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Port of Brisbane Motorway Alliance Enhances Geotechnical Outcomes

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Summary: The Port of Brisbane Motonvay was designed and constructed by an Alliance comprising Coffey Geosciences, Parsons Brinckerhoff, Leighton Contractors and Queensland Motonvays. The project was completed six months ahead of schedule and under budget to the satisfaction of the Alliance Partners and State Government.

The Motorway extends from the Gateway Motonvay in the west to the Port of Brisbane on the east and the Alliance was responsible for the design and construction of Package 3 of the project between the Gateway Motorway and Lindum Road. Package 1, located within Package 3, was carried out by others, but the Alliance was responsible for liaison of the whole project.

The Port of Brisbane Motonvay crosses variable ground conditions with weathered rock at shallow depth near the Gateway Motonvay and weak, compressible soils towards the east. The thickness of soft soils varied but was predominantly between about 20m and 30m. The geotechnical team working together with estimators, construction personnel, hydrologists and highway engineers, and peer reviewers fiom Queensland Main Roads provided a robust design within a short time frame and continued to provide input during construction to achieve the high standard set by the Alliance Partners. This paper describes the geotechnical challenges encountered and how they were overcome with proper Alliance spirit.

INTRODUCTION

Geotechnical Consultants participate in many major infrastructure projects but generally in the capacity of a sub consultant to the Principal Contractor or lead Design Consultant. This often restricts the role of the Geotechnical Consultant to that of a site investigator supplying appropriate geotechnical design parameters on request with no real opportunity to value add to the total design process. Greater opportunities exist under the Design and Construct approach but these are often restricted by financial and time constraints. Generally there is little opportunity for the Geotechnical Consultant to be involved on a continual basis during construction in a team environment where everyone is united in their aim to constantly look to improve on the initial designs. The role of the Geotechnical Consultant during construction is often limited to signing off that ground conditions at least meet the design assumptions with no opportunities for redesign that can achieve substantial savings.

The Alliance contract delivery mechanism (Ross, 2000) is ideally suited to projects where there are significant geotechnical issues to be dealt with during design and construction. Early in the bidding process for the Port of Brisbane Motorway project it was recognised that the alignment and location of the Motonvay presented significant ground risk to the success of the project. The formulation of an Alliance team for the Port of Brisbane Motonvay which included a Geotechnical Consultant as a full Alliance Partner proved to be a winning combination. The Alliance comprised Coffey Geosciences, Parsons Brinckerhoff, Leighton Contractors and Queensland Motonvays. The Alliance process allowed for close liaison between the geotechnical and civil designers and constructors. By virtue of this close teamwork, geotechnical solutions were developed which allowed the cost and programme constraints of the project to be overcome.

This paper does not focus on technical details but, rather attempts to give an overview of the problems encountered on the project, and describe the process adopted by the geotechnical team within the Alliance and the successful outcomes achieved.

LOCATION

The Port of Brisbane Motonvay (Package 3) extends from the Gateway Motorway in the west to Lindum Road in the east as shown on Figure 1. The road alignment runs to the south of Lytton Road, near to the existing railway line and passes through the residential suburb of Hemmant. The bulk earthworks of Package 1 was carried out by others and extends from the eastern edge of The Oxbow to just east of Bulimba Creek and is shown hatched on Figure 1.

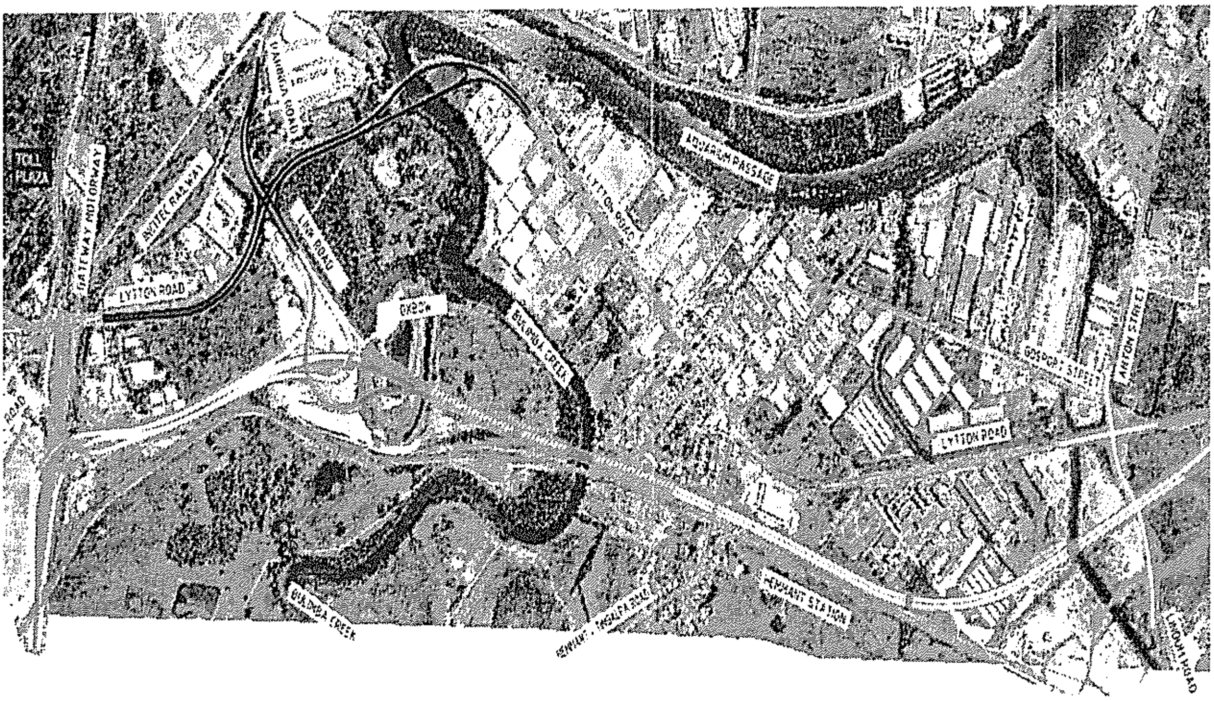

Figure 1. Plan of Port of Brisbane Motorway

GROUND RISK

Commencing at the Gateway Motonvay in shallow residual soils and weathered rock, the route of the Port of Brisbane Motonvay descends to a low lying area of mangrove swamps and alluvial flood plain associated with the Bulimba Creek and nearby Brisbane River. The route also crosses "The Oxbow", an isolated arm of the Bulimba Creek.

Much of the route traverses low lying flood plains (RL0.5m to RL1.5m). Underlying the flood plain is a sequence of Recent estuarine soils ranging in thickness from 0m (in the west) to more than 30m in the east. The Recent soils comprise mostly soft to firm dark grey clay of high plasticity with some more recent sandy or silty soils near the surface. Beneath the Recent soils is Pleistocene age Old Alluvium over residual soils and bedrock. The surface of the Old Alluvium has been deeply incised by a series of palaeochannels into which the Recent /Holocene estuarine soils have been deposited. Over extensive areas of the site there is old fill, containing ash at some locations. Groundwater levels along the alignment vary between RL1.5m and RL-1.0m and at some locations are influenced by tidal movements.

These soft ground conditions presented risks to the project which involved embankment stability, the likelihood of long term settlements which could affect both pavements and structures, and the potential to adversely affect adjacent utilities and also sensitive mangrove areas.

Specific problems to be addressed in the geotechnical design included embankment and bridge abutment settlement; settlement effects on a sewer passing under the route; the effects of preload and surcharge times on the construction programme; the stability of temporary access roads and crane working platforms on soft mud; and pavement designs to meet a 40 year design life which had to accommodate ongoing settlement of embankments.

TREATMENT OF THE OXBOW AREA

The Oxbow area is characterised by deep, soft, estuarine soils into which the relatively shallow Oxbow channel has been incised and filled with recent very soft sediments. In addition to the deep seated geotechnical issues, The Oxbow presented significant logistical problems to constructors in relation to achieving trafficability for construction equipment.

One of the aims of the Alliance Team was to, not only deliver a solution for the road construction, but also leave a positive environmental legacy by rehabilitating The Oxbow. The area had been severely degraded through past land use resulting in The Oxbow being cut off from the Bulimba Creek. The Alliance Team carried out extensive flood modelling in consultation with local stakeholders to optimise the reduced level of the road pavement in this area. Once the required level was established, the geotechnical team considered a large range of options for foundation treatment based on embankment construction, including staged loading with surcharge, lime/cement columns and displacement methods (rock fill and geonet). These three were eliminated early due to time constraints on surcharging and environmental impacts. Preliminary designs and costing were carried out for solutions involving stone columns, dynamic replacement techniques, a piled embankment, vacuum consolidation and excavation and replacement. In the end the Alliance Team adopted a structural solution involving the construction of a conventional viaduct. This solution would not be considered innovative but in the end, taking into account the proposed rehabilitation of The Oxbow, was judged by the team to be best for the project.

Although a geotechnical solution was not adopted in the end, the Alliance approach enabled the team to adequately explore a large number of options in arriving at the best for project solution.

PILING SOLUTIONS

In Queensland, most Main Roads bridges have 580mm precast hexagonal piles which are post tensioned in a single length. On The Oxbow viaduct (see Figure 2), pile lengths required were up to 30m, and hence special delivery and handling systems would have been required to install the piles. This would have been particularly difficult across the swamp conditions of The Oxbow. However such was the belief that nothing else would be accepted that these piles were documented without question. The geotechnical team was able to challenge the use of this piling instead of segmented, square, precast piling which is used commonly in other states of Australia. It was discovered that the main concerns in relation to segmented precast concrete piles was the potential for corrosion of reinforcement, particularly in acid sulphate soils. Given that such piles were known to be used in similar environments elsewhere in Australia, the geotechnical team challenged this concern. After long technical debates where corrosion specialists from Vicroads and CSIRO provided supporting opinions, the segmented precast concrete piles were accepted by the Main Roads peer reviewers. In addition to savings in direct piling costs, the other major benefits included transport to site without special permit vehicles, safer handling and installation, smaller piling rigs requiring much simpler access over the Oxbow swamp and a reduced construction period. This was a first for Queensland and is unlikely to have been achieved outside the Alliance process.

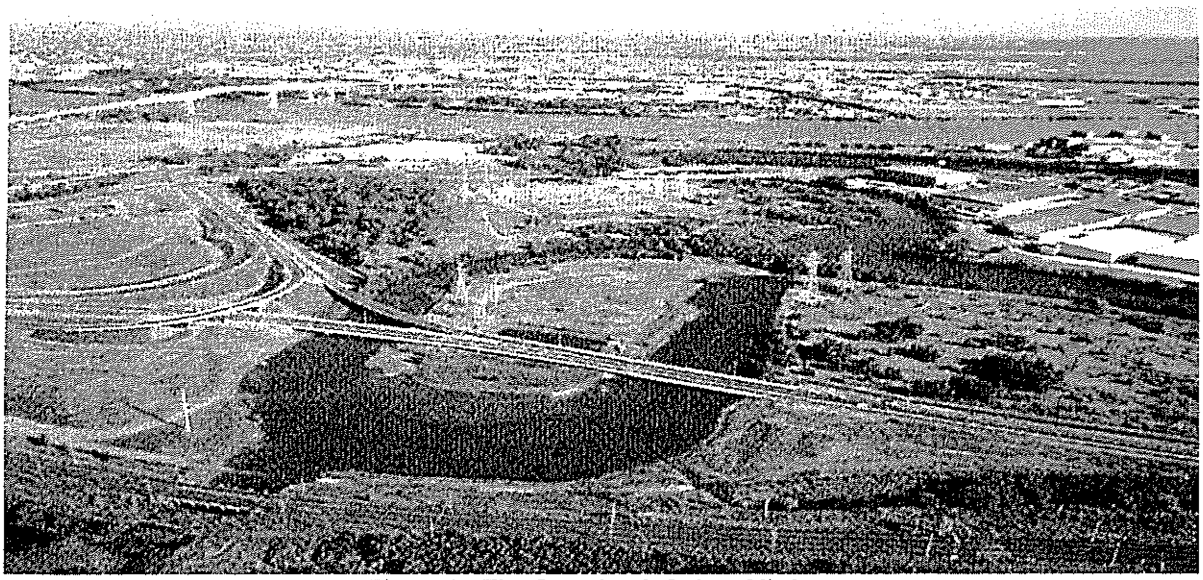

Figure 2: The Completed Oxbow Viaduct

OPTIMISATION OF EMBANKMENT HEIGHT EAST OF THE OXBOW

The initial concept design of the Motorway involved the placement of fill embankments of significant height and a stormwater drainage system for the overlying road pavement based on collection by kerb and channel and varying longitudinal grades along the road alignment. It was immediately clear to the geotechnical team that to build to the concept design would require extensive ground treatment to limit settlement to the tolerances required by the client.

The geotechnical team embarked on a detailed investigation of the ground conditions to assess the variation in thickness and over consolidation ratio (OCR) of the subsurface soils. The OCR was estimated from Casagrande/log-log constructions of laboratory consolidation test results validated against empirical correlations with cone penetration tests (Mayne & Mitchell, 1988). The culmination of this work was the subdivision of the alignment into five distinct OCR models which took into account factors such as:

- detection of different palaeochannels beneath the former Brisbane River flood plain giving rise to significant variations in the thickness of soft alluvium soils;
- identification of a rarely recognised lower clay member with stiffer characteristics within the Holocene alluvium;
- the presence and age of existing fill over the alignment, which has the effect of stiffening the profile in some models; and,
- differing drainage conditions within some sections due to the presence of a discontinuous sand layer within the upper parts of the profile.

The five OCR models were used to develop predictions of settlement under a variety of loading intensities and conditions in each section. Whilst relatively conventional soil mechanics theory was adopted for the assessment of settlements, finite element models were employed to assess the stress distribution beneath various embankment configurations. This data was incorporated into the models to arrive at settlement predictions under a variety of conditions taking into account features such as embankment shape due to super-elevation. Estimates of creep settlement followed the method suggested by Poulos (2001). Check analyses were carried out using Leroueil (1996) and resulting settlements were found to differ by less than 0.5%.

Final design of the embankments was conducted as a cooperative process between the civil designers, geotechnical team and hydrologists. The different ground models drove variation in the road vertical and horizontal alignment and allowed the design team to arrive at a geometrically viable solution without compromising performance in terms of long term settlement, flooding and drainage. The embankment heights were reduced and the drainage was changed from kerb and channel to a system of diverting cross fall runoff into open channels alongside the embankments allowing the longitudinal grade of the road to be largely independent of drainage considerations. The assessment of future performance took into account additional settlement and predicted changes in the profile due to construction of the adjacent duplication for the next stage of the Motorway. Reliability analyses (Duncan, 2000) were conducted for the benefit of the design team and the peer reviewers to evaluate the uncertainties in the parameters used in the settlement analyses and provide confidence in the design. The major benefit of the detailed subdivision of subsurface conditions was that ground improvement measures were limited to specific sensitive zones, rather than widespread treatment of the entire alignment.

The iterative geotechnical process required to achieve this solution is unlikely to have been possible outside the Alliance approach.

LINDUM ROAD OVERPASS

Towards the end of the construction period it became clear that the project was going to finish well ahead of time and significantly under budget.

A decision was made to construct an additional overpass at the eastern end of the project thereby eliminating an at grade crossing. If the overpass was to be completed within the Alliance's completion target date, only six months was available from the commencement of design to completion of construction.

The area is underlain by 30m of soft clay and the initial design of the overpass involved approach embankments up to 7m high. Settlement predictions confirmed by earlier preload monitoring nearby predicted long term settlements of up to 1.5m at the bridge abutments.

The geotechnical team and civil designers were able to modify the design to reduce the height of the approach embankments to 5.5m. Given the time constraints on construction it was not feasible to carry out foundation improvement using a conventional preload with surcharge and wick drains. The geotechnical team and civil design team worked through a series of options including extending the structure, piled embankments of several different configurations, and various light-weight fill options. As designs were completed in concept, the estimators on the construction team provided rapid feed back which allowed uneconomic options to be rejected and others optimised.

The overpass, which was composed entirely of precast concrete elements with polystyrene block approach embankments, was designed and constructed within five months. Construction was conducted in conjunction with the relocation of underground services and minor preloading to limit movements at the bridge abutment interfaces.

RETAINING STRUCTURES

The initial concept design for the three level interchange with the Gateway Motonvay at the western entrance to the Port of Brisbane Motonvay required the construction of extensive retaining walls to achieve the relatively high on-ramps required. Many of these walls were reinforced soils structures and added significant cost to the project. The Alliance enabled the geotechnical team to be involved throughout the design and construction and by careful attention to the use of earth/rock fill materials of suitable engineering properties it was possible to steepen slopes, modify the dimensions of many of the walls and in some cases eliminate walls resulting in significant savings to the project. Substantial reductions in foundation treatment beneath reinforced soil structures were possible due to the close liaison between the constructors and the geotechnical team.

GROUND PREPARATION

Close involvement of the geotechnical team during construction enabled the constructors to get embankments out of the ground through the swamp areas despite very soft surface soils and the presence of significant quantities of old ash fill. Normal construction practice on a conventional Queensland Main Roads project would have been to treat such fill as unsuitable and remove such materials which would have taken the construction onto softer ground with requirements for greater quantities of imported rock fill to construct bridging layers and building platforms. The geotechnical team carefully assessed the potential impact of the material on actual pavement performance and in the end very little of the old fill was removed because it had no bearing on road performance relative to the potential settlements in the underlying soft clay.

PAVEMENT DESIGN

In the 1980s, Queensland Main Roads adopted the use of cement treated base course (CTB) with asphalt cover of about 100mm in many pavements and ended up with cracks at 4m to 5m centres. On the Gateway Motorway (owned by Queensland Motorways Limited, the owner of Port of Brisbane Motonvay) flexible pavements were used but required major repair works within 5 years of construction. Parts of the Pacific Motonvay to the Gold Coast were constructed in concrete in the belief that it provided the best whole of life solution given the high traffic volumes.

Being a road authority, Main Roads takes enormous interest in its pavements and most people have an opinion on what is the best solution. Given the above background, the design team on the Port of Brisbane Motonvay was under close scrutiny by the owners, the Main Roads peer reviewer and the local Main Roads District office who were not involved in construction but who would have maintenance responsibility. When combined with the high traffic loads expected of the continuous stream of heavily loaded container transport vehicles to the Port, the deep soft clay foundations and settling embankments, the concern of those parties was very high. The geotechnical team had extensive Victorian experience of using CTB and asphalt with a minimum of 175mm thickness but, because it largely had less than 10 years proven track record in situ, there were doubts as to its long term performance. The geotechnical team considered the use of CTB as well as concrete and deep lift asphalt options and whole of life assessments were conducted on the designs.

The Alliance Team had a strong preference for CTB with AC surfacing due its confidence in this as a successful solution which had the lowest whole of life cost. Largely due to the contributions of the geotechnical team and its experience in designing many freeway pavements using this approach, a compromise design solution was achieved to allay Main Roads concerns about maintenance over the 40 year design life. Deep lift asphalt pavements were constructed in areas underlain by deep soft clays likely to experience large settlements with the CTB design adopted for the balance of the project.

The geotechnical team based the pavement designs on consideration of the entire embankment profile and adopted a significantly higher modulus for the CTB, compared to a maximum of 3500MPa adopted in Victoria. Field trials were conducted to convince the Alliance that the high modulus could be satisfactorily built, particularly in 200mm thicknesses. The trials were conducted using Falling Weight Deflectometers (FWD). In Victoria this method had been abandoned in the early 1990s as sensible repeatable results could not be obtained but the geotechnical team devised a method of interpreting the results which isolated the CTB layer fiom the underlying materials, allowing the modulus of the CTB layer to be confirmed. The results were confirmed by laboratory testing. Once this trial was used to gain confidence in the construction method, routine density testing was used for the main control on construction quality of the CTB. The pavements were delivered under budget and with the owner having a high degree of comfort. Whilst the geotechnical team would have liked to have been able to deliver what it believed to the best technical solution, recognition of client concern was taken into account in delivering the final outcome.

CONCLUSIONS

The Port of Brisbane Motorway was designed and constructed by an Alliance comprising Coffey Geosciences, Parsons Brinckerhoff, Leighton Contractors and Queensland Motorways.

The project was delivered under budget and six months early in an 18 month construction programme.

The geotechnical conditions along the Motorway route provided significant design and construction challenges but the Alliance process enhanced the geotechnical outcomes largely due to the presence of a Geotechnical Consultant as a full Alliance Partner.

The Alliance process allowed close teamwork between the geotechnical and civil designers, the constructors and peer reviewers. Significant positive outcomes were achieved in the areas of embankment design to reduce the extent of foundation treatment required; the use of segmented square precast concrete piles instead of hexagonal single length post tensioned piles was a first for a Main Roads project; polystyrene fill was used for the first time on a Main Roads project to minimise embankment loads on bridge approaches to reduce settlements; the need for foundation treatment under reinforced soils structures was minimised; areas of old fill were left in place under embankments to facilitate faster construction on soft ground and pavement designs were carried out based on the entire embankment profile.

It is considered that the outcomes achieved would not have been possible had the Geotechnical Consultant been engaged under the typical arrangement of sub consultant to the Lead Designer or Principal Contractor. The Alliance delivery mechanism significantly enhanced the geotechnical outcomes on this project.

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