

DESIGN AND CONSTRUCTION OF BRITOMART INTERCHANGE.

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SUMMARY

Britomart Station is an underground railway station currently under construction in the Central Business District of Auckland, New Zealand. The station is approximately 310 metres long by 45 metres wide and 11 metres deep. This paper outlines the design solutions developed to accommodate high ground water levels and variable foundation conditions along the site. Both top down and bottom up construction feature in the completed design. The site is also in close proximity to the sea and the design life is 100 years. Thus, careful consideration of water tightness and durability were also key aspects of the design.

INTRODUCTION

Britomart Station is an underground railway station that is currently under construction in Auckland, New Zealand. It is located in the Central Business District and will, when commissioned, connect to the Auckland regional rail network via an existing tunnel to the east of the site.

The client is Auckland City Council and the project is part of a region wide upgrade of the public transport system. The Britomart Station will form the hub of the upgraded system.

The underground station runs from Britomart Place to the back of the old Central Post Office (CPO) Building in Queen Elizabeth square. The project includes refurbishment of the old CPO to feature as the main entrance to the new station. However, the discussion in this paper is confined to the underground portion of the station.

The project returns the railway station to a site that it occupied 65 years ago, but this time places the station underground in order to maximise the use of the land above and to minimise conflict with ground level circulation. The construction is scheduled to be completed in May 2003.

Site Conditions

The site is located alongside the Auckland waterfront, on an area of reclaimed land. The fill material consists of locally sourced and imported fill materials, as well as some dredged materials. Some very soft Tauranga Group volcanic ashes underlie the fill material.

Beneath the Tauranga Group of soils is the Waitemata Group rock consisting mainly of soft

sandstones. Towards the west of the site there is a hidden valley that was part of the erosion topography when the sea was lower during the Ice Age. Figure 1 shows an indicative soil profile along the Britomart Station site.

With the location of the site close to Auckland's waterfront, the existing ground water level is high at Reduced Level +1.0m.

DESCRIPTION OF THE MAIN STATION STRUCTURE

Britomart station is 45m wide, approximately 310m long, and 11m deep from the ground level. There are five rail tracks within the station box. There is also provision for two light rail tracks to be constructed in future. These tracks will ramp up to the surface over the length of the station and pass through the existing CPO building where platforms will be provided. The provision for the light rail has meant that every centimetre of space allowed by the existing Resource Consent has been used.



Photo 1 : View from East End. Bottom up construction in foreground with transition to Top Down frames in the distance.

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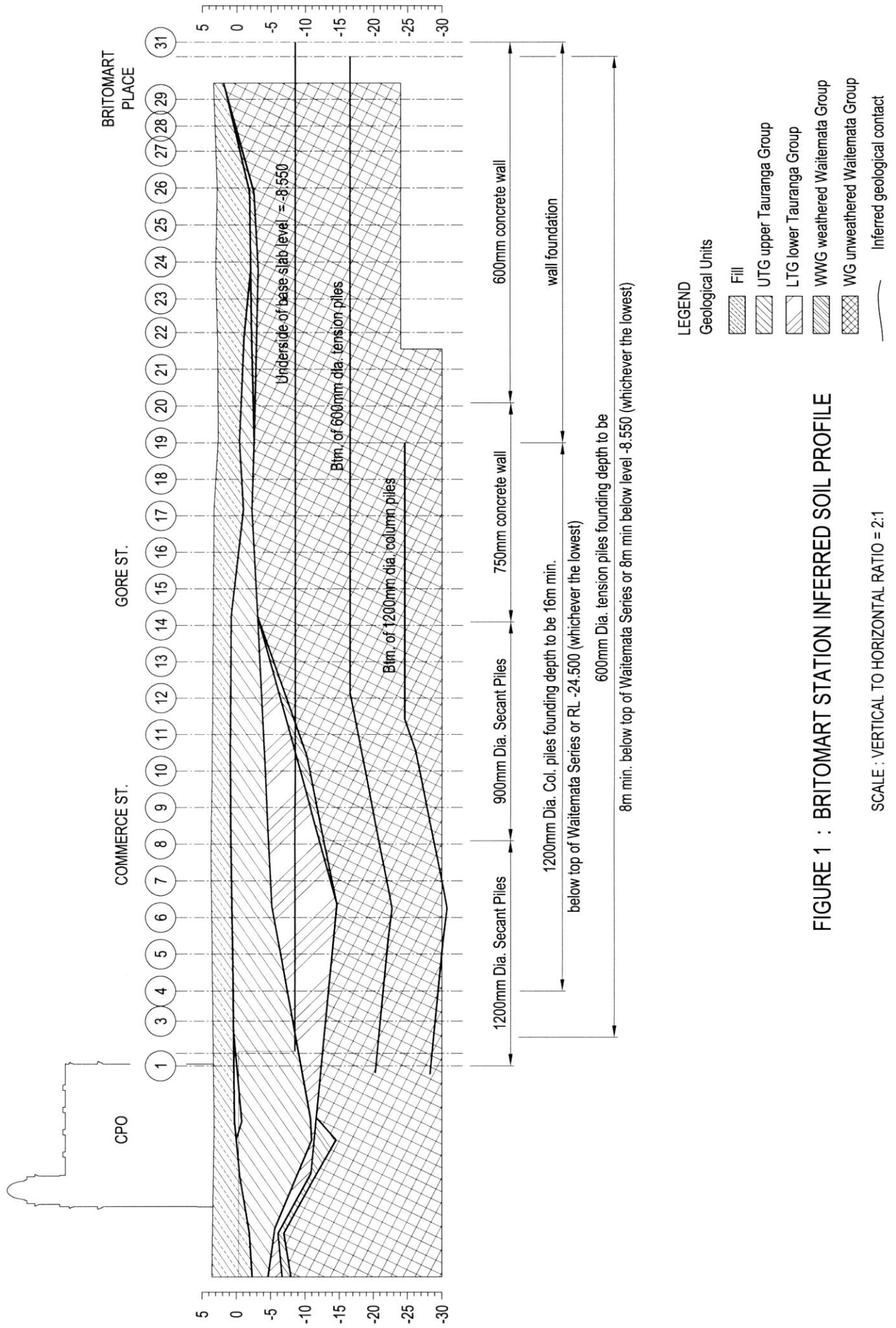


FIGURE 1 : BRITOMART STATION INFERRED SOIL PROFILE

SCALE : VERTICAL TO HORIZONTAL RATIO = 2:1

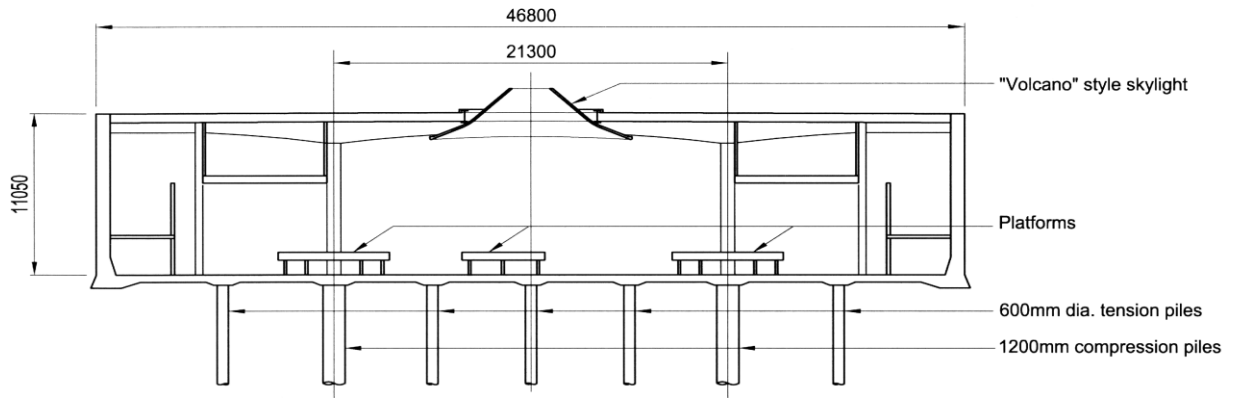


FIGURE 2 : TYPICAL TRANSVERSE SECTION
not to scale
(This Section is in the transition from Top Down to Bottom up Construction)

The structure comprises two distinct structural forms to accommodate the different site conditions:

- (i) At the West End top down construction was used. This comprises secant pile walls (1200mm and 900mm diameter) strutted apart by roof beams prior to excavation.
- (ii) The Eastern part of the site is largely constructed in the Waitemata Group soft rock where sheet pile and temporary rock support works (soil nails) allow bottom up construction using reinforced concrete walls of 600mm and 750mm thickness.

Photo 1 views the station under construction looking from the East End.

Development above the station is planned to allow for up to 8 and 12 storey building construction. By carefully arranging the geometry of the station it was possible to achieve a direct line of support to the proposed development above and also achieve a 22 metre clear span between the main columns as shown in Figure 2. This has achieved a dramatic open space in the main station box and has been enhanced by large 'volcano' skylights in the roof.

ANALYSIS AND DESIGN OF THE STATION

The station structure was analysed using two-dimensional computer models. Several models were developed for specific areas of the station. Analysis models were developed for the 900mm and 1200mm diameter secant pile walls, and the 600mm and 750mm reinforced concrete walls.

Key features of the analysis include:

- Water lateral load and uplift forces are significant. Definition of "normal" and maximum design water levels is a key design input in determining appropriate load combinations and factors.
- At the West End, to avoid disturbance to neighbouring structures, the water level of

the site and surrounding land was required to be maintained throughout construction and the life of the station. In addition allowable maximum lateral movement of the walls was tightly defined (eg 13mm maximum adjacent to the old Central Post Office).

- Provision for 8 and 12 storey building construction above the station in future.
- A site specific seismic appraisal gave a seismic zone factor of 0.4 compared with 0.6 from NZS 4203:1992 (Code of Practice for General Structural Design and Design Loading for Buildings). This represents a significant reduction in the seismic design load.
- Provision for walking and trafficked streets above.
- Careful consideration of construction methods since interim stages of construction are often critical design cases. For example, with top down construction the secant pile walls provide support both during construction and in the permanent structure. Critical design cases for the walls occur before the roof and base slab are fully constructed.
- Consideration of accidental train impact loads and avoidance of progressive collapse. This included accommodating a 1,500kN lateral force up to 1.5m above platform level.

Other features include:

- The station is designed as a watertight structure.
- The station has a 100 year design life.
- Further information on relevant design principles for underground stations are outlined in reference [1].

CONSTRUCTION METHODS

To accommodate the varying soil profile on site (see Figure 1), both top down and bottom up construction methods were adopted

Top down construction

Top down construction was adopted for the west end of the station, adjacent to the CPO, along to Gore Street. Here the unweathered Waitemata Group rock is at a substantial depth. This, combined with the soil movement limits placed on the structure, means the site cannot be excavated to base slab level without the threat of ground movement causing damage to the CPO and adjacent buildings.

The top down construction (refer Figure 3 and photos 2, 3 and 4) involves:

- Building the perimeter secant pile walls.
- Boring the 1200mm diameter compression piles 25-30m below ground level to embed deep into the Waitemata group rock. The top 8m of these piles reduce to 750mm diameter to become the final station columns.
- The 45m long main beams are then poured on top of the compression piles and act as struts to hold the secant pile walls apart when excavation beneath the beams is carried out. The outer part of the roof adjacent to the secant pile walls is also constructed at this stage to act as a waling beam.

The centre part of the station roof is left open until later in the construction process to avoid excavating in a confined space and to allow materials to be moved in and out.

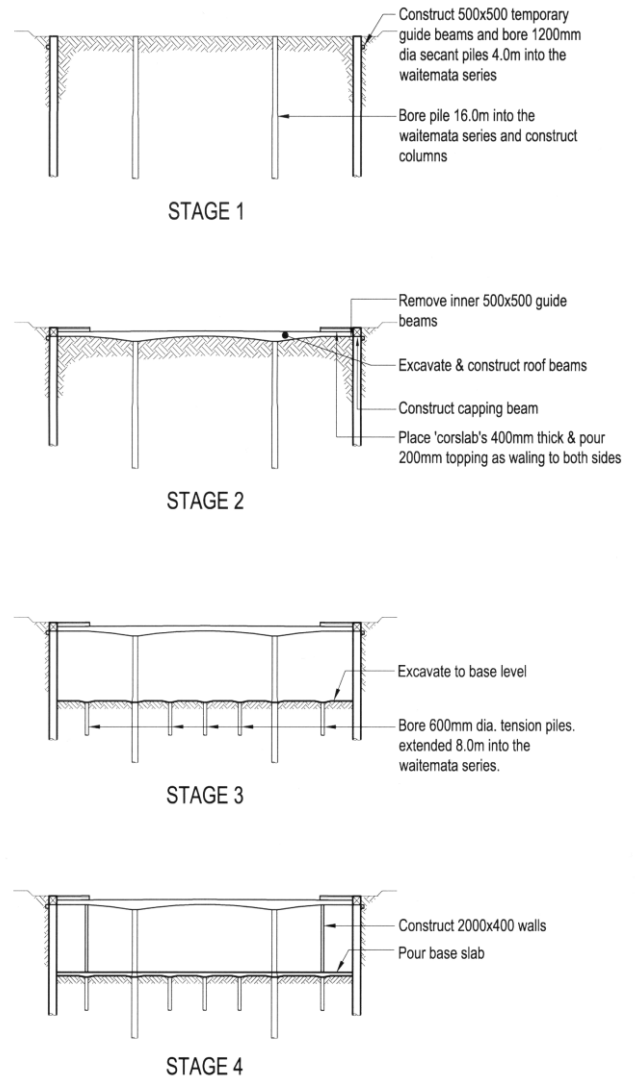


FIGURE 3 : TOP DOWN CONSTRUCTION SEQUENCE



Photo 2 : View from West End. Roof beams cast on ground.



Photo 3 : Transverse view at junction between top down and bottom up construction.



Photo 5 : View of walls and transfer slab after excavation



Photo 4 : View of secant pile walls and frames after excavation.

Top Down Construction adjacent to the CPO

Adjacent to the CPO, the Resource Consent Conditions gave a maximum allowable flexural movement of the secant pile walls of only 13mm. Earlier design solutions to meet this requirement provided 1500mm diameter secant pile walls with 5 levels of ground anchors.

The final design provided for construction of buttress walls beneath a transfer slab at B1 level. The slab transfers the thrust to the buttress walls and side walls of the station box. This allowed the secant piles to be reduced in size to 1200mm. This design also eliminated the need for ground anchors although a temporary tie back of the top of the secant pile wall was required to allow excavation to transfer slab level. Figure 4 shows the construction sequence in detail. Photo 5 also refers.

Bottom up construction

Bottom up construction is used for the east end of the site beyond Gore Street. The base of the station in this section is excavated in the soft rock of the Waitemata Group, allowing excavation using tied back sheet piling for the upper level and soil nails for the lower section. The intermediate floor provides additional strutting across the box to achieve reduced wall thickness. The walls are built using conventional construction methods.



Photo 6 : East End. Bottom up construction within sheet piles

This part of the station tapers to meet the existing two track approach tunnels and also includes a large amount of plant as well as supplementary station access.

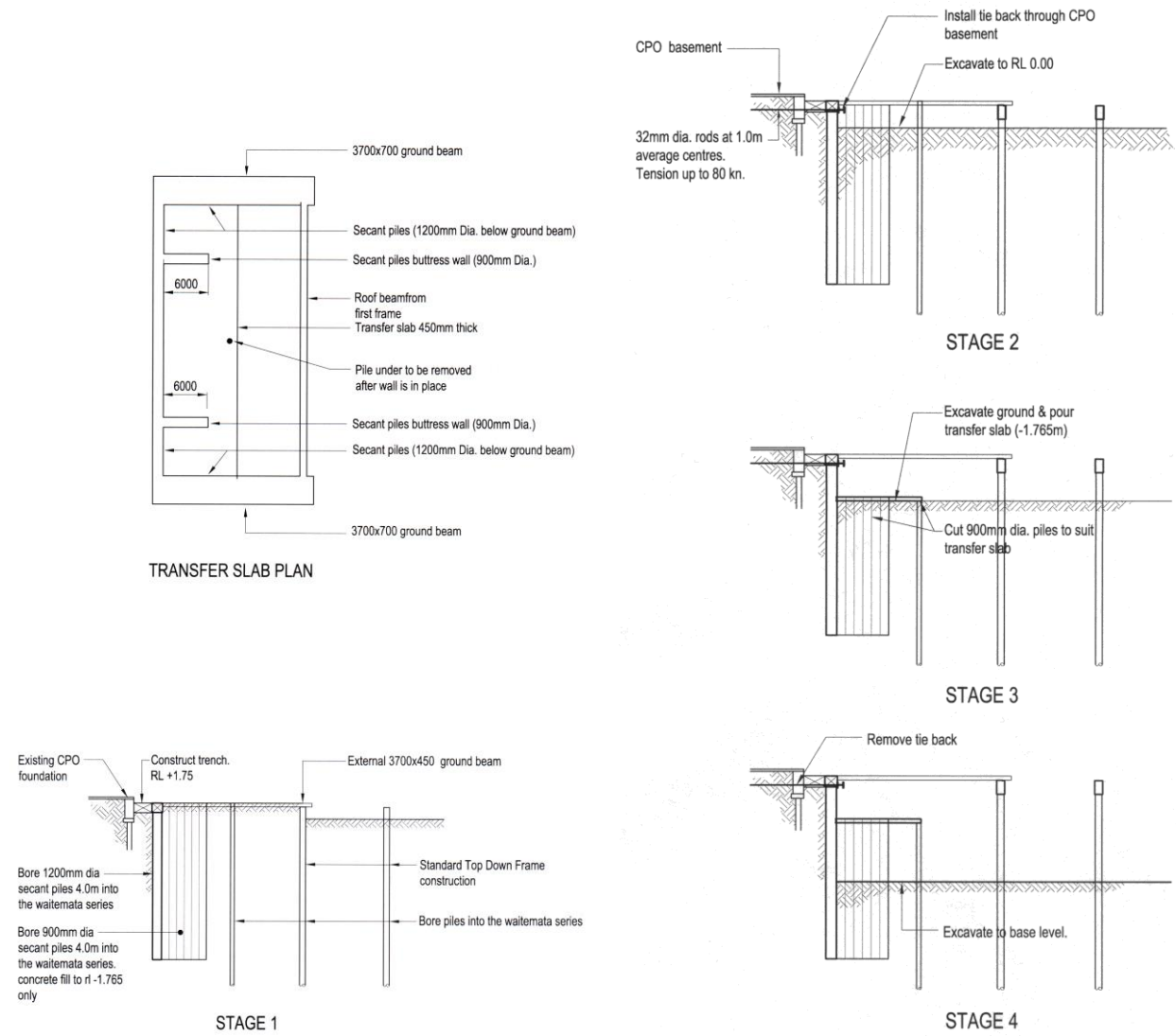


FIGURE 4: CONSTRUCTION ADJACENT TO CPO

BUOYANCY

The station is constructed within 100 metres of the harbour and the groundwater table is within 3 metres of the surface. Resistance to buoyancy is therefore a major consideration. The width of the station means that the contribution of the walls to the overall resistance to buoyancy is relatively low. To compensate, the base slab has been designed to be held down with tension piles into the Waitemata Group rock. The tension piles are to be constructed with a spiral reamed groove on the outside as this is considered to be easier to form than belled piles because of the occasional sandy seams in the rock. Tension piles extend 8 metres into the Waitemata Group rock. Spacing of the piles is 5.5m in both directions. This has the advantage of minimizing the thickness of the concrete base and thus reducing the susceptibility to thermal cracking caused by the heat of hydration.

CONCRETE

Specification and mix design

The concrete industry has indicated an interest in moving to performance based specification to give suppliers more scope to develop innovative solutions to site-specific issues. This project was seen as a prime candidate for a performance-based approach because:

- The combination of concrete characteristics required was demanding.
- The project was undertaken within a partnering framework with high levels of discussion and cooperation.

The maximum compressive strength requirement for most structural purposes was 35 MPa. However, the concrete was to be the principal mechanism of waterproofing, so had to be relatively impermeable and free from thermal and drying shrinkage cracks. The design criteria assumed that the groundwater salinity was equivalent to seawater, so the concrete in contact with groundwater also had to provide resistance to chloride ion penetration to minimise the risk of reinforcement corrosion.

A 100 year design life was required. Exposure conditions in the most corrosive environment were equivalent to the NZS 3101:1995 C zone, but C-zone cover and water to cement ratio requirements would have increased the risk of thermal cracking due to the high cement content this typically demands. To optimise resistance to cracking and to reinforcement corrosion the use of B2 zone strengths with supplementary cementitious

materials (such as silica fume, geothermal silica and slag) was suggested. Cover depths were increased, with cover depths of 65mm (formed surfaces) or 85mm (surfaces cast against ground). This compares with the 40mm minimum normally required in the B2 zone for 40Mpa concrete and a 50 year design life. Provision was made for installing corrosion monitoring systems at critical locations because rebar corrosion would be impossible to detect behind architectural cladding. It was also envisaged that Cathodic protection could be installed in future if required.

Criteria for water resistance, chloride ion diffusion and drying shrinkage could not be specified because they are not sufficiently well-defined to be used for acceptance purposes. Instead, the minimum compressive strength required for structural purposes was specified, the conditions and desired performance characteristics described qualitatively, and suppliers asked to submit data on the performance characteristics of their mix designs to support their proposals. Performance test methods were not specified so that suppliers could utilise existing data, rather than be forced to carry out new tests in a limited time frame. Compressive strength, the only well-defined performance criterion, was to be used for quality control.

A feature of this construction is that the risk of reinforcement corrosion is related to both the ingress of chlorides from the side of the concrete in contact with groundwater, and the evaporation of water from the opposite side. Chlorides will be concentrated at the drying front, the location of which depends on relative rates of water ingress and evaporation and cannot be predicted. The concrete is also likely to carbonate on the station side. Thus, service life predictions from models based on chloride diffusion are not relevant for this environment, although the chloride diffusion resistance of various concretes was compared to demonstrate the benefits of the proposed mix design.

A total of 24 mix designs were submitted for different structural and architectural purposes. Dialogue relating to the submissions was positive with the outcome being a common understanding and mutually acceptable solution. The issues discussed during review of submitted mixes included:

- Risk of alkali aggregate reaction
- Risk of Thaumasite formation
- Use of non-cementitious fillers
- Quality control of shotcrete

- Trade-offs to resolve conflicting needs for long-term durability while limiting the risk of cracking. For concrete that would be exposed to a high corrosion risk, mixes based on slag cement with a w/c of 0.46-0.49 were selected because of their low heat of hydration, and relatively good resistance to the ingress of chloride ions and water. The need for proper curing of this concrete was highlighted.
- Shrinkage compensating concrete in closing pours of floor slabs.

Self compacting concrete

For the construction of the secant piles the contractor used a self compacting concrete mix. This has considerable advantages in the construction of secant piles as it allows full height concreting of the piles from the bottom up in one operation.

On completion of pouring the tremie pipe is removed and the casing is removed without too much difficulty. Ordinary concrete would hang up in the casing. The self compacting concrete, being still fluid, fills the void completely.

Approx 385 secant piles were filled during the construction and only three piles caused problems. In one pile a section of casing was lost and in two others the casing snagged the reinforcement and, as the concrete was still fluid, the reinforcement was pulled out. In one of these cases the whole cage was removed and the pile was re drilled. In the other (as only part of the reinforcement was pulled out), a new pile was drilled behind the old pile and the pile was stitched to old pile as the excavation was carried out.

WATERPROOFING

The principal line of defence against water penetration will be the integrity of the structure. Sound concrete designed for crack control at serviceability loads was the adopted approach. The construction joints will be formed with hydrophilic waterbars and additional hydrophilic material on the outside. Thermal cracking in mass concrete is not expected to be a major problem because walls and slabs have been kept relatively thin and cement contents controlled.

The station box is to be tanked with a bentonite waterproofing membrane (see Figure 5 and Photo 7). This system was chosen because of the self healing nature of the material when damaged. Conventional tanking systems can lead to tracking of the water between the tanking and the structure when the tanking is damaged. With a large

structure under a high head of water, the location of the tracking would be very hard to find and virtually impossible to remedy. Practicality and budgetary restraints have meant that full tanking has not been provided to the secant piles and the base slab. The specified maximum leakage allowed for the secant piles is:

- 13ml per minute through any secant pile joint, and
- 10 cubic metres per day for the whole station (including leakage from all other parts of the work).

Remedial waterproofing will be by grouting or a secondary skin of steel-fibre reinforced shotcrete encapsulating a bentonite seal.

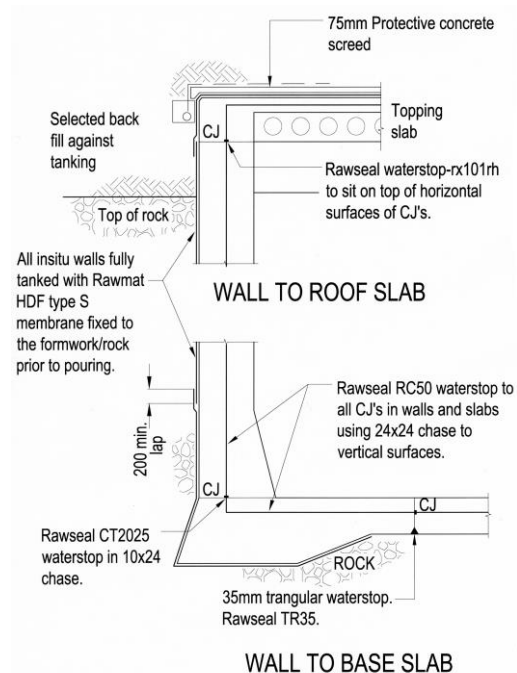


FIGURE 5 : BENTONITE TANKING DETAIL - SECTION



Photo 7 : Bentonite sheet nailed to rock surface prior to reinforcement placement

ECONOMY

The design was carried out within a tight budget regime. The tender for the construction of the underground station including architectural, mechanical and electrical engineering together with track laying and signalling for over 5.4 kilometres of track is approximately \$NZ 100M. About 50% of this sum relates to the station structure.

CONCLUSION

The design of the Britomart underground station has produced a well detailed and economical structure, representing the current state-of-the-art cut and cover construction. The result of the design is a practical and attractive station providing an exceptional large and visually attractive internal space. The design has met the budgetary requirements and the practicality and efficiency of the design has been confirmed by the lack of alternative designs submitted during the tender process.

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- URS New Zealand Ltd (Rail Systems Engineers)
- WT/Barrass (Quantity Surveyors)
- Beca Carter Hollings and Ferner Ltd (Project Managers and Geotechnical Engineers)

REFERENCE

[1] Williams, R. and Chalmers, G., 2000. '*Recent Developments in the Design of Cut and Cover Construction for Railway Tunnels and Stations*', RTSA Conference on Railway Engineering, Adelaide, Australia.