Foundation Treatment for the Port River Expressway

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Stage 1 of the Port River Expressway is currently under construction, at the north western suburban fringe of Adelaide. These works include approximately 4 km of new road, and three grade-separated intersections incorporating embankments up to about 10 m high. The site for the Expressway is a Holocene estuarine plain that was partly covered by mangrove swamp, and comprises normally consolidated sand and clay. Areas of uncontrolled fill, including municipal waste are also present beneath the road alignment to depths of 4 m in places.

The project challenges have required the use of a variety of ground engineering solutions, including staged embankment construction with preloading, in-situ treatment with an impact roller, stone column installation, and conventional methods of excavation and replacement. A case study of the geotechnical solutions adopted and a comparison between the predicted and actual performance of the various parts of the earthworks is presented, including an assessment of the improvement of soil stiffness by the installation of stone columns.

INTRODUCTION

Stage 1 of the Port River Expressway (PREx) is currently under construction, with Stages 2 and 3 at pre-tender. The overall project will deliver a dual carriageway expressway linking National Highway 1 (Port Wakefield Road) to the industrial areas and container terminals around Outer Harbor. The expressway will bypass the historic heart of Port Adelaide.

The Stage 1 works extend from Salisbury Highway in the east to Francis St in the west. A location plan is shown on Figure 1.

Most of the alignment is low lying and comprises several metres of soft soils. Uncontrolled dumping of various materials (including municipal waste) has raised the existing ground levels in some sections of the alignment.

Grade separated intersections are being constructed where the PREx intersects South Road, Hanson Road and Eastern Parade. Embankment heights at the intersections will vary up to about 10 m above existing ground levels.

Along the general road alignment, the finished pavement level will be slightly above RL 3 m AHD, requiring placement of up to about 2.5 m of fill above existing ground levels.

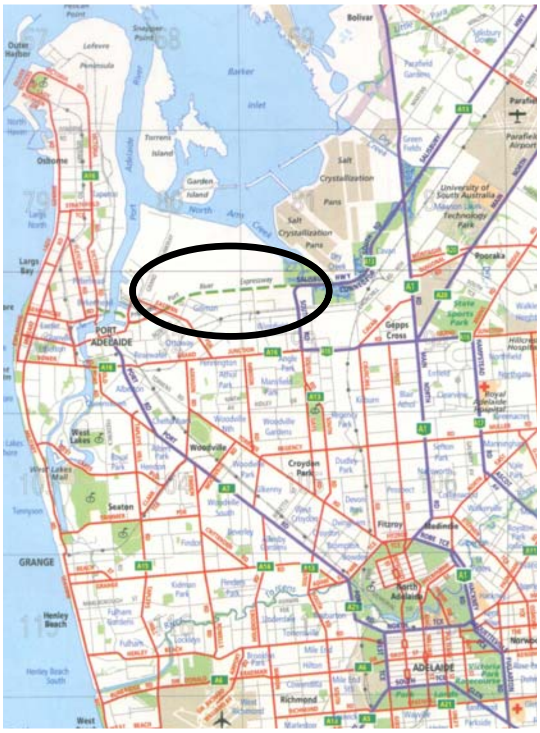

FIGURE 1: Location plan of Stage 1 of the Port River Expressway (Reference UBD, Universal Press Pty Ltd, 2003)

The Stage 1 works have been awarded under a Design and Construct contract, where the Contractor is responsible for maintaining the expressway for 10 years following practical completion. At the end of the 10 year period, the road must meet specified performance criteria when handed over to the State Government. The performance requirements include not more than 12 mm differential settlement over a 20 m length.

GROUND CONDITIONS

Prior to European development, the whole area for the Stage 1 works was covered by a Holocene estuarine plain, including mangrove swamps. Permanent groundwater is present at very shallow depths across the site, and lies almost at the surface in some areas (particularly during wetter months).

The engineering properties of the site are dominated by the Holocene estuarine deposits, known as the St Kilda Formation. These deposits typically comprise materials ranging from loose sand with shells, peat and soft to firm high plasticity clay. The soils typically have a high moisture content, and the organic, fine grained mangrove deposits are known to be highly compressible.

Underlying the St Kilda Formation, various different Pleistocene deposits are present. The Pleistocene deposits typically comprise very stiff (over consolidated) clay with some medium dense sand layers. The younger Pleistocene deposits comprise Pooraka and Glanville Formation soils at different parts of the alignment. The Hindmarsh Clay dominates the older Pleistocene deposits, and is expected to extend to a depth of about 90 m beneath the site.

FOUNDATION PREPARATION

General Alignment

Along the majority of the alignment, where the ground levels are typically being raised by not more than about 2.5 m, the foundation preparation comprised one of the following techniques:

1) Where little or no fill was present, and the ground was generally low-lying, the site preparation comprised removing the vegetation (but leaving the topsoil in-situ) and placing a “working platform”. The working platform typically comprised coarse, crushed recycled concrete (maximum nominal size 300 mm) up to about 1 m thick. The working platform was track-rolled during placement and proof rolled using a loaded articulated dump truck. Once a stable platform for construction traffic had been achieved, the embankment was constructed in a conventional fashion. Extensive use of re-cycled materials and blended site materials were used in the embankment construction.

2) Where municipal waste or deleterious fill materials were present, these materials were removed down to the natural soils. This involved excavations over large areas to depths of about 2 m below the groundwater level. The excavations were reinstated using coarse recycled concrete (similar to the working platform described above).

3) Where existing fill was present and it contained suitable material (no deleterious materials or high plasticity clay) the fill was largely left in place. The surface was stripped to a level corresponding to the top of the working platform, and rolled using an impact roller (square roller) to provide some compactive energy throughout the full thickness of the fill. Proof rolling was then performed with a loaded articulated dump truck. Any soft or weak areas were removed and reinstated with coarse recycled concrete. Any fill that had been stripped from these areas was generally re-used (and blended if necessary) in the general embankment construction.

In some areas where the existing fill had been left in place, and proof rolling indicated some minor surface deflections, plate load testing was used to better characterise the subgrade stiffness. In areas with marginally acceptable working platform stiffness, a biaxial geogrid was placed at the top of working platform level to improve the stiffness of the subsequent embankment layers.

All sections of the general Expressway embankment have been subject to preloading, prior to pavement construction. Design preload heights above the finished pavement level vary from 0.6 m to 2.5 m. The predicted preload duration varies from 1 month to 3 months. In all cases a 90 day "waiting period" has been adopted between removal of the preload and pavement construction, to reduce the anticipated magnitude of secondary consolidation of the pavement over the 10 year maintenance period to within the deflection requirements.

Eastern Parade Overpass

The Eastern Parade Overpass is a multiple span concrete bridge carrying the Expressway over the road corridor of Eastern Parade and a rail corridor. An elevation of the structure is shown by Figure 2.

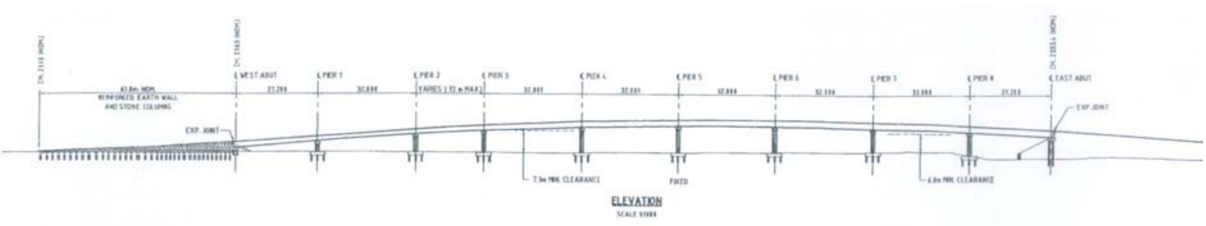

FIGURE 2: Elevation of the Eastern Parade Overpass (looking north)

Piled footings were required for the bridge piers. The abutments were also piled to limit differential deflection of the bridge deck. The piling system adopted was a driven cast-in-situ bulb base concrete pile.

Eastern Approach Embankment

The eastern approach embankment has a finished pavement level about 9 m above original ground levels. This embankment is underlain by typically 2 m to 2.5 m of the soft St Kilda Formation soils. A calcrete crust marking the upper surface of the Pleistocene Glanville Formation is present beneath the soft soils.

Space allows this embankment to be largely constructed as a conventional battered embankment.

The foundation preparation at the eastern approach embankment comprised construction of a geogrid-reinforced granular mattress 2 m thick.

Conventional embankment construction proceeded over the reinforced granular mattress, however, the rate of embankment construction was limited to a maximum of 1 m height each week to allow some drainage of excess pore water pressures from the St Kilda Formation soils. Piezometers installed at different depths within the foundation soils were monitored to ensure that pore water pressures remained at acceptable levels.

Once the embankment reached full height, an additional preload was placed at the top of the embankment and settlements were monitored to ensure that all primary consolidation settlements were complete prior to construction of the pavement. The rate of secondary consolidation was also observed during the preload period.

Western Approach Embankment

The western approach embankment was constructed in the middle of Francis Street, which was maintained as an operational public road throughout the overpass construction. Space restrictions required that this embankment be constructed with vertical sides. Reinforced earth retaining walls were selected to retain the embankment.

The western embankment was underlain by the Francis Street pavement and fill to a depth of about 2 m, and soft St Kilda Formation soils to a depth of about 6 m. In order to keep the imposed stresses at the base of the reinforced earth walls to relatively low levels, the embankment height was limited to about 3 m above the existing Francis Street pavement level.

Preloading of the embankment could not be performed after completion of the embankment construction as large settlements would adversely affect the reinforced earth walls. As such, the foundation preparation for the eastern approach embankment comprised installing a grid of stone columns, with a biaxial geogrid-reinforced granular mattress over the top of the stone columns. The stone columns were installed on a triangular grid, with spacings varying from 1.5 m centres to 2.5 m centres. The layout of the stone columns beneath the eastern embankment is shown by Figure 3. The columns were 0.8 m diameter, and extended to the top of the Glanville Formation, at a depth of about 6 m below the surface. The surface was then preloaded with a temporary preload embankment, and monitored for settlements. Following the preload period, the preload was removed and conventional construction of the reinforced earth walls and embankment proceeded.

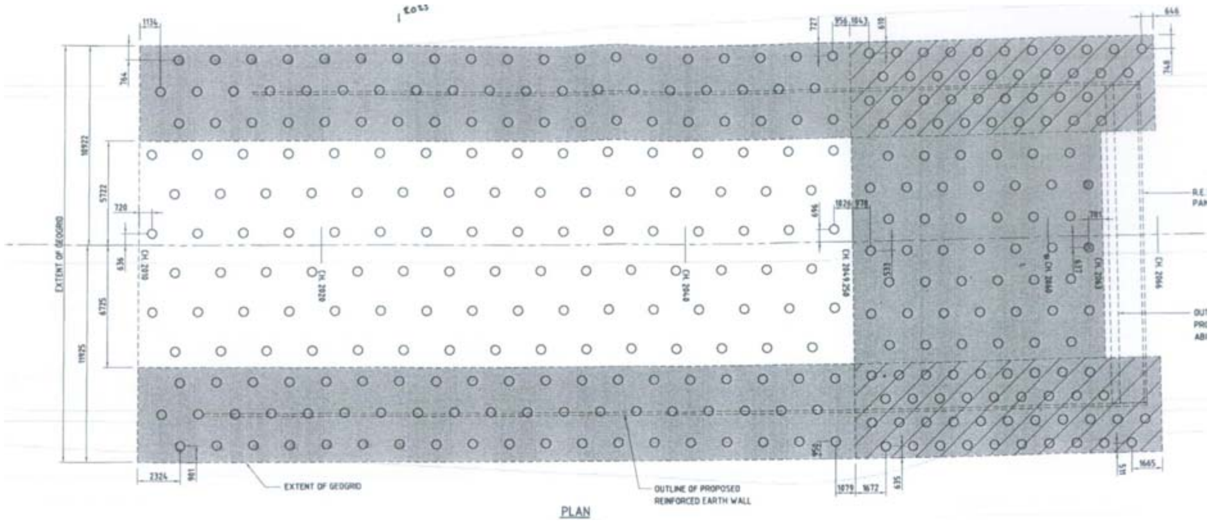

FIGURE 3: Stone column layout beneath the eastern embankment

Hanson Road and South Road Overpasses

Both of these overpasses require the construction of embankments up to about 9 m or 10 m above the original ground levels.

Both structures comprise a single span concrete bridge. As no intermediate piled footings were required for the deck, the abutments could be founded on spread footings founded at the top of the embankments, without subjecting the deck to potentially unacceptable differential deflection.

The foundation preparation at both of these bridges comprised excavating and removing all of the soft soils beneath the abutments and any retaining walls, and replacing the soft soils with recycled concrete. For the remainder of the approach embankments, the foundation preparation was similar to the general alignment, comprising a working platform, and a preload above the finished embankment surface.

The “remove and replace” foundation preparation under the abutments required excavations to about RL – 3.5 m at South Road and about RL -2.5 m at Hanson Road.

EMBANKMENT SETTLEMENTS

Table 1 presents a summary of the predicted and measured settlements for the various elements of the PREx.

TABLE 1: MEASURED AND PREDICTED SETTLEMENTS

Element	Primary Settlement (mm)		Secondary Settlement (mm per log cycle of time in days)		Imposed Surcharge (kPa)	St Kilda Thickness (m)
	Predicted	Measured	Predicted	Measured		
General Embankment: Sections A, B and C (up to 2.5m high)	varies up to 70	varies up to about 70	varies up to 15	varies up to about 10	Up to about 50	Up to about 2
Eastern Parade: Eastern Approach Embankment	275	Approx 280	10 to 12.5	15 to 20	About 200	About 2.5
Eastern Parade: Western Approach Embankment (stone columns)	125	Approx 80	15	10 to 15	About 80	About 4
South Road and Hanson Road Embankments	*Still under construction at time of writing (no data)*					

Primary consolidation settlements occurred fairly rapidly, and were generally complete within about 1 month.

The secondary consolidation settlements presented in Table 1 have generally been recorded over the duration of the preload period only, which in most cases is less than 100 days.

Based on the data presented in Table 1, (and assuming that the consolidation settlements are due to compression within the St Kilda Formation) a summary of the compressibility of the St Kilda Formation is presented in Table 2.

TABLE 2: COMPRESSIBILITY OF ST KILDA FORMATION

Element	Primary Settlement ÷ Surcharge ÷ Thickness of St Kilda (mm/kPa/m)
General Embankment Sections A, B and C (up to 2.5m high)	Up to about 0.7
Eastern Parade – Eastern Approach Embankment	0.56
Eastern Parade – Western Approach Embankment (stone columns)	0.25

From the data presented in Table 2, an improvement factor of about 2.2 was achieved for the soil stiffness from the stone column installation. Relationships derived by Priebe (reference 1) suggest a design improvement factor of about 1.7 for the stone columns at 2 m centres.

CONCLUSIONS

A variety of alternative foundation treatments have been adopted during construction of Stage 1 of the Port River Expressway. The measured performance of the earthworks has largely been consistent with expectations, although the secondary consolidation characteristics of the estuarine soils at the Eastern Parade overpass appear higher than elsewhere along the alignment.

A grid of stone columns was installed under the eastern approach embankment to the Eastern Parade overpass. Based on the measured primary consolidation settlements of the embankment over the stone columns, the magnitude of ground improvement achieved by the stone columns appears to be greater than predicted by current design methods. From the limited data available during secondary consolidation, it is not clear whether the same magnitude of improvement has been achieved for the rate of secondary consolidation.

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REFERENCES

1. Priebe, H.J, "The design of vibro replacement", Ground Engineering, December 1995, Pages 31 to 37.