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Geotechnical Risk Management and Contingency Plan for a Sheet Pile Wall Next to an Existing Highway

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Abstract: A cantilever temporary sheet pile wall was designed and constructed to support a 3.5m deep excavation in soft alluvial ground for construction of a new box culvert under an existing highway on the east coast of Australia. Soil-structure interaction software Wallap was used to analyse the deflection and forces of the sheet pile wall for structural design and impact assessment of the adjacent highway with live traffic. Instrumentation and monitoring was implemented during construction to verify design assumptions and to control excavation safety. During construction the wall moved much more than the design prediction after full excavation was completed at north-west corner. Cracks were observed in the pavement behind the wall. There was major concern that the sheet pile wall could fail which would pose significant safety risks to the construction workers and road users. This paper presents how the geotechnical risks were managed and a contingency plan developed to ensure the successful completion of the deep excavation in challenging ground conditions and the subsequent two-staged installation of box culvert under the existing highway without disruption of live traffic.

Keywords: geotechnical risk management; contingency plan; sheet pile wall; excavation; soft ground; observation method.

1 The Project

A 46m long, 55.8m wide precast concrete box culvert (PCBC) comprising 14 cells (3.6m wide x 1.2m high) was built in two stages on a highway upgrade project on the east coast of Australia in 2019. Figures 1 and 2 show the cross section and plan view of this drainage underpass. As shown on Figure 1, Stage 1 work was approximately 20m long in virgin ground next to the existing highway with live traffic; Stage 2 was approximately 26m long under the existing highway.

This structure is located in the floodplain of a major local river. The ground condition comprises Holocene aged soft sandy clay and loose clayey sand to 15m underlain by Pleistocene aged stiff to very stiff clay, see a typical CPT log on Figure 3.

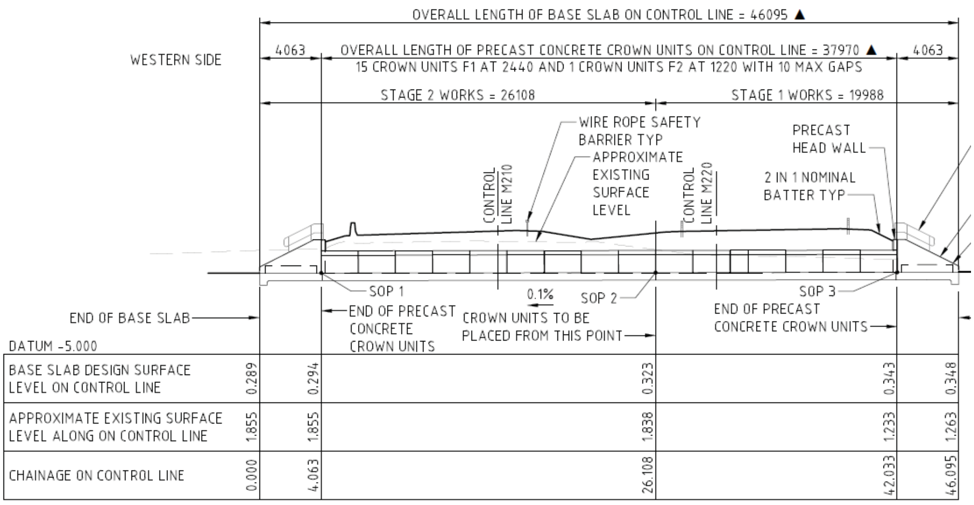

Figure 1. Cross section

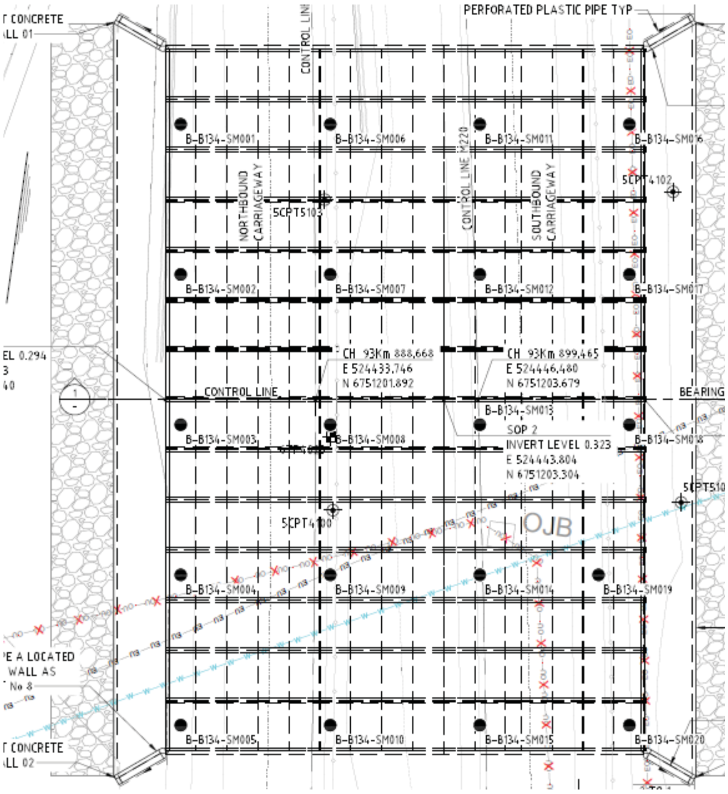

Figure 2. Plan view (black dots are settlement markers on base slab at 10m interval)

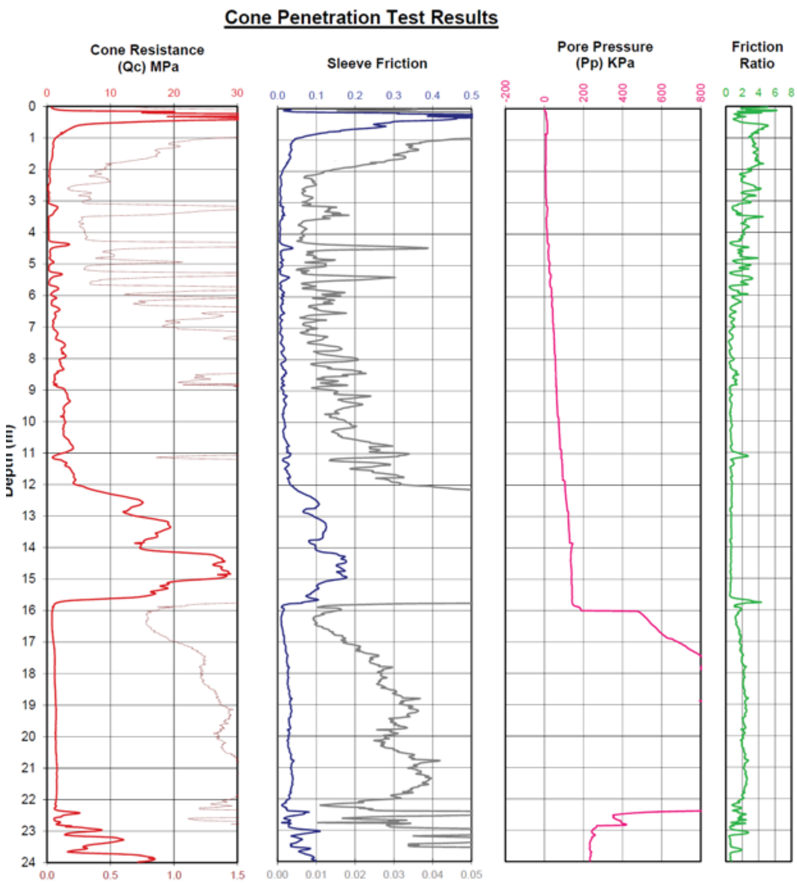

Figure 3. Typical CPTu log

The original design for the temporary support of up to 3.5m for Stage 1 work was a benched excavation. This was not considered adequate after three auger boreholes were drilled prior to construction indicating soft ground and relatively high ground water table. The consequence of slip failure at the existing highway batter was too high, thus a retaining wall was required to keep the excavation stable. The authors were requested to provide a temporary retaining wall design to support the cut at the interface of Stage 1 and 2 works.

2 The Temporary Excavation Support Design

After discussion with the construction team, a temporary sheet pile wall was proposed. Figure 4 shows the site investigation locations and the proposed temporary sheet pile location.

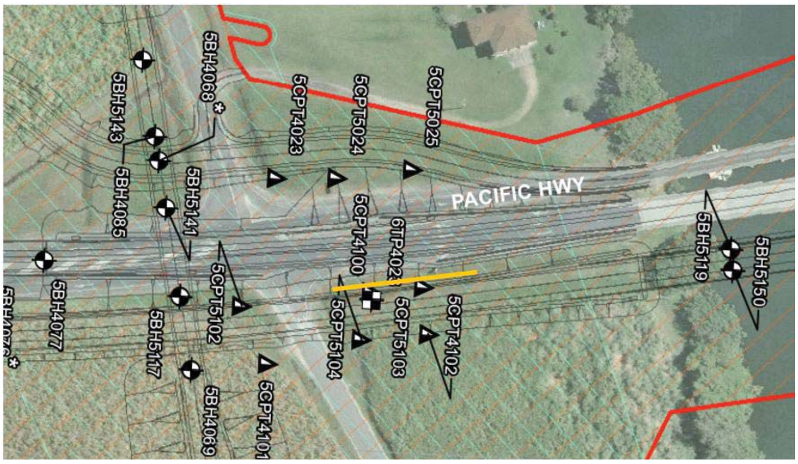

Figure 4. Approximate sheet pile retaining wall location (Orange line) and nearby investigation locations

The interpreted ground profile and design parameters are listed in Tables 1 and 2 below. Both clay model (undrained) and sand model (drained) were assumed for the upper soft sandy clay/loose clayey sand. Table 3 shows the sheet pile wall details.

Table 1. Undrained soil input parameters.

Soil type	Depth (m)	Young's Modulus (kPa)	Unit Weight (kN/m^3)	Undrained shear strength (kPa)
Fill	0 – 1	18000	20	60
F4a(u)	1 – 6	12000	17	40
F4a(l)	6 – 10	30000	17	100

Table 2. Drained soil input parameters.

Soil type	Depth (m)	Young's Modulus (kPa)	Unit Weight (kN/m^3)	Apparent cohesion (kPa)	Friction Angle (°)
Fill	0 – 1	20000	20	0	32
F4a(u)	1 – 6	18000	18	0	32
F4a(l)	6 – 10	30000	18	0	32
F6	10 - 16	70000	18	0	35

Table 3. Retaining wall design details

Wall type	Length (m)	Young's Modulus (kN/m^2)	Moment of Inertia per unit length of wall (m^4/m)	EI per length of wall (kN.m^2/m)
Larssen L720 Sheet pile	12	2.05×10^8	4.5×10^{-4}	90000

Initial groundwater levels were set to be 1.0m below ground level. A 20kPa surcharge load was applied to the top of the retaining wall to model ongoing traffic load.

The 2-D embedded retaining wall program Wallap was used to analyse the wall deflection and forces for structural design. Ground water level was assumed 0.5m below the excavation level at the passive side. The Wallap model is shown in figure 5 below.

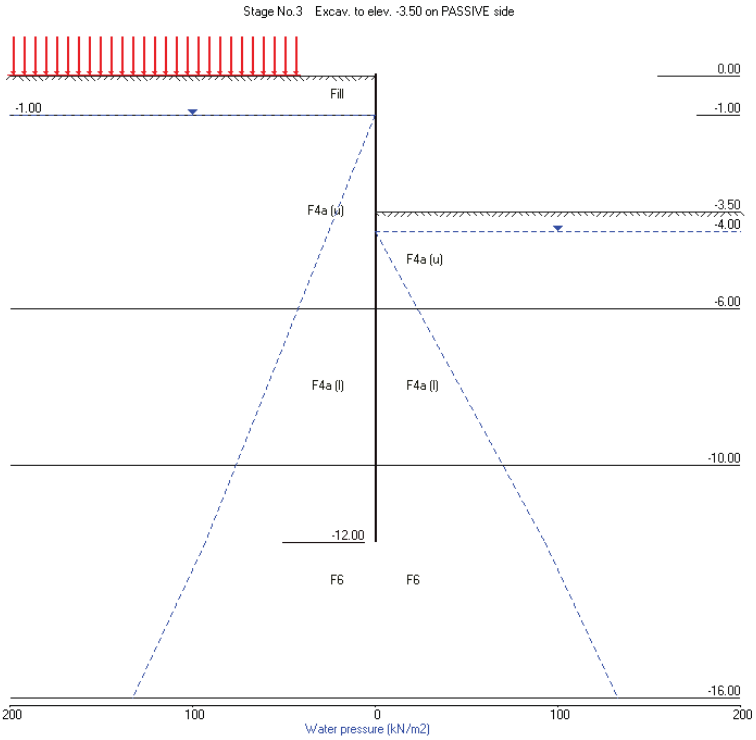

Figure 5. Wallap model at end of excavation (SLS)

Over-excavation of 0.5m was also considered as an ultimate limit stage. A summary of the predicted wall deflection/forces of the three cases are listed in Table 4 below.

Table 4. Predicted retaining wall details (2 cases: clay/sand)

Model Case	Maximum wall displacement (mm)	Maximum bending moment (kN.m/m)	Maximum shear force (kN/m)
Clay	29	63	31
Sand	60	168	62

The output for Case 2 – Sand model (which was the best estimate before construction) are presented in figure 6 below. The dashed line represents the shear force with the scale at the bottom.

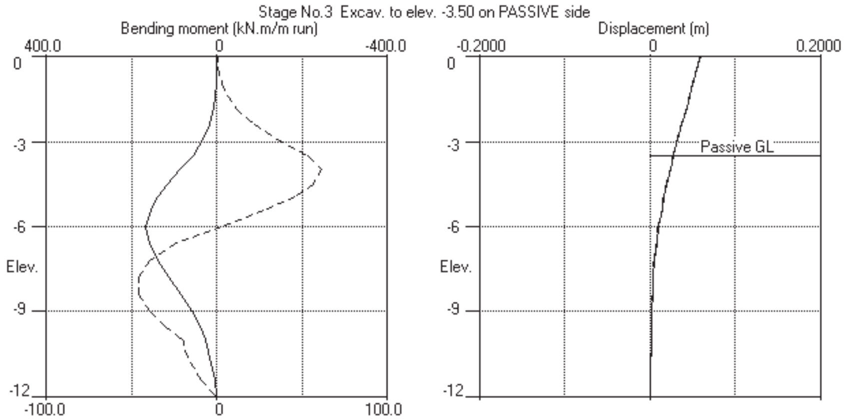

Figure 6. Wallap output for Case 2 at the end of excavation (SLS)

Fourteen prisms were proposed at top of the sheet pile wall to monitor the wall deflection to verify design assumptions and to control deep excavation safety in order to protect the workers and the public road users. Figure 7 shows the locations of these prisms.

3 Construction monitoring and contingency measures to address excessive wall deflection

Excavation was completed around northwestern corner on 15/09/2018 after the sheet piles were installed. Measured deflection at PS07 and PS08 exceeded the predicted max deflection of 60mm, indicating softer than expected ground response. Cracks (width of 20-30mm) were observed near the guardrail behind the wall. To inhibit the observed movement and allow time for design assessment, rock backfill was immediately placed to ground level on 18/09/2018 in the excavation where the worst measured deflection was picked up (PS07 at west wall and PS05 at north wall). A site meeting/visit was held on 19/09/2018 to discuss risk mitigation measures to control the lateral displacement in order to protect the pavement and public road users.

Back analyses were also conducted to match the measured deflection and to check the sheet pile wall adequacy to resist more movement. It was found that by reducing the soil moduli the wall deflection could increase to 200mm while the sheet pile capacity was still adequate. The sheet pile wall itself had a substantial amount of spare capacity meaning the risk of structural failure was considered minimal subject to ongoing monitoring. However from a serviceability perspective, additional measures were implemented to prevent further pavement and verge cracking along the existing highway. Two mitigation measures were adopted: (1) slotted excavation construction sequence, see Figure 7. (2) temporary steel bracing as a contingency measure if deflection/pavement cracking was excessive, see Figure 8 for strutting layout.

The following procedure was adopted to mitigate the risks: survey monitoring of the wall top movement was conducted a minimum of twice per working day: AM and PM. The reading frequency could be increased to three times per day or even hourly if the daily deflection rate exceeded 5mm. If the total deflection exceeded 150mm, the diagonal struts could be installed to stop the wall deflection and prevent the pavement cracking further.

During slotted excavation and subsequent backfill of 500 to 800mm gravel, the measured wall deflection increased to a maximum 120mm on 08/10/2018, significantly greater than the prediction but this remained stable until the first portion of the base slab was cast on 31/10/2018. The precast culvert units were all installed in early December 2018. The contingency temporary struts were not installed.

Stage 1 work was completed and traffic on the existing highway was diverted to the newly constructed pavement on the culvert in Stage 1 in August 2019. The sheet piles were later removed gradually to support the excavation for Stage 2 work. The ground under the existing highway was stiffer as expected thus there were no issues during the Stage 2 construction.

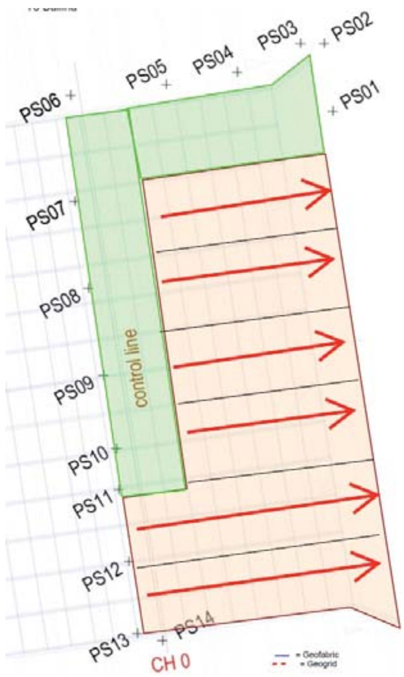

Figure 7. Prism (PS01 to PS14) locations and recommended slot excavation (arrow shows excavation direction, green area backfilled with gravel foundation)

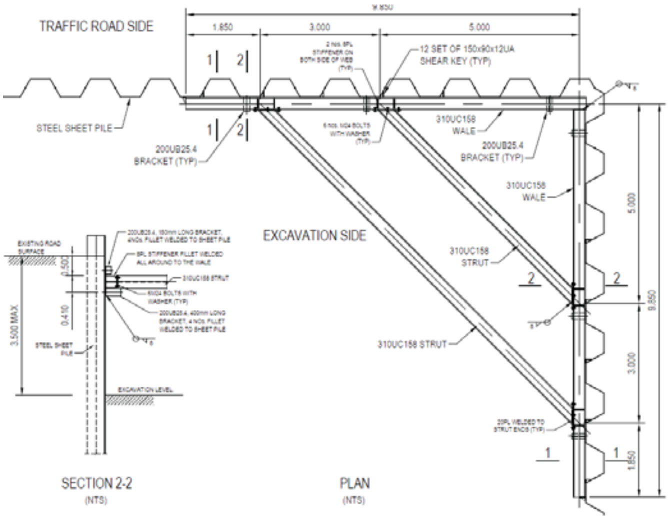

Figure 8. Strutting layout and details (contingency plan, not implemented)

4 With the benefit of hindsight

On page 126 of CIRIA Report C580, *for walls made up of U-profile sheet piles, it is common for designers to assume the full combined modulus, except in circumstances where shear transfer may not be fully effective, for example: piles forming cantilever walls. Williams and Waite (1993) report that the friction between the interlocks probably results in the development of at least 40 per cent of the full section modulus.*

Back analysis using 40% of EI for the sheet pile wall and sand model parameters (Case 2) indicated 119mm predicted wall deflection, which is very close the measured maximum deflection of 120mm. This implies that the ground behaviour is close to fully drained and CIRIA's recommendation on using reduced EI for cantilever U-shaped sheet pile wall is reasonable.

References

Gaba, A.R., Simpson, B., Powrie, W. and Beadman, P.R., Embedded retaining walls — guidance for economic design, *Construction Industry Research and Information Association (CIRIA) Report No. C580*, 2003, London, U.K.
Geosolve Wallap User's Guide Version 5, 2007

Project photos