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West Charlestown Bypass: Construction of Urban Freeway Embankments using High Plasticity Clays

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Summary: The completed West Charlestown Bypass project comprises a 6.5km length of urban freeway south west of the Newcastle CBD, in New South Wales, Australia. Significant quantities of the soil and weathered rock materials excavated from the cut areas comprised clays of high to very high plasticity, and low grade coal. Such materials would normally be considered as "unsuitable materials" (spoil) for engineered fills. However, it was a requirement of this project that all excavated materials were to be incorporated in the engineered fill embankments. The geotechnical design of embankments therefore required consideration of appropriate measures to facilitate the placing and compaction of high plasticity soils, to control potentially adverse impacts of the highly reactive soils on the overlying concrete pavement and to ensure adequate stability of low strength soils incorporated within the embankments.

Designs were prepared and the embankments were constructed using zoned fill, within which the poor quality "unsuitable materials" were encapsulated by selected, better quality fill materials. A large volume of general fill material also had to be lime stabilised to improve workability and moisture content, so that compaction could be achieved. Specifications were carefully written to distinguish between materials that could be placed without stabilisation, and those requiring stabilisation.

INTRODUCTION

The West Charlestown Bypass project forms part of the Newcastle Inner City Bypass, which, when completed will extend from the suburb of Windale in the south to Sandgate in the north. The route alignment was fixed about 50 years ago, so grade and space limitations dictated the freeway geometry and cut/fill depths. The urban environment of the Bypass project imposed constraints on the disposal of unsuitable site materials, requiring a balanced cut to fill earthworks design and the need to utilise all excavated materials within the earthworks.

The client was the Roads and Traffic Authority (RTA) of New South Wales, who also managed the project. The work included the movement of 670,000 cubic metres of earthworks and incorporated cuttings up to 17m deep and embankments up to 13m high.

Earthworks construction commenced in 2000 and the road was opened to traffic in early 2003.

This paper describes the soil characteristics of the earthworks material, the methods adopted to utilise the poor quality materials within the works and the earthworks specification prepared for the project. Issues relating to earthworks construction are also discussed.

GEOLOGICAL SETTING

The Bypass route traverses the upper formations of the Newcastle Coal Measures, which underlie the northern fringe of the Sydney Basin. The formations exposed along the route comprise, in increasing age, the Mount Hutton Formation, the Australasian Coal Formation and the Tickhole Formation (which incorporates the Charlestown Conglomerate Member). Clay and sandy clay Quaternary deposits occur along creek lines.

The Mount Hutton Formation comprises interlayered sandstone, siltstone and claystone. A thick sandstone member was exposed at the Willow Road cutting and this provided the only source of select fill material on the project. The lower parts of the formation (which were encountered along much of the route) comprise shaly siltstones and claystones with carbonaceous laminations and occasional silty sandstone bands. This formation was encountered in five of the seven cuttings, including the 17m deep Cut 7 at the northern end of the project.

The Australasian Coal Formation underlies the Mount Hutton Formation. It is about 9 to 12 m thick and contains claystone and numerous tuff bands. The bypass route interersected this formation in Cut 7, in the base of Cut 6 and further south at the Warners Bay Road cutting. This formation acts as a confined groundwater aquifer. A 2m thick seam of commercial quality coal at the base of the formation was mined in the 1890's with secondary extraction of coal pillars prior to the 1930's in the Cut 6/7 areas. The resultant mine voids located at shallow depth below the road presented interesting construction challenges for the project. These are not discussed in this paper.

The Tickhole Formation comprises conglomerate, sandstone, siltstone and claystone. It is typically about 66m thick and underlies much of the central section of the route and a short section at the northern end.

The rock strata present along the Bypass route have weathered to a range of soil materials, some of which posed difficult conditions for earthworks associated with the proposed construction. Significant rock and soil types that influenced the earthworks design and construction comprised coal and claystone strata, and clays of high plasticity.

SOIL PROPERTIES

Earthworks construction materials for this project comprised residual soils, some colluvial soils and weathered rock excavated from cuttings. The soils consisted mainly of medium to very high plasticity reactive clays, and some silts. Significant variation in soil type was identified, both laterally along the route and with depth within the soil/rock profile. The mean drained shear strength from 24 triaxial and shear box test results was Ø' = 28.5° with a standard deviation of 4.8°. The PI range of the tested samples varied from 14 to 59.

The weathered rocks excavated from cuttings were weak and generally broke down to soil-like properties on excavation. Other than isolated sources of select fill quality sandstone from the Willow Road and Myall Road areas, almost all other excavated material used in embankment construction (conglomerate, silty sandstone, siltstone and claystone) was of poor quality. The claystone in particular broke down on reworking to a low strength, high plasticity clay that was difficult to place and compact. The drained shear strength of this material was found to be in the range of 15° to 20°.

Tender stage soil classification test results are presented on Figure 1, including those for rock and modified soil samples. The extremely wide range of site materials is evident from this plot. The low plasticity results include the limited sandstone material from the Willow Road cutting, which was used as select fill, while the remaining medium to high plasticity results represent the material available for use as general fill. This included a significant quantity of very high plasticity, tuffaceous soils (LL > 80).

Figure 1 demonstrates that the adoption of a conventional upper limit PI of 35 for general fill would have excluded a high proportion of available material from the works. The upper limit PI was therefore increased to 50, but even then, a significant proportion of the test samples exceeded this value. It was therefore clear that the very high plasticity soils would require modification in order to make them suitable for incorporation in the works. Soil modification tests were conducted using various modifying agents (including lime kiln dust) to demonstrate that the PI could be reduced below the nominated upper PI limit.

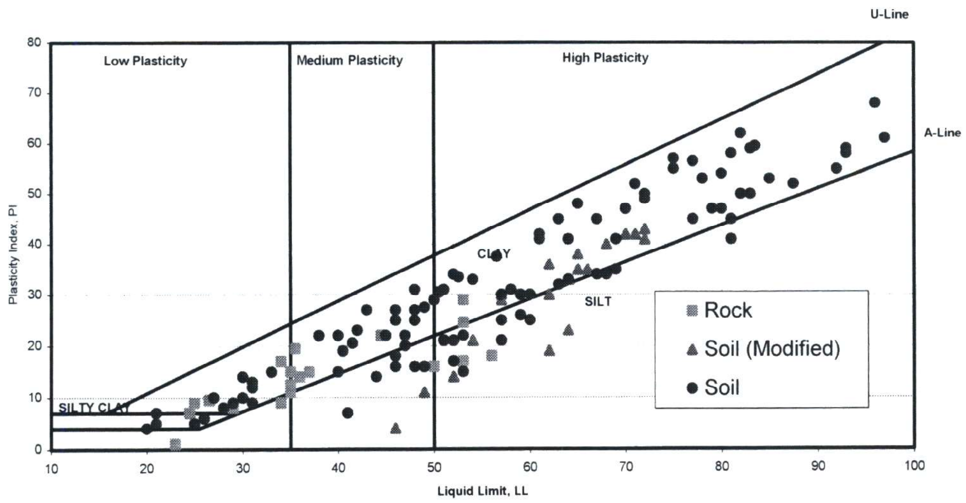

Figure 1: Plasticity Chart Showing Tender Stage Test Results

Earthworks construction using the reactive site soils presented a number of challenges to the construction contractor. The engineering and contractual issues associated with shrink/swell behaviour, low soil strength, moisture control and trafficability were assessed and addressed in the contract documents.

MATERIAL UTILISATION IN EMBANKMENT CONSTRUCTION

Material Usage / Earthworks Balance

To achieve the objective of utilising all excavated material within the earthworks, a zoned embankment design was developed so that the poor quality material could be encapsulated within selected, better quality fill materials. The design and specification of the zoned embankments required extremely careful fill selection, testing and earthworks control procedures by the contractor.

There was insufficient capacity within the encapsulated fill embankments to accommodate all the poor quality fill material from the excavations. Surplus poor quality material was therefore modified to reduce the plasticity to acceptable levels for use as general fill, and to improve workability and moisture content so that compaction could be achieved. Laboratory testing was carried out on soils from the Bypass route to assess the effects of soil stabilisation using quick lime, lime kiln dust and gypsum. Specifications were carefully written to distinguish between materials that could be placed without stabilisation, and those requiring stabilisation.

Constraints due to poor quality material

Due to their shrink/swell behaviour and low strength (particularly on wetting), utilisation of the reactive clays and claystones found within the route corridor presented abnormal conditions for earthworks construction. In particular, it was recognised that the following materials management issues associated with poor quality material would impact on the cost of the works:

- Close-tolerance compaction requirements were specified for the claystones, highly plastic clays, silts, coal, and carbonaceous materials. It was recognised that these would be difficult to achieve and that fill materials would have to be carefully managed to avoid the need for moisture conditioning, which could impact significantly on production rates.

- Traffficability by construction equipment over the clayey soils was anticipated to be generally difficult, particularly after rainfall periods. The preparation and maintenance of haul roads for heavy vehicles over the weak in situ soil was therefore expected to have a significant impact on production.

- Areas of suspected perched water table and waterlogged ground conditions, which were identified on either side of the Warners Bay Road cutting where the Australasian Coal daylighted, provided a further challenge to both access and materials management.

- Construction of the highway over a section of old mine workings at shallow depth was a major construction issue. This risk was recognised by the RTA and a section of the route was quarantined from the rest of the project to allow substantial remedial work to be carried out in this section of the route, independently of the main earthworks. This issue has not been addressed in this paper.

These matters were drawn to the attention of tenderers in the contract documents and were to be addressed by them as part of their materials management plan.

General fill design objectives

To successfully utilise highly reactive soils in embankment construction, without the risk of future shrink/swell problems, it is necessary to place the material at or near its equilibrium moisture content (EMC) and to protect the material from significant moisture change during its design life. If the field moisture content at placement is significantly lower than EMC, the reactive nature of the materials could be reflected in surface movements (heaving) of the fill as EMC conditions are progressively achieved over the life of the carriageway. Heaving of fill materials would have an adverse impact on pavement and drainage structures.

In the Newcastle area (and much of the New South Wales coastal region) EMC is likely to be close to or slightly wet of Standard optimum moisture content (OMC). Thus, OMC is the desirable moisture content for both compaction and long-term shrink/swell stability. To achieve material placement at or near OMC, a tight moisture control specification was adopted, allowing for a small moisture variation range in order to achieve a small (statistical) moisture content standard deviation.

Under such conditions it may be expected that differential movements associated with reactive soils incorporated in the general filling will be minimised. In terms of this design philosophy, moisture control during and after construction is a more important design constraint than the magnitude of potential displacements due to swelling of reactive material.

While the moisture content of near-surface soils will be influenced by prevailing climatic conditions, experience has shown that the soil moisture content below 1.5m depth in the Newcastle region will be close to the EMC/OMC. It was therefore recognised that construction risks could be minimised by excavating and placing high plasticity soils in a direct cut-to-fill operation, thus allowing minimal opportunity for soil moisture change. On the other hand, cut-to-stockpile methods expose the material to significant moisture variation due to atmospheric wetting or drying. The specification therefore required that claystones and clays were to be excavated and placed in a direct cut-to-fill operation, and that stockpiling of such material was to be avoided.

To minimise the risk of spontaneous combustion, the specification required that carbonaceous materials and coal were to be placed in the lower portions of embankment fills or noise mounds and compacted to achieve a low percentage air voids. A minimum 2.5m soil cover was required over these materials in the noise mounds.

ENCAPSULATION ZONE DESIGN

The reuse of claystones, high plasticity clays and some weathered coal materials from cut excavations for engineered filling in the bulk earthworks required recognition of the potential for reactive (shrink/swell) behaviour, as discussed above. Laboratory testing indicated that fill materials having high plasticity (LL>70, PI>50) and CBR swell values as high as 6% would need to be accommodated in the embankment fills. Furthermore, these poor quality materials have low shear strengths and are difficult to compact at OMC using conventional heavy earthworks equipment.

An encapsulated zone (EZ) within the embankment fills was adopted to accommodate the low strength and highly reactive materials in a manner that limited or eliminated the potential reactive behaviour. The design of the EZ is indicated on Figure 2. This design was initially developed in the early 1990's for the Sydney to Newcastle F3 freeway, which passes through the same geological formations to the west of Newcastle (refer Leventhal & Stone, 1995), and has performed successfully.

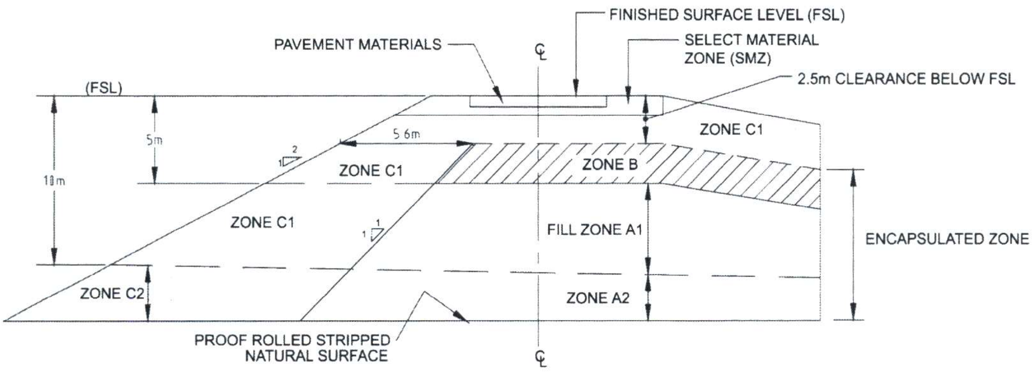

Figure 2: Typical Section – Encapsulated Fill

Refer to Table 1 for material specifications for Zones A, B and C.

Fill materials permitted within Zone A of the EZ comprised all coal, highly plastic and highly reactive soil that was capable of meeting the compaction specification, irrespective of moisture content. This allowed the placement of these materials at moisture contents well below OMC, thereby permitting more efficient compaction with large earthmoving equipment. The design relied on a minimum 5m of cover (overburden pressure of approximately 100kPa) to control potential swell movement in this zone.

Zone B material (2.5-5 m below Finished Road Level) preferably comprised general fill but permitted the use of EZ material (other than coal), subject to tight moisture control requirements (95-105% of OMC) to minimise the risk of heave. The shell material enclosing the EZ comprised general fill, placed at a moisture content of 90-110% of OMC.

SPECIFICATION

Earthworks

The standard RTA specification for cut to fill earthworks (Specification R42) was adopted and modified to suit the site conditions. In particular, provision was made for the following:

- Overexcavation of cutting floors in poor quality material and replacement with better quality fill and/or granular (slag) bridging layers where appropriate.
- "Unsuitable" material was classified as "Poor quality" material to be included in the works as "Encapsulated Fill" or, alternatively, stabilised and used as General Fill.
- "Spoil" was classified as surplus material not required to complete the works.
- The maximum PI for General Fill was increased from the usual value of 35 to 50 to accommodate the generally poor quality of fill material available on the site.
- A narrow moisture content range (close to optimum) was specified for fill compaction to minimise the potential impact of shrink/swell movement due to relaxation of the PI (plasticity) criteria referred to above.
- A detailed specification for the encapsulated zone embankment design (refer Section 5 above) was provided.

The standard RTA moisture range specification for general fill is 60-90% of OMC. This was developed for sandstone material in the Sydney area and is not considered appropriate for the compaction of high plasticity clay soils, as it could lead to significant heave of embankments due to wetting up of such clay soils after completion of embankment construction. With the equilibrium moisture content of the site soils being close to or slightly above OMC, clay materials compacted dry of optimum are likely to "wet up" as the equilibrium moisture content is approached in the long term. Changes to the standard RTA moisture range specification for the high plasticity clays on this project were justified on this basis.

The specification required that General Fill material that became unstable due to high moisture content was to be dried back, as part of the construction programme/methodology, at the contractor's expense, and incorporated within the works. However, excess Encapsulated Fill quality material (where moisture content limits were not specified) was to be stabilised and incorporated as General Fill at the client's expense, once all encapsulated fill zones were completed.

A summary of the material specifications for embankment materials is given in Table 1 below:

Table 1: Specifications For Embankment Materials

Material Zone	Material Specification			Compaction	Specification
	Min CBR * (%)	CBR Swell (%)	Max PI	Min Density (Standard)	mc range (% SOMC)
Select Material Zone	15	-	15	102	60-90
Upper Zone of Formation	10	<2	25	98	90-110
General Fill	3	-	50	98	90-110
Encapsulated Zone A	-	-	-	98 (soil) 102 (coal)	As required to achieve compaction
Encapsulated Zone B	3	-	50	98	95-105
Encapsulated Zone C1	3	-	50	98	90-110
Encapsulated Zone C2	3	-	50	98	70-110

* 10 day soak at 98% Standard Compaction after 3 cycles of pretreatment to simulate compaction breakdown.

Notes: 1 Standard RTA moisture content range specified for Select Material Zone (sandstone).

2 Moisture content close to OMC specified to control shrink/swell movement in high plasticity clay fill, but relaxed below 5 m depth in EZ, as adequate load applied to contain swell pressure.

3 Upper zone of formation (UZF) is the upper 600 mm of embankment fill, including the 300 mm thick Select Material Zone (SMZ).

Material management was recognised as critical to the successful utilisation of all available fill material within the embankments. The specification therefore called for the contractor to provide a materials management plan for select material, general fill, poor quality material, claystone and coal materials. The plan was intended to identify the zones where each of these material types was located and the methodology for incorporation of the materials in the embankments.

Stabilisation

Stabilisation of fill material was carried out in accordance with RTA Specification R50. 5% of Lime Kiln Dust was nominated as the preferred stabilising agent, as this material was available at a competitive price at the time of tender. 2% Quick Lime was nominated as an alternate stabilising agent for the embankment material. The stabilisation requirements using these additives were assessed prior to tendering, by laboratory testing of the soils from the Bypass route. By the time construction commenced, Lime Kiln Dust was no longer available at competitive rates so quick lime was used as the stabilising agent. Stabilised material was mixed and placed using purpose-built stabilising plant. The stabilisation was carried out in situ in the cuts prior to transport of the fill materials to the embankment placement areas.

CONSTRUCTION ISSUES

Tendering Process

In recognition of the complexities of earthworks and materials management, the RTA arranged for a two-step process in the procurement of a construction contractor.

Initially, an Expression of Interest (EOI) was called from pre-qualified contractors interested in tendering for the work. The EOI package included preliminary designs and geotechnical information. In response to the EOI, interested contractors were required to list and describe recent projects that included some or all of the following characteristics:

- Working with soft silty clays that are wetter than optimum moisture content.
- Management techniques that allowed wet soft silty clays to be used in embankments.

Potential tenderers were also required to present their understanding and approach to materials management for this project, including draft method statements, nomination of key personnel and proposed plant and equipment to be used to execute the works.

Following receipt and assessment of the EOI responses four tenderers were short listed for the Contract. These companies were considered to have demonstrated a high level of understanding of the complexities of the materials to be encountered and to have sufficient experience and personnel to undertake the work. A pre-tender meeting was also arranged with the 4 short listed companies at which a comprehensive presentation on geotechnical conditions was given.

Issues arising during construction

Earthworks construction commenced in July 2000 and following the clearing of the route and stripping of topsoil, an assessment was undertaken to further quantify the location and quantity of poor quality material (PQM). Although an extensive amount of data was available from the pre-construction investigations, the construction stage assessment revealed that there was a larger volume of PQM than previously anticipated. The presence of large quantities of PQM and the finite volume of the encapsulated zones available to accommodate this material was recognised in the specifications, as discussed above. Provision had therefore been made for the stabilisation of excess PQM to produce general fill. However, assessment of the volume of PQM at tender stage was always subject to interpretation and risk.

The final volume of PQM significantly exceeded tender stage expectations. Whilst an excess of PQM over and above the volume for encapsulation was catered for, the impact on the Contractors' assumptions was significant. Operational problems were also experienced as a result of the large variability in material quality within individual cuttings and from cutting to cutting.

As a result, lot sizes were reduced and operational flexibility suffered. The Contractor employed a primary production fleet of three Cat 631 Scrapers and associated push and spread plant, programmed to realise production in the order of 3,000 m^3 per day south of Hillsborough Road. The need to stabilise excess PQM to produce general fill, balancing volumes of stabilised and un-stabilised PQM and the smaller lot sizes resulted in actual production rates in the order of 50% of the Contractor's planned production south of Hillsborough Road. This position was not assisted by the generally wet weather conditions experienced in Newcastle in 2000 and 2001. The wetter conditions made the drying out of wet earthworks by traditional means such as tyning and ploughing ineffective.

Moisture Control

Tight moisture control specifications were nominated for zones B and C1 of the EZ in order to inhibit shrink/swell movement zones (refer to Table 1). The contractor experienced difficulty in meeting these requirements for a number of reasons. One of the problems was the wide variability in the quality of the material (as demonstrated in Figure 1), which made it difficult to achieve the required moisture content in each tested lot.

Questions also arose regarding the adequacy of the adopted Hilf method for compaction testing where a tight moisture content range was specified. This issue was the cause of some frustration to the contractor. In order to expedite the works, the RTA relaxed the moisture control specification on a case by case basis, depending on material type and location within the embankment, as the work progressed.

Interestingly, the material variability as experienced by the contractor was consistent with expectations from pre-tender geotechnical investigations, as the MDD/OMC results shown on Figure 3 illustrate. A number of inadmissible results (falling above the zero air voids line) were identified in plotting the results.

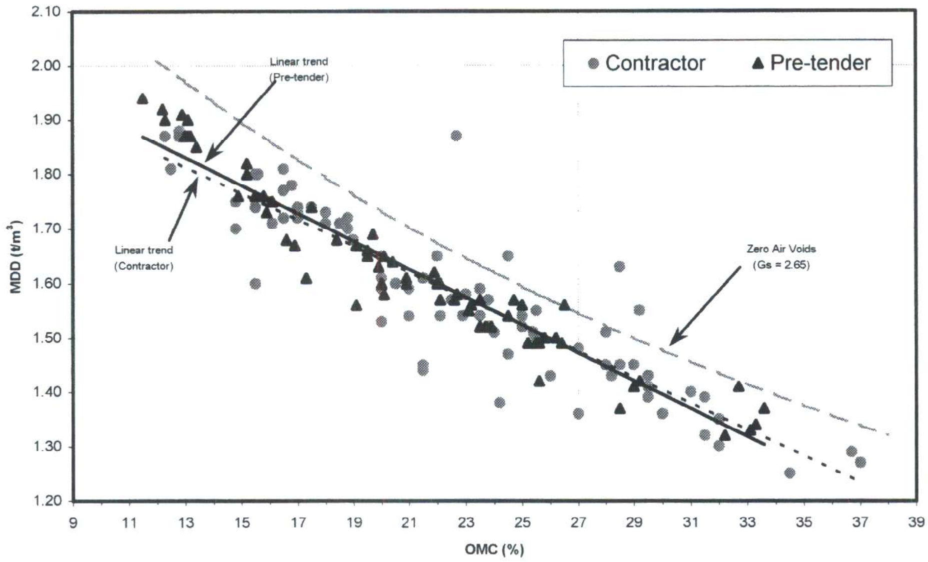

Figure 3: Comparison of Compaction Test Results

CONCLUSIONS

This case study provides an example of an apparently straightforward earthworks contract that was in fact quite complex due to the poor quality and variability of the materials that had to be incorporated in the works. There were also a number of other complexities associated with this project that are outside the scope of this paper.

This project demonstrated that it is feasible to utilise very poor quality material in earthworks construction, subject to careful design and control. While there is a cost premium associated with the use of such material, in this case it was cheaper than the option of spoiling and replacement due to constraints imposed by the urban environment. Further, the RTA had no alternative but to accept this impost due to environmental constraints on the project.

Both the client and the contractor are exposed to increased construction risks in projects that involve engineering with poor quality materials. It is difficult for tenderers to assess the risks associated with such works and still provide commercially competitive rates, while the client is exposed to increased risks associated with unexpected material variations (in terms of quality and moisture condition) and the vagaries of the weather over the construction period. These risks tend to be accentuated when working with poor quality materials due to their low strength and moisture sensitivity.

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