AN INNOVATIVE CONSTRUCTION TECHNIQUE FOR EXTENSIONS TO EXISTING REINFORCED EARTH RETAINING WALLS.

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ABSTRACT

Extensions of existing RE (Reinforced Earth) bridge abutment walls to allow for bridge widening or bridge duplication are difficult because of the need to maintain uninterrupted traffic flow whilst sections of the existing bridge abutment walls and embankments are removed.

A system which provides temporary support of the bridge structure whilst allowing for the staged removal and replacement of exiting RE wall sections to support the new section of bridge or bridge extensions was developed by The Reinforced Earth Company (RECO) and Menard Bachy. This system was recently used on a number of bridge extensions on the Southern Expressway in Adelaide.

The concept involved the installation of a row of jet grouted stabilised soil columns within the existing Reinforced Earth mass gravity volume. Their location and method of installation were specifically chosen to avoid or minimise any damage to the existing Reinforced Earth components that might compromise the short term structural integrity.

The final design required detailed consideration of the interaction of construction installation and bridge loading on the existing RE abutment walls as a whole. Reinforced Earth designers assessed the potential short term effect of damaging existing reinforcing strips during both the initial drilling stage and during the installation of grout elements. Once the grouted columns are completed, these sections of retaining wall will behave as a weakly cemented mass gravity structure, allowing for the staged removal of existing wall sections without affecting the stability of the bridge and embankment.

This paper describes this new bridge widening method, explains the required construction stages and shows the application of the system in a recent project.

INTRODUCTION

Road Duplication/Extension projects allow for an increase in traffic capacity for an existing road once it reaches its design limits. As a consequence, several bridge structures have to be widened or duplicated.

The duplication of an existing RE structure usually comprises of the following steps. (Figure 1)

- Identify panels to be dismantled/demolished or replaced later on.
- Identify panels to remain in place. This includes panels for which original design allows for the new load requirements and panels that can’t be removed for stability reasons.
- Provide a method to strengthen the wall area identified previously that will not be able to take the new loads.
- Implement the new design in order to reconstruct the wall and build the duplication as per new bridge project requirements.

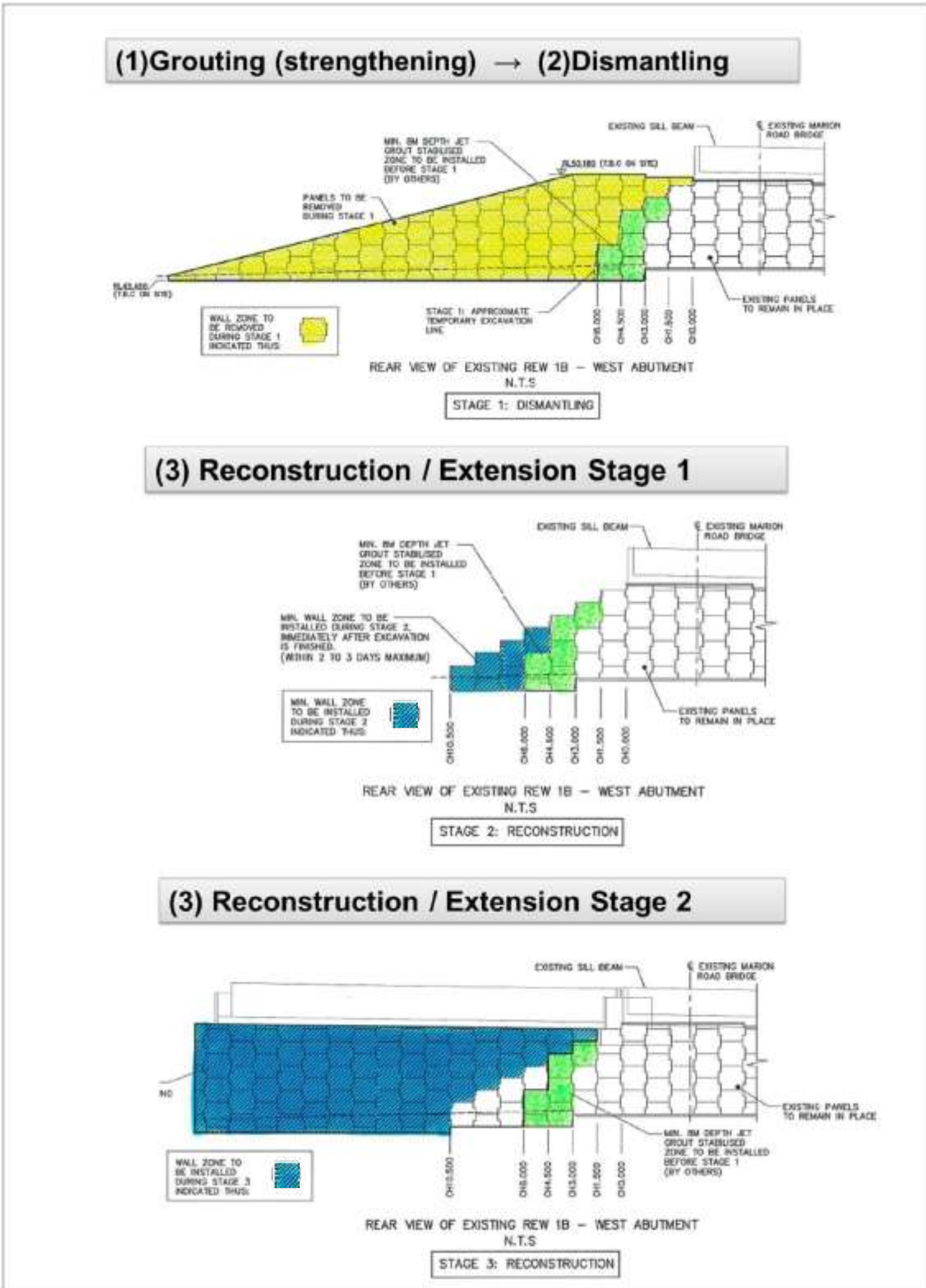

Figure 1: Typical RE bridge abutment duplication staging

The following sections explain a new and different approach to RE abutment duplications and the first application of this system on the Southern Expressway Duplication in Adelaide (Australia). It also describes the design and construction advantages of this form of construction to allow for extensions and modifications to existing Reinforced Earth walls over traditionally used soil nailing method.

THE PROJECT

The Southern Expressway in Adelaide was originally built as the world's longest reversible one way freeway. Originally proposed as 'Noarlunga Freeway', it was built as a corridor to improve traffic flow during rush hours in the major arterial, Main South Road, in Adelaide's south. At certain times of the day, freeway lanes changed direction, depending on the peak flows of traffic. The freeway featured electronic overhead signs at the approaches to the entry and exit points indicating the direction of traffic.

The expressway was built in two stages, the first completed in late 1997, the second in 2001.

RECO designed and supplied twelve RE structures over the two stages.

However, since completion of second stage, traffic requirements increased. Therefore, a decision was made to turn the expressway into a regular two-direction freeway, providing greater travel efficiency and better access for commercial traffic to industrial areas and facilities in Adelaide’s south while also improving road safety for commuters and improving emergency service access.

As a result, the expressway needed to be widened to cater for the new traffic requirements. The design proposal involved the addition of a new road to be built on the western side of the current roadway, consisting of four lanes between Reynella and Marion Road.

Baulderstone Abigroup Joint Venture, the projects managing contractor, awarded Menard Bachy the specialist geotechnical works to address the duplication design requirements. Jet Grouting was proposed to satisfy the duplication requirements. At this stage RECO was engaged by Menard Bachy to design and supply three RE Bridge Duplication structures; Beach Rd, Marion Rd and Sherriffs Rd Bridges. (Figures 2 & 3)

Recently completed, the expressway is now open 24 hours a day, in both directions, meeting the new traffic requirements.

Figure 2: Sherriffs Road Bridge (above), Marion Road Bridge (below).

Existing structures before duplication

Figure 3: Beach Road Bridge. Existing structure before duplication

Works are currently underway, and the 2-way expressway is expected to open to traffic in 2014

THE PROBLEM

Most often, a large amount of panels from existing structures cannot be demolished and replaced without affecting the integrity of the existing abutment. Panels surrounding the existing sill beam or underneath it cannot be dismantled as the integrity of the existing abutment will be compromised. A safe excavation profile (usually 2H:1V) has to be provided during temporary dismantling earthworks due to global stability requirements. Additionally, panels in that area were originally designed to cater only for wingwall loading as the sill beam loads were not affecting that wall area.

As a consequence of the above, there will be an area of the existing structure that has to be strengthened in order to provide the same required capacity for the whole structure. Traditionally, the most widely used RE wall strengthening method has been soil nailing. Certainly Soil nailing has been proved as a reliable solution most of the time, however there are quite a few inherent inconveniences:

- After installing soil nails (by drilling the existing RE facing) a new facing has to be provided in order to anchor nail heads and at the same time conceal them. Most of the time, aesthetical/architectural requirements do not allow for “exposed” nail heads. (Figure 4)

- Soil nailing requires that certain areas in front of the existing structure have to be occupied during nailing operations (Figure 5). Sometimes this is not possible at all, for example a train corridor right in front of the existing structure that can´t be occupied.

- Global stability requirements for temporary excavation earthworks usually imposes 2H:1V profiles. Most often, temporary stiffer profiles (1H:1V or even 1H:2V) are required. These profiles cannot be safely achieved by installing nailing from the front face of the wall. Soil nailing from the front does not necessarily provide an additional protection against transversal slip failures in exposed excavation faces during construction. Sometimes, an additional lateral shoring solution has to be provided in order to achieve stiffer temporary lateral excavation profiles.

Most of the referred inconveniences above can be solved by providing a different RE wall strengthening method. The following explains one such method.

Figure 4: Typical soil nailing strengthening operations

Figure 5: Cast in situ "new facing" to anchor and conceal nail heads

THE SOLUTION

A new RE structure duplication/strengthening system has been developed using Jet Grouting.

Once the RE block strengthening area has been identified at design stage, Jet Grouting columns are to be installed within the RE block for the whole extent of the reinforcing strips in that area.

Essentially the system consists of installing Jet Grouting columns in certain nominated areas within the existing RE block by following standard Jet Grouting procedures (Figure 6)

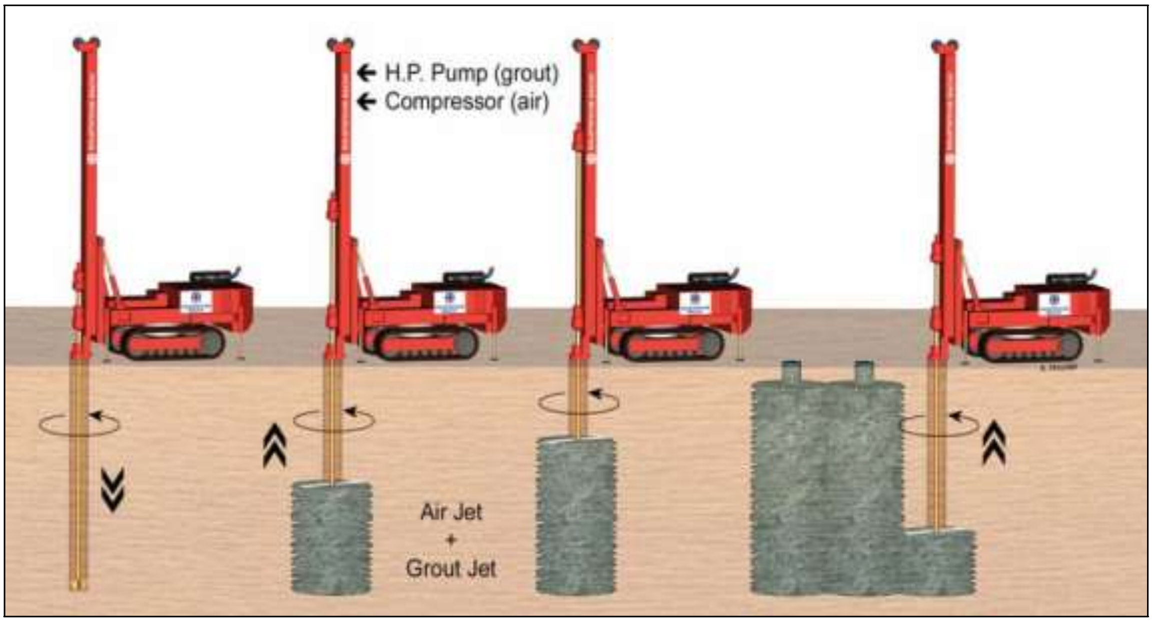

Figure 6: Jet grouting procedure

Jet Grouting Principles

Jet grout columns are installed by initially drilling a small hole, typically 100 mm in diameter to the required depth. Then the soil is eroded by a high pressure jet of grout, air-enshrouded grout, or water and the simultaneous injection of cement suspension grout into the disturbed soil by means of a nozzle. The injection pressure can be up to 60 MPa.

Then the drill stem and nozzle are simultaneously raised and rotated so as to combine the grout with a portion of the original soil to form solidified soil mixed material. The end product is cementitious round columns.

The working sequence follows the technical requirements and the conditions of the structure to be treated

Jet Grouting systems

There are three major systems for jet grouting: the single, double and triple fluid systems.

In the single fluid system a special hollow drill rod which is equipped with a monitor containing a horizontal jet nozzle at the tip is lowered into the hole. Cement suspension grout is pumped down the drill rod at a very high pressure while the drill rod and monitor are simultaneously rotated and withdrawn. The grout that exits the jet nozzles at high velocity disintegrates the soil and mixes with it to form soilcrete.

In the double fluid system the grout is encased within a shroud of compressed air. The air acts as a buffer between the groundwater and the grout, greatly increasing the cutting efficiency. It also creates turbulence in the waste spoil, improving the efficiency of its removal. In this method a special coaxial drill string and jet monitor are used.

The triple fluid system requires a triaxial drill stem and monitor with appropriate nozzles. In this system an air-enshrouded jet of water erodes the soil while the grout is simultaneously injected through separate nozzles. The cutting jets are located above the grout supply, which allows a nearly complete replacement of the soil with grout as the monitor is withdrawn. The three grouting systems are shown schematically in Figure 7.

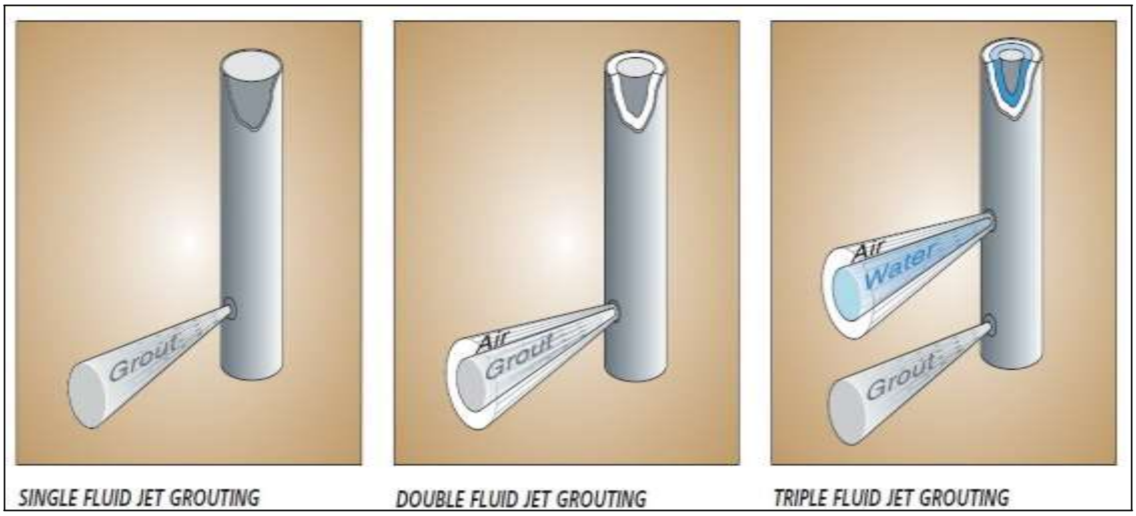

Figure 7: The three most common Jet Grouting Systems

Jet grout columns can be constructed in all soils; however the effective radius and strength depends on the properties of the soil and the jet grouting parameters used. In granular soils jet grout columns can have a strength of about 10 to 15 MPa or more; however the strength of jet grouted columns in clay can be quite less and as low as 1 MPa. Jet Grout strength is primarily determined by the soil type. However, the amount of cement used per unit volume and the water cement ratio also has an effect on the Jet Grout strength. Typical water-cement grouts have a water-cement ratio in the range of about 0.6 to 1.2 by weight.

For the single fluid system jet grouted columns, typically diameters are on the order of 0.4 to 0.6 m in cohesive soils and up to about 1.2 m in granular materials. In double fluid system column diameters are on the order of 0.8 to 1.2 m in cohesive soils and up to about 2.5 m in granular soils. Implementation of the triple fluid system allows the construction of larger diameter columns whereas in cohesive and granular soils the diameters can be respectively up to 1.5 m and 3.6 m.

Typical injection parameters for different Jet Grouting systems are shown in Table 1.

Table 1: Typical injection parameters for different jet grouting systems

Jet Grouting System	Single fluid	Double fluid	Triple fluid
Grout injection rate (l/min)	40-360	70-360	70-360
Grout pressure (MPa)	20-60	30-60	3-17
Air flow (l/min)	-	3700-6000	2700-6000
Air pressure (MPa)	-	0.6-1.2	0.6-1.2
Water flow (l/min)	-	-	70-150
Water pressure (MPa)	-	-	20-50
Rotation (RPM)	4-25	4-15	2-15
Withdrawal rate (cm/min)	10-50	7-50	5-40

Jet Grouting Design

Limit state design methodology has been adopted in the design of jet grouting wall strength and stability assessments.

Menard Bachy carried out all the internal design and installation of the columns following RECO's Bridge duplication design.

Deep Seated Failure

Limit equilibrium method has been used to design the wall against deep-seated failure. This involved analyses using STARES (**ST**ability **A**nalysis of **RE**inforced **S**oil) software developed by the University of Sydney. Drained soil parameters have been used in the global stability analysis for the jet-grouted RE wall.

Internal Stability

Finite element analysis has been used to assess the internal stress development within the wall for internal stability assessment. This involved analyses using Plaxis 2D software package.

The designed mechanical properties of the jet-grouted material was taken as follows:

- Bulk unit weight = 21kN/m3
- Unconfined compressive strength UCS = 3.5MPa
- Ultimate average shear stress (*v*u0) along a critical jet-grouted wall section: 0.175 MPa (*v*u0=0.15*UCS1/3)
- Maximum tensile stress (*f*ct): 0.673MPa (*f*ct=0.36*UCS0.5)
- Approximate elastic Young.s modulus: *E* = 910MPa

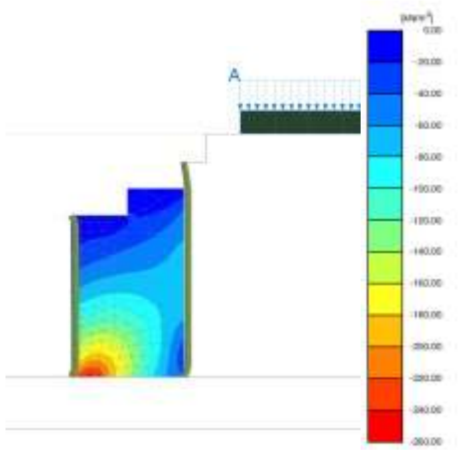

Figure 8: Finite element analysis for verification of stresses and

deformations (Marion Rd Bridge)

Once Jet Grouting is finished all the strips embedded into the jet grouted block become redundant. Technically speaking, this section of the RE block is not an RE block anymore as it has been “replaced” with a mass gravity block (built by grout injection). This grouted block will provide the required capacity for the new structure.

Potential Effect of Cutting RE Strips

RECO's in house RE wall design software Valdez and Zaraus, have been used to assess the potential effect of the grouting operations cutting some of the existing reinforcing strips. The jet grouting is installed using a 100 mm diameter drill bit and hence cannot cut more than a single strip at any one level of reinforcement.

Our analysis indicates that under the proposed short term conditions the cutting of one strip at each level will not compromise short term stability or endanger the wall. We have had considerable previous experience with this jet grouting process through RE walls. After the grouting has been completed this section of wall will behave as a cemented mass gravity structure. The RE strips will then be redundant in the long term structure.

Installation of Jet Grouting Columns (Southern Expressway Duplication Project)

A total of five temporary jet grouted wall have been installed at three different bridges using the double jet systems.

Prior to the commencement of the jet grouting works, trials were performed onsite to ensure that anticipated production jet grouting parameters met or exceeded the design requirement.

Two trial columns have been installed at Beach Road. After a curing period of 12 hours, the column tops were excavated in order to confirm column diameters with the RE backfill.

In addition, jet grouted test columns were subjected to UCS testing on wet grab samples. The tests demonstrated that the minimum required UCS had been achieved.

Figure 9: Trial Column exposed at Beach Road Bridge

Pre-excavation of the first 500 mm was required to expose and locate the first row of strips in order to avoid hitting obstruction and / or having the strips wrapped around the rods when drilling down.

Special construction staging was applied to the columns to allow for sufficient setting time of the grout as required. Adjacent columns have not been installed within any single 12 hours shift.

Visual observation of the spoil flow and features of the spoil return at the surface have been maintained at all times to mitigate the risk of ground heave and lateral displacement.

In order to ensure minimum pressure of jet grouting apply on the existing reinforcement wall, a distance of 800 mm between the centre of the first row of column and the external face of the R.E. wall was considered. Prior to commencement of the grouting operation, the RE wall joints were sealed to avoid grout leakage

Both drilling and jetting were monitored by digital recording hardware. During drilling, depth, advance speed, rotary speed and thrust pressure were recorded. Grout pressure, grout flow, grout volume, stationary time, air pressure, air flow, uplift speed and rotation speed were monitored during the jetting phase. The start and stop time for each column was also recorded. Furthermore, the grout density and viscosity were measured during each working shift.

Figure 10: Installation of JG Columns at Beach Rd prior to wingwall dismantling

CONCLUSION

The RE block area that requires strengthening can be significantly reduced through the incorporation of Jet Grouting columns within the existing RE block instead of installing other strengthening solution as soil nailing.

Jet grouting acts as a mass gravity block in both the normal and parallel direction to RE facing. It will retain the soil during temporary excavation earthworks as well as allowing for stiffer excavation profiles during construction. (Figures 11, 12 & 13)

By using this strengthening system there is no need to build a “new facing” (Figure 5) therefore aesthetical requirements can be achieved easily. (Figure 14,15 & 16)

All Jet Grouting operations will be executed from the top of the structure. Whether possible, drilling and grouting can also be done through the existing road when required.

Occupancy of the road/rail track above or below the bridge can be avoided. If access is not possible from the top road due to traffic control requirements then the rig can easily reach the site by providing a temporary access ramp on top of the existing embankment.

Traffic control above and below the existing RE structure can be minimised or even avoided during construction stage.

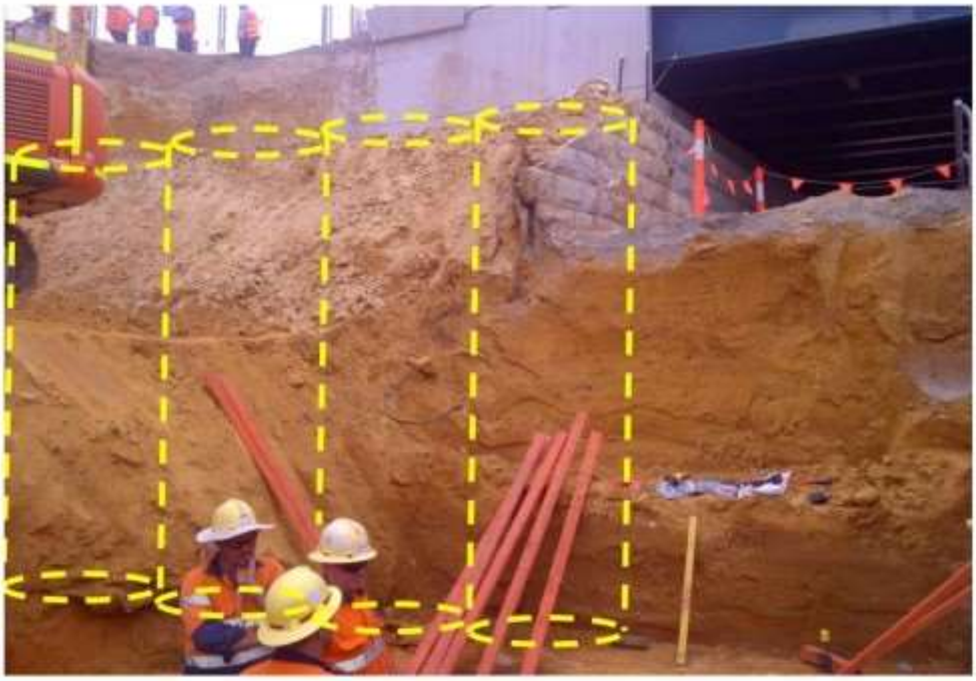

Figure 11: Beach Rd. Bridge. Concept extent of grouted columns (previously installed) Note almost vertical excavation profile after grouting

Figure 12: Beach Rd. Bridge. The installation of jet grouting columns allowed for an almost vertical excavation profile

Figure 13: Beach Rd. Bridge. The installation of jet grouting columns allowed for a stiffer excavation profile than other solutions

Figure 14: Beach Rd. Bridge. Duplicated abutment facing following completion of construction

Figure 15: Beach Rd. Bridge. Bridge abutment duplication finished and bridge deck already installed

Figure 16: Sherriffs Rd. Bridge. Bridge abutment duplication finished and bridge deck already installed

This system provides a new approach to RE Bridge abutment duplications.

Neither RE structures or Jet Grouting are innovations nowadays in the field of engineering. However both systems combined in this particular manner actually provide a reliable and innovative engineering solution.

AUTHOR BIOGRAPHIES

Antonio Ramirez received his B.E. Civil degree in Urban Development & Design and Environmental Engineering from the Polytechnic University of Madrid, Spain, in 2002. In 2000, he joined Tierra Armada S.A. (Spanish branch of The Reinforced Earth Company) for an engineering software development internship program in the R&D department. After graduating he was appointed as design engineer in Tierra Armada S.A.

After eleven years working in Tierra Armada S.A.(Spain), in 2011, Antonio moved to Australia to join the Australian branch of The Reinforced Earth Company in Sydney. Since then, he's been working as a project engineer in the design department of the Company.

Tom Fitzpatrick received his B.E. Civil (Honours) degree in Civil and Environmental Engineering from the University College Cork, Ireland, in 2010. After graduation he has worked on site in Scotland.

Since 2011, Tom has worked with Reinforced Earth in their Sydney office, working across the mining and infrastructure sector. Although predominantly based in design, he has worked on site carrying out on site supervision in Australia and Indonesia.

Alexandre Hubaut received his Master of Engineering specialised in Civil engineering from the School of Mines, Ales, France, in 2010. During his education, he undertook a workplace base training program where he gained experience working on infrastructure projects for the Vinci Group in South East of France and been introduced to Oil & Gas industry for Total E&P in Congo, Africa. In 2010, he studied at the School of Civil and Environmental Engineering at the University of New South Wales as an exchange student.

In 2011, he joined Menard Bachy, a subsidiary of the Vinci Group based in Australia, where he has been involved with several aspects of geotechnical engineering including tendering, design and project management for ground improvement projects.