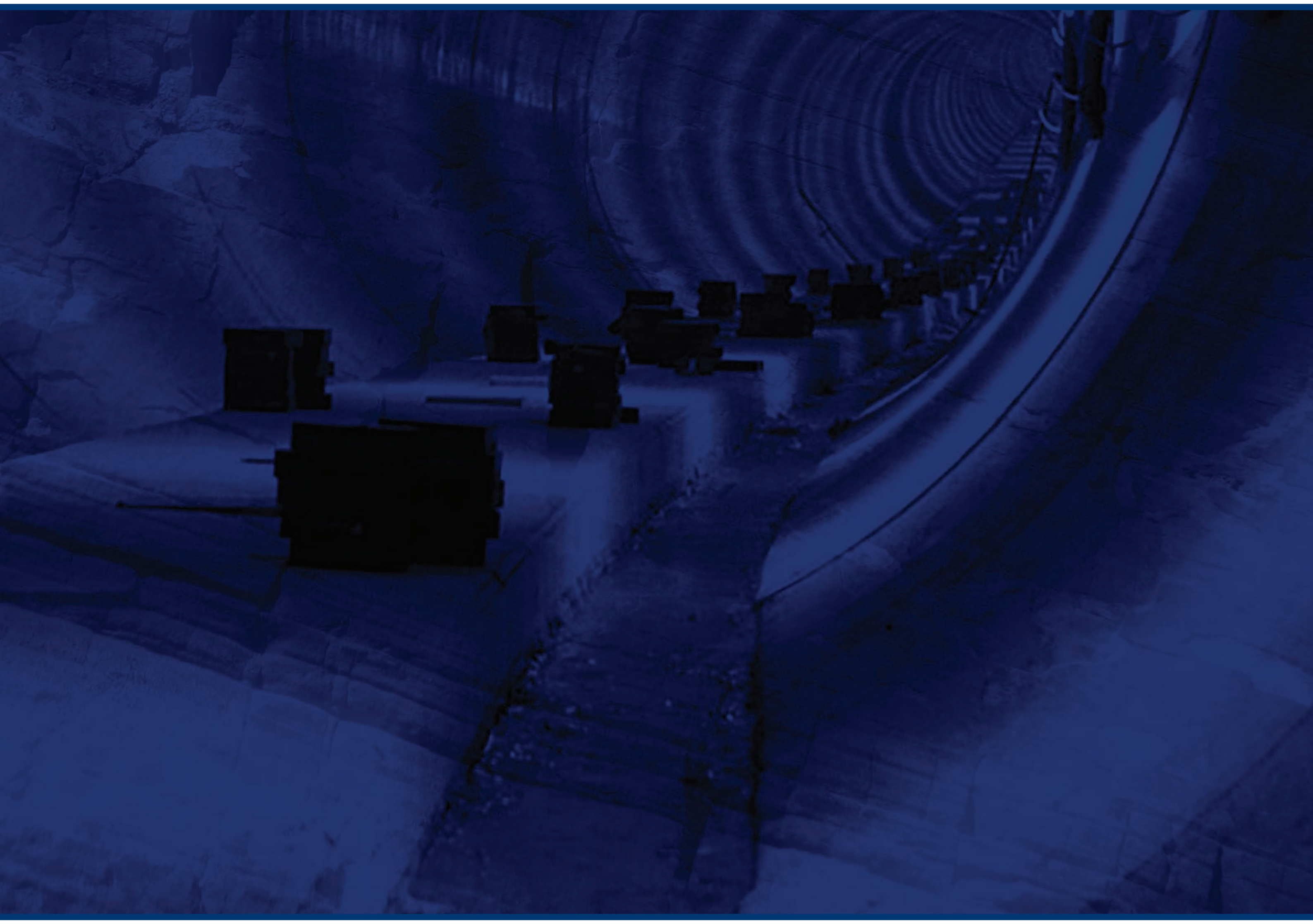
PROCEEDINGS

2018 AUSTRALIAN GEOMECHANICS SOCIETY VICTORIAN SYMPOSIUM

Geotechnics and transport infrastructure

Wednesday, 24 October 2018, 8:00am – 6:00pm
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER

Global Synthetics

PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2018 Australian Geomechanics Society Victorian Symposium on ‘Geotechnics and transport infrastructure’ held on 24 October 2018.

In recent years Victoria has seen significant investment in transport infrastructure as part of a plan to manage the demands of a growing population and expanding urban fringe. The construction of Melbourne Metro, a second crossing of the Yarra River, rail and freeway upgrades as well as numerous level crossing removal projects are just some of the major transport projects currently underway in Melbourne and regional Victoria. Many of these projects carry numerous complex geotechnical challenges.

The 2018 Australian Geomechanics Society Victorian Symposium covers a variety of geotechnical challenges associated with transport geotechnics and present overviews of current infrastructure challenges, state of the-art practices, innovation, new research results and case studies demonstrating applications of advanced techniques and cost effective solutions in the construction and design of local transport infrastructure. The Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of transport infrastructure and associated geotechnical challenges and applications.

ORGANISING COMMITTEE*

Vladimir Lopez Suarez (Chair)

Daniel King

Richa Shukla Potdar

Erin Lee

David Glover

*a sub-committee of the AGS Victoria committee

SPONSORS

Platinum

Global Synthetics Pty Ltd

Gold

Chadwicks Geotechnics

Acciona Geotech

Silver

Geotesta

Foundation Specialists Group

TECHNICAL REVIEWERS

All technical papers in these proceedings, excluding the keynote addresses, were peer reviewed. The reviewers are acknowledged and listed below:

Daniel King (Editor)
Chris Coulson
Joel Gniel
Jay Lee
Jie Li
Nimal Nilaweera
Bhavikh Riyat
Ben Shannon
Sri Srithar
Manh Tran

AUSTRALIAN GEOMECHANICS SOCIETY

A technical society of

ENGINEERS AUSTRALIA

Ground improvements and supports for embankments and structures of Regional Rail Link - City to Maribyrnong River

K. Chen*

Associate Director, AECOM, Collins Square, Tower Two, Level 10, 727 Collins Street, Melbourne VIC 3008; Phone +61488211262
email: kejing.chen@aecom.com   *formerly Golder Associates.

ABSTRACT

This paper discusses ground improvement and foundation support that were adopted in Melbourne's Regional Rail Link development that was completed in 2015. The development included realignment of rail track within the existing rail corridor and additional bridges, viaducts, and embankments. The project site was a "brownfield" within a relatively complex geological domain of Yarra Delta Sediments including the recent marine deposits locally called Coode Island Silt (CIS) which is a highly compressible and very low strength clay. The presence of CIS and its variable thickness imposed special challenges for design and construction of the rail link and necessitated ground improvement and support works, including: a) preformed driven, bored and CFA piles for bridges, viaducts and underpasses; b) ground support using controlled modulus columns (CMCs) for the embankments with estimated long term settlement ≥ 150 mm; c) preloading and surcharging for embankments with estimated long term settlement <150 mm. The paper will first cover general geotechnical design considerations for ground improvement using CMCs. A case study will then be presented on the detailed design of the North Melbourne Flyover embankment widening.

Keywords: soft clays, CMCs, geosynthetic reinforced column supported embankment.

1 BACKGROUND OF PROJECT

The Reginal Rail Link (RRL) was a $4.5 billion project to build a 47.5 km length of railway from the CBD though to the western suburbs of Melbourne, Victoria (see Figure 1). The main purpose of RRL was to separate regional V/Line Ballarat, Bendigo and Geelong services from the electrified Melbourne suburban services, therefore removing bottlenecks from the rail network. The outcome of the project was to increase the rail capacity and reliability. The project involved the building of an extra pair of tracks from Southern Cross station to Sunshine along the existing rail corridor, and a new line from Deer Park, which joins with the Warrnambool line at Werribee.

The RRL was at the time the largest transport infrastructure project being undertaken in Australia. Construction commenced in 2009 and was completed by June 2015. The project was delivered in six work packages as detailed in Table 1. As part of Melbourne's RRL development, City to Maribyrnong River (RRLCMR or RRL Package B) represented an approximately 5 km corridor from Melbourne City to Maribyrnong River (see Figure 1). The embankment widening and new embankments. The project was delivered in 2015 by RRLCMR Alliance comprising V/line, Metro, Lendlease (formerly Abigroup), John Holland, Coleman Rail, AECOM and GHD. Golder Associates were subcontracted to the RRLCMR Alliance to provide geotechnical design services. The geotechnical design described herein was carried out by the author while working for Golder Associates. Some of the key components of the RRLCMR are included in Table 3 and the locations of these components are shown in Figure 2, namely:

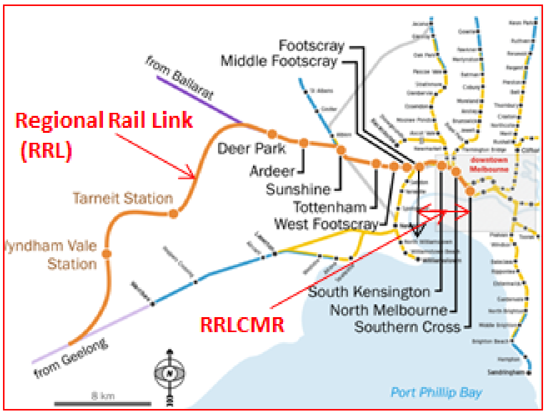


Figure 1 - Route of Reginal Rail Link (Courtesy of Victorian Government)

- North Melbourne flyover and ARTC dive structure
- North Dynon Lead Embankment widening
- Maribyrnong River bridge and viaduct works

This paper will first cover general geotechnical design considerations for ground improvement (CMCs) focusing on the detailed design of the North Melbourne Flyover. For the North Dynon embankment and Maribyrnong River bridge, refer to King et al (2014, 2017, 2018) and Gniel and Haberfield (2015).

Table 2 - Work Packages

Work Packages	Type	Entities
Southern Cross	MTM Franchisee	John Holland, Coleman Rail, & Alstom - AECOM
City-Maribyrnong River	Alliance	John Holland, Abigroup, Coleman Rail, AECOM, GHD, MTM, V/Line & RRLA
Footscray-Deer park	Alliance	Thiess, Balfour Beatty, PB, SKM, MTM, V/Line & RRLA
Deer Park-West Werribee	Design& Construct	Baulderstone Leighton Joint Venture
West Werribee J	Design& Construct	Leighton-Downer Joint Venture - AECOM
Rail System	Alliance	UGL, RPS, MTM, V/Line & RRLA

2 GEOLOGY AND GROUND CONDITIONS

The project was located in a "brownfield" area within a relatively complex geological domain of Yarra Delta Sediments. The subsurface conditions along the railway corridor typically comprise variable fill, over soft Coode Island Silt (CIS), over stiffer sediments such as Fisherman Silt (FBS) or other deposits, over Melbourne Formation (MF) siltstone. Basalt intrusions are present to a shallow depth in North Melbourne Flyover site. CIS is a recent marine deposit - a highly compressible (e_0 =1.2 to 2.8), very low strength (c_u= 20 to 30 kPa) and up to 20 m thick clay soil. The details of geological origins and engineering properties of CIS are well documented (Neilson 1992, Ervin 1992, Srithar 2010 and King et al 2016).

Groundwater was typically encountered between RL 0.5 to 2 m (AHD), or about 2 m to 5m below the existing ground surface.

3 GROUND SUPPORTS AND GROUND IMPROVEMENT

The presence of CIS and its variable thickness imposed special challenges for design and construction of the rail link. The ground improvement and supports works (see Table 3) were necessary to meet the strength and serviceability requirements. Where bridges, viaducts and underpasses were proposed the sub-structures comprised preformed driven piles (e.g. 400mm square reinforced concrete piles and steel tube piles), bored and CFA piles, of which a total length of 18,000 linear meters were installed.

Where new embankments and widening of existing embankments were required, different forms of - ground improvement were adopted depending on estimated long term settlements. Ground improvement using controlled modulus columns (CMCs, see Section 4 for more details) was adopted for embankments with estimated long term settlement ≥ 150 mm. A total length of 35,000 linear meters of CMCs were installed. Preloading and surcharging was adopted for embankments with estimated long term settlement <150 mm where sufficient space and time was available within the project boundaries and programme.

Application of CMC ground improvement for railway embankments founded on soft ground was probably the first time for a large railway project in Australia. Comprehensive field instrumentation was undertaken for one of the CMC supported embankments during construction as a joint research between Golder Associates and Monash University (King et al 2014, 2017, 2018) with support from the RRLCMR Alliance.

The retention system for both permanent and temporary works comprised reinforced soil structures (RSS), gabion walls, soil nail walls and sheet pile walls. A tied wall/gabion wall system (Gniel and Haberfield, 2015), that was adopted as an alternative to a conventional RSS wall system, allowed a low quality backfill material to be utilised leading to significant cost savings for the project.

4 DESIGN CONSIDERATIONS OF CMC GROUND IMPROVEMENT

4.1 CMCs ground improvement

The controlled modulus column (CMC) ground improvement involves adding vertical concrete columns to a depth of generally greater than 4m below the ground surface, which, together with the surrounding soils, forms a composite foundation. As there is no reinforcement, CMCs have only limited bending moment capacity and are designed primarily to take compression load. As such, CMCs are treated as a type of ground improvement that increases the strength and reduces the overall settlement of the embankment. The CMCs used for this project comprise 450 mm diameter columns spaced at a typical 2 m to 2.7 m spacing on a square grid, depending on the embankment loading and ground conditions. The CMCs were installed by a displacement method using a CFA rig with a special drilling head (See Figure 3).

Conventional piles are generally designed for settlement to be less than 20 mm. However, CMCs are mainly designed to act as settlement reducers and the anticipated settlement may be in range between 50 mm to 100mm. Consequently, the design geotechnical strength of CMCs can be taken to be close to its serviceability load to allow the CMC founding soil to

Table 3 : Ground improvement and support works for RRLCMR

Site	Bored piles	CFA* piles	Driven piles	CMCs^	Preload	Soil Nails
North Melbourne flyover/ARTC dive structure	Yes	Yes	Yes	Yes	Yes	
North Dynon Lead embankment widening				Yes	Yes	Yes
Maribyrnong River bridge/approach works			Yes	Yes	Yes	Yes
Linear meter of installation	540	384	17,075	35,000		

[a] Continuous flyer auger ^ controlled modulus column.

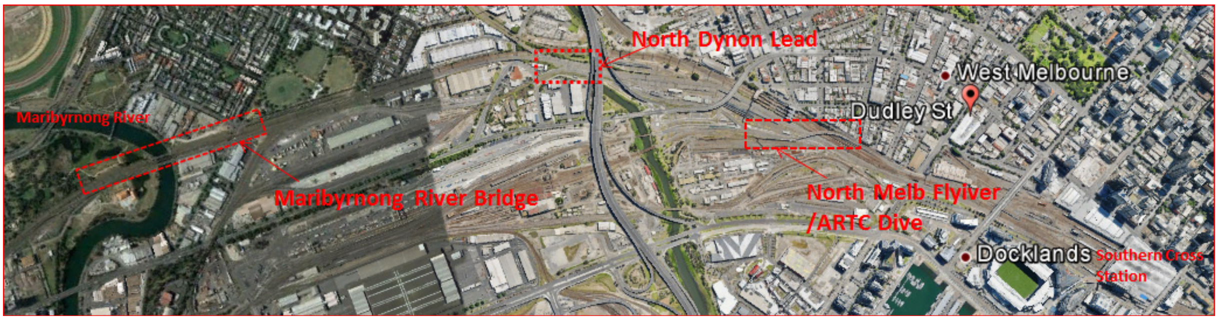


Figure 2 – Key components of Reginal Rail Link: City to Maribyrnong River

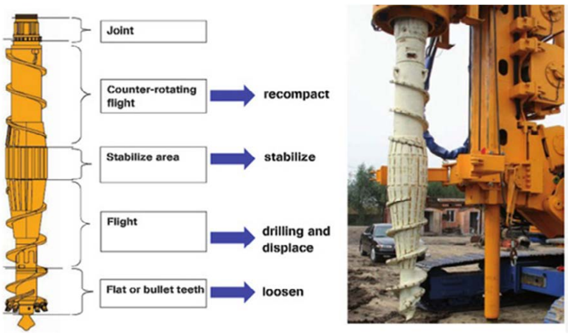


Figure 3 - CMC rig

locally reach its yield stress under the serviceability condition while the global stability of CMC foundation is still maintained.

To ensure the effective load transfer, enlarged heads measuring 1 m in diameter were provided at the top of CMCs (Figure 4). A geogrid reinforced load transfer platform is constructed above the CMCs to ensure embankment load is supported evenly by the CMCs and loading of the soil between columns is minimised.

An enlarged head for the CMCs enables design of an economical geogrid reinforced load transfer platform. The smaller the CMC diameter at surface level, the thicker and heavier the reinforced load transfer platform needs to be to provide adequate shear and punching resistance. The following is relevant to the load transfer platform design:

- A 650 mm thick load transfer platform. Well graded sound rock with a maximum particle size of 75 mm and not more than 5% fines Geogrid reinforcement - factored working loads within the geogrid reinforcement of about 100 to 300 kN/m. This load will need to be supported in two directions (parallel and transverse to the alignment). Accounting for durability, environmental and creep factors, geogrid with an ultimate tensile strength of 400 to 1000 kN/m (at 10% strain) were required in each direction.

4.2 Strength Design

The strength design for CMCs needs to meet both geotechnical and structural requirements.

The design geotechnical capacity was assessed in a manner similar to the design for a single pile in accordance with AS 2159 (Piling – Design and Installation). Capacities were estimated to be in range between 600 kN to 800 kN – the summation of the end bearing resistance and shaft resistance. Due to the potential development of negative skin friction for part of CMCs in CIS, the shaft resistance for the part of the ground profile that induces negative friction was ignored. The design geotechnical strength was verified by PDA testing during construction.

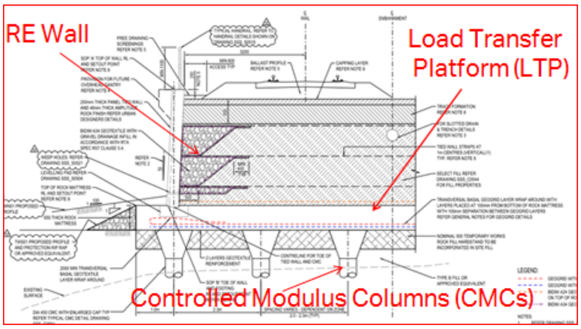


Figure 4 - CMCs supported Railway embankment

The structural strength of a single CMC column can be assessed in accordance with AS3600 for plain concrete ($N = 0.45f_c'A_c$, where $f_c' = 0.6f_c$, A_c = area of CMC, f_c = characteristic compressive strength). For a 450 mm diameter f_c = 25 MPa concrete column, its design structural capacity is estimated to be about 1080 kN. The CMC design strength shall be taken as the minimum of the geotechnical and structural strength.

The length and spacing of CMCs were selected based on the design principle discussed above.

4.3 Serviceability design

During the bidding stage, the deformation analysis for CMCs ground improvement was undertaken in accordance with design principles similar to those adopted for stone columns (Chen & Liu 1993). The deformation analysis at that time was undertaken using FEM (PLAXIS 2D) with the zone of ground improvement (CMCs and surrounding soil), and was modelled as a volume element with an equivalent stiffness selected proportional to the stiffness and area of CMC and soil.

During the detailed design stage, the design analysis of the CMC supported embankment was further assessed using PLAXIS 2D to consider the CMCs as a grid of plate elements. Due to the CMCs being unreinforced and having only limited bending stiffness, the stiffness for the plate element was initially selected based on cracked modulus of concrete with its bending capacity limited to be 1% of full section moment capacity (Gniel and Haberfield, 2015). The proposed embankment geometry and soil stratigraphy were modelled using the parameters presented in Table 4. The serviceability design was undertaken based on limiting settlement to 50 mm for both during and post construction.

4.4 CMC installation

Testing and quality control in CMC construction have been covered by Gniel and Haberfield (2015). As discussed in Section 4.1 CMCs are installed by displacement of the surrounding soils. Key issues associated with CMC installation is the potential for ground lateral displacements (Suleiman et al 2015 & King et al 2018) and excess pore pressure that is generated associated with the ground movement and possibly with high pressure of concrete pumping. The former may potentially significantly displace the existing ground or underground facilities, or may cause cracking of the adjacent installed CMCs that have not fully cured. The latter may cause delayed additional settlement associated with the dissipation of the excess pore

Table 4 - Soil parameters adopted for analysis

Soil Unit	ɣ (kN/m^3)	c' (kPa)	φ' (°)	E (MPa)	μ	c_u (kPa)
Fill	18	5	28	30	0.3	-
CIS	16	1	25	2	0.45	30
Stiff clay	19	5	28	30	0.3	100
MF	22	50	30	500	0.15	-

Where: ɣ = unit weight of soil, c' = effective cohesion, φ' = effective angle of internal friction, E – Young's modulus, μ = Poisson's Ratio.

pressure. To minimise the impact of CMC installation CMCs are typically installed by “hit one and miss one” approach. However, it could be argued that some extent of the cracking in the CMCs is inevitable. The excess pore pressure issue was identified both in this project and other projects undertaken by the Author. It was found that the magnitude of the pore pressure that is generated, and the longevity of the excess pressure that remain post installation can influence performance. Therefore, more attention should be paid to the excess pore pressure issue during CMC ground improvement design.

5 CASE STUDY - NORTH MELBOURNE FLYOVER EMBANKMENT AND ARTC HEADSHUNT DIVE STRUCTURE

5.1 Scope of works

The North Melbourne Flyover embankment (NMFE) supports approximately 300 m of track to the west of the existing North Melbourne Flyover structure.

This location comprises a complex integration of proposed and existing tracks, embankments and structures. The ground conditions and general plan layout of the site is presented in Figure 5. The key components of the site works consist of the following:

- Widening of an existing embankment to accommodate the new RRL tracks and the existing Flyover Tracks. The embankment is typically about 6 m high and sits on top of a load transfer platform supported by CMCs.
- Construction of box and trough structures to accommodate the ARTC Headshunt Dive – Freight Link Tracks) that passes beneath/beside the proposed RRL embankment.
- Construction of a new section of RRL embankment to the west of the ARTC Headshunt dive box section. The proposed new embankment is up to about 3 m high next to the box section, reducing to existing grade level near the Dynon Road bridge to the west.

5.2 Constraints and challenges

As shown Figure 5), the NMFE site is underlain by a layer of soft CIS with variable thickness ranging from <2 m to nearly 20 m. The CIS thickness changes both longitudinally and transversely (Figure 6). The key design challenges are the potential for significant primary consolidation, creep, and differential settlements between the existing tracks and embankment widening. Constraints that affected the design and construction of the ground improvement and embankments include:

- Construction close to live tracks -Train lines remaining active near to the proposed construction zones throughout means various stages of construction are required. Potential ground movements as a result of excavations near existing tracks cannot impact the safe operation of these lines.
- Proximity of the existing and proposed flyover embankments to the dive structure and associated issues of stability and constructability.
- Groundwater - Construction of ARTC Dive structure is below the water table
- Uncertainty regarding the material within the existing embankments and presence of contaminated fill.

5.3 Design Solutions

The reference design provided for NMFE was based on a piled (driven piles) embankment which was deemed to be costly, partly due to piling code compliance costs. The design team for the RRLCMR Alliance was able to revise the design to use CMCs which was considered to be ground improvement. This change resulted in significant cost reduction and partly contributed to the wining of the project tender.

During the design and construction stage, more rigorous design analyses were undertaken to resolve some of the design issues identified during the bidding stage. Key issues included the numerical modelling of CMCs and estimation of differential settlements near the box/trough structures. Figure 6 presents a cross section through the dive structure which is bounded by the widening of the existing Flyover tracks to the left, and new RRL embankment to the right. In order to minimise the potential down drag settlements of existing live tracks, both the widening/ new embankments were supported by CMCs which are founded into stiff soil. The box structure was supported on 400mm square RC piles driven to siltstone bedrock. In addition to differential settlement transverse to the tracks, the differential settlement longitudinally along the tracks also needed to be dealt with given the soft compressible layer thickness increases from less than 2 m to nearly 20m within a distance of about 40 m as shown on Figure 5. The longitudinal differential settlements were managed by the following approach:

- Where the embankments are supported on CMCs, the target settlements were controlled to be no greater than 50 mm.
- Where the CMCs supported embankment terminates, a transition zone was provided by gradual shortening the CMC depths.

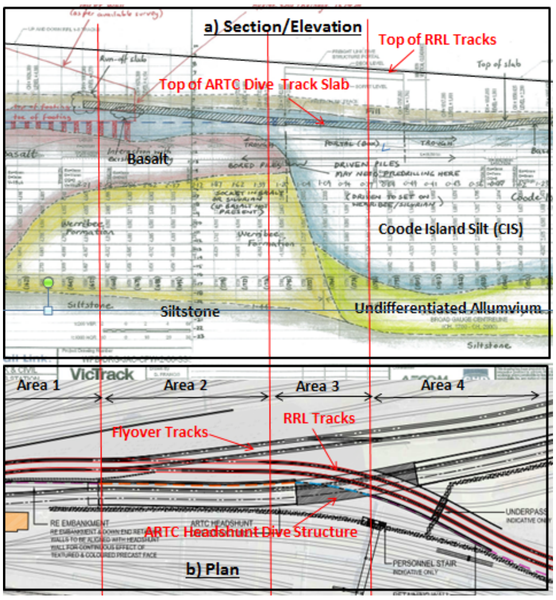


Figure 5 Layout plan and section/elevation - North Melbourne flyover embankment/ARTC Headshunt Dive

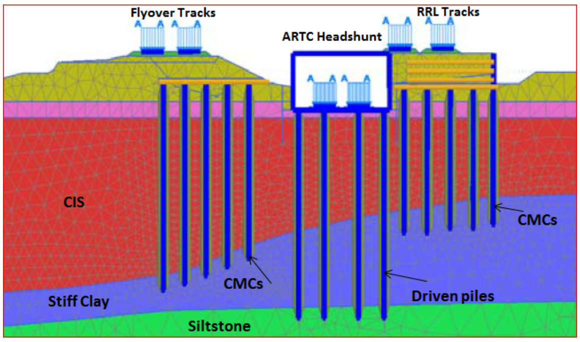


Figure 6 - FEM model for design analysis

- Where the embankment was founded on the natural ground, a preloading of earth fill was applied along the tracks.

Due to the complex integration of existing and proposed tracks, embankments and structures, the design of ground improvement and support works were separated into 4 key Areas (Figure 5) and described in the following sections.

5.3.1 Area 1

This area involves widening the section of flyover embankment by up to about 2m and ARTC lines are close to existing ground level. The ground conditions comprised shallow fill and CIS (less than 2m thick) over basalt rock as indicated in Figure 5. The design of the widened embankment involves bolting a precast concrete panel to the face of the existing retaining wall which is supported on existing mass concrete footing founded on basalt rock. The sizes and condition of existing concrete mass footings were confirmed during the construction to ensure that the existing mass footings have the capacity to take the widening load.

5.3.2 Area 2

This area involves widening the existing embankment to support the proposed RRL Up and Down lines as illustrated in Figure 7. The section of widened embankment measures up to about 12 m wide and 3.5 m high and is supported laterally by a piled trough structure. Due to the relatively thin layer of CIS between the fill material and basalt, ground improvement within the footprint of the widened embankment is not necessary.

5.3.3 Area 3

Similar to Area 2, this area involves widening the existing embankment to support the proposed “RRL Up and Down” lines and “Up and Down RRL Flyover” lines, as illustrated in Figure 8. The section of widened embankment is up to about 20 m wide and 3.5 m high, and is supported on a grid of 450mm dia. CMCs spaced at 2.7m. The embankment is supported laterally by the piled trough structure east of RRL.

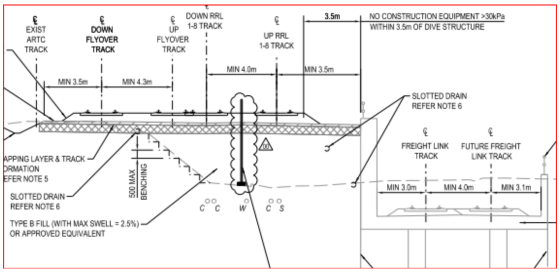


Figure 7 - Design solution for Area 2

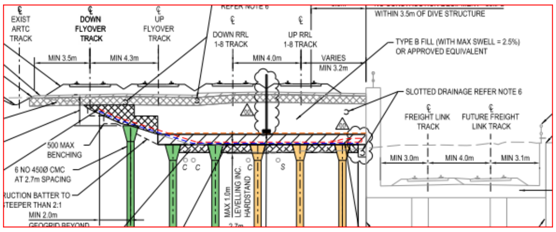


Figure 8 Design solution for Area 3

5.3.4 Area 4

This area involves widening the existing embankment to support the proposed “Flyover Up and Down” lines and building new embankment (incorporating “box” dive structure) to support “Up and Down RRL Flyover” lines, and to accommodate the underpass for the ARCT headshunt tracks as illustrated in Figure 9. The section of widened embankment measures up to about 12 m wide and 5 m high, and is supported on 450mm dia. CMCs spaced at 2.5m. The Up and Down RRL track alignment passes over the box section of the dive structure. The box structure is supported on piles and the approach embankments either side of it on CMCs.

6 CONCLUSION

Extensive ground improvements and supports were undertaken for the railway embankments in Melbourne’s Regional Rail Link - City to Maribyrnong River that was completed in 2015. A case study of the North Melbourne Flyover embankment demonstrates the successful application of an effective and economic design option of ground improvement for railway embankments founded on highly compressible and varying thickness of soft clay. Some of the CMC installation issues identified during design and confirmed during the construction that are worth noting include ground disturbances and excess pore pressure associated with the CMC installation. These affect the structural integrity of the CMCs and the long term performance of CMC ground improvement and should be considered during design.

7 ACKNOWLEDGEMENTS

The author is grateful to Regional Rail Link – City to Maribyrnong River (RRLCMR) Alliance for allowing this project paper to be published. The author would like to thank Gary Chapman, Chris Haberfield, Joel Gniel of Golder for their support during both the tender and design stages of the project.

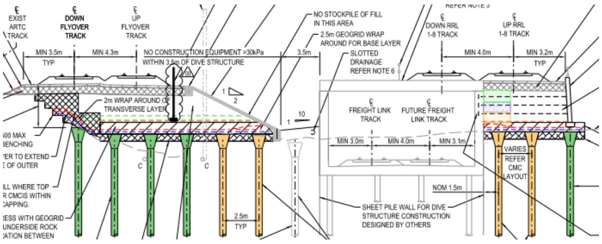


Figure 9 - Design solution for Area 4

REFERENCES

Chen, K., Liu, H. 1993. Compaction Effects of Vibroflotation method on a weak and liquefiable silt, Proceedings of the 3rd International Conference on Case Histories in Geotechnical Engineering, 1993, St. Louis, USA. pp. 1039 - 1044.

Ervin, M. C. 1992. Engineering properties of Quaternary age sediments of the Yarra Delta: In Engineering Geology of Melbourne. W.A. Peck, J.L. Neilson, R.J. Olds and K.D. Seddon (Eds.). A. A. Balkema. Rotterdam, Netherlands. pp. 245-259.

Gniel, J., and Haberfield, C. 2015. Design, construction and performance of a tied-wall embankment supported on concrete column ground improvement. In Proceedings of the International Conference on Geotechnical Engineering: Soil–Structure Interaction, Underground Structures and Retaining Walls. St. Petersburg, Russia, June 2014. IOS Press. pp. 18–27.

King, D. J., Gniel, J., Bouazza, A., Ha, H. H. and Rowe, R. K. 2014. Preliminary observations from a geosynthetic reinforced piled embankment. Proceedings of the 10th International Conference on Geosynthetics. Berlin, Germany. 21 - 24 September 2014. German Geotechnical Society.

King, D.J., Bouazza, A., Gniel, J., and Bui, H.H. 2016. The compressibility, permeability and structured nature of the Coode Island Silt. Australian Geomechanics, 50(2): 45–65.

King, D. J., Bouazza, A., Gniel, J., Rowe, K. R. and Bui, H. H. 2017. Load transfer platform behaviour in embankments supported on semi-rigid columns: implications of the ground reaction curve. Canadian Geotechnical Journal, 54(8): 1158-1175. doi: 10.1139/cgj-2016-0406

King, D. J., Bouazza, A., Gniel, J., Rowe, K. R. and Bui, H. H. 2018. Geosynthetic reinforced column supported embankments and the role of ground improvement effects. Canadian Geotechnical Journal, 55(6): 792-809. doi: 10.1139/cgj-2017-0036

Neilson, J. L. 1992. Geology of the Yarra Delta. In: Engineering Geology of Melbourne. Peck, W.A., Neilson, J.L., Olds, R.J. and Seddon, K.D. (Eds.). A. A. Balkema, Rotterdam, Netherlands. pp. 223-243.

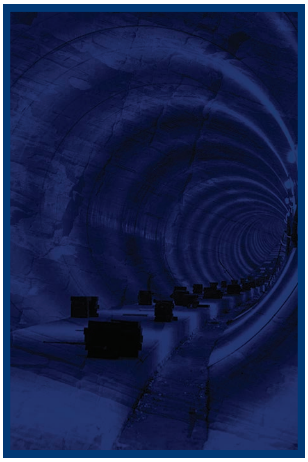
Srithar, S. T. 2010. Settlement characteristics of Coode Island Silt. Australian Geomechanics, 45(1): 55-64.

Suleiman, M. T., Ni, L., Davis, C., Lin, H. and Xiao, S. 2015. Installation Effects of Controlled Modulus Column Ground Improvement Piles on Surrounding Soil. Journal of Geotechnical and Geoenvironmental Engineering, 142(1). doi: 10.1061/(ASCE)GT.1943-5606.0001384

Wong, P. and Muttuvel, T. 2012. Economic design of controlled modulus columns for ground improvement. Proceedings of the 11th Australian New Zealand (ANZ) Conference on Geomechanics. 15-18 July 2012. pp. 680-685.

2018 AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIAN SYMPOSIUM

Geotechnics and transport infrastructure



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER