Temporary Works for a Car Dumper in the Pilbara

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ABSTRACT

Expansion of port iron-ore handling facilities at a site in the Pilbara region of Western Australia includes construction of a new car dumper close to the coast. Construction of the permanent reinforced concrete vault structure requires an excavation of about 25 m depth, extending about 20 m below groundwater level. The selected construction methodology involves multi-level sheet pile temporary retaining structures to support an excavation within which the permanent structure was built bottom-up. Mechanical and drilled and grouted ground anchors were used to support the sheet pile walls. Deep dewatering bores were installed external to the temporary retaining structures, with sump pumps installed as the excavation advanced to depth, to accommodate a peak design total dewatering discharge rate of about 100 L/s. The design of the temporary retaining structures and dewatering system is described in the paper. Some of the challenges faced during construction are described and the results of monitoring during construction are compared with the design predictions.

Keywords: deep excavation, retaining wall, sheet pile, dewatering, anchors, constructability

1 INTRODUCTION

Expansion of port iron-ore handling facilities at a site in the Pilbara region of Western Australia includes construction of a new car dumper close to the coast. The facility dumps iron ore loaded in incoming rail cars into chutes that feed into an outgoing conveyor that leads to adjacent stockyards. Construction of the permanent reinforced concrete vault structure containing the car dumper and chutes requires an excavation of about 25 m depth, extending about 20 m below groundwater level. A steel conveyor tunnel of about 160 m length leads out from the lowest level of the vault.

The car dumper is situated within a relatively confined area between a rail line leading into a nearby operating car dumper and a rail-supported ore stacker machine operating along the side of an adjacent ore stockyard. Given the spatial constraints at this location, an open battered excavation was not feasible and some form of excavation support was required. The nearby car dumper, located approximately 200 m to the north-west, had previously been constructed bottom-up in 2005 by using a temporary retaining structure comprised of multi-level (stepped) anchored sheet-pile retaining walls with a series of dewatering wells located external to the excavation. Prior to commencing the geotechnical site investigation for the new car dumper, a review of various forms of retaining systems that could be adopted for construction of the new car dumper was undertaken. Various options for constructing the new car dumper were assessed, including diaphragm walls in conjunction with either top-down or bottom-up construction. The temporary sheet-pile wall retaining system was selected as the preferred approach on the basis of various considerations, including cost, the criticality of waterproofing the permanent structure, the impracticality of top-down construction for this facility and being able to draw on the experience from similar previous construction of the nearby car dumper.

2 EXPERIENCE FROM PREVIOUS CONSTRUCTION OF NEARBY CAR DUMPER

During the preliminary design stage, the experience from construction of the previous car dumper was reviewed and a number of significant design and construction issues were identified. Design changes for the new car dumper which addressed these issues are described below.

A significant amount of on-site welding had been carried out to: (a) stitch weld the clutches of the Larssen (U-shaped) sheet pile sections that were used; and (b) weld the components of the waler sections together. These activities slowed the rate of construction. It was decided to avoid these issues for the new car dumper by: (a) using Frodingham (Z-shaped) sheet piles; and (b) developing a waler design that was more modular and would require less on-site welding.

Difficulties had been experienced with installation of sheet piles within some of the cemented materials encountered on site which necessitated pre-boring and the mobilisation of heavier sheet pile installation equipment. For the new car dumper, pre-boring and the type of installation equipment (including a Bauer BG45) were specified.

The dewatering discharge rate for the previous car dumper was about three times higher than expected during design. The dewatering system was not designed for a tripling of pumping rate and the dewatering wells were therefore not capable of achieving the required drawdown, which resulted in a greater amount of seepage into the excavation than expected. This led to much greater demand on the drainage sumps within the excavation and problems were then experienced with clogging of the discharge pipelines with soil and grout from the anchoring operations. The seepage into the excavation was also a safety concern given the large amount of welding carried out. The design objective was to provide a more robust dewatering system design for the new car dumper.

Problems occurred with grouted anchor installation related to the poor quality of the grout mix water and the initial method of anchor installation. Clearer specification of water quality, grout mix trials and the specification of duplex drilling methods were adopted for the new car dumper.

3 SUBSURFACE CONDITIONS AND GEOTECHNICAL PARAMETERS

3.1 Investigation Scope and Stratigraphy

A geotechnical investigation was carried out at the location of the structure using a combination of cored geotechnical boreholes, cone penetration tests, flat plate dilatometer tests,shear wave velocity testing and pull out testing of grouted anchors. Laboratory testing included classification testing, undrained triaxial and uniaxial compressive strength testing.

Groundwater monitoring wells screened over various lithological units and vibrating wire piezometers were installed to measure groundwater levels/pressures and tidal effects. A groundwater pumping test was not carried out due to regulatory restrictions associated with disposal of the pumped water, since the site is positioned relatively close to a known (monitored) hydrocarbon plume.

The stratigraphy at the site is illustrated on Figure 1 and is listed in Table 1. The stratigraphy was found to be relatively consistent with that encountered at the nearby the previous car dumper and other nearby structures. However, the thickness of the Mangrove Mud was found to be less than at the other sites, interbedding between the Dune Sand and Mangrove Mud layers was evident and the Upper and Lower Red Beds units were less well distinguished.

3.2 Geotechnical Parameters

A previous review of the performance of the previous car dumper temporary works against the design estimates had shown that the observed wall deflections were generally only about 10% to 20% of the design estimates and anchor loads that were about 50% to 60% of the design estimates. The review cited a number of possible reasons for the discrepancy, including conservatism in the adopted geotechnical parameters and design surcharge loads. Using this information, a back-analysis of the previous car dumper temporary retaining structures was carried out using the software PLAXIS during the initial design stage for the new car dumper. Soil stiffness parameters were modified to produce estimates of deflection and anchor load that were more consistent with the previous car dumper monitored results. This back-analysis suggested that the Upper Red Beds unit was significantly stiffer than originally adopted for the previous car dumper design and this increased stiffness was adopted in the new car dumper design.

The other geotechnical parameter that involved significant uncertainty was the design cohesion of the Red Beds material. A cohesion of 5 kPa was adopted in the design of the previous car dumper since this represented a lower bound to the laboratory test data and accounted for the weaker zones within the variably cemented Red Beds. This lower bound was supported by the test data from the new car dumper geotechnical investigation, although it was recognised that this parameter was conservative due to the presence of significantly stronger material in some zones and an apparent increase in strength with depth in this stratum. Further discussion on this item is included in Section 5.3. The geological units and parameters adopted in the PLAXIS analysis are summarised in Table 1.

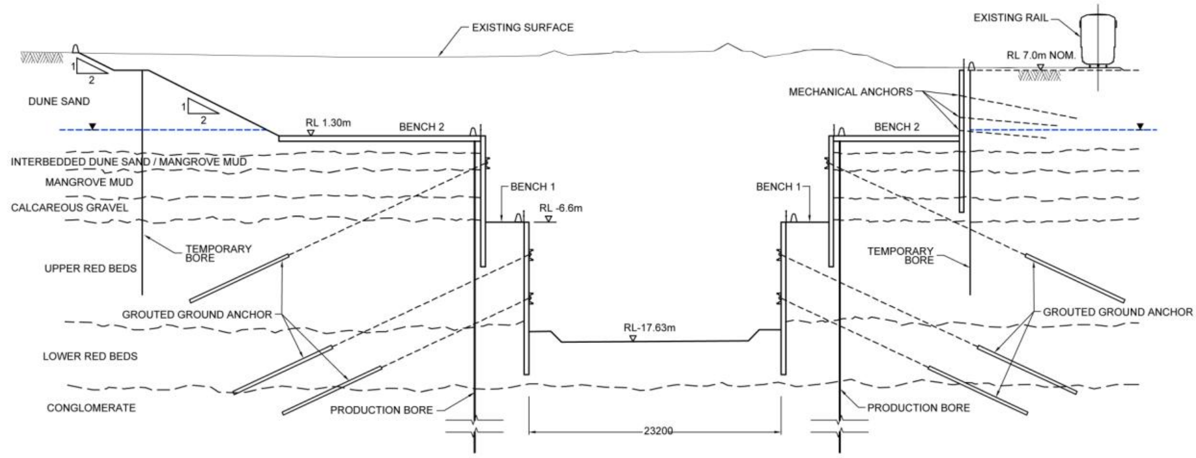

Figure 1: Stratigraphy and section through deepest section of temporary works

Table 1: Geological Units and Geotechnical Parameters

Unit Description	Top of Unit (m AHD)	γ_{sat} (kN/m^3)	E (MPa)	c' (kPa)	ϕ' (°)	ψ (°)
Dune Sand	Surface	19	80	0.2	37	7
Interbedded Dune Sand/Mangrove Mud	RL 0.0	20	20	0.2	33	2
Mangrove Mud	RL -1.8	21	λ^* = 0.030 κ^* = 0.010	0.2	22	0
Calcareous Gravel	RL -4.4	21	25	0.2	32	2
Red Beds	RL -6.4	22	250	5	33	5
Conglomerate	RL -17.0	22	300	50	38	8

The PLAXIS "Soft Soil" model was adopted for the Mangrove Mud. λ^* and κ^* are compressibility parameters used in the model in place of Young's modulus. Hardening soil model used for other materials.

3.3 Hydrogeological Parameters

A shallow unconfined aquifer (Upper Aquifer) which comprises Fill and Dune Sand units is present beneath the new car dumper site. The Upper Aquifer is underlain by the Mangrove Mud which act as a Semi-Confining unit to the underlying Lower Aquifer which is comprises the Calcareous Gravel, Red Beds, Conglomerate and Sandstone units collectively. Groundwater levels varied over the new car dumper area and between the aquifers from RL 1.3 m AHD to RL 2.3 m AHD

The Dune Sand was expected to have the highest hydraulic conductivity of the lithological units, possibly ranging from about 5 m/d to 20 m/d. Test pumping results for the previous car dumper indicated an average hydraulic conductivity of 2 m/d to 5 m/d over the tested Calcareous Gravel and Red Beds. Slug test results from the Lower Red Beds indicated a hydraulic conductivity of 1 m/d to 2 m/d; however, experience from the previous car dumper dewatering indicated that the Lower Red Beds was non-uniform, with pockets of high yielding zones; therefore the average hydraulic conductivity could be higher than 1 m/d to 2 m/d.

Given that test pumping of the two pumping wells at the new car dumper was not carried out, limited hydraulic data was available for the Lower Red Beds and none for the Conglomerate strata. The dewatering operation at the previous car dumper suggested that there is groundwater interaction between the upper and lower aquifers at the previous car dumper. At the design stage, the major uncertainties in the conceptual understanding of the hydrogeology were the groundwater interaction between the upper and lower aquifers and the hydraulic properties of the Conglomerate.

A groundwater model was established for the dewatering system design using Visual Modflow. The model was calibrated utilising the available pumping and groundwater level monitoring data obtained during the previous car dumper construction dewatering until the modelled groundwater levels provided a satisfactory visual fit to the observed groundwater levels. The abstracted water was re-introduced into the model as recharge at the location of the large soakaways used during construction. Table 2 presents the hydraulic properties used in the calibrated groundwater model.

Table 2: Calibrated Hydrogeological Properties Used in Design

Unit Name	Top of Layer (m AHD) *	Horizontal Hydraulic Conductivity, K_h (m/d)	Vertical Hydraulic Conductivity, K_v (m/d)	Specific Yield	Specific Storage (1/m)
Fill and Dune Sand	RL 10	12	1.2	0.2	0.05
Mangrove Mud	RL 0	0.03	0.06	0.01	3×10^{-6}
Calcareous Gravel	RL -3	3	0.3	0.05	2×10^{-4}
Upper Red Beds	RL -6	1	0.1	0.02	1×10^{-6}
Lower Red Beds	RL -16	3	0.3	0.05	2×10^{-5}
Conglomerate	RL -22	7	0.7	0.1	8×10^{-5}
Sandstone & Conglomerates	RL -34	4.5	0.45	0.05	3×10^{-5}

* The elevations of some of the units vary from those used in geotechnical analysis of the retaining structures since the hydrogeological model represents a significantly larger plan extent than the geotechnical model

4 TEMPORARY WORKS DESIGN

A plan view of the excavation layout is shown in Figure 2, indicating the position of the sheet piles and the dewatering bores. A sectional view through the deepest part of the excavation is included in Figure 1. The layout of the excavation allowed cranes to be positioned on Bench 2 to enable heavy modules and equipment to be lifted into the excavation to construct the permanent works. The design allowed for 60 kPa surcharge load on Bench 2, or alternatively 450 kPa average bearing pressure on 1.2 m x 8 m long crane tracks.

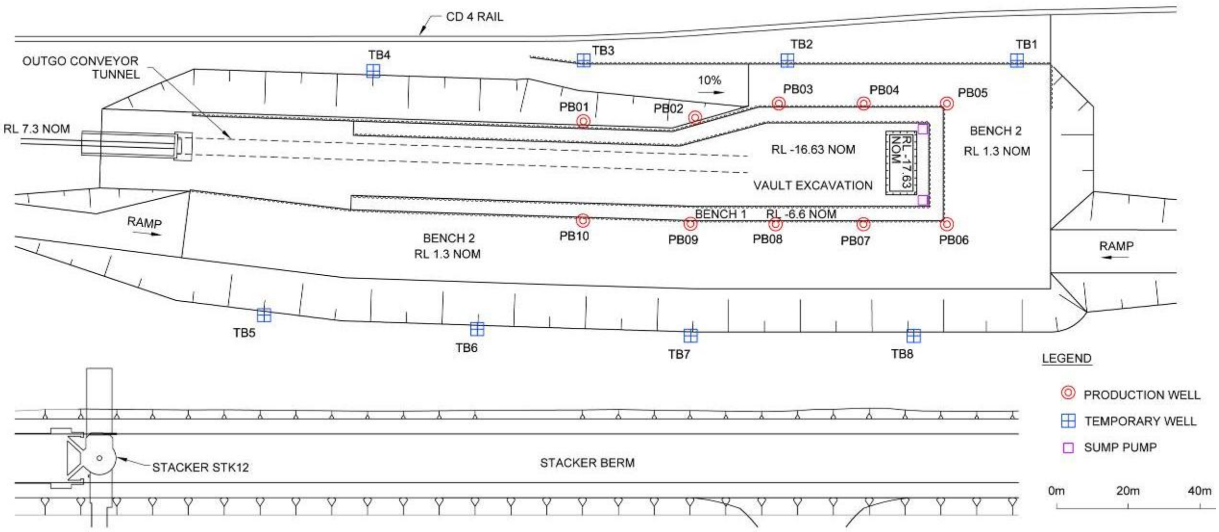

Figure 2: Car dumper excavation plan showing layout of dewatering system

4.1 Sheet Pile Wall Design

The design of the temporary works was divided into seven sheet-pile walls. Each wall was analysed over a number of subsections where excavation levels or other conditions varied along the length of the walls. Retaining wall analysis using the WALLAP software package was initially used for assessing the required depth of embedment as well as providing an indication of sheet-pile wall bending moments, shear forces, displacements and anchor loads at each design subsection. This software was adopted for the initial stage of analysis so that the relatively large number of design sections could be assessed relatively quickly. While the WALLAP software was useful for providing a basis for design of each section, finite element analysis of the new car dumper excavation was required to assess effects that could not be accurately modelled using WALLAP alone. In particular, this included more direct consideration of tiered retaining structures and overall global instability. The finite element analysis was carried out using the PLAXIS 2D software package. Two full-width sections of the new car dumper excavation were modelled – one cross-section was defined through the deepest part of the excavation and another through the ramped area of the excavation. The Arcelor AZ25 sheet pile profile was initially selected but was later substituted for a cold-rolled WRZ25-635 sheet pile profile based on supply cost.

4.2 Ground Anchor Design

The design of temporary anchors for the new car dumper was initially based on those specified for the previous car dumper, with later revisions resulting from the performance of anchor trials at the new car dumper site during the investigation stage. The final design specified three rows of mechanical anchors within the Dune Sand and three rows of grouted ground anchors within the cemented Red Beds material. Each grouted ground anchor comprised 8 x 15.2 mm diameter tendons installed within a borehole of 150 mm diameter, with a fixed-length of 10 m and a free-length of between 15 m and 20 m. The design working load of the grouted ground anchors was 800 kN, with a pre-stress of 350 kN applied to each anchor. Each anchor was load tested to a maximum load of 1200 kN during construction.

4.3 Dewatering System Design

The dewatering system comprised (refer to Figure 2 for location):

- Eight temporary wells, which were installed around the excavation from the ground surface to a level of RL -23 m AHD (into the Upper and Lower Aquifers). The purpose of the wells was to achieve drawdown of the upper aquifer to allow installation of the production wells at Bench 2. The estimated pumping rates for each well were 3 L/s to 5 L/s;
- Ten production wells, which were installed on the outside of the first row of sheet piles at RL 1.8 m AHD to a level of RL -44 m AHD (into the Lower Aquifer). The purpose of the wells was to achieve drawdown to below the required excavation level of RL -17.6 m AHD. The estimated pumping rates for each well were 3 L/s to 10 L/s, with a progressive increase in dewatering rates as the excavation deepened;
- Two sumps with pumps were installed within the excavation. The purpose of the sumps was to capture any seepage and drilling fluid from the anchor installation within the new car dumper vault area.

The groundwater model results indicated an average total pumping rate of 66 L/s with a maximum rate of 94 L/s. Dewatering is required for approximately 13 months, which results in a total estimated dewatering volume of 2.15 GL.

4.4 Specified Monitoring

Monitoring was specified during the design to assess whether the field response was in accordance with design expectations and to facilitate advance warning of unsatisfactory performance. The results of the monitoring are discussed in Section 5.3. The monitoring comprised:

- Conventional survey of the sheet piles and adjacent critical facilities.
- Ground anchor load cells.
- Borehole inclinometers to measure the ground movement adjacent to the deepest excavation.
- Groundwater level measurements in monitoring bores.
- Dewatering discharge flow rate from individual bores and total flow rate.
- Groundwater quality field measurements and sampling for laboratory analysis.

5 CONSTRUCTION PERFORMANCE

5.1 Sheet Pile Installation

The construction of the sheet pile wall was generally completed in accordance with the design intent, with the exception of issues resulting from encountering ground more competent than expected and from delays with commencing dewatering. Significant pre-augering of sheet piles embedded into the Red Beds was needed due to difficulties experienced in achieving the design toe levels. In some places localised voids developed adjacent to the sheet piles as a result. In one area of the lowest tier of sheet piles the design toe level was not achieved due to the presence of stronger cemented material within the lower part of the Red Beds. De-clutching of the sheets may have occurred in this area. It is possible that the substitution of the cold-rolled sheet pile profile for the hot-rolled profile initially selected may have led to a reduction in robustness, due to the different clutching arrangement.

5.2 Dewatering System

The response of the dewatering system generally followed expectations. When the base of the excavation was reached, work was undertaken in dry conditions with minimal sump pumping required. The average pumping rate at that stage was 60 L/s, with a peak maximum discharge of 84 L/s - slightly lower than the design estimate.

The dewatering system response suggests that there is less groundwater interaction between the Upper and Lower Aquifers at the new car dumper than expected, which resulted in greater difficulty in drying up of the Upper Aquifer. This was managed by continuing pumping of the temporary wells, although a small area of seepage through the sheet piles remained. It is also apparent from the pumping activities that the hydraulic conductivity of the Conglomerate is lower than inferred from the limited information available at the design stage. In hindsight, had this been known, a greater number of shallower production wells would have been used to provide a more effective system. Other challenges included the corrosion of submersible pumps due to the salinity of the water.

5.3 Monitoring

The horizontal movements of the upper row of mechanically-anchored sheet piles were broadly in-line with predictions, suggesting that the design parameters for the Dune Sand were appropriate. The measured ground anchor loads were less than design expectations (about 70% of design working load). Back analysis was carried out for an area subjected to heavy crane loading on Bench 2. This indicated that the cohesion of the Red Beds had to be increased from 5 kPa to 50 kPa to achieve a reasonable match with the measured anchor forces and wall deflections. A cohesion value of 50 kPa is consistent with the properties of the more well-cemented Red Beds materials. Design estimates of horizontal deflection of the lower two tiers of sheet pile walls were in the range of 50 mm to 80 mm. The actual deflections measured with borehole inclinometers were in the range of 15 mm to 40 mm. This observation is also consistent with the inferred higher cohesion of the Red Beds described above.

5.4 Design Surcharge Loads

During the design process, about one year prior to selection of the construction contractor, an estimate of the crane surcharge loads for Bench 2 was made based on previous similar construction work. However, it later proved necessary for the contractor to use a 30% heavier crane to install various modules within the permanent works. The stability of the excavation under this heavier loading was assessed and found to be adequate, partly on the basis of the monitoring data described above. Following back-analysis of the monitored response of the temporary works prior to operation of the heavy crane, it was found possible to accept the heavier loading provided that spreader plates were used and close monitoring of sheet pile wall deflection was carried out during the heaviest lifts, referenced against trigger/alarm levels of movement. The trigger/alarm levels were set to provide advance warning of excessive movement as the loading increased at various stages of each lift.

6 CONCLUSIONS

Experience and monitoring data obtained from the construction of the previous car dumper provided valuable input into the design, specification and construction of the temporary works and dewatering system for the new car dumper. Stronger cemented zones within the Red Beds were encountered which inhibited installation of sheet piles, even with preboring. Estimated sheet pile deflections were close to measured values for the upper row of mechanically-anchored sheet piling. Measured anchor loads and sheet pile deflections were lower than the design estimates, probably due to higher strength of the Red Beds than adopted in the design. Dewatering rates during construction were within 10% of the design estimates.

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