USE OF TEMPORARY ANCHORS IN REINFORCED SOIL WALL CONSTRUCTION FOR THE M4 MOTORWAY WIDENING

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ABSTRACT

The M4 Motorway has in excess of 100,000 vehicle movements per day with the projection exceeding 150,000 vehicle movements per day by 2030. To facilitate the projected traffic flow increase, the M4 Motorway has been upgraded by adding an additional lane in each direction (eastbound and westbound) to the existing three lanes. The upgrade comprises widening a 7.5 kilometre section of motorway between Parramatta and Homebush including the construction of 2 kilometres of viaduct with 49 spans, 3 bridges and 24 retaining walls (including RSWs, soldier pile walls, soil nail walls and reinforced concrete walls).

This paper focuses on the sections of motorway widened using Reinforced Soil Walls (RSW) and presents a case study of the use of temporary Platipus anchors, to retain up to 9 metres of existing engineered fill embankment of the motorway. The construction of the RSWs required excavation of the existing motorway embankment at between 45° to 75° for excavated heights typically between 6 metres and 9 metres. Platipus anchors were selected in preference to soil nail or sheet pile solution to increase the stability of the steep temporary batter, expedited the excavation process, reduced the amount of excavation of the embankment and reduce the total construction cost. The design considered the stage excavation process and ensured adequate factor of safety at each stage of the excavation process. In addition, the design confirmed that the settlement of the existing M4 pavement immediately adjacent to the excavation was within tolerable limits.

The paper provides discussion on the feasibility assessment of the use of the 'Platipus' anchors and the design undertaken for the temporary retention system. It also provides a discussion on the installation process for the anchors, anchor testing undertaken, instrumentation monitoring and construction challenges for integration of the temporary support into the permanent works.

1 INTRODUCTION

The M4 Motorway upgrade was undertaken between 2014 and 2017 to increase the traffic capacity along the main east-west motorway of Sydney. The project is located approximately 13 kilometres to the west of the Sydney Central Business District and generally follows the alignment of the existing M4 Motorway. It was constructed as the first stage of a wider Westconnex Motorway project, which is a 33 km new motorway that connects two of Sydney's main motorways – the M4 in western Sydney and the M5 in southwestern Sydney.

The M4 Widening upgrades 8 km of roadway and includes construction of the following features:

- A new two lane viaduct for westbound traffic, on the southern side of the existing viaduct structure between Church Street, Parramatta and Wentworth Street, Granville.
- Reconfiguration of the traffic lanes on the existing viaduct structure so that there is two lanes westbound and four lanes eastbound. The result of the reconfiguration provides four lanes in each direction.
- A new bridge widening over Duck River at Auburn.
- Widening of the existing motorway to the south of the westbound carriageway between Wentworth Street, Granville and Duck River, Auburn.
- Over 20 retaining walls including reinforced soil walls, soil nail walls, soldier pile walls and reinforced concrete L-shaped walls.

This paper focuses on the widening undertaken between Wentworth Street Granville and Duck River in Auburn. This section of the existing M4 is founded on fill embankments up to 9 m in height constructed along an industrial corridor. Due to space constraints, standard embankment widening was not a feasible solution. Solutions which included construction of retaining walls were required to reduce the impact on communities. Consideration was given to both the permanent and temporary works required when assessing the solution to be adopted.

2 TOPOGRAPHIC SETTING

The M4 Motorway Widening Project is located near the floor of the Sydney Harbour topographic basin and travels south of and typically parallel to the Parramatta River. Surface elevations range from near RL 0 m AHD, close to the Parramatta River tributaries of Duck River, Duck Creek and A'Becketts Creek, to approximately RL 25 m AHD close to the western limit of the project. In the eastern half of the project, the alignment traverses gently undulating terrain, where the existing motorway travels in shallow road cuttings and low height embankments, reflecting the local topographic environment. In the western half of the project, the existing motorway travels along the general alignment of A'Becketts Creek, Duck Creek and over Duck River. This section is constructed on a combination of elevated viaduct and embankment, with the surrounding ground levels dominated by the waterway floodplains, at or near RL 5 m AHD.

Land use within the immediate vicinity of the M4 Widening section is dominated by moderate and heavy industry along much of the route. Residential land use is limited to smaller pockets close to Parramatta and Silverwater.

3 PROJECT CONTRAINTS AND DESIGN CONSIDERATIONS

For the section of motorway constructed over existing fill embankments, there were a number of constraints that influenced the design solution. Physical constraints that guided the solution included the presence of existing roads and Duck River to the south, the Sydney Speedway and industrial land-use standard embankment widening was not a feasible solution for the upgrade. Widening of the motorway was not as simple as constructing additional embankment width. Typically, where widening was required, existing structures or properties prevented the procurement of additional land on which to construct widened embankments.

Retaining walls were required to facilitate the widening and achieve the design embankment width for pavement construction. To construct the widened pavement but without impacting the adjacent land, the following options were considered:

- Embankment widening where possible.
- Cantilever piles supporting reinforced concrete walls.
- Reinforced concrete L-shaped walls.
- Reinforced soil walls.

To select the permanent retaining wall type, a number of factors were considered, including:

- Capital cost of the permanent works solution.
- Whole of life cost – which includes maintenance of the structure throughout the design life.
- Community impact - the impact to the existing motorway traffic flow needed to be considered to reduce any adverse effects on traffic flow as much as possible.
- Environmental considerations - management of potentially contaminated material and the principal of onsite containment in preference to off-site disposal was adopted when assessing retaining solutions.
- Construction time – risk to keeping to the design schedule was also a factor considered.

For the nominated section, the adopted permanent works solution predominantly comprised reinforced soil walls (RSW) constructed adjacent to the existing fill embankments.

4 TEMPORARY WORK DESIGN OPTIONS

Following adoption of the RSW for the permanent works, temporary excavation of the existing embankment was required to facilitate construction of the Reinforced Soil Block. The temporary batter was assessed to be between 5 m and 9 m in height and range between 45° and 75° in slope. Options considered to maintain temporary stability of the existing embankment included:

- Option 1 – A Platipus anchor reinforced slope.
- Option 2 – A soil nail reinforced slope.
- Option 3 – A temporary sheet pile wall.

The factors considered for each of the temporary support options included space requirements for the installation, the time of installation, the cost of installation, environmental effects such as noise and vibration, and the effects on the community.

- Space constraints - Due to the limited space available for temporary works installation, Options 1 and 2 were preferred to Option 3, for the size of the rig required to install the temporary support. Significant platforms would need to have been constructed to facilitate sheet pile installation.
- Time constraints – Platipus anchors were assessed to be quicker than soil nails due to the curing time of the grout required before the soil nails can be loaded and tested.
- Noise, vibration, community – the Platipus anchors and soil nails were assessed to have a lesser impact on the community from a noise and vibration perspective compared to the sheet pile option. The visual impact of 12 m long sheet piles being installed immediately adjacent to a live motorway was also considered.
- Cost – the cost of installation was borne by the contractor so a final comparison was not available to the authors. It is understood that with factoring in the total cost of installation (such as working pad construction and time of installation) the anchor options were marginally cheaper than the sheet pile option.

On the basis of the above, Platipus anchors were selected as the proposed temporary support methodology.

5 DESIGN CRITERIA

The design criteria adopted for the reinforced soil walls and temporary Platipus anchor reinforced slope included the following:

- A permanent works design life of 100 years.
- A total post construction settlement at any bridge approach slab of 50 mm.
- A limit differential settlements in any direction to a maximum change of grade of 0.3%
- Other requirements specified in the project RMS D&C Specification R57 Design of Reinforced Soil Walls. This included the requirement for long term and short term global stability.

6 GROUND CONDITIONS

The geotechnical conditions within the western half of the project area is dominated by the alluvial soils associated with the three watercourses in the area. The embankment fill was assessed to be derived from ripped shale and was encountered as gravelly clay. The alluvium comprises Quaternary age sediments, potentially derived from erosion of shale bedrock. The alluvium is generally encountered as a stiff to very stiff silty clay. Some firm clay deposits, with some areas of soft, clay alluvium, were encountered as discrete lenses/pockets, occasionally including organic material. The Ashfield Shale, beneath the alluvium was assessed to have a relatively thin weathered profile, with slightly weathered to fresh shale noted in borehole logs approximately 1 m to 2 m below the bedrock surface.

For the area under consideration between Wentworth St and the Duck River Bridge, the existing M4 Motorway is constructed on a fill embankment approximately 5 m to 9 m high. The embankment is situated approximately centrally between Duck River and Duck Creek, with the confluence of the two watercourses immediately to the north of the Duck River Bridge western abutment.

Figure 1 provides a cross section of the ground conditions cut throught the embankment that required widening.

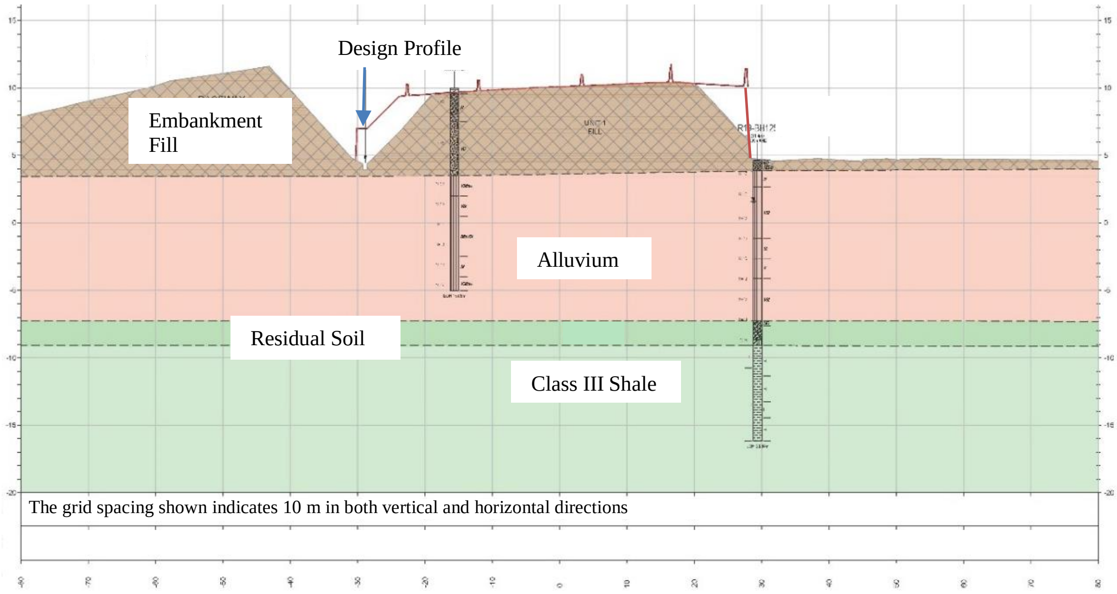

Figure 1: Geological Cross Section of M4 Embankment that required widening

7 PLATIPUS ANCHOR DESIGN AND INSTALLATION

7.1 MECHANISM OF PLATIPUS ANCHOR

The adopted temporary anchor solution comprised Platipus anchors. Platipus anchors consist of five components as shown in Figure 2(a). Two types of anchor (Stealth and Bat) have been introduced by Platipus Earth Anchoring System, based on the proposed usage and capacity required. To suit the load requirements, wire tendons and solid rods can be used for installation of anchors. Strand wire tendon can be used for the application requiring lower loads and locations where access and space are restricted. High yield solid rods can provide a higher ultimate load, and can also provide sacrificial corrosion resistance for design life considerations.

The installation of the anchor is shown in Figure 2. During driving of the anchor, the anchor plate will be aligned parallel to the rod as shown in the Figure 2(b). Once the required depth is achieved, the anchor will be load-locked as shown in the Figure 2(d). In this stage, the anchor plate will rotate perpendicular to the rod or wire.

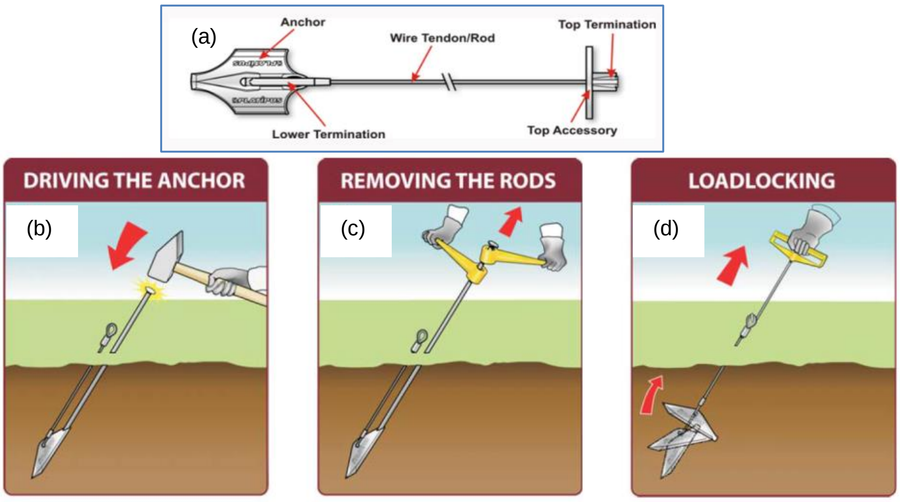

Figure 2: Schematic diagram of Platipus anchors (Platipus Anchor Limited (n.d.))

The stress distribution in front of a loaded anchor can be assumed based on foundation theory. The performance of an anchor within the soil is defined by the load at which the stress concentration immediately in front of the anchor exceeds the bearing capacity of the soil. Factors that affect the ultimate performance of the anchor include:

- The shear angle of the soil in which the anchor is embedded.
- The size of the anchor.
- The depth of installation of the Platipus anchor head.

At the load-lock stage, the initial load is applied to the anchor to rotate the anchor plate into its load-locked position. Figure 2 shows the schematic variation of required load and anchor displacement. At the compaction and load stage, the anchor system is generating a frustum of soil immediately in front of the anchor. At this point, load normally increases with minimum extension. The soil type will affect the overall extension.

At the maximum load stage, the anchor produces its ultimate load. As the anchor load approaches the bearing capacity of the soil, the rate of increase in load will reduce, until bearing capacity failure of the soil takes place. If the mechanical shear strength of the soil is exceeded, the residual load will decrease with continued extension as the anchor shears through the ground. If the load is further increased, shear strength of the soil is exceeded and the anchor shears through the ground.

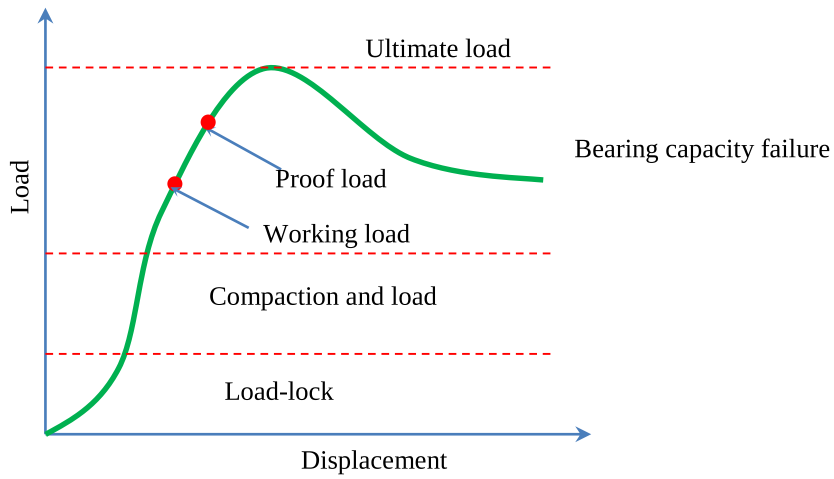

Figure 3: Schematic load-displacement behaviour of Platipus anchor (Platipus Anchor Limited (n.d.))

7.2 GEOTECHNICAL DESIGN PARAMETERS

Table 1 provides details of the geotechnical parameters adopted in the design. The existing embankment consists of fill to a thickness of about 5 m overlying stiff to very stiff alluvium to a thickness of 12 m.

Table 1: Geotechnical Design Parameters used Temporary Excavation

Unit	Bulk Unit Weight (kN/m^3)	Effective Friction Angle (Deg)	Effective Cohesion (kPa)	Undrained Shear Strength (kPa)	Ultimate Bond Strength (kPa)	Young's Modulus (MPa)	Poisson's Ratio
Existing Fill	19	28	10	25	15	25	0.35
Stiff Alluvium	20	26	5	50	50	35	0.35
Class V Shale	21	26	20	200	150	75	0.3

7.3 LOADING

A vertical surcharge live load of 20 kPa for stability and 10 kPa for serviceability was used in the design of the temporary excavation, where traffic loading exists behind the wall. A vertical surcharge live load of 10 kPa was considered for stability where no traffic loading exists behind the retaining wall.

7.4 TEMPORARY EXCAVATION OF THE M4 EMBANKMENT

The temporary slopes excavated into the existing M4 embankment were designed using Platipus anchors for reinforcement, considering the stability of the slope and ground deformations at the crest of the existing M4 embankment. Figure 4 provides a sketch of the temporary excavation to facilitate the construction of the Reinforced soil wall along the existing M4 motorway.

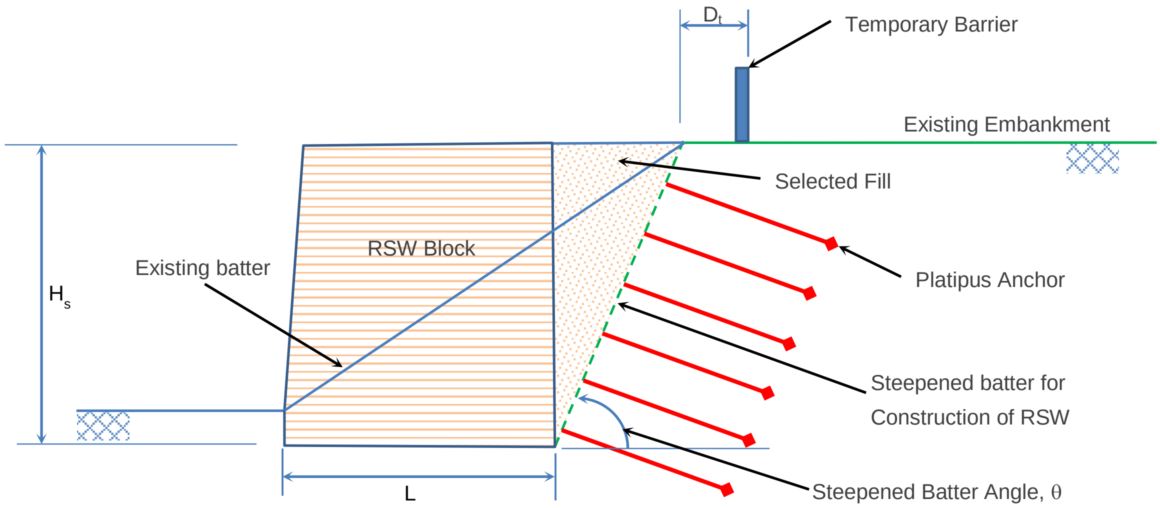

Figure 4: Layout of Temporary Excavations and Anchor Arrangements

This paper provides detail of the design methodology and design outcome of temporary slopes stabilised with Platipus anchors. Retaining Wall RW-05 is presented in this paper as an example of the retention system used on the project. RW-05 is about 300 m in length and 5 m to 7 m in height. It is located on the southern side of the M4 Westbound carriageway, adjacent to Matha St, Granville. Table 2 provides the geometry of the proposed steepened temporary batter, positioning of the temporary traffic barrier and the general anchor configuration.

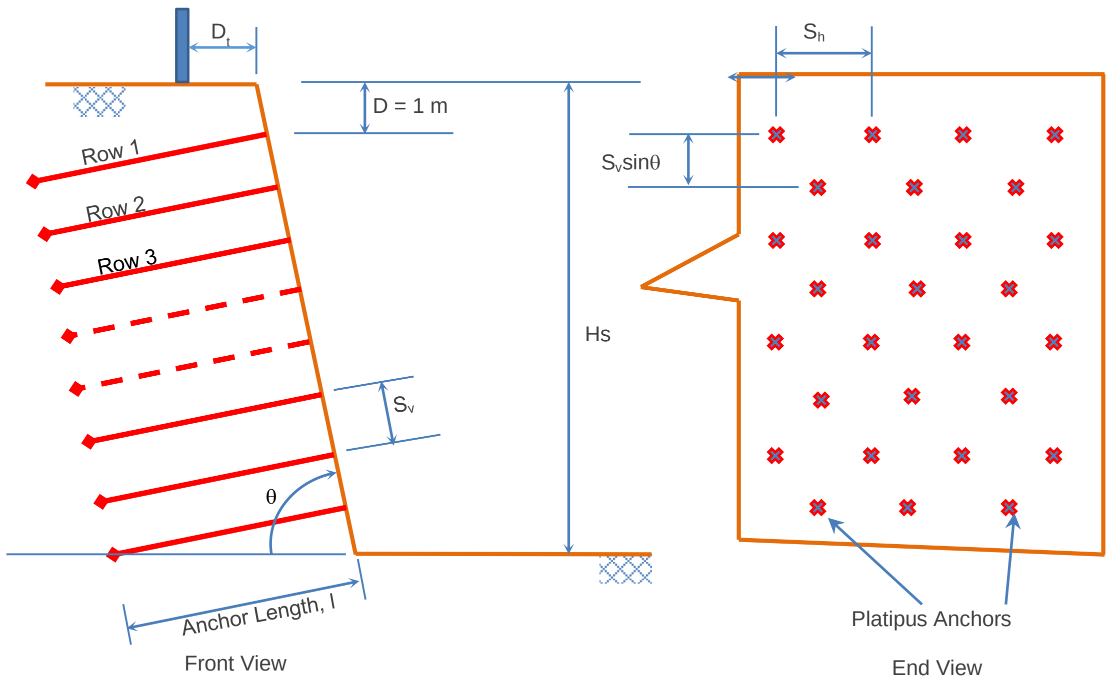

Figure 5: Typical Platipus Anchor Layout in a Temporary Slope

Table 2: Details of Temporary Batters and Anchors Design at Retaining Wall RW-05

Station	θ (Deg)	D_t (m)	H_s (m)	Platipus Anchor Details		
				S_v (m)	S_h (m)	l (m)
0-30	55	2.0	8.3	2.0	2.0	4
30-70	60	3.0	7.7	2.0	2.0	4
70-100	60	3.7	6.7	2.0	2.0	4
100-130	60	3.5	6.1	2.0	2.0	4
130-163	60	3.3	5.8	2.0	2.0	4
163-200	55	3.1	6.1	2.0	2.0	4
200-237	55	5.9	6.1	2.0	2.0	4

Notes

1. Spacing S_v is measured along the temporary batter slope.
2. Anchors should be pre-stressed as described below.

Where:

D: Depth of first anchor from embankment level (m) = 1.0 m

D_t: Minimum distance to the temporary traffic barrier from edge of the existing embankment

l: Minimum length of anchor embedded following proof load test (m)

S_v: Vertical spacing of the anchors (m), measured along the temporary batter slope

S_h: Horizontal spacing of anchors (m)

H_s Depth of excavation below ground level (m)

θ Maximum temporary batter slope angle (to the horizontal plane)

The anchors were pre-stressed and load-tested as specified in Table 3 below. Every anchor installed was load tested as detailed in Section 9.1.

Table 3: Details of Temporary anchor plates and loading

Anchor Rows	Proposed Min. Plate Size (mm)	Test Load (kN)	Pretention Load (kN)
Row 1, Row 2	300 x 300 x 10	50	15
Row 3 and below	450 x 450 x 10	75	25

7.5 ANCHOR DESIGN PARAMETERS

Anchors have been modelled as soil nails with length and spacing as specified in Table 2. As the stress distribution in front of the anchor plate governs the reinforcement mechanism in the slope, the anchor plate diameter (equivalent) was assumed as the bond diameter of the nails. The tensile capacity of the steel rod (310 kN) was assumed as the tensile capacity of the nail and shear capacity of 15 kN was also assumed.

8 ANALYSIS

8.1 GLOBAL STABILITY

Stability analyses of the temporary excavation was carried out using the commercially available computer programs SLOPE/W, adopting the temporary slope geometry provided in Table 2 to assess the factor of safety (FoS) against instability and the parameters provided in Table 1. The anchors were modelled as soil nails with equivalent resistance. The minimum FoS of 1.2 was achieved for the temporary excavations with installation of anchors. An example output of a stability assessment of the temporary slope is provided in Figure 6.

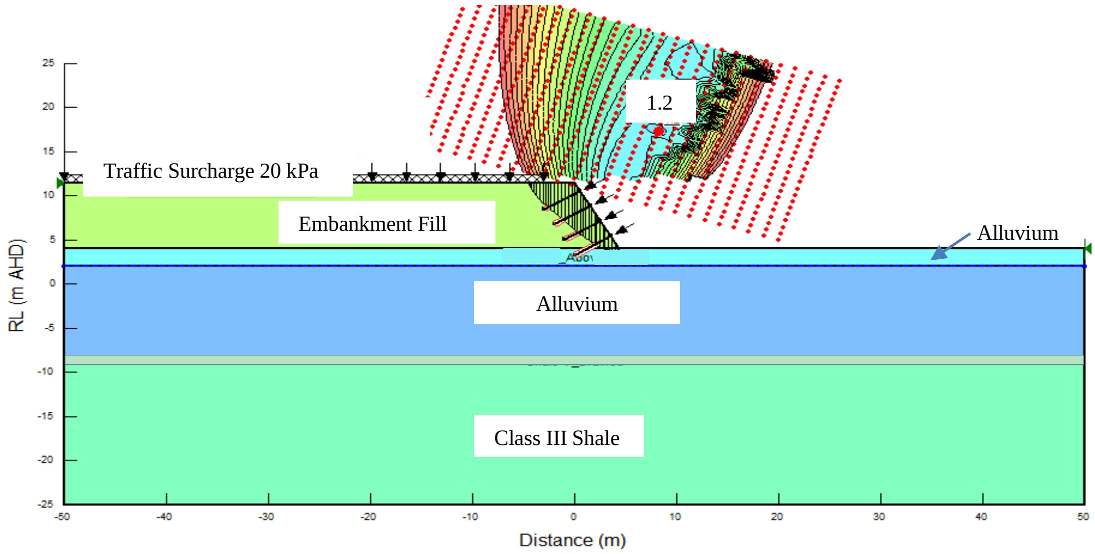

Figure 6: Example Slope stability assessment

8.2 GROUND DEFORMATION ASSESSMENT

The ground deformation (at the crest of the existing embankment) was assessed using PLAXIS2D during the temporary excavation. The assessment considered a staged excavation approach, with a maximum excavation depth of 2.0 m per stage. Anchors were modelled with a free length and fixed length to approximate the end anchored nature of the temporary support. The estimated vertical and horizontal movements in the existing embankment are in the range of 10 mm to 25 mm. An example output of the PLAXIS2D analyses is provided in Figure 7 where the scale represents displacement of 14 mm (blue) to -26 mm (red).

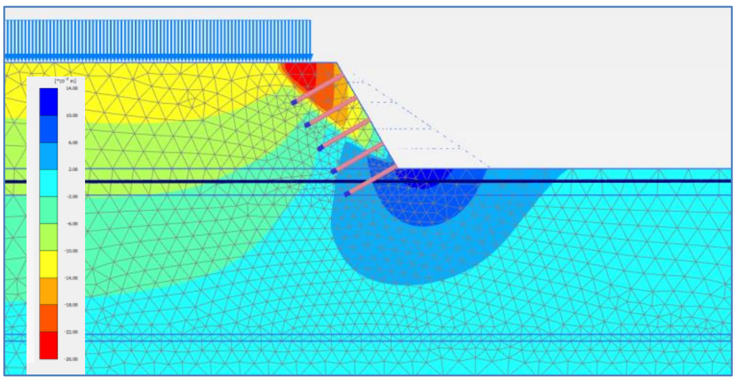

Figure 7: Ground movement assessment

Unfortunately, survey data was not available to the authors for comparison with design movements, however no evidence of distress of the pavement at the crest of the embankment was observed throughout the excavation of the temporary slope.

9 DESIGN VERIFICATION

9.1 TESTING OF TEMPORARY ANCHORS

The anchors were tested for the load capacity by adopting a minimum working load factor of 1.5 (refer Table 3 for test loads). The purpose of the testing was to assess whether site conditions were consistent with the assumed working load capacity adopted in the design. A verification load test on a non-production anchor was undertaken at each wall to verify that the design anchor installation depth and design load can be achieved. The design was reviewed following the testing to assess whether modifications to the documented anchor design was required.

9.2 TEMPORARY EXCAVATION MONITORING

Temporary works were observed by a representative of the geotechnical design team to assess whether the ground conditions encountered were consistent with the design assumptions and whether the design parameters to be adopted were generally appropriate. Survey monitoring points were installed at the crest of the temporary excavation and the slope of the excavation to monitor the ground movement during construction. Monitoring points were installed at every 10 m.

Readings were taken a minimum of weekly, every excavation bench and after significant rain events. An increased monitoring frequency was adopted initially to gain confidence in the construction method. Daily observations were carried out by the geotechnical site representative to assess for evidence of ground movement, such as tension cracks.

9.3 OTHER CONSIDERATIONS

A tensioned double twist wire mesh capable of spanning between the anchors with face plates to prevent minor surface slumping was installed. A geofabric was also be installed that can span between the wire mesh and prevent fill penetrating the mesh.

Appropriate drainage was constructed to avoid the surface water ponding at the crest of the temporary excavation. The drainage was directed to an appropriate outlet to prevent the infiltration into the temporary slope.

Another consideration was that as part of the load-lock process of the anchors, some deformation of the soil is required to enable the anchor plate to rotate and mobilise the load. Where the anchors are installed in granular soil, flow of the soil particles would occur in the vicinity of the anchor plate as the load is mobilised. Where the soil is cohesive, there is potential for voids to occur as the cohesive soil has the potential to span over zones of soil movement. Such voids could have the potential to adversely affect the embankment performance. In this instance, it was considered that any voids would not adversely affect the performance of the pavement or the embankment stability on the basis of the following:

- The embankment was observed to be well compacted as evidenced by difficulty in driving the anchors and in excavation of the fill.
- The anchor plates (and any zone of soil disturbance was relatively small when considering the depth from the surface.
- A compacted “raft” of pavement materials and engineered fill existed within the uppermost 3 m of the embankment that would help span over any zones of less compacted fill that may have occurred as a result of the anchor installation. This included the Upper Zone of Formation, which was constructed in accordance with the requirements of RMS D&C R44 Earthworks Specification.

10 CONSTRUCTION CHALLENGES

Construction challenges that arose during construction of the temporary works included the fact that stiffer than anticipated ground was encountered within the embankment. Due to the unknown nature of the fill within the embankment, there was some concern that the Platipus anchors may not have been able to be driven to design depth or they may have refused on obstructions. For example at one location, a layer of asphalt was observed within the embankment material that the Platipus anchor could not penetrate. In this situation, the row of anchors that were affected by the impenetrable material was able to be adjusted downwards by half a metre. The platypus anchor solution was sufficiently flexible that obstructions could easily be dealt with.

Another construction challenge arose during the backfilling stage, following completion of the reinforced temporary slope. During RSW construction, an item to be addressed for the long term performance of the embankment was for the RSW Fill to be appropriately keyed into the existing embankment material. The concern was that the interface between the temporary works may provide a zone for potential settlement due to the presence of the reinforcement and geofabric between the anchor plates. To manage the risk, the design required that at nominated bench relative levels, the mesh and geofabric would be cut horizontally, exposing the embankment fill. The new RSW fill could then be keyed into the embankment. A “bridging raft of engineered fill” was also proposed for the uppermost 1.5 m, below the pavement, to further reduce the risk of any embankment material movement adversely affecting the pavement.

11 CONCLUSIONS

This paper has presented a case study where Platipus anchors have been successfully adopted as temporary reinforcement, to facilitate construction of the embankment widening for the M4 Motorway. An assessment was undertaken to consider different temporary retention solutions and Platipus anchors were found to provide a cost effective solution that met the installation space constraints and the program constraints of the project. Analyses were undertaken to confirm that the temporary anchor solution would not adversely affect the permanent works, both from a stability and settlement perspective. During installation, the temporary works solution was found to be sufficiently adjustable during construction that unanticipated ground conditions could be managed in the field by local movement of anchor locations, where ground conditions prevented anchor installation to design depth.

12 ACKNOWLEDGEMENTS

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