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The geotechnical works for the construction of the Travis Brow link road, Stockport, UK

Les travaux géotechniques pour la construction de la route Travis Brow link, Stockport, Royaume-Uni

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ABSTRACT: The Travis Brow to A6 link road created a new highway connection in Stockport. The construction of the two-lane dual carriageway required the implementation of a variety of geotechnical construction techniques, including soil nailing, contiguous pile walls and the installation of prestressed rock anchors with hard facing to support the rock beneath the foundations of two piers of the Grade II* listed Stockport viaduct, which carries the West Coast main line rail service. This paper describes the design and construction of the geotechnical works carried out for the scheme, focussing particularly on the undercutting of the viaduct footings, which was carried out following a staged construction sequence, with excavation works carried out in bays both horizontally and vertically. The results of rock anchor testing are also discussed.

RÉSUMÉ: La route de liaison Travis Brow à A6 a créé une nouvelle connexion autoroutière à Stockport. La construction de la route à deux voies à deux voies a nécessité la mise en œuvre d'une variété de techniques de construction géotechniques, y compris le clouage du sol, des murs de pieux contigus et l'installation d'ancrages rocheux précontraints avec un revêtement dur pour soutenir la roche sous les fondations de deux piliers du viaduc de Stockport, classé Grade II*, qui transporte le service ferroviaire de la ligne principale de la côte ouest. Cet article décrit la conception et la construction des travaux géotechniques réalisés pour le projet, en se concentrant particulièrement sur la sous-découpe des piles du viaduc, qui a été réalisée selon une séquence de construction par étapes, avec des travaux d'excavation réalisés dans les travées horizontalement et verticalement. Les résultats des essais d'ancrage rocheux sont également discutés.

Keywords: Ground anchor; finite element analysis; stress testing.

1 INTRODUCTION

The new Travis Brow highway provides a link from the M60 Junction 1 to the A6 in Stockport. The project has several challenges associated with urban developments and steep topography as illustrated in Figure 1, as well as presence of contaminated soil and fitting works around an old buried cut and cover tunnel and buried masonry wall.

A variety of geotechnical works were required for the construction of the highway. A short initial section within traditional cutting is followed by a 100m long section supported by 555 No. soil nails with flexible complex facing and green finishing on a 45 degrees slope with a gravity wall at the toe of the slope. As the cutting deepens, contiguous pile walls are used as earth retention system for a 150m long section, with retained height between 5 and 8m, after which the road reaches the Stockport Viaduct.

The new carriageway bisects the Stockport Viaduct, with the alignment undercutting the pad foundations of the 1840s Grade II* listed structure, which carries the West Coast Main Line.

Figure 1. Image of the New Link Road looking east towards the Stockport Viaduct, with the M60 to the south.

Undercutting of the Viaduct pad footings was essential to achieve a safe gradient and standard highway width, but it also presented a complex geotechnical challenge and required approval from Network Rail, the owner and maintainer of the Viaduct.

2 THE STOCKPORT VIADUCT

Having been widened to accommodate four tracks in the 1880s, the Viaduct is founded at two significantly different levels featuring stepped profiles, with the foundations of the extension being deeper than the foundations of the original structure. The new road passes between span 23, where the piers are 3m thick and 12.2m high. An ‘Archie-M’ structural analysis of arch and piers carried out to assess the load at foundation level indicates that under live train loading, a trapezoidal pressure distribution develops under each pad with peak bearing pressure of 1220kPa.

The excavation for the construction of the proposed highway required undercutting the footings for a depth of up to 2.5m in temporary conditions and 1.7m permanently, with a 70-degrees rock slope as illustrated in Figure 2.

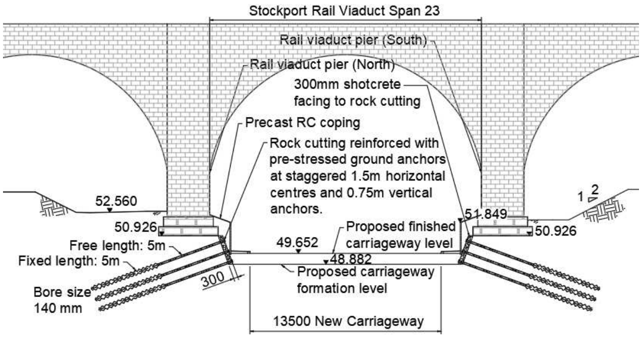

Figure 2. Section at span-23 illustrating anchor layout.

3 GROUND CONDITIONS

The formation to the viaduct pad footings comprises the Chester Pebble bed formation of the Triassic Sherwood Sandstone unit. This rock is typically very weak medium to closely bedded red SANDSTONE, with bedding dipping typically 20-degrees to the west. A less persistent steeply inclined joint set is also encountered in this formation. Project specific investigation revealed extrapolated Standard Penetration Test (SPT) N values in the range of 231 to 945. Point Load and Unconfined Compressive Strength laboratory testing verified the SPT results and gave an average UCS of 3.5MPa to be used for ‘best estimate’ SLS prediction of ground movement. Some judgement was applied to establish a worst credible UCS of 1.9MPa. The data on rock quality and strength was processed through the RSData software to obtain the equivalent Mohr-Coulomb strength parameters using the Hoek-Brown criteria, and provided best estimate ϕ_p’ 49^0, c’ 40kPa and E_r’ 750MPa, and worst credible ϕ’ 40^0, c’ 20kPa and E_r’ 400MPa, where ϕ_p’ is effective peak friction angle, c’ is effective cohesion and E_r’ is drained rock mass modulus.

Figure 3. Trial trench perpendicular to pier at Arch 23 illustrating the quality of the rock and bedding.

4 DESIGN & CONSTRUCTION

A robust design solution was required due to the high bearing pressures of the Viaduct footings, the critical importance of the structure hosting 4 overhead tracks of the West Coast Mainline and its heritage value.

Conceptual design options considered were i) Top-down excavation after installation of a 450mm diameter contiguous piled wall with either propping in front of the walls below the new road or by means of ground anchors behind, ii) Pre-stressed rock anchors and hard facing with each unsupported excavation being confined to as small an area as practical.

The Contractor’s preference was the second option due to cost and programme savings and for similarity with historical works at Pier 20 (Golders, 1977).

The design of the viaduct undercutting was carried out in accordance with BS EN 1997-1:2004, using the finite element software Plaxis 2D. Some judgment was required to analyse a 3D problem in a 2D FE program.

Several sensitivity tests were run to establish the optimum anchor pre-stress level, which was identified as the value of pre-stress above which there was very little improvement in reduction in SLS elastic deformation. The tightest practical anchor spacing was used to reduce the risk of large inelastic movement along unfavourably orientated rock discontinuities exposed by the excavation.

The Plaxis analyses predicted a distribution of elastic rock mass deformation as illustrated in Figure 4. This assumed plane strain conditions, with each anchor being stressed before excavating below.

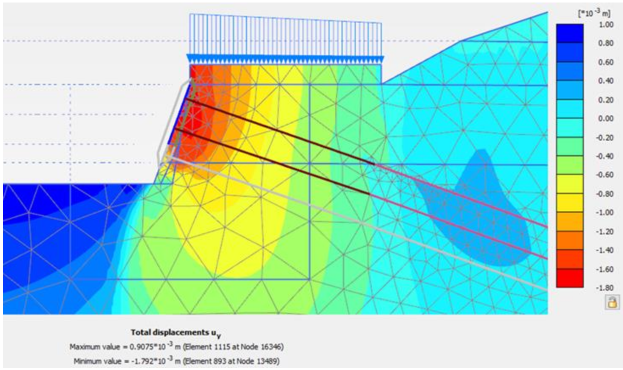

Figure 4. Output of SLS predicted elastic rock movements at finished excavation, before installation and prestressing of the bottom row of anchors.

However, in order to keep the sub-contractor working continuously, two vertical levels of anchors were installed at the same time with adjacent support being provided from a rock buttress (as illustrated in Figure 5) or by recently installed and stressed anchors, with the gang working on a horizontal 'hit-and-miss' basis across 5 bays on each side of the arch and then working down and along the bottom line of anchors.

Figure 5. Placing hard facing to the initial working bay below the north footing of arch 23.

The best estimate and worst credible predictions of elastic rock deformation on the cut face were 0.5 and 2.0mm respectively. The associated rotations of the base of the viaduct pier were also estimated, which were 1:10,000 and 1:4,000 for best estimate and worst credible cases respectively, hence acceptable.

The final design comprised on 32 anchors per footing at 1.5m horizontal and 0.75m vertical spacing. Anchors were 10m long with 5m fixed and 5m free (unbonded) length, inclined at 20-degrees to the horizontal and comprising a 40mm Gewi bar with double corrosion protection in a 140mm diameter grout filled bore. Design prestress was 250kN per anchor.

Anchors installation was carried out in accordance with BS EN 1537:2013 and BS 8081:2015.

5 INSTRUMENTATION & TESTING

Each face of the viaduct had 45 mini prisms installed to monitor the movement of the viaduct and establish baseline movement levels due to wind, temperature change and rail traffic.

Background movements of the Viaduct were greater than predicted movements due to the Works. It was therefore essential to directly measure the ground movements to understand if, and how much, these affected the superstructure.

Extensometers were installed into the new rock faces. These recorded maximum ground movements of 0.5mm beneath the north pier and 0.8mm beneath the south pier, as illustrated in Figure 6.

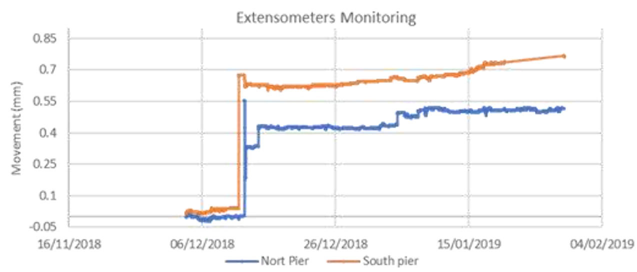

Figure 6. Extensometer results validating SLS predictions.

Selective anchors were fitted with load cells for future monitoring. During the first reading of the load cells, in June 2019, a measured load up to 60% less than the specified lock-off load was noted in all monitored anchors. The cause of the reduced load was investigated by an expert sub consultant.

Increased monitoring of the load cells was implemented, and lift-off tests were carried out on all accessible anchors. The tests confirmed that all anchors held a lower load than specified, with a reduction ranging from 30% to 65% of the nominal 250kN lock-off load.

Following the results of the lift-off tests, restressing of two anchors, subsequent increased monitoring, and a review of the anchor drilling reports, it was established that the likely cause of the reduced load was the procedure adopted for the initial lock-off of the anchors, which did not allow for any lock-off loss due to transfer of load from the jack to the nut. The consequence was that all the anchors were likely to have load at levels significantly less than specified, including the lower row of anchors no longer accessible because buried beneath the finished road level.

As a remedial measure, all accessible anchors were re-tested for acceptability and locked-off at 275kN, 110% of the original design SLS load, in January 2020, thus increasing the average load imposed to the rock face to an average force of 205kN closer to the original design value and equivalent to 1mm of lock off loss. No adverse effects on the viaduct have been recorded to date.

6 CONCLUSIONS

The design of the Stockport Viaduct undercutting provided Network Rail, owner of the asset, with confidence that the Viaduct footings could be undercut by a 70-degress slope to 2.5m depth with works being monitored and contingency strutting implemented between the two footings if ground movements exceeded predictions.

The ground conditions encountered were generally as expected. There was one small wedge failure from unfavourably oriented joints which was addressed quickly by sprayed gunite dentition.

Low anchor stress was identified during monitoring and in turn investigations revealed non-confirmances with the locking-off methodology. It is important to establish what amount of additional stress is required to provide allowance for lock-off losses, especially for short anchors in competant rock where lock-off losses can be very significant. This should be done by immediate lift-off checks to confirm the specified load is locked into each anchor.

The anchor testing was carried out in accordance with BS EN ISO 22477-5:2018 Test Method 1, as per standard UK pratice, which prescribes that the anchor is loaded in steps on one or more load cycles increasing to proof load, with measurement of displacement carried out over a prescribed fixed period at each load step.

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REFERENCES

British Standards Institution (2013), BS EN 1537:2013 Execution of special geotechnical works – ground anchor, BSI Standards Publications, London, UK.

British Standards Institution (2020), BS 5930:2015 + A1:2020 Code of practice for ground investigations, BSI Standards Publications, London, UK.

British Standards Institution (2015), BS 8081:2015 Code of practice for grouted anchors (+A2:2018), BSI Standards Publications, London, UK.

British Standards Institution (2018), BS EN ISO 22477-5:2018 Geotechnical investigation and testing - Testing of geotechnical structures, Part 5 - Testing of grouted anchors, BSI Standards Publications, London, UK.

Golders Associates (1977). Stockport Viaduct Stabilisation of Pier 20. Rep L77003.

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