figure 8. Measured lateral displacement in inclinometer.

2.4 *Discussion*

The maximum measured settlement was considerably lower than that calculated at the design stage. The difference is inferred to be due to the following reasons:

- A single compression index value was used for the entire 14 m thick Unit 1a materials. The moisture content measurements in this unit indicate decreasing trend with depth and hence it is possible that the compression index of the materials could decrease with depth.
- The materials were assumed to be mostly normally consolidated. A detailed assessment of the pre-consolidation pressure from the cone penetration test results as suggested by Mayne et al. (2009) indicates that the over consolidation ratio (OCR) in Unit 1a material could be over 2 (see Figure 9).

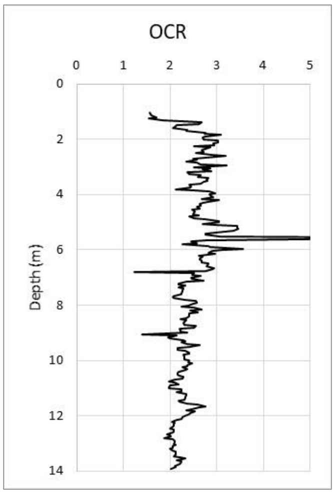

Figure 9. Assessed OCR from CPT results in Unit 1a materials.

If the settlement calculations are made based on an OCR value of 2 and compression index values decreasing with depth, then settlements comparable to the measured settlements are obtained.

It is noted that the maximum lateral displacements measured were about 7% of the maximum settlements measured. Typically, in modelling of soft clays, a Poisson's Ratio in the range of 0.1 to 0.2 is considered. The measured lateral displacements suggest that the Poisson's ratio that needs to be adopted in such modelling could be as low as 0.07. A similar ratio of lateral displacements was also reported in Srithar and Ervin (2000) at the My Thuan Bridge site in Vietnam.

3 MOUNT EMU CREEK BRIDGE

Mount Emu Creek Bridge is part of the Western Highway and is a 5 span bridge across Mount Emu Creek and Trawalla Road, in Trawalla, Victoria, Australia. The approach embankment discussed in this paper is for the eastern approach for the bridge. The approximate location of the bridge is shown in Figure 10.

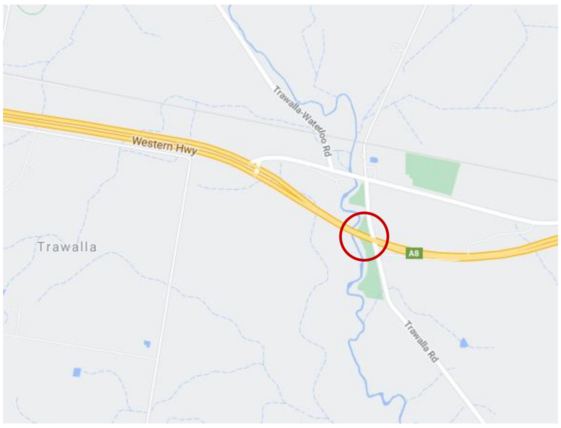

Figure 10. Location of Mount Emu Bridge (Source: Google Maps).

3.1 *Subsurface conditions*

A summary of the subsurface material units below the original ground surface in the area of the eastern approach embankment is presented in Table 2. The relevant material parameters are also presented in Table 2. Groundwater was assumed to be close to the existing ground surface based on the measurements in standpipes at the site, but there was some uncertainty about this as it may represent a perched groundwater level rather than the regional groundwater level in the area.

Table 2. Subsurface material units and parameters – Eastern approach

Material unit	*Unit 1*	*Unit 2*	*Unit 3*
Description	Soft and firm clays (CI - CH)	Stiff and very stiff sandy clays (CL - CI)	Very stiff to hard clays and silts (CL)
Depth range (m)	0 - 6	6 - 19	>19
Unit weight (kN/m^3)	17 to 18	19	20
Undrained shear strength (kPa)	15 + 1.2 z* 40#	100	200
Eff. friction angle (deg)	25	28	28
Eff. cohesion (kPa)	2 to 4	15	40
Liquid limit (%)	48 to 78	29 to 32	-
Plasticity index (%)	32 to 49	17 to 19	-
Compression index	0.25 to 0.5	0.1	N/A

* z is the depth below top of layer
\# undrained shear strength of firm clay
^ based on consolidation tests on samples from shallow depths

The results of a typical cone penetration test in the area are shown in Figure 11.

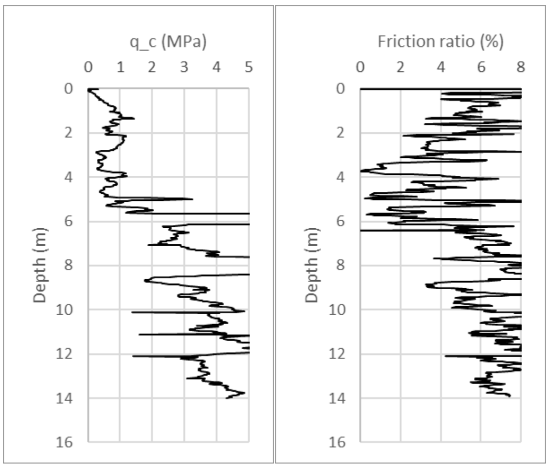

Figure 11. Results of a typical cone penetration test.

Based on the review of the geotechnical information for this site, it is considered that a C_v of 20 m^2/year and drainage path length of about 2 m are reasonable for the assessment of consolidation settlements.

The over consolidation ratio for the Unit 1 clays were assumed to be in the range between 1.2 (in soft clays) and 5 (in firm clays).

3.2 *Approach embankment design*

The maximum height of the approach embankment was about 10 m high. The embankment had side batters at a slope of about 5H:1V. Based on the limited thickness of the soft and firm clays and the rate of embankment construction of about 1.2 m/week, it was assessed that about 80% consolidation will occur at the end of construction. The strength gain associated with the consolidation during construction has been considered in the stability assessment. A minimum factor of safety of 1.3 was targeted during temporary construction stages and 1.5 was targeted for long term conditions. Two layers of high strength geogrid (characteristic ultimate strength 200 kN/m) were provided at the base of the embankment to obtain adequate factors of safety.

For a 10.5 m high embankment, based on the parameters presented in Section 3.1, total settlements up to about 550 mm was calculated. The time for 98% consolidation was assessed to about 4 months.

The embankment was subjected to a 2 m high surcharge over a period of about 3 months to remove most of the primary consolidation settlements and to reduce the potential long term creep settlement.

3.3 *Settlement monitoring results*

The approach embankment was instrumented with 8 settlement plates placed within a 150 m length of the approach embankment. Due to the presence of water and recent soft sediments in the flood plain of the creek, where the approach embankment was to be constructed, it was necessary to place about 800 mm thick coarse open graded rock fill to create a working platform for the embankment construction. The settlement plates (referred as M1 to M8 in Figure 12) were placed on the working platform.

The measured settlements at the settlement plates with time along with the corresponding embankment fill level are shown in Figure 12.

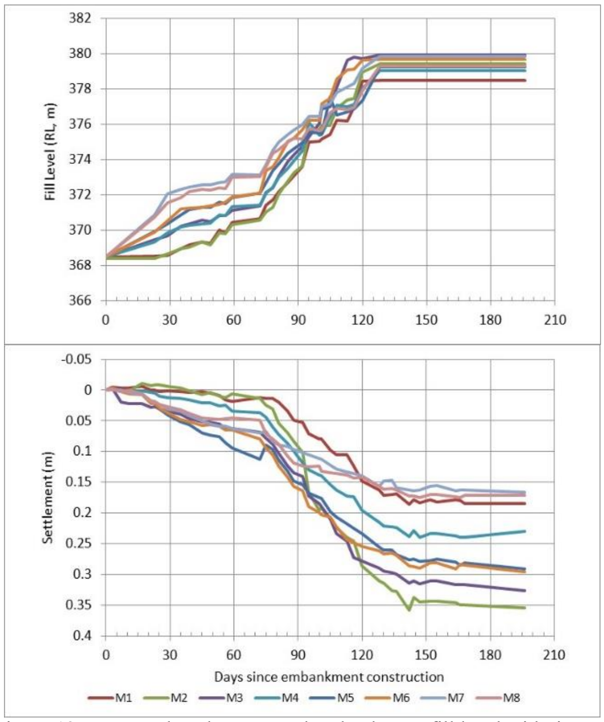

Figure 12. Measured settlements and embankment fill level with time.

3.4 *Discussion*

The observed rate of settlement was faster than expected. As it can be seen from Figure 12, most of the settlement has occurred in about 30 days of completion of embankment construction. It is inferred that the field C_v is higher than assumed or the available drainage path is shorter than assumed or combination of both. For example, a C_v of 25 m^2/year and drainage path length of about 1 m would result in more than 98% consolidation in 30 days.

The maximum measured settlement was lower than that calculated in the design stage. There are also considerable variations in the settlements measured at various settlement plates although the variations in fill height is limited to about 1.5 m. These differences are inferred to be due to a combination of the following reasons:

- Variations in subsurface conditions, in particular the variations in thickness of the firm and soft clays within Unit 1.
- A detailed assessment of the pre-consolidation pressure from the cone penetration test results as suggested by Mayne et al. (2009) indicate that the over consolidation ratio (OCR) in Unit 1 could be much higher than those assumed (mostly greater than 3 in the soft clays and greater than 10 in firm clays).
- The true groundwater level may be deeper at the site and the assessment of vertical effective stresses based the assumption of groundwater at the surface may be conservative for the settlement assessment.

4 CONCLUSIONS

Based on the design and performance of the approach embankments at two bridge sites discussed in this paper the following remakes can be made:

- Embankments on soft clays can be constructed successfully by adopting a staged construction approach and considering the strength increase in soft clays during construction.
- Pore pressures measured in piezometers may not be reliable for assessment of degree of consolidation in areas where vertical drains are installed at very close spacing.
- Pre-consolidation pressure (or over consolidation ratio) is an important parameter in the assessment of primary consolidation settlements in soft clays. This is often difficult to assess from laboratory consolidation tests. Assessment of pre-consolidation pressure from cone penetration test results can be considered to obtain a better assessment of the primary consolidation settlements.
- In the two case histories presented in this paper, the rate of field consolidation was observed to be faster than those assessed from laboratory consolidation tests. The C_h, values obtained from dissipation tests during cone penetration tests may provide a better indication. It is inferred that presence of very thin sandy layers within the soft alluvial clays would provide shorter drainage lengths leading to faster consolidation in the field.
- The lateral displacements associated with consolidation settlements in soft clays could be lower than 10% of the settlements.

5 ACKNOWLEDGEMENTS

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