SUCCESSFUL APPLICATION OF MIXED ABUTMENT CONSTRUCTION TO A FREIGHT RAIL FOUNDATION ON GRANULAR SOIL

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ABSTRACT

The abutment structures for the Glenfield Flyover on the Southern Sydney Freight Line (SSFL) present an interesting application of mixed abutment construction using the Reinforced Earth System. The abutments support a long deck that spans over the Main South Line (MSL) tracks that run under the flyover. The abutments are not only to retain the embankment on either side of the MSL but also to support the deck structure. The abutment structures are long because of the geometry of the flyover, with a crossing angle of 15^{o}. The foundation conditions are of loose sand with minor clay layers that overly rock at about 11 m depth. Conventional concrete retaining wall construction would require large diameter piles or an equally expensive equivalent constructed from raked and vertical driven piles. An advantageous alternative is to adopt a mixed abutment, which has a piled frame to support the flyover deck with the Reinforced Earth construction to retain the embankment and protect the frame columns from collapse under accidental impact from railway traffic. The Reinforced Earth foundation can be constructed to provide a wide footing to suit the ground conditions of relatively deep sands.

1 INTRODUCTION

Mixed abutments are a conventional construction form, with a Reinforced Earth wall to retain the approach embankment and a reinforced concrete frame that is immediately in front of it to support a bridge deck. Differential settlement between the deck and the Reinforced Earth block that is behind it is accommodated with an approach slab. Typically this form of construction is limited to applications on stiff ground, residual soil or rock, as that situation will be accompanied by minor settlement of the Reinforced Earth block and no issues with its foundation stability. This paper describes the analysis and detailing that was adopted for this development of the mixed abutment structures using the Reinforced Earth technique on relatively loose sands within a freight corridor over a live passenger rail line. Figure 1 shows the aerial photograph of the structures taken in July 2012.

While the overall design of the flyover has been prepared by Aurecon Australia, the design of the reinforced soil block has been carried out by the Reinforced Earth Company to accommodate the differential settlements and internal strains that are set up by the restraint on the front of the block that arises from the abutment frame, and to accommodate the convoluted set out of the wall facing that is required to engage the abutment frame.

Figure 1: Aerial photograph of the mixed abutments in Glenfield as at 17 July 2012.

The mixed abutment configurations for the Glenfield Flyover, in plan and cross section, are shown on Figures 2 and 3.

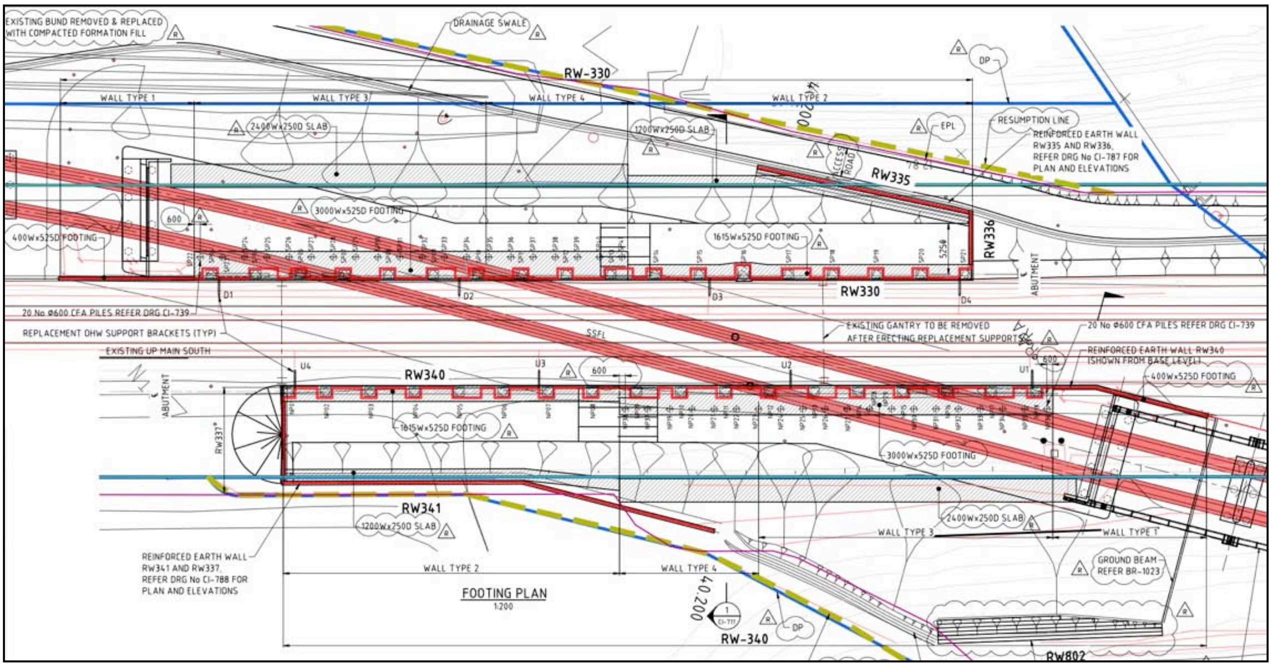

Figure 2: Overall plan of the Glenfield Flyover

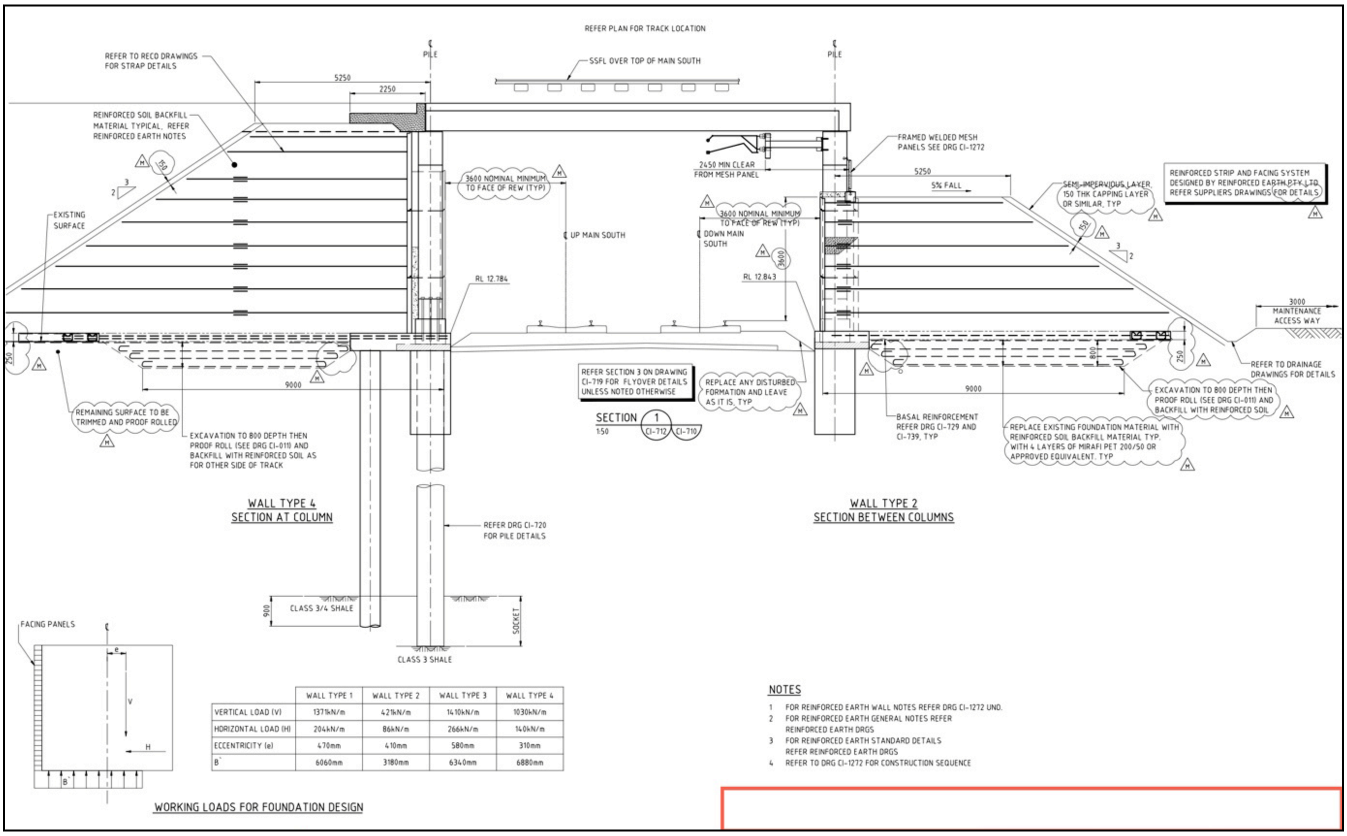

Figure 3: Typical section of abutment structure with embankment section on left-hand side and deflection wall section on right-hand side.

2 CONSTRUCTION SEQUENCE

The arrangement of a mixed abutment conventionally allows either the deck and the abutment to be constructed first or the embankment to be constructed first, though an application to construct over an operating railway, as has been carried out in this case will require the Reinforced Earth wall to be in place to brace the abutment frames against collapse in the event of an accidental impact from rail traffic.

The construction sequence progressively develops the composite structural action within the abutment while allowing the foundation movement to occur:

- Construct the piles and pile caps.
- Construct the base block using stabilised sand or mass concrete between the piles.
- Erect the abutment frames.
- Excavate the ground behind the base block down to the founding level of the Reinforced Earth block and construct the Reinforced Earth block, starting with the Reinforced Earth below ground level, then proceeding with the basal layer and finally constructing the Reinforced Earth block above ground level.
- Erect the deck beams and cast the composite slabs and kerb beams that tie them together.
- Grout the abutment frames into the Reinforced Earth wall and construct the approach slabs.

3 ADAPTATION OF CONSTRUCTION TO AN OPERATING RAIL CORRIDOR

A crucial aspect of the choice of abutment form is the consideration of construction activity for the site of the abutments immediately next to operating railway tracks. Some activities were carried out under track possessions:

- Boring the piles.
- Casting the base block between the piles.
- Erecting the abutment frames and erecting a temporary safety fence between the abutment columns.
- Erecting the precast deck components.
- Casting the composite deck slabs.

All the activities in-between these could then be carried out during rail traffic because the base block and the abutment frame separate the construction activity from the rail operation.

4 STRUCTURAL ACTIONS WITHIN THE ABUTMENT BLOCK

4.1 THE PILES

The piles in a mixed abutment provide the foundation for the abutment frames, but in the case of this development, they also provide the foundation to the base block. The base block supports the front of the Reinforced Earth block and is cast between the pile caps. As such this base block applies both vertical and horizontal load to the piles, and so the piles are heavily reinforced, particularly at the top of the pile. Continuous Flight Augers (CFA) construction was used to bore the piles, with the construction taken down to the underlying rock and a short socket bored into the rock (Class 3 or 4 Shale in accordance with the rock classification system established by Pells *et al*. in 1978).

4.2 THE BASE BLOCK

A base block is constructed between the piles by excavating a trench between each pair of piles and filling it with sand cement or mass concrete. This work has to be carried out under possession of the track. This block spans between the piles to provide permanent vertical support to the facing and temporary horizontal support to the track bed while the excavation for the Reinforced Earth block is carried out.

The base block is then essential both for providing support to the front of the Reinforced Earth block and also for retaining the shallow part of the footing foundation under the basal layer of the Reinforced Earth block. In both actions it then adapts the Reinforced Earth construction to the ground conditions of granular soil.

4.3 THE ABUTMENT FRAME

The abutment frame is entirely comprised of precast concrete, with:

i) precast columns at 4,500 mm spacing that have an enlarged base to accommodate bolts that extend into the pile caps.
ii) precast headstocks that span between the columns with a stitch pour that incorporates a welded joint for the top reinforcement in the headstock.

The headstock is designed to support the bridge deck in the event that one of the columns is removed in an impact. The bridge deck is a composite construction with 600 mm x 600 mm precast prestressed deck units and a cast-in-place slab, 230 mm thick. The deck, abutment headstock and approach slabs are braced together with large diameter dowel bars that are cast into sleeves with "O" rings to centre them to allow for shrinkage and foundation movement, and there are two dowel joints across the deck and abutments to further facilitate shrinkage movement.

The abutment wall footing is a slab that is cast on top of the base block that extends between the piles, and the basal reinforcement is cast into that footing and is then anchored by the weight of the Reinforced Earth wall above it.

4.4 THE REINFORCEMENT OF THE SOIL BLOCK

The attainment of the required load capacity in the retaining wall foundation requires both the loose sand foundation at shallow depth to be reinforced, and the sand below about 800 mm depth to be proof rolled. The process of removal of shallow sand cannot be carried out in close proximity to an operating railway without a separating wall, and that is provided with the base block between the piles, which also serves to support the front wall of the abutment. The base block is an essential means of adapting both to the restraint of the shallow depth of sand in the footing under the basal layer and the support of the front of the Reinforced Earth block.

The lateral force in the shallow ground under the Reinforced Earth block is retained by the heavy basal reinforcement that has been detailed, with the top layer of basal reinforcement being of steel straps that are anchored into the Reinforced Earth wall footing. The basal reinforcement at the bottom of the base block is a crucial element in the structure, as it spreads the horizontal load from the retained soil and anchors the base block between the piles to provide restraint against horizontal movement at the base of the Reinforced Earth block.

These layers of reinforcement define a soil block that is supported on one side by the pile frame, and which spans flexibly to the footing support behind the frame, with the soil block reinforcement above undergoing deflection to follow the settlement of the ground as the block is constructed. The section of the abutment frame that is next to the full height abutment wall requires two lines of piles to reduce the settlement of the foundation and prevent rotation of the frame foundation.

4.5 COUPLING BETWEEN THE RETAINING WALL AND THE ABUTMENT FRAMES

Railway bridges require impact protection for their supporting columns and, for a mixed abutment, that means that the columns of the abutment frames have to be built into the abutment wall with an alcove in the wall that accommodates each column so that the wall is used to brace the abutment frame against longitudinal crash impact as well as transverse impact. The requirement for composite action between the frame and wall under impact loading requires the space between the frame columns and the wall to be grouted over the height that is exposed to major impact, and the back of the wall is stiffened with a cast in place rib that is then able to react against the side of the columns and is connected to the back of the panels by the reinforcement that is anchored in them.

The connection in the completed structure between the abutment frame and the reinforced soil block facing is therefore necessarily a rigid one, and so the facing has to be supported on a base block of stabilised sand or mass concrete that is constructed by filling a trench dug between the piles.

4.6 ANALYSES OF SETTLEMENTS IN THE FOUNDATION

The construction of the abutment structure with its integral piled frame has been studied with a finite element model using the PLAXIS 2D computer programme to model the development of plastic strains in the foundation and embankment through the various construction processes. The application of this analysis has been essential to the development of the design.

A selected output from the PLAXIS 2D analyses is shown in Figure 4. Table 1 summarises the calculated settlements at the level of the lowest reinforcement in the reinforced abutment block. Note the PLAXIS 2D analyses predicted a maximum ground settlement of the order of 116 mm within the area to the rear of the reinforced soil block.

Table 1: Calculated settlements at the level of the lowest reinforcement in the abutment block.

Point location	Deflection wall section (mm)	Embankment wall section (mm)*
At the back of the reinforced soil block facing	11	10
At the back of the pile cap	13	11
3 m behind the back face of the wall	46	46
6 m behind the back face of the wall	56	106

* This wall has two rows of piles.

These settlements are considered to be a likely upper bound to the actual settlements. Settlements will occur as the fill is placed. It is expected that the first half of the settlement for Wall Type 3 (refer to Section 6.2 for definition of various wall types) will occur with the placement up to 3.5 m above top of rail, and the rest with the following 3 m of placement.

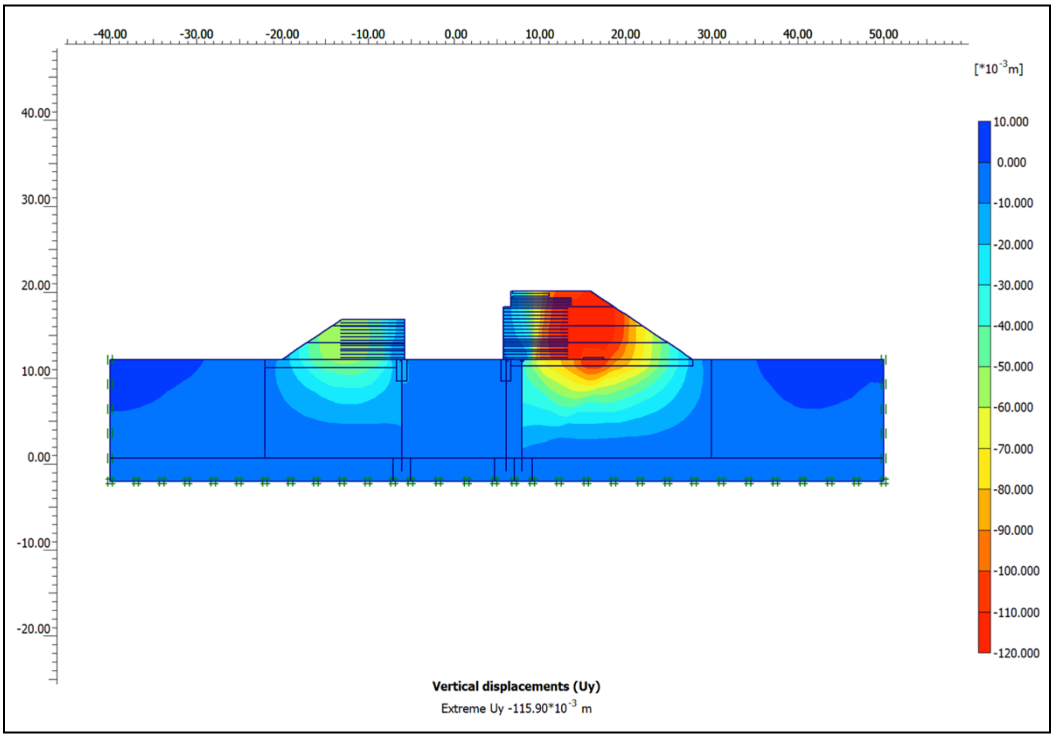

Figure 4: Settlement profile as predicted using finite element analyses.

5 THE ABUTMENT AS A COMPOSITE STRUCTURE

5.1 THE DEFLECTION WALL SECTION OF THE ABUTMENT

In an overpass structure of this configuration, half of the length of each abutment is opposite the embankment on the other side of the tracks but has no embankment behind it, the Reinforced Earth block for this part of the structure is then provided purely to brace the abutment frame against impact, and is then only required to extend to the 3,600 mm above top of rail that is required by the design codes for that purpose

This section of wall is then little over half the height of the embankment section, and the PLAXIS 2D analyses show that with the block dimensions of the design the extent of plasticity in the sand during construction was limited. The base block settles away from the abutment frame as it is made, and this movement is allowed for as the filling between the columns and the wall is only applied after the Reinforced Earth block has been constructed.

5.2 THE RETAINING WALL SECTION OF THE ABUTMENT

The section of the abutment frame that is in front of the embankment is under the bridge deck section supporting the SSFL tracks, and has an approach slab between the bridge deck and the embankment fill. The approach slab has an extended width at the end of the abutment frame, and is heavily reinforced.

For the embankment wall section, the extent of plasticity at depth in the sand foundation during construction is about twice as great as it is for the deflection wall section. So the front of the abutment is supported on two rows of piles to avoid the settlement of the fill leading to rotation of the base block and bending of the front row of piles.

It is worth noting that there was an option to construct the abutments with a short side span for the deck above them, and that would have allowed the entire length of the abutment to be constructed as a deflection wall.

6 REINFORCED EARTH WALL DESIGN

6.1 REINFORCED EARTH WALLS

A reinforced soil wall is a construction material formed by the association of earth and reinforcement. Flexible, linear reinforcing elements are placed in a granular earth fill. Frictional forces between the soil and the reinforcing elements provide a cohesive strength to the earth fill forming a composite material, 'Reinforced Earth'. In order to retain the reinforced material, the reinforcing elements are attached to concrete facing panels. Due to the composite action of the two major components, earth and the reinforcing strips, the mass tends to act as a monolithic body, supporting its own weight as well as the external loadings applied.

6.2 DEFINITION OF WALL TYPES

The Reinforced Earth structures at the Glenfield flyover comprised four main wall types. Loading conditions and geometries differed for all walls with Wall Type 3 being the most heavily loaded. This wall type was designed to support the railway live load both on and behind the Reinforced Earth block. Wall Type 4 was designed to carry the railway live load on the approach slab only, with a 20 kPa surcharge elsewhere. This is due to the shallow crossing angle of the flyover. Wall Types 1 and 2 were designed for a nominal loading of 10 kPa. The geometry of the footprint of the works required that wall Type 4 loading affected some walls of Type 2. The Western section of RW341 is an example of this. This geometry and associated embankments also had implications for minimum cover over strips. The geometry of retaining walls RW335 and RW341 was altered to provide sufficient cover to the Reinforced Earth block reinforcing elements, many of which were draped and/or skewed to attain required frictional capacity. In instances where reinforcing strips were skewed from normal, calculations were carried out to find the associated strength reduction of the strips. Where needed, extra strips were added to cater for this reduction in strength.

6.3 CATERING FOR DIFFERENTIAL SETTLEMENTS

The design accommodates the calculated differential settlements of the block. The internal strains due to the maximum differential settlement of 106 mm within the reinforced zone (see Table 1) are significant. Hooke's Law is used to calculate the stresses these strains induce in the high adherence reinforcing strips. The cross-sectional area of the strip at the end of the design life is then used to calculate the force in the strips due to the differential settlement. The allowable tensile force in the strips was reduced to account for this.

6.4 FLEXIBILITY

The Reinforced Earth wall is a flexible structure. This flexibility allows the steel reinforcements to adapt to reasonable deformations of the subgrade. To satisfy the requirements for composite action between the frame and the wall under impact loading, a cast-in-place rib stiffens the rear of some wall sections. In instances where reinforcing strips passed through this rib, flexibility of the strips was maintained through isolating them from the rib by wrapping with two layers of bituminous tape. This provided a separating medium from the concrete.

6.5 DETAILING

The convoluted engagement requirement of the abutment frame was catered for in the design and detailing process. Detailed drawings have been prepared (refer to Figure 5) to assist the construction team onsite. In addition to this, each panel was fabricated according to its own specific requirements. A detailed fabrication drawing was created for each panel allowing for various geometries, strip and lifting locations.

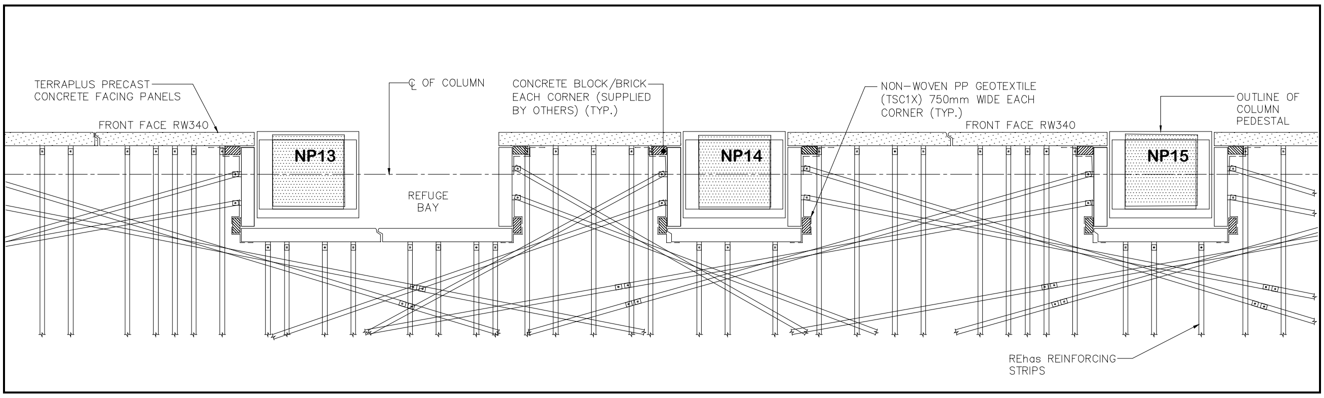

Figure 5: Typical panel layout plan.

7 QUALITY CONTROL AND MONITORING

7.1 QUALITY CONTROL AND ASSURANCE WORKS

An inspection and testing plan was developed prior to construction. Hold points were in place for critical activities during pile installation, such as verifying pile locations by topographical survey, construction materials approvals, verification of foundation works and concrete mix design. There was a hold point on the inspection of the excavated founding level of reinforced soil wall construction. An experienced geotechnical engineer inspected the excavated surface as soon as excavation was completed. The final excavated surface was proof rolled with at least eight passes of a 10 tonne vibratory roller under the direction from the geotechnical engineer, followed with blinding concrete formation. Additionally, the geotechnical engineer verified the socket conditions of the piled foundations supporting the flyover, assisted by real-time monitoring of CFA installation parameters.

7.2 MOVEMENT MONITORING

The project specification called for weekly movement monitoring of the flyover headstocks through a series of survey pins at the top of the precast columns until the deck slab and edge beams were poured and reached a characteristic compressive strength of 25 MPa at 28 days.

The movement monitoring commenced on 10 April 2012 and ceased on 26 July 2012. There were no significant changes in the measured settlements and lateral displacements of the flyover columns throughout the monitoring period. The measured settlements of the columns on both the up and down sides of the SSFL were in the order of 5 mm. The maximum lateral movements in the directions parallel and perpendicular to the SSFL were recorded to be about 4 mm and 13 mm, respectively. The measured movements were considered to be within expectations and in line with design calculations.

8 CONCLUSION AND DISCUSSION

Comprehensive detailed design analyses, complemented by extensive quality control and monitoring works, have led to the successful adaption of mixed abutment construction using The Reinforced Earth System founded on relatively loose sands within a freight corridor over an operating passenger rail line.

Staging of mixed abutment construction enables the progressive development of structural actions within the abutments while allowing for effective work planning with critical activities occurring during track possessions.

Satisfactory performance of the abutment structures was deemed achieved for the reasons that they were constructed in general accordance with the project specifications and that the measured lateral and vertical movements were within tolerance.

The Reinforced Earth block solution was adopted as it can accommodate significant differential settlements under large loads. Given the segmental panel arrangement, it can easily accommodate any geometry with minimal cost.

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