

BRIDGE APPROACH TREATMENT WORKS ON THE COOPERNOOK TO HERONS CREEK SECTION OF THE PACIFIC HIGHWAY UPGRADE

Paul Hewitt, Stephen Summerell and Yuffrey Huang
Cooperook to Herons Creek Alliance

ABSTRACT

The Cooperook to Herons Creek Alliance was formed with the New South Wales Roads and Traffic Authority (RTA), Parsons Brinckerhoff and Thiess Contractors to design and construct the upgrade of 32.7 km of the Pacific Highway to dual carriageway between Cooperook and Herons Creek on the NSW Mid-North Coast. The upgrade works involved the construction of 15 new bridges, including two major river crossings over the Stewarts River and the Camden Haven River, which will duplicate the existing bridges. Both bridge approaches were constructed on embankments supported by a geotextile reinforced granular platform over soft ground adjacent to the existing bridges. Embankment movement, if significant, would not only affect the pavement performance but also impose additional loads on the piles supporting the adjacent bridge structures.

To mitigate settlement effects, the bridge approach treatment works consisted of displacement columns to support the bridge approach embankments and a geotextile reinforced load transfer mat constructed on top of the displacement columns to assist in distributing embankment load. The main challenges were construction on soft ground, requirements to maintain design life of the existing bridges and the need for an accelerated construction technology for timely delivery of the project. This paper outlines the project, presents the case history of the bridge approach treatment works, and discusses analysis, design and construction monitoring.

1 INTRODUCTION

The new northbound bridges over the Stewarts River and the Camden Haven River required solutions for embankments on soft ground using geosynthetics to achieve pavement performance criteria and maintain design life of existing bridges. Risks included the potential impact of the new works on the existing bridge abutment piles, which had tight tolerances for the allowable additional lateral movement imposed by the new works, cracking of the embankment and pavement and a tight design and construction program.

2 BACKGROUND

Since 1995, the Roads and Traffic Authority of New South Wales (RTA) has spent over \$3.9 billion to upgrade the Pacific Highway between Sydney and Brisbane to dual carriageway as part of the National Land Transport Network. The section of road between Cooperook and Herons Creek on the New South Wales Mid-North Coast is the longest section of road upgrade by the RTA on the Pacific Highway. When this section of road is built, 52% of the Pacific Highway upgrade program will be complete, leaving 324 km of highway yet to be upgraded (source: RTA website, February 2009).

The RTA is delivering the Cooperook to Herons Creek section of the Pacific Highway Upgrade using an alliance project team with Parsons Brinckerhoff (PB) and Thiess, which was formed in November 2007. The Alliance was given the task of designing and constructing the 32.7 km dual carriageway upgrade of the Pacific Highway between Cooperook and Herons Creek by December 2009. The upgrade work, which provides 110 km/h posted design speed, comprises extensive earthworks, ground improvement works, drainage, service relocation, property adjustments, pavements, retaining walls, culverts and 15 separate bridge structures, including two major river crossings over the Stewarts and Camden Haven Rivers. This section of Pacific Highway is jointly funded by the NSW State and Federal Governments at a total cost of approximately \$500 million.

The two major river crossings involved duplicating the bridges over the Stewarts River and the Camden Haven River, and associated bridge approach treatment works. Figures 1 and 2 show the existing bridges and the new bridges under construction. The new bridges form the northbound carriageways while the existing bridges, which currently carry traffic in both directions, become the southbound carriageway. The concept design had end spans longer than those on the existing bridge to minimise interaction effects on the existing bridges.



Figure 1: Existing Stewart's River bridge.



Figure 2: Existing Camden Haven River bridge.

Our design reduced the end spans at both the Stewart's River and Camden Haven River bridges by using bridge approaches constructed on a geosynthetic reinforced load transfer mat, and displacement columns to support the new embankment works and provide a transition from the new bridge to the surrounding floodplain sediments.

The geotechnical challenges required solutions for embankments on soft ground to achieve pavement performance criteria and maintain design life of existing bridges. Risks included the potential impact of the new works on the existing bridge abutment piles, which had tight tolerances for the allowable additional lateral movement imposed by the new works. Both bridges are under construction and will be open to traffic when the Cooperbrook to Herons Creek section of the Pacific Highway is completed at the end of 2009. On completion, the RTA will own and maintain the bridges.

Project design took place on the basis of preliminary geotechnical investigations by Arup Geotechnics, Robert Carr & Associates, and RTA, and detailed investigations by the Alliance. In total, investigations across the project included 370 test pits, 366 boreholes and 50 cone penetration tests.

3 GEOTECHNICAL CONDITIONS

3.1 GEOLOGY

The bridge areas lie in Holocene and Pleistocene alluvium and estuarine sediment-filled valleys, underlain by Triassic bedded sedimentary rocks. These overlie a sequence of Carboniferous meta-sedimentary rocks intruded by microsyenite/rhyolite dykes. The southern and central sections of the alignment were intruded by granitoids during the late Triassic period followed by some basaltic dykes during the Tertiary era.

3.2 STEWARTS RIVER

The southern approach to the new Stewart's River bridge includes new fill embankments up to 7.8 m maximum height and 21 m wide located immediately west (upstream) of the existing Stewart's River bridge embankments and approaches. Soft clay soils were not encountered beyond the northern bridge abutment of Stewart's River and settlement criteria were addressed without bridge approach treatment.

The Alliance's geotechnical investigations at Stewart's River included boreholes, cone penetration and piezocone tests (CPTu, CPT) and continuous sampling. Vane and dilatometer testing was used to provide site-specific correlations of undrained shear strength.

At Stewart's River, significant thicknesses of soft soils (generally >2 m) occur over a 30 m section south of the bridge abutment. The 'soft' soil at the bridge abutment location is about 4 m thick and comprises highly variable interbedded organic clay, silty clay and sandy clayey silt. Silty/sandy firm clay overlying sandy gravel was encountered at 8 m depth at the transition zone location.

The CPT and dilatometer results indicate the silt and clay layers at the abutment zone are generally in a firm condition, with undrained shear strength of 25 kPa to 30 kPa with an upper crust layer of about 1 m to 2 m thickness with inferred undrained shear strengths of 40 kPa to 60 kPa. The constrained modulus measured in dilatometer tests ranged from 6 to 20 MPa in the upper crust layer to 2 m depth and averaged 2 MPa from 2 m to 3.8 m, then increased typically to above 30 MPa.

3.3 CAMDEN HAVEN RIVER

The existing road embankment at the Camden Haven River north floodplain was constructed without any ground improvement in 1984. Settlement of the order of 0.7 m occurred relatively quickly within 6 months to 12 months of construction. Post-construction settlement of the existing road embankment was measured over the 12 and 23 years to 1996 and 2007.

The new embankments affected by soft soils associated with the Camden Haven river floodplain correspond to a 240 m section on the south side of the bridge and a 660 m section on the north side of the bridge, see Figure 3. The embankment height ranges from 8.7 m at the southern bridge abutment to 13.7 m on the southern end of this section and is generally around 4 m to 5 m high along the northern approach. On both sides of the river two distinct layers exist within the Holocene or “new” sediments which comprise the soft soil profile:

- an upper zone, comprising a highly variable fluvio-deltaic sandy and interbedded sandy clay layer including a near surface, over-consolidated crust of variable thickness (clay/ clayey sand).
- a lower zone comprising a more homogenous soft, silty clay layer (estuarine clay).

On the south side the base of the soft soils extends to about 10 m depth, typically increasing in depth to the north. On the north side the base of the soft soils extends to between 9 m and 13 m. There is a deep gravel-filled palaeochannel near Stn 45440 which corresponds with the area of existing road embankment showing the maximum measured settlement.

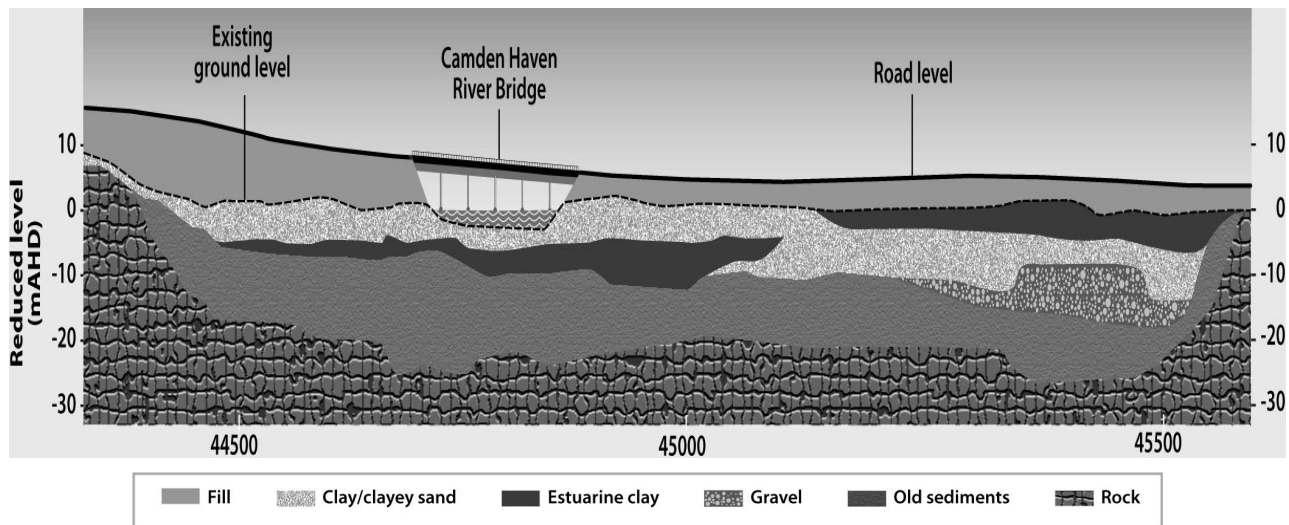


Figure 3: Camden Haven River geological long section .

4 DESIGN CONCEPT

4.1 GEOTEXTILE REINFORCED GRANULAR PLATFORM OVER DISPLACEMENT COLUMNS

Ground treatment with geosynthetics was used to control differential settlement, which would have been a major issue where embankments were constructed over soft ground adjacent to rigidly support bridge abutments. A wide range of ground treatment systems has been developed to build embankments on soft soils. These techniques take advantage of various ground modification concepts, such as densification, reinforcement and consolidation (Hewitt & Munfakh, 2006).

To address the prospect of significant settlement of the embankments and damage to adjacent bridges the project included bridge approach treatments using displacement columns and geosynthetics for the southern bridge approach adjacent to Stewarts River and the southern and northern bridge approaches adjacent to Camden Haven River.

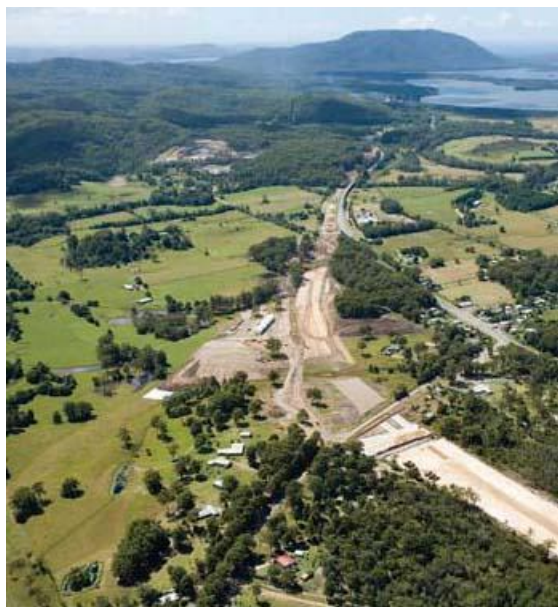


Figure 4: Aerial view of the Coopernook to Herons Creek upgrade.



Figure 5: Construction of new Stewarts River Bridge.

Displacement columns were installed by displacement auger techniques within the abutment zone to limit the post-construction settlement and lateral ground movement at the location of the adjacent existing abutment piles. Other sections of highway embankments located over soft soils used combinations of staged embankment construction, preloading and vertical (wick) drains outside the bridge approach treatment areas over 1.5 km of the route.

4.2 BRIDGE FOUNDATIONS

The bridge piles were installed before the embankment was built. At Stewarts River, we used rock-socketed, cast-in-place, reinforced concrete piles with temporary casing for the foundations. Temporary steel casing supported the unstable soft soil and gravel layers in the alluvial floodplain sediments until the concrete pile was cast, see Figure 5. We used precast, composite-driven piles (600 mm square with 310UC cast in steel section) for the Camden Haven River bridge substructure (which is 174 m long) because they are easy to install over water. The design required the piles to be socketed into sandstone and tuff at depths of about 20 m to 25 m to achieve the required geotechnical capacity and to limit bridge settlements. Bridges elsewhere have used pad footings, driven precast concrete and bored piles.

5 GROUND TREATMENT

5.1 PERFORMANCE CRITERIA

The objectives of the bridge approach treatments were to:

- Minimise the impact of new embankment displacement and the induced ground movement on the existing and proposed bridge structure and pavement.
- Provide a transition zone between the bridge abutment and the non-supported (consolidated by wick drain) embankment to meet the structural and serviceability requirements of the pavement.

For embankments on soft ground, the safety factor (FoS) was defined as the ratio of the available shear strength to the minimum shear strength needed for equilibrium. The minimum required global FoS post construction under permanent loading was 1.5.

5.2 OPTIONS CONSIDERED

During the Alliance Target Outturn Cost period we proposed an embankment supported by piles, instead of an additional bridge span, as an effective means of reducing settlement interaction impacts on the existing bridge approaches and addressing ‘value for money’ objectives. Time was critical for this project and thus a wick drain and surcharge solution was not acceptable.

We also considered deep soil mixing, stone columns and lightweight fill to support the embankment. Lightweight fill such as polystyrene (geofoam) was used on the Port of Brisbane Motorway. After discussions with the Port of Brisbane motorway alliance design team, of which PB was a member, this alternative was not considered further due to cost and issues associated with detailing the geofoam covering adjacent to piles. Lightweight fill (furnace bottom ash-FBA) was also considered to reduce imposed loading of the embankment on the existing piled bridge. During design development, both Plaxis 2D and 3D modelling demonstrated the limited effects of including the FBA as opposed to select or general fill. On this basis the FBA was not considered further, due to cost and applicability.

Displacement columns were preferred for the following reasons:

- Predicted settlement-The predicted settlement for a stone column was greater than twice the predicted settlement with displacement columns. The settlement requirement was also too strict to allow an economical solution using stone columns
- Field performance-The alluvial layer was too soft to safely install the stone columns to support the embankment. The presence of soft clay and high loadings from the embankment, raised the possibility of bulging problems and insufficient lateral confinement to ensure the stability of the stone columns
- Cost, environmental and program benefits - Stone columns were not considered suitable due to cost, uncertainty over stone quantities, disturbance to potential acid sulfate soils and concerns over spoil disposal
- Soil mixing was considered difficult to implement in the field due to the requirement to have a well defined strength and stiffness and associated construction stage surveillance and testing requirements
- They were considered to be more sustainable than traditional pattern-driven timber piles and stone columns.

In the embankment areas on soft ground careful planning and staging of earthworks eliminated the need for high strength geosynthetic or stabilising berms to address short-term embankment stability.

5.3 DISPLACEMENT COLUMN SYSTEM

Displacement columns, also called controlled modulus columns (CMC) or concrete injected columns (CIC), are a ground modification system, originally developed in France, that reinforces soil by screwing a hollow auger into the soft soil and installing a low-pressure, cement-based grout column through the hollow auger. The combined effect of densification and reinforcement improves the properties of the soft ground. The system uses a displacement auger powered by equipment with a large torque capacity and high downward thrust, which displace the soil laterally with virtually no spoil or vibration. The installation stages associated with displacement columns are shown in Figure 6 (source: Piling Contractors website, August 2009). Figure 7 shows column installation and monitoring used to measure ground heave associated with installation.

Features of displacement column technology include:

- material is grouted in place with the use of a displacement auger without spoil
- deformation modulus is 100 to 3,000 times that of soil
- soil properties are improved around the columns by compression resulting from the lateral displacement
- diameter is determined on the basis of auger size (usually in the range from 350–500 mm)
- common installation practice is based on a square grid with centre-to-centre spacing in the range of 1.2 m to 3 m
- maximum depth of treatment is 26 m.

The design parameters needed to define the column system included:

- depth of the columns and their penetration length in the founding layer
- diameter of the columns
- pattern and configuration of the columns grids
- stiffness of the grout used to make the column.

The column design includes estimating the bearing capacity of single columns, checking pre-design parameters by a numerical procedure, performing stability analysis and developing the final design to ensure installation effects are addressed.

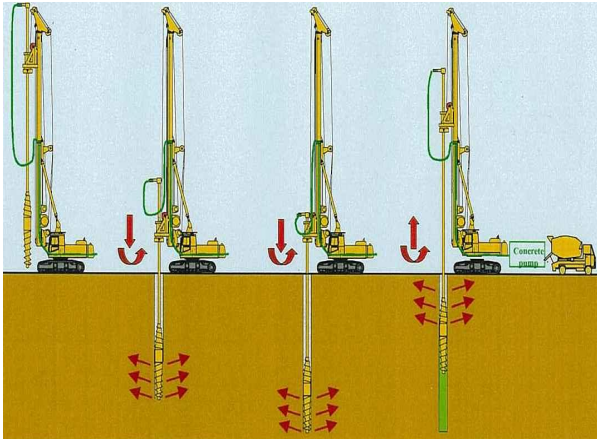


Figure 6:: Displacement column system construction process



Figure 7: Column installation.

5.4 DISPLACEMENT COLUMN LAYOUT

The bearing capacity of the columns was assessed using conventional static analysis based on the geotechnical conditions at each of the bridge approaches. The column pattern was estimated by dividing the applied load by the required bearing capacity. The result is the maximum area of influence that can be associated to a single column. The columns were founded on medium-dense sand and dense gravel and were designed to support a maximum working load of 500 kN. The structural requirement of the unconfined compressive strength of the displacement columns at 28 days was 5 MPa.

Each bridge approach zone was divided in two zones consisting of the following:

Zone 1 – displacement columns extending to incompressible ground around the new bridge abutment to minimise the long-term differential movement between existing piled bridge abutment and new embankments and reduce the deformation induced by the new embankment on the existing bridge structure and pavements

Zone 2 – shorter length, more widely spaced displacement columns with reduced embedment in stiff/dense alluvium to minimise the long-term differential movement between Zone 1 and non-supported embankments

A geotextile reinforced load transfer mat (LTM) on top of the displacement columns to support and distribute embankment load, and reduce tensile loads transmitted to the perimeter columns.

Due to the very soft and variable ground conditions, we adopted a column grid of 1.0 x 2.0 metres with a diameter of 375 mm for Zone 1 and a grid of 1.5 x 3.0 m for Zone 2, see Figure 8. This corresponds to a replacement ratio of 7.8% and 4.4% for Zone 1 and Zone 2 respectively.

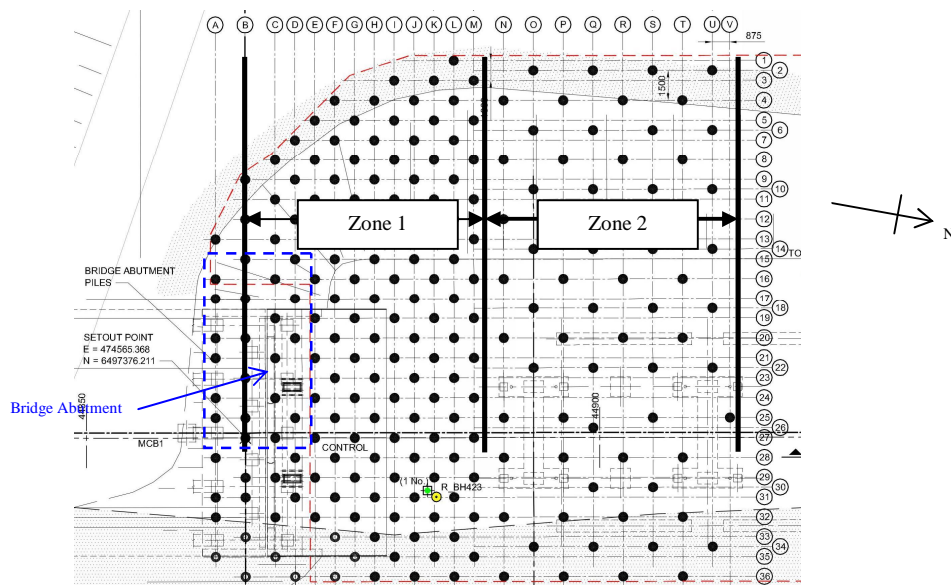


Figure 8: Column configuration at Camden Haven north bridge approach.

5.5 ANALYSIS METHODOLOGY

The design components of the bridge approach treatment include the columns, the geotextile reinforced bridging layer/load transfer mat over the columns, and flexible pavement. Design models were calibrated using post- construction settlement monitoring from the existing road embankment at Camden Haven River north.

Due to the complexity of the system and the interaction between all the treatment components we used:

- Two-dimensional (2D) numerical modelling using the finite element package PLAXIS v.8 to analyse the effectiveness of the system and provide information for structural and pavement design
- Three-dimensional (3D) PLAXIS modelling to assess the effect of new embankment construction on the existing bridge abutment piles and the level of individual loading in the existing bridge abutment piles due to the existing embankment.

We adopted British Standard BS8006 (1995), and results of PLAXIS modelling for the design of the LTM over the columns. This includes the assessment of the strength of the geotextile embedded in the LTM over the working platform.

Figure 9 shows example output from the numerical model at Camden Haven River south bridge approach. This method meant we could look at the behaviour of the embankment, geotextile and the transition layer and the strain and stress distribution between the soil and the columns. Short-term and long-term conditions were analysed to assess the time-related behaviour of the improved ground.

The impact of the new embankment on the existing bridge structure was of major concern. The heads of the existing bridge piles at Camden Haven River were estimated to move 5 mm in the short term, which indicated the design adopted is unlikely to cause an adverse impact or significantly reduce durability and design life of the existing structures due to ground movement.

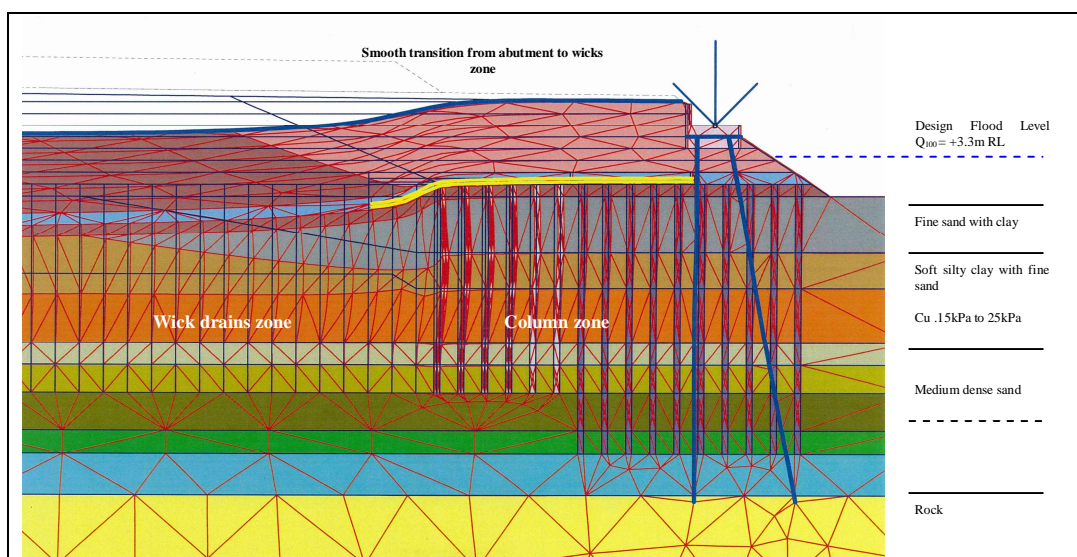


Figure 9: Finite element modelling for Camden Haven River south bridge approach showing transition between sediments and rigidly supported bridge structure

5.6 GEOSYNTHETICS

A geotextile-reinforced LTM designed for a 100-year design life, was chosen to allow for smooth transitions of the pavement during a 40-year design life. The LTM comprised two layers of structural geotextile encapsulated in medium-grained sand embedded in three (3) layers of compacted granular fill (average 250 mm thick each layer) constructed over the columns. The structural geotextile was designed to a uniaxial working strength (characteristic value) at 5% (working) strain of 150 kN/m. One of the geotextile layers was placed in the longitudinal direction of the embankment and the other in the transverse direction of the columns.

Analyses indicated that, provided the LTM is constructed with granular, dilatant, competent fill, the loads in the tension resistant, geosynthetic material are less than required using the BS8006 design. The BS8006 design was shown to be

overly conservative for LTM design as it considers using poor quality fills and relies on a catenary approach to assess geosynthetic loads.

The PLAXIS modelling indicated the geotextile tension forces predicted using BS8006 are overestimated. However, in keeping with the principles of BS8006, recommendations of Kupec & McGown (2007) and to provide additional redundancy, a reduced strength geotextile was included to transfer the embankment load from the LTM to the displacement columns. In Zone 1, the columns act as a ‘block’ due to the closer spacing, which further permits effective ‘arching’ between the columns and a lower lateral displacement-settlement ratio.

Benefits of using a geotextile-reinforced LTM included:

- allowed column caps to be omitted
- limited settlement between columns
- reduced tensile loads transmitted to columns
- increased the factor of safety against shear failure and
- allowed bridge lengths to be reduced.

6 CONSTRUCTION, MONITORING AND PERFORMANCE

6.1 CONSTRUCTION CHALLENGES

The presence of the existing bridges imposed construction challenges on the ground reinforcement system in some areas. At Camden Haven River, the requirement to protect the existing bridge piles against displacement was addressed by using a section of concrete load transfer mat rather than a granular load transfer mat reinforced with geotextile. With those construction changes, the predicted long term differential settlement along the bridge abutment piles was less than 10 mm, which was compatible with the rigidity of the bridge.

We addressed the risk of damaging freshly grouted surrounding columns when an adjacent new column is installed by modifying the conventional construction method and monitoring ground displacement. The columns were installed in two different interleave passes, each with 1.5 m x 3 m, and 1 m x 2 m triangular grids, as shown in Figure 8.

The risk of significant ground movements was addressed by the adopted column spacing and construction sequence. The columns were specified to be installed in a sequence to minimise potential detrimental heave and lateral displacement effects on the ground and the adjacent bridge abutment. To minimise heave, the design required construction to start with installing the columns at the existing embankment and then working away from the existing embankment and piles, to ensure the installation effects were minimised. By doing this, the soil will tend to displace laterally away from the existing embankment thus reducing displacement of the existing piles. With the adopted construction sequence and careful monitoring, the potential ground heave was limited to less than 50 mm during column installation. Monitoring indicated the existing bridge was not affected by ground movements during column installation. We installed 705 columns within two months, at an average production rate of 290 m/day per rig. The column schedule is given in Table 1.

We also placed medium-grained sand on both sides of the geosynthetics to reduce potential damage such as pinching and piercing from angular gravels in the mat. Sand placement lengthened the LTM construction time, however it was considered important to maintain the quality of the LTM so durability was not compromised. The placement of the load transfer mat with geosynthetics is shown in Figures 10 to 13.

Table 1: Bridge approach treatment schedule.

Bridge Approach	Maximum fill height at bridge approach (m)	Estimated settlement of embankment beyond column zone (m)	As-built column details		
			Length (m)	No. of columns	Cumulative length (m)
Stewarts River south	7.8	0.4	11-18	239	3340
Camden Haven River south	8.7	0.6	13-16	237	4335
Camden Haven River north	5.7	0.7	15-24	229	3200



Figure 10: Installed column layout at Camden Haven River.



Figure 11: Placing geotextile in transverse direction.



Figure 12: Placing geotextile in longitudinal direction.



Figure 13: Completed load transfer mat showing section of concrete load transfer mat.

6.2 MONITORING

The quality of execution of each of the columns was controlled by monitoring and recording the following for each individual column:

- depth, speed of rotation and advancement of the auger
- torque, down-thrust and drilling energy applied during advancement
- pressure and volume of injected grout, from which the profile of the columns is assessed.

We used a combination of coring and ultrasonic integrity tests to verify the constructed quality of the unreinforced injected columns. Ultrasonic tests on selected columns verified the column integrity in dimension and detected any major cracks. In some cases, the initial integrity tests revealed cracking of the upper column shaft, probably due to tracking of the rig over recently completed columns and absence of a column at one test location.

The quality of the grout was controlled regularly by unconfined compressive strength tests at 7, 14 and 28 days. Four samples were taken for every 100 m³ of grout for testing. In addition, core samples were taken from the trial columns and tested to verify the strength and stiffness of the grout supplied on site.

In the soft ground areas, a displacement monitoring system, including settlement plates and settlement pegs, was installed to record the potential displacement during and after embankment construction. We assessed the embankment stability and the associated rate of surcharge filling using the methods described by Loganathan *et al.* (1993), Matsuo & Kawamura (1977) and Tavenas and Leroueil (1980). These use measurements of the maximum lateral deformations recorded by inclinometers and the settlement at the centreline of the embankment to indicate impending instability, as indicated by the ratio of lateral displacement to settlement. Displacement markers in the form of survey prisms were installed at the bridge abutment structures to monitor the abutment movement due to column installation and embankment construction.

6.3 PERFORMANCE

At the time of writing, the overall construction is 70% complete. Monitored instruments have confirmed that the granular platform reinforced with geotextile is effective in supporting the bridge approach. At Camden Haven River south the fill height is 3 m at the bridge approach area. For the current fill height, the design prediction for existing piles was a movement of 5 mm to the west of the 'as-built' position. Markers indicate movement of 5 mm to the west, which is considered excellent agreement. The measured average embankment settlement is approximately 7 mm; beyond the column zone the maximum measured embankment settlement is 0.7 m under a fill height of 6 m.

7 CONCLUSIONS

The case history project presented here demonstrates the effectiveness of the bridge approach treatment foundation system using geosynthetics for timely project delivery and meeting serviceability requirements. The main challenges were associated with construction time limitations, the soft ground condition of the site and requirements to minimise additional loads on the piles supporting the adjacent bridge structures. In the evaluation of alternatives, stone columns or soil mixing were not feasible, and the conventional vertical drain solution was not practical because of time constraints, and insufficient stiffness to control displacement of the existing bridge abutment. The bridge approach embankment design consisted of displacement columns to support the bridge approach and a load transfer mat reinforced with geotextile on top of the displacement columns. The design helped to distribute embankment load, was effective in maintaining stability and reducing displacement, saved on bridge span lengths and allowed the bridge piles to be installed before preloading the embankments.

The design of the bridge approaches has involved close collaboration between the Alliance's non-owner and owner participants. The new bridges over the Stewarts and the Camden Haven Rivers are a result of a close and successful collaboration between the Alliance participants in using an appropriate, innovative and cost-effective solution.

8 ACKNOWLEDGEMENTS

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