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Windsor Road Upgrade, Northwest Connect Alliance, Extraordinary Outcomes - A Geotechnical Perspective

Tony Gourlay
Weeks White
Patrick Wong
Coffey Geotechnics Pty Ltd, Australia

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ABSTRACT

The Windsor Road upgrade between Roxborough Park Road and Norwest Boulevard, Baulkham Hills, and between Acres Road and Old Windsor Road, Kellyville, has recently (August 2006) been completed by the Northwest Connect Alliance (the Alliance) within budget and well ahead (5 months) of the scheduled completion date. This was an extraordinary outcome for the Alliance which was achieved through the application of Alliance principles and the subsequent development of project specific innovative solutions to the engineering and construction challenges that presented themselves.

This paper provides a geotechnical perspective on the extraordinary outcomes achieved by delivering a project within an Alliance framework. It outlines the results of the geotechnical investigations carried out and the subsurface conditions encountered on the Windsor Road alignment, highlights some of the construction and geotechnical challenges faced by the Alliance and gives an account of the project specific innovative geotechnical design and construction solutions that were adopted or considered by the Alliance. Particular attention is given to the geotechnical aspects of pavement thickness and retaining wall design and construction, including material parameter selection and the importance of construction trials, stringent construction control monitoring and compliance testing.

1 INTRODUCTION

Following a competitive tendering process, in late December 2004, the Roads and Traffic Authority of NSW (RTA), Leighton Contractors Pty Ltd (Leighton), Maunsell Aecom Pty Ltd (Maunsell) and Coffey Geosciences Pty Ltd (now Coffey Geotechnics) formed the Northwest Connect Alliance (the Alliance) for upgrading the Windsor Road in the north western suburbs of NSW. Coffey’s involvement as a major Alliance participant comprised the provision of geotechnical services including geotechnical investigations, laboratory testing, geotechnical design, pavement thickness design, on site laboratory testing and construction stage monitoring.

This paper summarises the project background and existing site conditions. It provides an outline of the geotechnical site investigations and laboratory testing that was undertaken. In particular, this paper focuses on the geotechnical aspects of pavement thickness, and retaining wall design and construction, and how the Alliance challenged conventional approaches to design and construction, through innovation, in order to achieve extraordinary outcomes.

2 BACKGROUND

The project involved upgrading Windsor Road between Baulkham Hills and Kellyville from an existing two-lane carriageway to a four-lane, median-separated, dual carriageway over an approximate length of 5.5km. The improvements were aimed at reducing congestion, increasing traffic flows, improving safety and improving the environmental and aesthetic features of the road corridor.

The upgrade comprised two distinct sections:
The proposed widening was achieved with the use of conventional earthworks wherever practicable. However, due to space constrictions along parts of the route, this resulted in the need for some seventeen (17) retaining walls of heights up to approximately 4m.

The route crosses three creeks namely Smalls Creek and Caddies Creek in the northern section, and Quarry Creek in the southern section. The Smalls Creek and Caddies Creek crossings required the construction of new bridge structures, approximately 35m and 45m in span respectively. The Quarry Creek crossing involved the extension of the existing culverts and construction of an energy dissipation pond.

3 EXISTING SITE CONDITIONS

3.1 Topography

The site extends from Baulkham Hills, at the southern end, to Kellyville, at the northern end, in the Hills District region of Sydney. The Windsor Road runs in a north-westerly direction through this area, primarily through residential areas with a number of industrial and commercial developments adjacent to the carriageway. The northern upgrade route descends from about 80m AHD at Acres Road, at chainage 170m, to 50m AHD at Smalls Creek, at chainage 1150m. The route is relatively flat from Smalls Creek to the northern extent of the works, at Caddies Creek, at chainage 2498m. The southern upgrade route follows an undulating ridge, which typically ranges from 90m AHD to 110m AHD. There is a creek crossing at Quarry Creek, at chainage 5160m, close to the southern extent of the upgrade, where the road elevation drops to approximately 80m AHD.

3.2 Geology

The site is predominantly underlain by Ashfield Shale. This formation typically comprises thinly bedded to laminated dark grey to black shale, claystone, and siltstone with minor inter-bedded sandstone. The shale is typically mantled by relatively thin residual soils and minor colluvium deposits. Both the residual soils and colluvium typically comprise silty clay with angular rock fragments and are typically less than 1m to greater than 1.5m thick (Penrith 1:100,00 Geological Sheet, 1991). Alluvium deposits occur in the flat valley areas and at Caddies and Smalls Creeks are between 4m and 6m deep and at Quarry Creek are about 4m thick, overlying weathered Hawkesbury Sandstone. The alluvium typically comprises sandy silty clay with occasional sandy and gravelly lenses. Fill material comprising predominantly ripped shales and residual soils overly the shale, residual soils and alluvium in areas of the existing alignment which were formed by filling. The thickness of pre-existing fill typically varies from about 0.5m to 2.0m. Groundwater was typically encountered in the low lying areas adjacent to the three creeks that pass through the proposed area of works, as described in Section 2.

4 SITE INVESTIGATIONS

Fieldworks were carried out by the RTA and other consultants prior to commissioning of the Alliance and subsequent supplementary fieldworks were also carried out by the Alliance. The fieldworks comprised boreholes, test pits, pavement holes, auger holes, Dynamic Cone Penetrometer testing and Ground Penetrating Radar. Laboratory testing was typically carried out in accordance with RTA test methods, and where not available, in accordance with Australian Standard test methods.

5 THE ALLIANCE FRAMEWORK

In an alliance framework, the economic risks of failure and success are shared between the alliance participants. This framework therefore drives a behaviour that encourages collaborative
innovation, by challenging convention, without compromising on engineering quality. It was noted by the authors, that on this project, the RTA (Principal) was willing to engage in technical debate as well as investigate alternative approaches to design and construction, provided stringent construction trials, construction control monitoring and compliance testing was carried out. This approach ultimately led to significant time and cost savings that would not ordinarily be achieved using alternative delivery mechanisms.

It is important to note that the Alliance environment allows much greater scope for conventional practice (e.g. client’s specifications) to be challenged on sound technical grounds unlike traditional delivery methods such as Design and Construct, where the client’s standard specifications or design guidelines must be strictly followed. Therefore, in the context of this paper, an innovation or extraordinary outcome was typically achieved by challenging the client’s conventional or preferred approach to design and construction.

6 PAVEMENTS

6.1 Background

A flexible Deep Strength Asphalt pavement, comprising a Heavily Bound Sub-Base (HBSB) below minimum 175mm dense graded asphalt, was the selected pavement type for the new sections of Windsor Road. A flexible pavement was chosen over a rigid pavement primarily due to the staging, road geometry and time constraints which would have made a rigid pavement impractical. A complementary Full Depth Asphalt pavement was also designed for every deep strength asphalt pavement to give flexibility to the construction team where constraints precluded the use of a Deep Strength Asphalt pavement.

The overall pavement thickness above subgrade level varied depending on the condition of the subgrade, but was typically between 650mm and 950mm thick, including the Select Material Zone below the structural pavement layers and a subgrade capping layer. Based on the assessed CBR and swell test results, the subgrade was categorised as either “expansive” or “non-expansive”. If the 10-day soaked CBR was < 2% and/or the swell was > 2.5% the subgrade was considered to be “expansive” in accordance with RTA guidelines for this project (RTA Technical Direction 99/7).

Based on the Alliance’s initial subgrade assessment using the above guidelines, approximately 2200m out of 5500m of subgrade was categorised as expansive. In accordance with the guidelines, the subgrade was required to be capped with a 300mm thick layer of material having a CBR ≥ 5%, a swell ≤ 1% and a permeability of less than 5 x 10⁻⁷ cm/s. The requirement for capping was therefore going to increase the time and cost of construction. Options for capping included, importing suitable material (e.g. dense graded gravel) or in situ stabilisation of the subgrade.

6.2 Design Approach

The pavements were designed in accordance with the Alliance Brief, RTA’s Technical Directions and design guides and Austroads (1992) “Guide to the structural design of road pavements”. The Windsor Road pavement thickness was designed for a minimum design life of 40 years.

6.3 Innovations

Complex construction staging to maintain satisfactory service levels for road users, road geometry and timing, combined with challenging ground conditions, service relocations and construction of a myriad of new in-ground services lead to the consideration and/or implementation of a number of project specific pavement innovations as discussed in the subsections below.

6.3.1 Specific CBR and Swell Testing

As noted above, substantial areas of the subgrade were classified as “expansive”, which appeared to be inconsistent with the general absence of smectite minerals (based on petrographic analysis) in the clay soils and the absence of indications of distress in the existing pavement arising from reactive subgrade conditions. Liquid Limits and Plastic Limits typically varied from 25% to 65% and
5% to 40% respectively, which would normally classify the soil as only moderately reactive. This was noted to be in contrast to the basaltic clay conditions in Melbourne, where swell criteria were first adopted for pavements due to significant pavement damage from reactive clay subgrade conditions.

In accordance with the RTA test method for a soaked CBR (T117a), a surcharge of 4.5kg is applied to the compacted soil in the CBR mould prior to soaking. This surcharge nominally represents a pavement thickness in the order of 100mm to 150mm. When compared to the actual pavement design thickness of about 650mm over the subgrade (excluding the capping layer), this is equivalent to a surcharge in excess of 13kg (7.0kPa). Consequently, consideration was given to assessing the CBR and swell of the subgrade materials under the influence of a higher surcharge load which is applied to the compacted soil in the CBR mould during soaking. It was anticipated that under a higher surcharge the CBR would increase and the swell would decrease, such that the changes in CBR and swell could lead to significant reclassification of a subgrade from expansive to non-expansive.

After agreement by the Alliance team, a series of CBR and swell tests were conducted with surcharge loads of 4.5kg (2.4kPa), 9kg (4.9kPa) and 13kg (7.0kPa) respectively. The results typically showed an increase in CBR and varying degrees of reduction in swell, although one sample in the test program showed a significant increase in swell when the surcharge was increased, the reason for which was not directly apparent from Atterberg limit test results. The results of the test program also showed that the CBR / swell criteria for “expansive” subgrade were likely to classify significantly more subgrade soils as expansive, as compared to previously adopted criteria based on plasticity.

While considerable effort was devoted to better refining the test requirements for classifying expansive subgrades to match observed performance of existing pavements, the RTA was unable to accept the recommendations as the test results were not conclusive and the originally specified test methods were retained for the project.

6.3.2 Placement of Thick Heavily Bound Sub Base (HBSB)

The standard RTA specification limits the thickness of HBSB to a 200mm compacted thickness. There is considerable initial and whole of life cost advantage in using a thicker HBSB layer, which can be readily compacted using modern construction equipment.

Following in-principle agreement with the RTA, the Alliance carried out field construction trials to verify that:

- the compacted layer thickness could be constructed to within the thickness tolerances required by the specification;
- the relative compaction requirements could be achieved over the whole of the layer within the nominated working time - this was carried out by measuring the density of the upper half and full depth of the layer thickness, to calculate the density of the lower half of the layer; and
- the additional compaction effort did not result in unacceptable ground vibrations at adjacent property boundaries.

The results of the field trial met the objectives and use of a 250mm thick HBSB layer was approved and adopted. It was observed that the use of slow setting binders, as specified in the RTA standard specifications, is a valuable aid to ensuring that the compaction and thickness objectives were met.

6.3.3 Placement of Thick Select Material Zone (SMZ)

It is a characteristic of Alliance projects that “standard” methods can be challenged and re-engineered to achieve an improved project outcome. Consequently, in a similar manner as for HBSB, construction of the SMZ in a single 300mm thick layer was successfully trialled and implemented. The reduced construction time associated with placement and compaction in a single layer contributed to the achieving of critical staging times and overall project completion time.
7 RETAINING WALLS

7.1 Background

Some seventeen (17) retaining walls, totally about 1750m in length, were designed and constructed as part of the project. The heights of the walls varied from 0.5m to 4.5m and were typically 1m to 2m high. The walls were typically constructed on the road corridor boundaries to maximise the available useable space for the road widening. The wall types consisted of:

- L-shaped reinforced segmental block gravity walls;
- L-shaped reinforced concrete gravity walls;
- Cantilever embedded walls.

7.2 Design Approach

The retaining walls were designed in accordance with the requirements of AS5100: 2004. The retaining structures were designed for a 100 year design life. The design of each wall was characteristically dependent on, retained height, backfill inclination, surcharge loads, lateral loads, foundation conditions, properties of the backfill material, location of existing and proposed underground services, groundwater conditions and construction staging. In accordance with AS5100, the following strength limit states (equivalent working stress factors of safety (FOS) given in brackets) were typically considered for design:

- Sliding at the base of wall (FOS = 2)
- Rotation/Overturning of the wall (FOS = 2)
- Bearing failure (FOS = 2.5)
- Global (overall) stability (FOS = 1.6)

7.3 Innovations

7.3.1 Design Parameters

Given the total length of the retaining walls, the subsequent volume of backfill material needed to construct the gravity walls and the limited space available to stockpile materials, it was agreed by the Alliance team that the on site materials would be re-used as “engineered backfill” to save on time and cost of construction. The on site soils used as fill typically comprised ripped weathered shales and residual soils.

Traditionally, it has not been normal geotechnical practice to adopt characteristic effective drained cohesion ($c'$) values of more than about 2kPa for retaining wall backfill materials comprising clay soils, such as the residual silty clays and weathered clayey shales. The Alliance team therefore challenged this convention and adopted a characteristic effective drained cohesion ($c'$) of 10kPa and a characteristic effective friction angle ($\phi'$) of 28° for design. This innovation was verified by shear box testing, which resulted in reduced retaining wall dimensions and subsequent time and cost savings associated with construction.

7.3.2 Shear Box Testing

To verify the characteristic soil parameters adopted for the engineered backfill, shear box testing was carried out on representative soil samples to accurately model (as closely as possible) the compacted backfill conditions. Preparation of the samples comprised:

- Pre-treatment (RTA 102 - Method A);
- For each representative soil sample, compaction of six (6) separate sub-samples into individual 70mm x 70mm x 40mm shear box moulds was carried out. (i.e. the sub-samples were compacted to a Standard Maximum Dry Density Ratio (SMDDR) of 98% at the Optimum Moisture Content (OMC) to model actual compaction criteria of the backfill);
- The six (6) sub-samples were then split into two (2) sets of soil samples, each comprising three (3) sub-samples;
- The two (2) sets of soil samples were then sheared slowly at a rate of 0.02mm/minute with each sub-sample sheared at a different stress level (i.e. 40kPa, 80kPa and 160kPa) to model...
typical overburden stresses for the range of retaining wall heights being considered. One set of three (3) sub-samples were sheared at the OMC and the other set of three (3) sub-samples were sheared after the samples were inundated with water to model a saturated soil condition.

The shear test results showed that for compacted samples sheared at the OMC, the effective friction angle typically varied from 28 to 45 degrees and the effective cohesion typically varied from 38kPa to 125kPa. For the compacted samples sheared after inundation, the effective friction angle typically varied from 26 to 33 degrees and the effective cohesion typically varied from 8kPa to 20kPa. Clearly the results demonstrated that a characteristic effective cohesion of 10kPa and a characteristic effective friction angle of 28 degrees were reasonable for the overburden stress levels that can be anticipated behind the retaining walls. Vertical drains were provided behind all walls to limit water pressure build up and the risk of saturation of the backfill.

7.3.3 Compliance Testing

The earthworks specification was written such that it called for representative soil samples of the backfill material to be obtained for shear box compliance testing during construction. The specification required that a minimum of two-thirds of shear box results must comply with the effective shear strength requirements. All samples were inundated prior to shearing and it was shown that the required results were readily achieved.

7.3.4 Low Height Walls

For low height gravity walls (i.e. up to 1m), it was found that in the requirement of AS5100 for factors of safety of 2 on sliding and overturning resulted in unreasonably wide footings which presented problems in relation to space constraints on the boundaries of the road corridor. As a result, an innovative risk assessment approach to design was agreed with the RTA for a number of low height walls. This approach involved assessing the risk of failure of the wall and the consequences of failure for a particular width of footing. If the level of risk was accepted by the Alliance, the retaining wall design was confirmed for construction, resulting in cost savings and reduced construction time.

8 CONCLUSIONS

This paper has outlined a number of geotechnical innovations that were considered or implemented by the Northwest Connect Alliance on the Windsor Road Upgrade. These extraordinary outcomes were achieved within an Alliance framework where the RTA (Principal) and the other alliance participants were willing to challenge convention and verify the success of the innovations by way of construction trials, stringent construction control monitoring and compliance testing.

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