Sheet Pile Retaining Walls – Design and Construction in a Brown Fields Environment

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ABSTRACT

This paper describes design and construction of sheet pile retaining walls as a permanent solution for the soil-retaining structure adjacent bridges. Amongst different types of retaining walls such as cantilevered concrete walls and cantilevered concrete piles, sheet piles are favourable due to their fast construction, comparative light weight, high resistance to driving stresses, and long service life above and below the water table. In addition, in a brown field environment where challenges include dealing with live rail environment, existing services, and operational roads and nearby residents adjacent to the work area, sheet piles possess several advantages over other types of retaining walls.

The paper also outlines a case study of a recently completed retaining wall project in Melbourne. The sheet piled wall was installed as a part of the earth retaining structures for the level crossings removal project at Bentleigh and McKinnon stations. Furthermore, the basis of the design including corrosion allowance and stray current, staged construction, temporary propping and support for base slab uplift due to water pressure will be discussed. Construction of this type of retaining walls by two different sheet piling installation methods and the main advantages and disadvantages of each system will also be highlighted.

Keywords: infrastructure, bridges, retaining walls, steel sheet piling, construction

INTRODUCTION

1 Background to Level Crossing Removal Project Package 1 (LCRP1)

The Level Crossing Removal Project Package 1 (LCRP1) was the first package of works released by the Daniel Andrews State Government as part of its commitment to 50 road/rail grade separations within eight years. The package consisted of four grade separations including four accompanying stations to be rebuilt. These separations occurred at:

- Burke Rd and Gardiner Station Glen Iris (Glen Waverly line)
- North Rd and Ormond Station Ormond (Frankston line)
- McKinnon Rd and McKinnon Station McKinnon (Frankston line)
- Centre Rd and Bentleigh Station Bentleigh (Frankston line)

Sheet piled retaining walls were only used as a permanent structure at Bentleigh and McKinnon stations; therefore this paper focuses on these projects.

LCRP1 was constructed by an alliance between KBR, John Holland, The Level Crossing Removal Authority (LXRA), VicRoads, Public Transport Victoria (PTV) and Metro Trains, with KBR taking the role of design lead and John Holland the construction partner.

Due to the narrow corridor at McKinnon and Centre Roads grade separations, the new rail had to be installed along what was essentially the same alignment. This required the excavation and much of the construction to occur while the rail was offline. To minimise the amount of construction while the rail was offline, it was critical to construct as much as possible while the rail was online and only constructing what was absolutely necessary during the 37 day rail occupation.

2 McKinnon and Bentleigh Grade Separations

The retaining walls consisted of free standing sheet pile walls and soldier pile walls with a concrete base slab. CFA bored piles were used mainly for wall retention within the platform area with infilling jet grout columns and secant piles to provide wall

water tightness. Sheet pile walls supported by temporary and permanent anchors were also proposed in some sections.

A 'tanked' waterproof retaining wall system has been adopted at McKinnon and Bentleigh stations as the groundwater levels are above much of the rail grade line.

Figure 1 View of retaining walls at McKinnon station

BASIS OF DESIGN

1 General

The retention system comprised of a combination of; post and panel, sheet pile and continuous flight auger piles. These systems were also used in combination at locations with soil anchors and permanent props.

Surcharges of 5 kPa and 20 kPa have been adopted along the wall alignment based on conditions present behind the wall. Crane loading has been considered to be no worse than the existing building / surcharge allowances, however localised checks were carried out at construction stage for different crane positions adjacent to the wall.

Design life of the retaining walls was assumed 100years as per AS5100 requirements. The deflection criteria was H/100 where H is the free retained height from ground surface behind the wall to top of base slab/capping in front of the wall.

2 Corrosion Requirements and Stray Current Effects

AS5100.3 states that steel surfaces that are in contact with soil shall be designed for a corrosion rate of 1.5mm total for entire life of the structure for each face in contact with soil. Direct stray currents from high voltage lines such as live rail environment can also present corrosion problems. Therefore, a total of 3.0mm corrosion rate was adopted in the design of sheet piles. For this purpose, structural characteristics of standard sheet piles were modified with reduced steel thickness (by 3.0mm) and used in the analysis of the retaining walls.

3 Methodology

The retaining walls consisted of cantilevered and propped or anchored soldier pile and sheet pile walls. The cantilevered walls will retain a soil height up to 10 m. Retaining walls supported by single level anchors or props had been adopted for higher areas adjacent to car parks (permanent anchors) or where buildings are adjacent to the walls (concrete prop). The concrete base slab has also been considered as a prop for the 'tanked' retaining wall system.

The geotechnical design of the retaining wall involves an ultimate limit state assessment of the overall stability of the structure in terms of rotation and global failure which is the main failure mechanism in the given ground conditions.

Temporary dewatering within the excavation has been allowed for the construction, as such piping and basal failures of the excavation base are not considered an issue with the lowered groundwater level.

3.1 Dewatering

For ease of construction and to mitigate risks of soil collapse between CFA piles, temporary dewatering was undertaken to lower the groundwater at Bentleigh and McKinnon.

The dewatering involved a number of bores with groundwater pumps located in each of them to pump the groundwater out to locally draw the groundwater level down below the future formation level in addition to a number of monitoring bores to track the progress of the dewatering. Due to the very fine silty soil some of the pumps were suffering from the fines flowing past the prefilters. The process, however, proved successful as the groundwater did not pose an issue during the occupation, allowing a relatively dry base to construct the base slab on.

3.2 Sheet Pile Wall

Four wall types had been proposed for the wall assessment as follows:

- Free standing and base slab propped wall up to 4 m height
- Free standing and base slab propped wall with temporary anchor up to 6.5 m height
- Base slab propped wall with permanent anchor up to 8.5 m height
- Base slab propped wall with composite concrete infill and temporary propping up to 8.5m height. In this special case there was no possibility to install permanent anchors under adjacent properties for long term.

The sheet pile wall was installed after pre-drilling by augering had taken place to assist in drivability especially in dense to very dense Brighton Group sands. For wall height less than 4 m, the concrete base slab was installed after the full depth of excavation was reached, forming a base propped free standing wall. For wall heights between 4 m and 6.5 m, temporary anchors were required at 1.5 m below ground level (Figure 2). Permanent anchors were required for wall heights from 6.5 to 8.5 m along the west wall within the platform area only at Bentleigh station (Figure 3).

There were some locations with heights above 6.5m that permanent/temporary anchors were not allowed as the required embedment for anchors could encroach boundaries of the adjacent properties behind the wall. In these locations a temporary support system consisting of waler beam and proprietary props was used. To limit the wall deflection, a composite concrete infill proposed consisting shear studs welded to the sheets and additional reinforcement as a shown in Figure 4.

	Figure 2 P	ermanent anchors (left), and temporary anchors (right)
62		
VNIOOS MAIL OLEANNINGE	Figure 3	Temporary prop system for wall height above 6.5m
	Figure 4	Composite sheet pile wall to reduce wall deflection

3.3 Cantilever soldier pile wall

The soldier pile wall consists of bored piles constructed by the Continuous Flight Auger (CFA) method. The cantilevered soldier pile walls range from 3 m up to 9 m high. The pile diameter varies from 750 mm to 1200 mm centre to centre spacings ranging from 1.5 m to 2.5 m. Single level propped and anchored walls are also proposed for the wall heights from 6.5 m to 9 m.

CONSTRUCTION AND DESIGN METHODOLOGIES

A combination of Offline and Online construction methodologies were utilised for LCRP1.

Offline construction methodologies were adopted where there was sufficient space adjacent to the existing rail alignment. Thereby reducing and minimising the number and period of rail occupations and their impact upon the network and community. At the ends of the new alignment online construction techniques are needed to interface the old to the new. Online methods are adopted where the new rail alignment closely follows the existing. This method is used where there is insufficient space adjacent to the existing rail line, thus requiring construction of retaining walls either side of the existing alignment while trains are in operation. Compared to the offline methodology, the main occupation is longer and has critical construction activities attached. The challenge is to limit disruptions and to de-risk the main occupation by completing as much work as possible prior to the main occupation.

In locations where there was not adequate room for CFA piles, sheet piles were adopted, using the innovative Giken 'silent-piler' (Figure 5). Steps were undertaken to reduce noise and vibrations caused by installation of the retention system using the GIKEN 'silent-piler'. The Giken uses a push method to drive the sheets. Other significant advantages associated with its use include minimising rail disruption and suitability for tight corridors working close to rail and private properties. Another method employed on the project was the use of a high frequency resonator, which minimised damage from hammering vibrations. The Giken traverses and uses the previously installed sheets as a reaction point. The pre-borer was also used to facilitate installation. The high frequency resonator was also used in less geometrically and environmentally constrained areas. The sheet piles used were sourced from overseas and left untreated.



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1 Versatile design

When time is critical and tolerances are high, flexible designs must be considered. A crucial step in the construction program to ensure trains resumed running on time is the construction of the overhead wiring gantries.

1.1 Sheet Pile Infill

As a Metro requirement for train collision, retaining walls should have a flat and smooth surface up to 2.4m above rail level. In addition, permanent uplift forces against the concrete base slab develop due to the hydrostatic pressure when temporary dewatering ceases. Restraint against hydrostatic uplift was provided by a combination of screw piles and the main retaining walls to which the slabs are connected with galvanized dowels, reinforcement, and shear studs.

Therefore, to meet above requirements sheet piles infill designed to provide enough strength against base slab uplift. Sheet pile infill consisted cavities filled with concrete to the mentioned height including necessary shear studs and reinforcement for the uplift resistance. To account for this, four different types of infill were adopted depending on the level of uplift forces as shown in Figures 6 and 7. Sheet piles had to resist 120kN/m, 150 kN/m and 200kN/m uplift force for types A, B and C, respectively. Type D was a special case designed as a full height composite section. This type was required for both uplift resistance of 200kN/m and increasing stiffness of wall for deflection control where installing permanent anchors weren't possible.



1.2 Overhead Gantries

Due to the narrow rail corridor, overhead structures had to be included within the walls, however there was insufficient room for a base slab attachment or piled solution. Due to the non-uniformity of the sheet piles, a flexible attachment detail was required to allow for variation in sheet angles and spacing.

Two main sheet pile attachment details were developed for the job. The first detail was developed to attach the structure on top of the sheet piles. This detail was used in locations where the rail corridor was at its narrowest and required the overheads to be out of the way. It was also commonly used where the rail cutting was shallower meaning the structures were more likely to impede the train kinetic envelope.

The attachment bolted to the inner face of the outer flange of the sheet piles with a 310UC with coped flanges to fit between the sheet pile webs and a steel backing plate with a matching bolt pattern, as can be seen below in Figure 8.

NOTE: PROTECTIVE BOLT COVER TO BE APPLIED TO PUBLIC AREAS - ROAD OR CARPARK

RET - SHEET - TOP (ELEVATION)

Figure 8 Top of sheet pile overhead attachment

The second detail was developed to attach to the inside face of the cutting. This was the preferred option as it kept the structures inside the retaining wall boundaries which meant for better aesthetics and less interfacing was required with fencing and shared user paths (SUP's). Similar to the sheet pile top arrangement, the sheet pile face arrangement is bolted to the sheet piles with a backing plate, however in this case it is fixed to the inside face of the inside flange as shown in Figure 9.

RET - SHEET - FACE (ELEVATION) SCALE 1 : 20

FLANGED

Figure 9 Face of sheet pile overhead attachment

The overhead structure sheet pile attachments were predominantly fixed in place prior to the major occupation and excavation, with erection of the overhead masts and bridges occurring during the occupation. All sheet pile attachments have the same base plate type to simplify and streamline the fabrication process.

Prior to the fabrication of the masts, the angle of the sheet piles at each location was measured and compared to the angle of the opposite wall. This survey information was then used to find the angle between the corresponding masts for each overhead portal frame. This angle was provided to the fabricators and the top base plates of the masts were rotated to ensure the portal bridges were bolted up at the correct orientation. Additional tolerances were built in to ensure there were no issues during the erection of the structures towards the end of the occupation by using enlarged bolt holes at the top of the masts and using a clamped arrangement at one end of the portal to allow for variation in the span. Despite these tolerances, spans were still surveyed prior to fabrication to account for variation in retaining wall as-built locations.

CHALLENGES ENCOUNTERED

Challenging issues were encountered with test and production anchors during the occupation; the load capacities required from anchors were not being reached. Investigation attributed this to the encountered soil in combination to the testing regime. In future it would be prudent to anticipate and provide provision of readymade design solutions.

At some of the deepest sections the retention piles and sheet-pile wall were temporarily supported by walers and proprietary steel props. These were used to facilitate the bulk out and construction of the tanked base slab solution. This tanked base slab then provided propping to the retention walls at formation level.

The existing level crossing has numerous services running along and across the proposed cutting. These services need to be realigned and routed either below the cutting or across through the bridge structures. Services encountered include Gas, Electricity (LV, HV), Water, Sewer, Drainage, Telstra/NBN, CSR (signals etc), and VicRoads signals.

1 Bentleigh Bathtub

One of the major services realignment occurred at south of Bentleigh station. Existing 1750 water main and 350 sewer drains at Bentleigh relocated and designed as a 'Siphon'. The drains are shown in Figures 6 and 7. To install the siphon, drains first dropped to below rail base level crossing the rail corridor by construction of pits behind the main retaining walls (Figure 8). In this particular location, a combination of sheet wall retaining wall composite with concrete base slab was proposed. Sheet piles designed to partially embed to above the drains, clutching with fully installed sheets at either side of the drains. A stagged excavation was proposed to this particular location, at first stage excavation carried out to half height of partially installed sheets. In this stage a temporary propping system installed to prop the sheets before second stage of excavation. The propping system included horizontal main props with knee bracing to half height of the sheets, creating an "upside down" cantilever wall" (Figure 9). As shown in the Figure 9, sheet piles terminate just above the drain. At this location, base slab designed to have wing walls compositing 2 meters length with sheets providing a cantilevered retaining wall. Cross section of concrete base slab and composite wall can be seen in Figure 7. BEN_S0218

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	Figure 10	Plan of retaining wall and drains at Bentleigh Bathtub
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Figure 1	1 Cross	section (half section) of walls at Bentleigh Bathtub (right), composite detail (left)
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	Figure 12	Temporary pit for drains connection at Bentleigh Bathtub
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EXPANSION J UP TO +/- 1.0r

Figure 13 Temporary propping for partially installed sheets

CONCLUSION

In an accelerated construction program, it is vital that design and construction teams collaborate closely to ensure that the project is delivered, safely, on time and with minimal disruption to the community. The design was optimized in line with the carefully chosen construction methodology to ensure expedient delivery whilst maintaining technical and safety metrics. Where possible offline construction is preferable in limiting disruption whilst providing freedom for design and construction. However, where online construction techniques are necessary, it is vital that the construction methodology of the soil retention system and bridges are rigorously investigated to provide a commensurate design. From a design perspective, especially when working in a tight brownfields environment, it pays to anticipate and provide allowances for construction loads upfront. It is also critical to provide flexible designs that provide sufficient construction tolerances. As demonstrated, when working on time critical accelerated construction programs, it is essential that good communication and support is provided to both design and construction personnel. Issues are inevitable however, these can be guickly overcome if the required resources are available.