This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.
Sportsmans Creek Bridge - Approach embankment design and construction over 30m thick alluvial flood plain

V. Nguyen
Coffey Services Australia Pty Ltd
P. Wong
PKW Geosolutions Pty Ltd
G. Rayward
Road Maritime Services

ABSTRACT: A new concrete bridge crossing Sportsmans Creek at Lawrence, New South Wales was constructed to replace the existing timber truss bridge. The northern approach embankment of the new bridge was underlain by shallow high strength sandstone bedrock of the Grafton Formation. However, the southern approach embankment was underlain by up to 32 m thick soft and loose alluvium of the Clarence River flood plain. The initial proposed southern bridge approach embankment was up to approximately 3.8 m height at the abutment. Due to the thick soft soil at the southern approach, a number of ground treatment options were considered and studied. The studied options were (1) preloading with or without Prefabricate Vertical Drains (PVD) with conventional fill or ultra-light weight fill; (2) hard ground treatment using piled embankment or hard inclusion with concrete injection columns (CIC); (3) extension of the bridge over the thick soft soil area. Construction cost, construction time, and long-term operation requirements of these ground treatment options for the southern approach embankment were studied to short-list the preferred approach treatment. The selected solution comprised a combination of Option (3) extending the bridge by 30 m to lower the approach embankment height, and Option (1) soft ground treatment for the southern approach embankment using preloading with conventional fill without PVD. The soft ground treatment was proceeded to construction stage. The ground movements and pore pressure dissipation during the approach embankment preloading period were monitored and back analysed. This paper presents the option study and comparisons between design prediction and actual embankment performance monitoring during construction and the preloading period. Back analysis results of the ground settlement and excess pore water pressure dissipation together with forward predictions of future post-construction settlement are also presented.

1 INTRODUCTION

The southern approach embankment of the new bridge crossing Sportsmans Creek at Lawrence, New South Wale is underlain by up to 32 m thick soft and loose alluvium of the Clarence River flood plain. A soft ground treatment option study was undertaken considering three options (1) using PVD with surcharge and preloading; (2) hard ground treatment piled embankment; and (3) bridge extension. The option study results are summarised as basis for selection of the suitable ground treatment.

Bridge extension of approximately 30 m south from the initial abutment location (in the concept bridge design) was selected as the preferred construction option. The bridge was extended south to CH 152 m and the approach embankment height is approximately 1.7 m – 2 m at this chainage.

Bridge approach embankment fill was constructed in Oct 2016. The embankment was monitored during 3-month preloading period. Back analysis of the embankment settlement was carried out with forward prediction of the long-term settlement of the approach embankment.

Figure 1 - Site location plan
This paper summarizes the ground treatment option study results and presents the back-analysis results of the southern approach embankment settlement.

2 SITE LOCATION

Figure 1 shows the alignment of the new Sportsmans Creek Bridge, which is to the west of the existing timber bridge. The southern bridge approach embankment initially jointed the existing road intersection at approximate Chainage CH 120 m and finished at the bridge abutment at approximately CH 180 m.

The finished surface level varies from approximately 0.5 m at CH 120 m up to approximately 3.8 m at approximately CH 180 m above the existing ground surface. The existing road leading to the southern bridge approach embankment (from CH 0 m to CH 120 m) was upgraded with additional fill thickness of less than 0.5 m above the existing road surface.

3 GEOTECHNICAL CONDITION

The geology of project area comprises unconsolidated Quaternary sediments, which are associated with fluvial, estuarine and marine sediments of the Clarence River and Sportsmans Creek floodplains and marine delta, underlain by sedimentary rocks of the Mesozoic Clarence-Moreton Basin.

Figure 2 shows the geotechnical section along the new bridge alignment. Generally south of and beneath Sportsmans Creek, the sediment stratigraphy comprises thin Holocene floodplain sediments (clay and sand) overlying extensive thick Holocene estuarine clay (Unit FL2) with minor sand (Unit FL3). The total Holocene sediment is up to 32 m thick under the proposed southern approach embankment.

North of Sportsmans Creek, the sedimentary stratigraphy comprises thin Holocene floodplain sediments (clay and sand) directly overlying weathered bedrock.

![Typical geotechnical model at southern abutment (approximate CH 140 - 180)](image)

Figure 3 shows a typical geotechnical model at the proposed southern bridge abutment together with soil parameters from in-situ and laboratory testing.

4 DESIGN CRITERIA

Ground treatment option study for the southern bridge approach was undertaken based on the use of flexible pavement and a design traffic speed limit of 50 km/hr for the local roads. The following bridge approach embankment performance criteria were adopted in the option study:

The Post Construction Settlement (PCS) criteria for the bridge approach structural zone and transition zone embankments are 50 mm and 100 mm over 10 years and 40 years respectively.

The differential PCS settlement is 0.5% over 10 years.

Minimum factor of safety of 1.3 against embankment uplift during flooding for the ultra-light weight fill option, based on the flood levels:
- 1:5 yr flood level is at 3.5m AHD,
- 1:100 yr flood level is at 5.3m AHD, and
- 1:2000 yr flood level is at 6.7m AHD.
5 GROUND TREATMENT STUDY

5.1 Studied options

Ground treatment option study for the southern bridge approach was undertaken for the following feasible options in Table 1.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Preloading with conventional fill with surcharge and PVD at 1.2m c/c spacing</td>
</tr>
<tr>
<td>1b</td>
<td>Preloading with ultra-light weight fill without PVD</td>
</tr>
<tr>
<td>2a</td>
<td>Piled Embankment with concrete injected columns</td>
</tr>
<tr>
<td>2b</td>
<td>Piled embankment with driven piles</td>
</tr>
<tr>
<td>3</td>
<td>Approximate 30 m bridge extension to CH 152</td>
</tr>
</tbody>
</table>

Figure 4 – Option 1b Preloading with ultra-light weight fill embankment

Figure 5 – Option 2a Piled Embankment using Concrete Injected Columns (CIC)

Table 2. Option comparison summary

<table>
<thead>
<tr>
<th>Item</th>
<th>1a</th>
<th>1b</th>
<th>2a</th>
<th>2b</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction time (months)</td>
<td>≥ 24</td>
<td>≤ 5</td>
<td>≤ 4</td>
<td>≤ 3</td>
<td>≤ 3</td>
</tr>
<tr>
<td>Construction cost $ (x1000)</td>
<td>855</td>
<td>350</td>
<td>1000</td>
<td>550</td>
<td>1500</td>
</tr>
<tr>
<td>Embankment height (m)</td>
<td>7.3 -</td>
<td>3.5 -</td>
<td>3 -</td>
<td>3 -</td>
<td>3 -</td>
</tr>
<tr>
<td>Surcharge height (m)</td>
<td>9.4</td>
<td>4.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Preloading settlement (m)</td>
<td>1.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.01</td>
<td>≤ 0.1</td>
</tr>
<tr>
<td>PCS over 10 years (mm)</td>
<td>50</td>
<td>50</td>
<td>&lt; 20</td>
<td>&lt; 10</td>
<td>50</td>
</tr>
<tr>
<td>PCS over 40 years (mm)</td>
<td>75</td>
<td>75 - 75</td>
<td>&lt; 20</td>
<td>&lt; 10</td>
<td>50 - 100</td>
</tr>
<tr>
<td>PCS over 100 years (mm)</td>
<td>100</td>
<td>75 - 150</td>
<td>&lt; 20</td>
<td>&lt; 10</td>
<td>100 - 150</td>
</tr>
</tbody>
</table>

The predicted post construction settlement (PCS) of the southern bridge approach embankment for each of the soft ground treatments are summarised in Table 2.

5.2 Option comparison

The predicted post construction settlement (PCS) of the southern bridge approach embankment for each of the soft ground treatments are summarised in Table 2.

Ground treatment Option 1a requires more than 2 years construction time and preloading time. This Option also requires high strength reinforcement and/or temporary stability berm to maintain embankment stability during preloading. The required surcharge thickness and the predicted preloading settlement are relatively large thus the cost of these options is comparatively high.

Option 1b using ultra-light weight fill is expected to be the lowest cost option. However, the predicted PCS beyond 40 years is still relatively high due to the depth below the existing ground surface. Option 3 involves approximately 30 m bridge extension to CH 152 m. The bridge approach embankment at CH 152 m is maximum 1.7 m height and can be preloading with a nominal of 0.5 m thick surcharge for two to three months prior to construction of the bridge abutment piles.
weight of the fill over the EPS to resist uplift during floods.

Option 2a using rigid inclusions will result in low PCS but has a relatively high cost due to the depth of soil softs at this site.

Option 2b using a piled raft to support the approach embankment will result in low PCS and has a low to medium cost by minimising the number of piles effectively using a reinforced concrete raft. Driven pile length varies from 31 to 35 m below existing ground level.

For Option 3 (bridge extension), because the approach embankment height is approximately 1.7 - 2 m at CH 152, the predicted PCS of the approach embankment would be similar to the predicted PCS in Option 1a but has the highest cost of the options studied.

## 6 PREFERRED TREATMENT OPTION

Based on the option study, it appears that Option 2b using piled raft embankment may be a viable option that would provide good long-term performance at a reasonable capital cost, with low long-term maintenance cost compared to the other ground treatment options. However, Option 3 with bridge extension south from CH 180 m to CH 152 m was finally selected as the preferred option for the southern bridge approach. The approach embankment at CH 152 has a height of approximately 1.7 – 2 m. Soft ground treatment design for the approach embankment at CH 152 involved preloading with embankment fill and 0.5m of surcharge for 3 months.

Consideration of each option is detailed below:
The 2 years construction time and preloading time for Option 1a meant that this option was not suitable to meet construction timing.
The use of ultra-light weight fill in Option 1b was not considered suitable.
The rigid inclusions greater than 25m for Option 2a was considered difficult to construct and imposed an unsuitable construction risk.

The 400–450mm driven piles with lengths of 31 to 35 m in Option 2b were considered unsuitable given the lack of lateral support provided by the soft soils. Larger diameter bored piles could be considered. However, this would effectively be a buried bridge, with construction costs similar to those for option 3. Option 2b was not considered further.

By extending the bridge (Option 3) by 30m the effective height of the approach was reduced from 3.8m to 2.0-1.7m with imposed loading close to the pre-consolidation pressure of the soft soil to reduce primary consolidation. The extended bridge removes the settlement issues between CH 152 and CH 180.

The reduced height of embankment allows for the required settlement to take place in 3 months. This is suitable time frame and could be carried out by the contractor while other site works progress.

It is for the above reasons that a 30m bridge extension and preload with surcharge was selected as the preferred option.

## 7 EMBANKMENT SETTLEMENT

### 7.1 Embankment construction

Filling of the southern bridge approach embankment at CH 152 was commenced from 4 Oct 2016 to 17 Oct 2016. To speed up the preloading process, a surcharge thickness of 0.5 m was added on top of the embankment. The maximum embankment pressure was 50 kPa (approximately 2.5 m thick fill height).

A preloading period of 3 months was specified for the approach embankment to remove as much elastic deformation of the ground as possible. The remaining consolidation settlement and the subsequent creep settlement of the ground was calculated to be within the design criteria.

### 7.2 Embankment monitoring

Instrument were installed for embankment monitoring as shown in Figure 7, which include the following:
- Two settlement plates (SP),
- One extensometer (EXTM) with top magnet plate at the existing ground surface (RL 2.3 mAHHD) and 3 spider magnets at depths of 14.3 m (RL -12 mAHDD), 22.3 m (RL -20 mAHDD), and 30.3 m (RL -28 mAHDD),
- Vibrating wire piezometers (VW) at depths of 4.3 m (RL -2 mAHDD), 14.3 m (RL -12 mAHDD), and 19.3m (RL -17 mAHDD),

One Inclinometer at the toe of embankment.

![Figure 7 – Instrument plan](image)
7.3 Settlement back analysis

7.3.1 Geotechnical model
The back analysed geotechnical model is summarised in Table 3. Groundwater was assumed at RL 0.8 mADLI. The back analysed soil parameters in this table are generally in line with the parameters adopted in the soft ground treatment design.

Table 3. Back analysed geotechnical model

<table>
<thead>
<tr>
<th>Soil Unit</th>
<th>Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>top</td>
<td>base</td>
<td>γ</td>
<td>C&lt;sub&gt;e&lt;/sub&gt;</td>
<td>C&lt;sub&gt;re&lt;/sub&gt;</td>
<td>OCR</td>
<td>C&lt;sub&gt;ov&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>FL1</td>
<td>2.3</td>
<td>1.3</td>
<td>18</td>
<td>0.15</td>
<td>0.006</td>
<td>20</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>FL2</td>
<td>1.3</td>
<td>0</td>
<td>17</td>
<td>0.23</td>
<td>0.009</td>
<td>22</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>FL3</td>
<td>-2.5</td>
<td>-6.5</td>
<td>17</td>
<td>0.18</td>
<td>0.007</td>
<td>6</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>FL4</td>
<td>-6.5</td>
<td>-14</td>
<td>17</td>
<td>0.35</td>
<td>0.013</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>FL5</td>
<td>-1.4</td>
<td>-50</td>
<td>17</td>
<td>0.35</td>
<td>0.013</td>
<td>12</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>FL6</td>
<td>-30</td>
<td>-32</td>
<td>18</td>
<td>0.2</td>
<td>0.007</td>
<td>6</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1 Reduced Level (mADLI); 2 Vertical consolidation coefficient (m²/yr); 3 Bulk unit weight (kN/m³); 4 Compression Ratio C<sub>re</sub> = C<sub>e</sub>/(1+ε<sub>0</sub>) and Recompression Ratio C<sub>ov</sub> = C<sub>ov</sub>/(1+ε<sub>0</sub>);

7.3.2 Embankment settlement
Settlement back analysis of the approach embankment at CH 145 to CH 152 was undertaken using Coffey’s in-house software CAOS, which considers consolidation analyses with or without wick drains and 2-dimensional stress distribution with depth from a fill embankment. CAOS is written by Poulos (2008) adopting Finite Different Method for consolidation and settlement analyses. Time dependent (creep) settlement of soft soils commences at the end of primary consolidation (consolidation ≥ 90%). Creep settlement reduction due to over consolidation effect is calculated in accordance with Wong (2010).

An embankment height of 2.5 m (including 0.5 m surcharge) and width of 15 m was analysed. Figure 8 shows the monitored ground settlement compared with the back-analysis results using CAOS. Extensometer magnet plate at the initial ground surface showed a settlement of approximately 170 mm after 100 days. However, the two adjacent settlement plates only captured up to 120 mm of the ground surface settlement over this period.

Monitored settlements of the spider magnet were relatively low. At 14.3 m depth, the observed settlement from the magnet spider was approximately 10 mm after 100 days. At 22.3 m depth, the measured settlement was less than 5 mm over 100 days.

Settlement back analysis with extensometer was extended for forward prediction the long-term settlement of the approach embankment.

7.3.3 Pore water pressure
Figure 9 shows the monitored pore pressure in the piezometers compared with the back-analysis results. VW1 installed at 4.3 m depth detected a minor pore pressure increase during the embankment placement. It is anticipated that this VW1 reflected the minor groundwater fluctuation (2 - 3 kPa) during the embankment placement and preloading period. The proximity to ground surface and the underlying sand layer together with the relatively high C<sub>e</sub> could cause the low excess pore pressure reading in VW1.

VW2 installed at 14.3 m depth (RL -12 mADLI) experienced up to 20 kPa of pore pressure increase (excess pore pressure) during 12 days of embankment filling (from 4 Oct 16 to 17 Oct 2016). Pore pressure dissipated approximately 7 – 8 kPa after 100 days at the end of the preloading period in Jan 2017.

VW3 installed at 19.3 m depth (RL -17 mADLI) had approximately 5 kPa excess pore pressure during the embankment filling period. Pore pressure dissipated approximately 2 – 3 kPa at the end of the preloading.
After 100 days of preloading, approximately 40% and 50% reduction in the excess pore pressures occurred in VW2 and VW3 respectively.

The measured maximum excess pore pressures at 14.3 m and 19.3 m depths were approximately 20 kPa and 5 kPa respectively following the embankment placement. Relatively small settlements of 10 mm and 5 mm were observed in the extensometer at the two depths correspondingly after approximately 40% - 50% excess pore pressure dissipation. This indicates that the soil layers at and below 14.3 m depth could be working in the over-consolidation stress range.

7.4 Lateral ground movement

Figure 10 shows the monitored lateral ground movement from the inclinometer installed at the toe of the approach embankment. The depth shown in this figure references to the top of the inclinometer tube at 1.3 m above the initial ground surface. Lateral movement of 6 mm to 10 mm occurred over the top 9 m depth below the initial ground, and gradually reduced to less than 1 mm at and below 20 m depth.

![Figure 10 – Monitored lateral ground movement](image)

8 BRIDGE COMPLETION

Figure 11 shows the bird eyes photos of the new constructed Sportsmans Creek bridge looking east toward the old timber bridge and Clarence River. The new bridge was opened to traffic on 24 Feb 2018.

9 CLOSURE

This paper summarises the process from the soft ground treatment option study to the design and construction monitoring of the southern approach embankment of the new Sportsmans Creek bridge. Three soft ground treatment options were studied for the approach embankment, which is underlain by up to 32 m thick soft loose alluvium. Advantages and disadvantages of these treatment options were presented and compared to provide basis for selection of the preferred ground treatment.

Extending the bridge from CH 180 m to CH 152 m with preloading the approach embankment was selected as the preferred option. At the bridge approach at CH 152 m, the embankment height of 1.7 – 2 m was preloaded with 0.5 m thick fill surcharge for 3 months. Embankment construction was commenced in early Oct 2016 and monitored until Jan 2017.

Back analysis of the approach embankment settlement indicated the embankment settlement behavior during preloading was generally in accordance with the soft ground treatment design. Surcharge was removed in Jan 2017 to allow for construction of the abutment piles and the bridge deck. The bridge was completed and opened to public in Feb 2018.

10 ACKNOWLEDGEMENT

The authors are grateful to the NSW Roads and Maritime Services for the use of the monitoring results and their approval for publishing this paper.

REFERENCES
