

DESIGN AND CONSTRUCTION OF THE NEW LYNN RAIL TRENCH

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ABSTRACT

The New Lynn Rail Trench project comprises the lowering and duplication of approximately a 1.2km length of the North Auckland Railway Line together with the construction of a new underground station in the New Lynn town centre.

Design and construction of the trench is being carried out for ONTRACK by Beca Infrastructure Ltd, Synergine Ltd and Fletcher Construction Ltd. Construction is well underway and scheduled for completion mid 2010.

Some 40,000m³ of concrete and 7000 tonnes of reinforcement will be consumed on the project.

This paper describes the background and details of the design concepts implemented, together with the construction sequencing and techniques being used to deliver the project.

INTRODUCTION

Project DART (Developing Auckland's Rail Transport) is a series of improvements to Auckland's rail network which, when completed, will allow more frequent and reliable passenger services and improve traffic and pedestrian safety around the rail network.

The New Lynn Rail Trench project, the sixth in the DART series of projects, is located at the existing rail corridor in New Lynn town centre. The works involve lowering and duplicating a 1.2km long section of the North Auckland Line rail track between Whau Creek and Titirangi Road. The track lowering achieves grade separation between the rail tracks and four local road crossings, in particular the notoriously busy roundabout at the intersection of Clark Street, Rankin Avenue and Totora Avenue. The project also includes construction of a new underground station facility.

The project is being delivered using an 'Early Contractor Involvement' (ECI) contract. Fletcher Construction Ltd engaged Beca Infrastructure and Synergine to provide design services.

SITE DESCRIPTION

The site comprises the existing narrow rail corridor and is closely bounded by busy roads, commercial and residential development.

Broadly, the ground conditions consist of Tauranga Group alluvial deposits overlying competent (SPT N>50) Waitemeta Group sandstone. The alluvial deposits vary in depth from 7 to 35 metres and typically comprise clay, silts and pumiceous sands.

PROJECT REQUIREMENTS

The Principal's Requirements for the project included the following constraints on the design and construction:

- The North Auckland Line (NAL) was to be duplicated;
- The rail tracks shall be depressed with respect to the local road crossings, and the crossings were to remain nominally at the existing at grade level;
- Design, scheduling and programming of the proposed works was to minimise disruption to traffic circulation and to rail services;
- The rail line through the site must remain operational by commuter and freight trains throughout construction;
- The trench structure was to be 'watertight' to control groundwater levels and flows and ensure that there were no detrimental affects on the adjacent properties, buildings, infrastructure and utilities;

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- The design and construction of the trench shall include appropriate measures to control ground movements to an acceptable limit and minimise the risk of long-term on-going movements;
- A central island platform was to be provided between the tracks with associated station facilities.

DESIGN SOLUTION

The first stage of the contract was to conceive and then evaluate several options for the trench structure. This involved undertaking sufficient preliminary design work and construction planning in order to develop and agree a total out turn cost for the project.

The primary trench structure is approximately 900m in length with a maximum retained height of 8m. The trench width varies from 11m to 18.5m over its length.

The key components of the structure are the retaining walls and base slab, which form the watertight trench, together with a hold down system for resisting the significant buoyancy effects.

A number of alternative retaining wall systems were considered, including steel sheet pile walls, pile and slurry walls, diaphragm walls and secant pile walls. Overall the diaphragm walls, consisting of fully integral cast in situ concrete, were selected as the preferred solution with advantages over other systems in both constructability and cost.

Diaphragm wall construction is a 'top-down' construction technique that involves the progressive excavation of the wall using specialised equipment. Excavation stability is maintained throughout by the use of a support fluid, in this case bentonite slurry was utilised. After insertion of a prefabricated reinforcement cage into the excavation, concrete is deposited using tremie methods, progressively displacing the bentonite.

At commencement of the project, diaphragm wall construction of this scale had not previously been undertaken in New Zealand.

Various alternatives were considered for the base slab and hold down piles. Ultimately, a conventional solution of a cast in situ, uniform thickness, flat slab together with ordinarily reinforced concrete bored piles were selected. The piles are socketed into the underlying Waitemata sandstone and resist uplift loads via shaft friction.

Both the retaining walls and base slab are designed to ensure limited crack widths and therefore limited permeability. Construction joints and element interfaces incorporate PVC water stops and hydrophilic sealants to further ensure a limited permeability trench.

Refer to Figures 1 and 2 for the trench structure general arrangement details.

RETAINING WALL DESIGN

The primary function of the diaphragm walls is to retain earth pressures. They are not considered to support any vertical loads (via bearing on the underlying soils) other than their own self-weight. However, once the base slab is constructed they form part of the load path to transfer vertical loads down from the bridges and concourse to the bored piles located underneath the base slab.

The diaphragm wall is sequentially constructed in 7m wide panels, with each panel interlocking with the previous by a formed shear key (incorporating a PVC water stop). The length of panels varies between 7m to 16m based on the required retaining height (approximately, half of the panel's length projects above the base slab level). The thickness of diaphragm wall is typically 800mm, reducing to 600mm thick over a short distance at each end of the trench where the retained heights are less.

Crack width limitations of 0.3mm were applied to the design for both durability and to limit permeability.

The north and south walls are propped against each other (either permanently or temporarily) to limit displacements and design moments and shears. The propping requirements vary depending on the retained height.

Concrete with 28 day compression strength of 30MPa was employed. The mix design utilised a high cement content to compensate for potential water inclusion during tremie pour.

Bentonite properties were specified in accordance with international practices to ensure that it could be readily displaced during subsequent concreting operations and to avoid any detrimental effects or contamination of the concrete.

CAPPING BEAM DESIGN

A continuous capping beam is cast along the full length of each retaining wall. The beam primarily serves to span between the discretely positioned

permanent or temporary props to distribute lateral soil pressure loads. Additionally, it provides the interface with the station concourse, local road bridges and other surface features. The north wall cap beam is also utilised during the construction period to carry trains until the permanent track is installed in the trench.

The north wall cap beam is 1.9m wide (to suit the train track width) and 1.2m deep. The south wall cap beam varies in width from 0.9m, 1.1m or 1.4m and is either 0.9m or 1.2m deep.

Due to the dimensions of the beam cross section and the large scale of the concrete pours, particular attention was given in the design to heat of hydration effects and mitigation against early age thermal cracking. The recommendations of 'CIRIA Report C660: Early age thermal crack control in concrete' were referenced in this regard.

Flexural demands dictated that a minimum longitudinal reinforcement content of 0.9% (expressed as percentage of reinforcement area over the gross concrete area) be provided. The adequacy of this reinforcement ratio to control crack spacing and widths was then assessed against CIRIA Report C660. Additionally, it was specified that the concrete mix, formwork and curing method should limit peak core temperatures to less than 70 °C and differential temperatures to less than 25 °C within a single pour (i.e. core versus surface temperature).

PERMANENT PROP DESIGN

Permanent reinforced concrete props are provided at the top of the retaining walls over the central section of the rail trench (between Veronica St and the Clark/Rankin roundabout), where the retained height is the greatest. They span between the cap beams of the north and south walls and are spaced at approximately 10m centres. At the bridges and station concourse the spacing and/or configuration varies to suit the coverage required.

The props are designed to withstand the axial loads induced by lateral loads from static earth pressure, hydrostatic pressure, surcharge, incremental seismic earth pressure and the seismic inertia force. Additionally, some props are utilised to carry vertical loads such as the super-imposed dead loads and live loads associated with the station concourse.

Cross section dimensions vary depending on prop location and load demands. They range from 750mm

wide x 750mm deep to 1000mm wide x 1025mm deep). Prop lengths range from 10m to 17.5m.

To facilitate construction preferences, the props were detailed as precast elements. The connection to the capping beams at each end was achieved by an in situ stitch pour, undertaken overnight while there were no trains running on the north capping beam. This was to mitigate against any detrimental effects due to traffic vibration. Additionally, a high cement content concrete was specified to ensure maximum early age strength prior to train movements recommencing the following morning.

The permanent props are critical for the stability of the trench retaining walls. To safeguard against collapse, the design considered an extreme event scenario where a prop is removed due to fire or other incident.

BASE SLAB DESIGN

The primary functions of the base slab are to provide a dry trench and transfer the vertical loads from the diaphragm walls to piles underneath the slab.

Initially, when uplift forces from groundwater and soil rebound pressures (result of excavation) are minimal, vertical gravity loads due to the structure self weight and superimposed loads from trains, pedestrians on the concourse, and traffic on the bridges are transferred through the diaphragm walls via the slab to the supporting piles.

In the long term, once groundwater recovery is complete and soil rebound pressures are fully realised, significant uplift forces are generated underneath the base slab, of a magnitude much greater than the downward forces.

The base slab consists of cast in situ reinforced concrete, typically 800mm thick and reducing to 600mm thick for short lengths at the ends of the trench where excavation depth is reduced and uplift pressures are minimal. The slab has grades longitudinally and across the trench for drainage.

The slab is being cast in 7m lengths, with construction joints coinciding with those in the diaphragm wall. This was intended to mitigate the effects of differential concrete shrinkage between the walls and the slab, by ensuring the shrinkage related movements are kept small (by the short 7m slab length) and confined to the construction joint location.

Construction joints in the slab and at the wall/slab interface will be made waterproof by using rear guard PVC water stops and hydrophilic sealants.

For fatigue related effects, a stress range limit of 150MPa is applied to the design of all principle slab reinforcement under SLS demands caused by fluctuating loads (train and other live loads).

As for the capping beam, sufficient longitudinal reinforcement is provided in the slab to control crack spacing and widths due to concrete shrinkage and early age thermal effects.

Two plinths, each 200mm high and 2,100mm wide, on which to fix the rail tracks are constructed on top of the slab. ONTRACK's preference was that the plinths were unreinforced to facilitate future modifications to the track fixings and the installation of additional drill and grout anchors. To mitigate against potential for delaminating under composite flexural action with the base slab, the plinths are connected with shear connectors in accordance the requirements of NZS3101:2006 section 18. The plinth concrete contains 35kg/m³ of steel fibre reinforcement for additional crack width control.

BORED PILE DESIGN

Bored piles are provided beneath the base slab along the length of the trench, at 7m centres. These provide the primary vertical load carrying system; resisting uplift pressures (due to buoyancy effects caused by the natural water table levels) and gravity loads due to the structure self weight and superimposed loads such as trains.

The piles are embedded into the underlying competent Waitemata sandstone (N>50) and resist vertical loads (uplift or downward) by shaft friction. The sandstone socket lengths range from 6m to 16m, depending on load demands. In addition to a desk top study, a pile load test was carried out to ascertain the reliable shaft friction.

The piles are 750mm in diameter and range in length from 16m to 36m. Having been installed from the existing ground level, the tops of the piles are in the order of 8m below ground to coincide with the base of the trench. Reinforcement content ranges from 1.4% to 3%.

BRIDGE DESIGN

There are four road over rail bridges; Veronica St Bridge, Hetana St Bridge, Memorial Ave Bridge and

the Clark/Rankin Bridge. Each bridge consists of a single span, ranging from 10m to 17.5m.

The trench retaining walls and capping beams are utilised as the substructure to resist all lateral and vertical loads. The superstructure comprises 535mm deep precast prestressed inverted 'T' beams together with a cast in-situ concrete deck slab.

The selection of the precast girder type was primarily driven by cost considerations and the opportunity to use an already established fabrication yard set up for another project.

CONCOURSE DECK SLAB DESIGN

The concourse deck slab consists of 100mm thick precast prestressed slab units with a 100mm cast in situ topping, spanning between the permanent prop beams and additional intermediate beams as necessary.

The top of the rail trench capping beam is a variable distance below the finished ground level (the cap beam vertical alignment is dictated by temporarily running trains on top of the north wall). To build the deck surface level up to tie in with the finished levels of the adjacent local roads, lightweight (foam or pumice aggregate) concrete will be placed on top of the primary deck structure.

STATION PLATFORM DESIGN

The 225m long platform will consist of a perimeter of cast in situ reinforced concrete retaining walls, backfilled with a compacted granular fill material and overlain with concrete blinding and bluestone pavers.

OVERALL CONSTRUCTION SEQUENCE

The lowering of the rail line and construction of new station are being undertaken while trains remain in operation.

To achieve this, the existing track was initially slewed to the southern extent of the rail corridor, creating sufficient working room for construction of the northern trench wall. The train was then relocated onto the northern wall cap beam allowing construction of the southern wall, base slab, platform, props, bridges and concourse. The final sequence is laying track and relocating the train into the base of the trench.

Generally, the site is very constrained. It is extremely narrow and, in conjunction with the live train track

through the site, plant access and maneuverability is severely limited. It was necessary to stage significant construction activities in a linear and sequential nature, to avoid competition for operating space. Additionally, certain activities such as large crane lifts adjacent to the track were restricted during train operating hours for safety reasons, leading to 24hr operations.

Refer to figure 3 for details of the general construction stages.

DIAPHRAGM WALL CONSTRUCTION

Excavation was undertaken on three work fronts, spread along the length of the trench. Heavy cycle cranes, ranging in size from 65T to 120 T, were used to operate rope suspended hydraulic grabs. The grab buckets measure 3m in width, stand some 8.5m high and weigh in the order of 19 tonnes.

Bentonite slurry was utilised to maintain stability of the wall excavation throughout construction. A network of pipes was set up to distribute benetonite back and forth between the work front and the storage and processing facility.

Control of bentonite properties is paramount in ensuring excavation stability and quality of the subsequently placed concrete. The slurry needs to be easily displaced during concreting and its properties such that it does not coat the reinforcement to such an extent that the bond between the concrete and reinforcement is impaired. Accordingly, its properties were monitored throughout construction for compliance with the specification, which largely follow the recommendations of BS EN 1538:2000. The specified bentonite slurry properties are provided in the following table.

Table 1: Specified Bentonite Slurry Properties

Property	Fresh	Ready for Reuse	Prior to Placement of Reinf. Cage
Mud Balance Density (g/ml)	<1.10	<1.25	<1.15
Marsh Funnel Viscosity (seconds)	32 - 50	32 - 60	32 - 50
Fluid Loss (ml)	<30	<50	N/A
Gel Strength - 10 minute (N/m ²)	4-40	4-40	N/A
Filter cake in mm	<3	<6	N/A
Sand Content (%)	N/A	N/A	<4
pH	7 - 11	7 - 12	N/A

Immediately prior to placement of the reinforcement cage and concreting, the bentonite within the excavation was exchanged to ensure that the properties were suitable. The contaminated bentonite was recycled back through the processing plant to undergo de-sanding to remove contaminants and prepare for its reuse.

Reinforcement cages were prefabricated at a dedicated facility established close to the site by Fletcher Reinforcement Ltd. The repetitious nature of the fabrication and consistent detailing of the cages, allowed for the extensive use of set out templates and guide frames, leading to significant productivity gains. For transportation purposes, two separate 3.25m wide cages were supplied to site for each 7m wide wall panel and subsequently spliced together. Splicing was undertaken by inserting both cages into the wall excavation, then progressively lifting them as a pair to allow installation of splice bars at a convenient working level. This greatly saved on the required space on site.

After insertion of the reinforcement cage into the excavation, concrete was deposited using tremie methods, progressively displacing the bentonite. Two 200mm internal diameter tremie lines were used, positioned evenly across the width of the panel to ensure that a relatively uniform concrete level was maintained during placement. Concrete within each tremie line was carefully maintained at a similar level.

The concrete mix design employed was relatively conventional. The only specific considerations were a relatively high cementitious content of 380kg/m³ to allow for any additional fluid inclusion during the tremie pour and a high slump of 220mm to ensure adequate concrete flow through the heavily congested reinforcement.

To validate the construction methodology and verify the soundness of the deposited concrete, integrity testing, in the form of sonic logging, was carried out on a selection of wall panels.

CAPPING BEAM CONSTRUCTION

To ensure that uncontaminated and sound concrete was achieved at the top of the diaphragm walls, the pour continued past the required finish level. Although the majority of this 'over-pour' was removed while the concrete was still green, some subsequent break down of the hardened concrete was necessary prior to commencing capping beam construction.

During this breakdown process, it became evident that some bending of the diaphragm wall reinforcement, which would project into the capping beam, was inevitable. The bars were 25mm and 32mm in diameter, grade 500MPa, and manufactured using the microalloy process. Straightening these bars was of some concern, given the well known issues with strain hardening and embrittlement of cold worked reinforcement. Fortunately, the initial bending during the break down resulted in relatively large bend radii, far greater than the minimum bend radii specified in NZS 3101. An extensive regime of non destructive testing confirmed that the bars could be straightened by cold re-bending without damage to the reinforcement.

Reinforcement cages for the capping beam were prefabricated off site in 14m lengths. A steel formwork system was utilised and concrete pours were carried in lengths of up to 24m.

A 35MPa concrete strength was specified. The mix design developed included a 30% flyash content to control early age heat of hydration temperatures to within the specified criteria. Theoretical predictions of the concrete internal temperatures were undertaken based on CIRIA C660 guidelines, with due consideration given to the proposed formwork arrangement, construction methodology, curing regime and ambient temperatures. For the 1900mm wide by 1200mm deep north capping beam, a peak core temperature of 60°C and a differential temperature of 22 °C was predicted.

During construction, thermocouples were used to validate the theoretical predictions for core and differential temperatures. A good correlation between the predictions and field results was found.

PROP CONSTRUCTION

The precast props were fabricated offsite and delivered to site for overnight installation, while trains were out of operation.

Access for craneage presented some difficulties, with the heaviest props weighing 40T. However, in general prop installation proceeded without issue.

BORED PILE CONSTRUCTION

Pile construction adopted conventional bored pile techniques. Bentonite slurry was utilised to maintain stability of the pile excavation and concreting used tremie techniques, similar to the diaphragm walls.

Integrity testing by sonic logging was carried out on a small selection of the initial piles to confirm suitability of the construction methodology and verify soundness of the deposited concrete. For additional quality assurance, every 3rd pile constructed will be subjected to further integrity testing using the sonic pulse method with a single transducer at the top of the pile.

As for the diaphragm walls, concrete was over-poured and then subsequently broken down to the required level to ensure that sound concrete was achieved. Hooks for anchorage of the 32mm diameter pile bars into the base slab are being site bent in a controlled fashion with a portable hydraulic bar bender.

BASE SLAB CONSTRUCTION

Prefabrication of the reinforcement cages has facilitated swift installation and is expected to lead to decreases in slab construction cycle times.

The logistics of depositing concrete into the base of the trench, amongst the myriad of temporary and permanent props are being overcome by the use of a temporary monorail system, suspended beneath the props. The largest slab panels require a concrete pour of 105m³.

Particular attention is being paid to the early application of curing methods to mitigate the risks of plastic settlement cracks.

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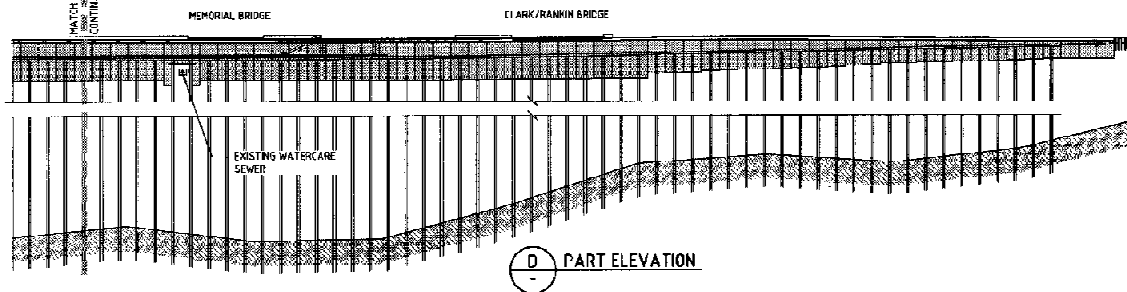
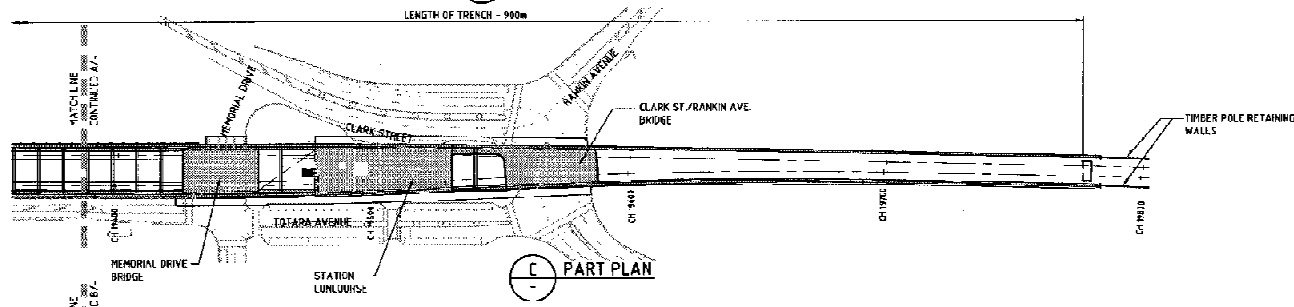
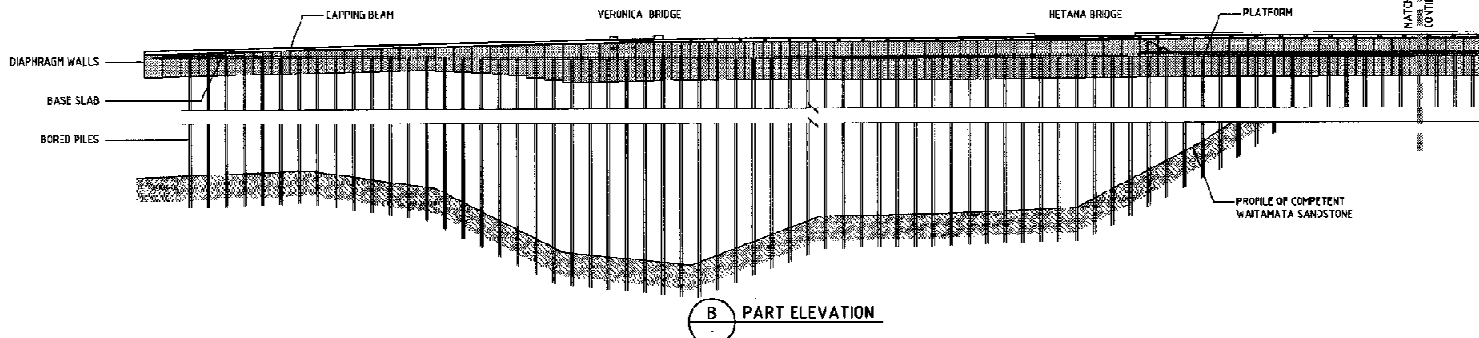
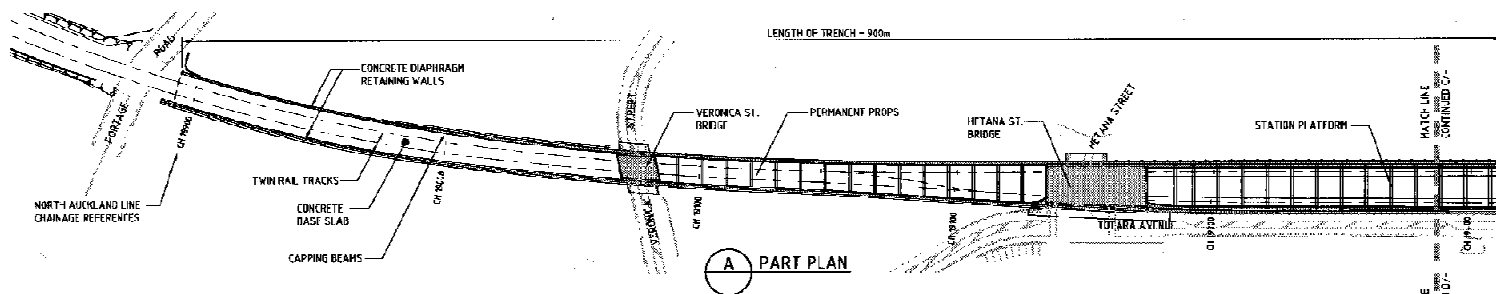
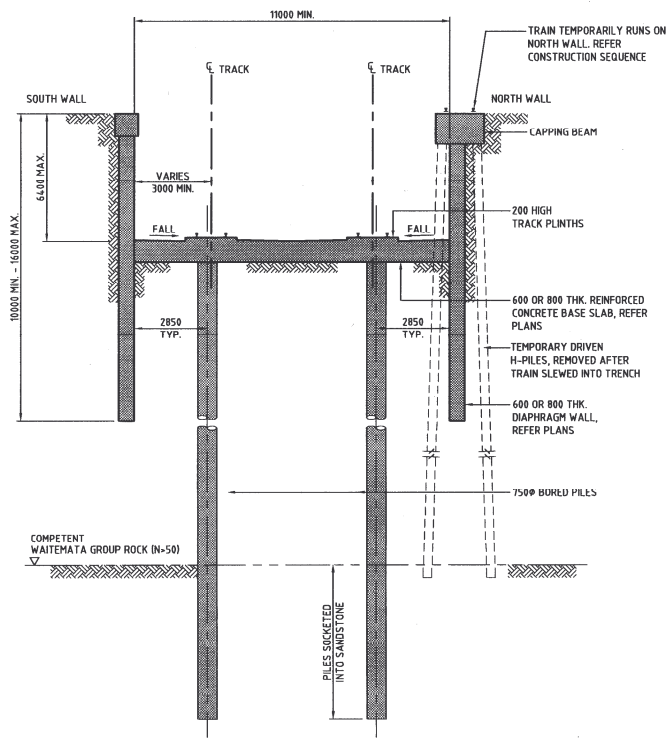
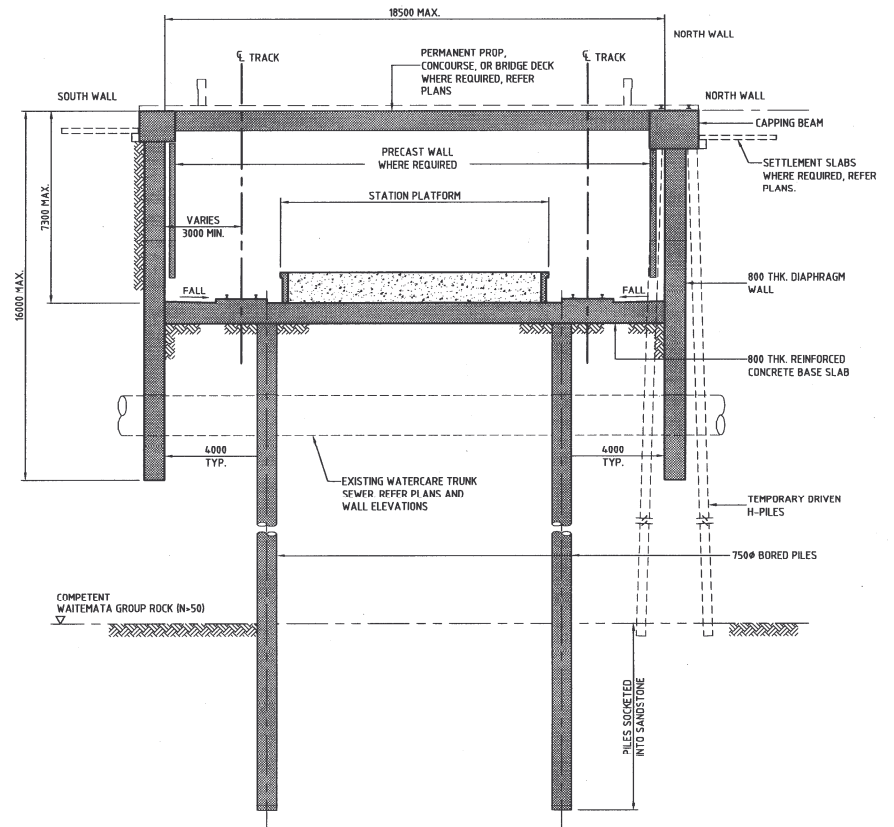


FIGURE 1: GENERAL ARRANGEMENT PLANS



TYPICAL SECTION - PORTAGE RD TO VERONICA ST
AND CLARK ST/RANKIN AVE TO WESTERN END



TYPICAL SECTION - PERMANENT PROPS AT TOP

FIGURE 2: TYPICAL CROSS SECTIONS

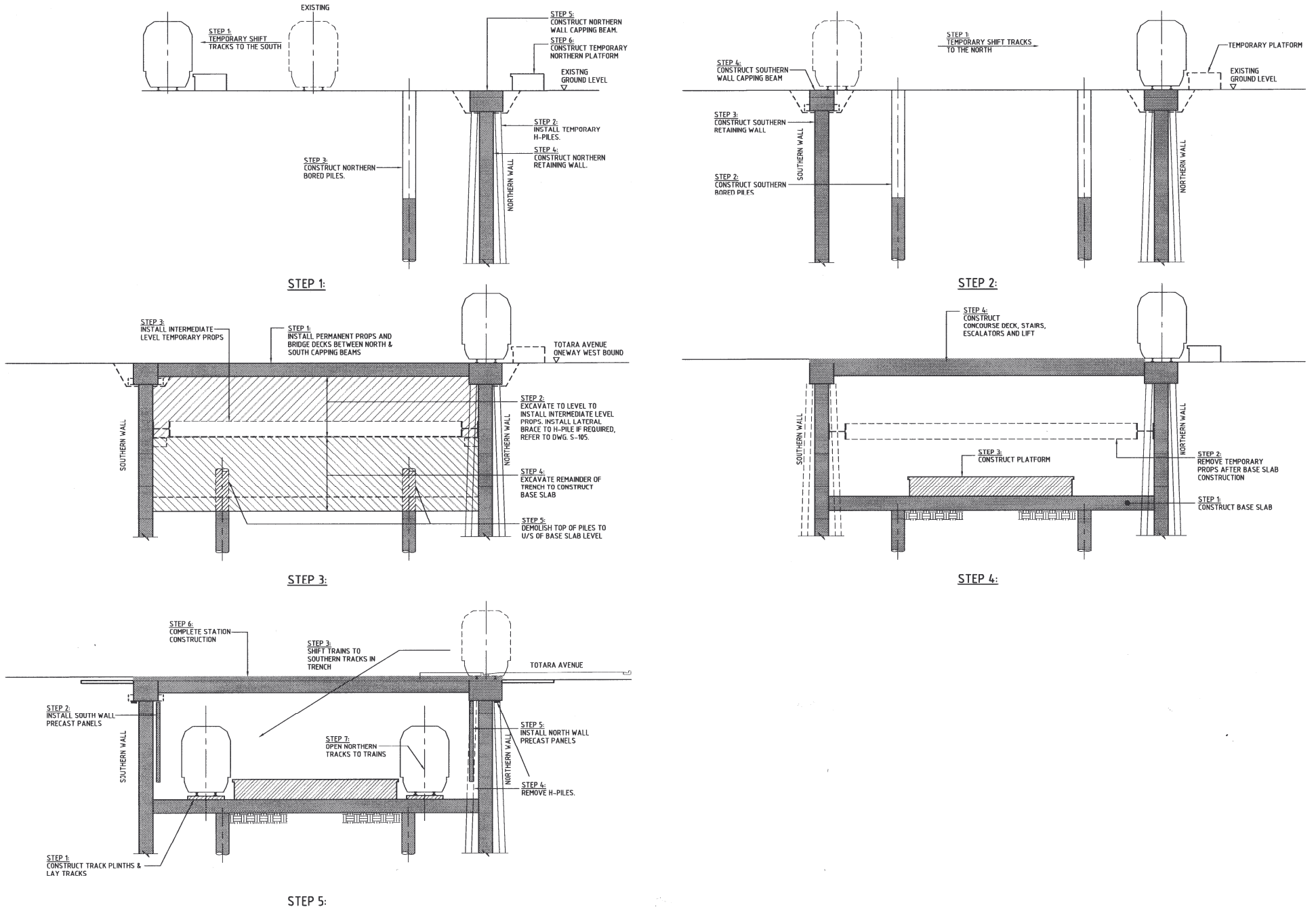


FIGURE 3: GENERAL CONSTRUCTION SEQUENCE