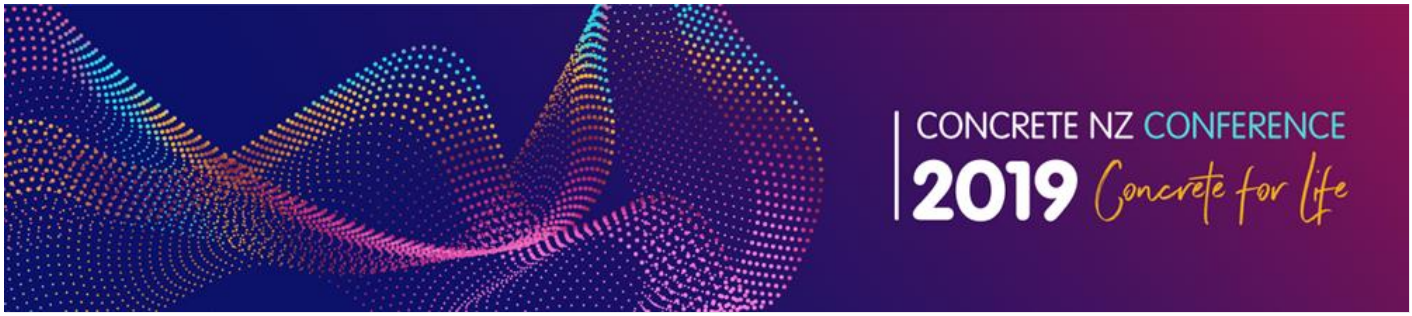

COMMERCIAL BAY AND THE CITY RAIL LINK – THREADING RAIL TUNNELS BENEATH AUCKLAND'S LARGEST MIXED-USE COMMERCIAL DEVELOPMENT

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SUMMARY

The Commercial Bay project involved the major redevelopment of an entire city block in lower Queen Street, Auckland. The Commercial Bay site incorporates two underground rail tunnels for the City Rail Link (CRL) project, delivered as part of the Commercial Bay development under an agreement permitting the tunnels to pass through the site.

The design and construction of the CRL tunnels through the Commercial Bay site was a key component of the project. The alignment of the CRL could not avoid passing through the Commercial Bay site and this had a significant impact on the design and construction of the basement and building structures above the tunnels.

This paper discusses the design, detailing and construction of the CRL tunnels within the Commercial Bay basement, challenges with tunnel design requirements, coordinating and fitting these beneath and around a large multi-story commercial office tower development.

INTRODUCTION

Commercial Bay

Commercial Bay is a major mixed-use retail and commercial office development undertaken by Precinct Properties in Auckland. The site comprises the city block bounded by Queen Street and Lower Albert Street, Quay Street and Customs Street West.

The development includes a new 39 storey commercial office tower, multi-level basement with carparking, multi-level retail podium at the base of the tower and redevelopment of existing buildings adjacent to the main site (Figure 1).

City Rail Link

The City Rail Link (CRL) is a major investment in public transport to provide two new underground railway tracks from Britomart Station to Mount Eden Station.

The CRL tunnels extend from the Britomart Station, passing beneath Queen Elizabeth Square and the Commercial Bay development site before heading up Albert Street. Tunnels beneath the Commercial Bay site link with adjacent sections of the CRL which are designed and constructed by other parties.

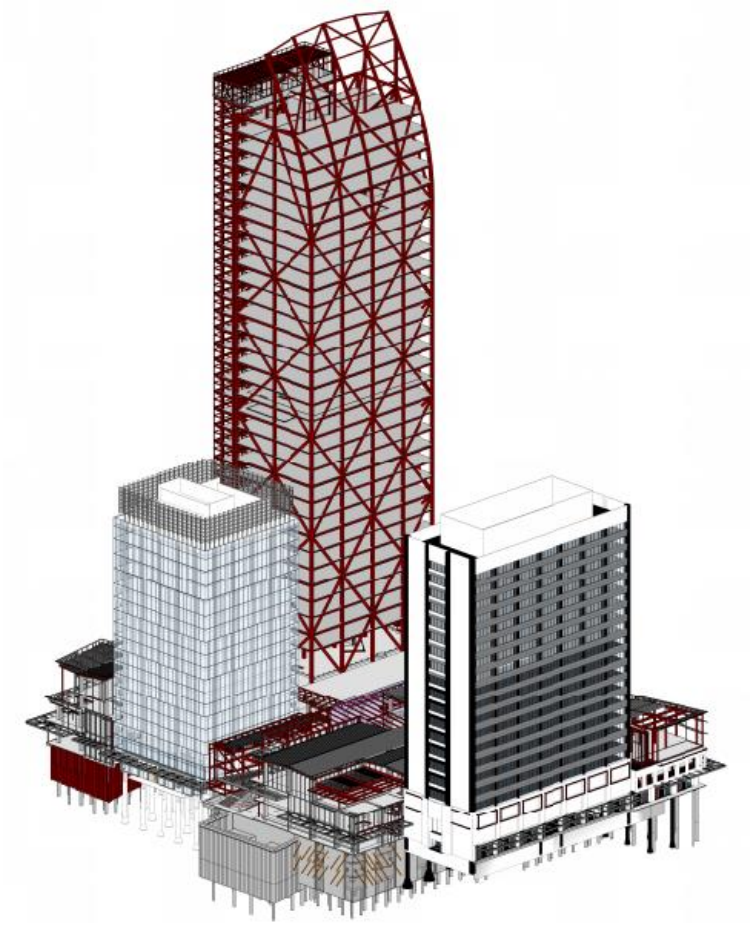


Figure 1 Commercial Bay structural model showing existing adjacent buildings within the development

The two underground tunnels are relatively close to the surface, with the alignment of the rail tunnels essentially fixed. Accordingly, the CRL tunnels had to be incorporated into the design of the Commercial Bay basement, including the significant impacts on the new commercial office tower foundations and new retail podium buildings above.

GENERAL DESCRIPTION OF THE CRL TUNNELS

The CRL tunnels through the Commercial Bay site comprise two “cut and cover” single box structures. The tunnels run from the eastern side of the site beside lower Queen Street and converge, forming a double box tunnel, toward the south western corner of the site. Figure 2 shows the plan alignment of the CRL tunnels through the Commercial Bay site and relative locations of existing and new buildings that were influenced by the CRL tunnel location and/or construction.

The CRL tunnels comprise a reinforced concrete tunnel box, constructed within the Commercial Bay basement area, essentially as a “box within a box”. The CRL tunnels are structurally independent of the Commercial Bay basement structure and isolated with respect to potential noise and vibration effects. Figure 3 shows the general cross sections of the CRL tunnels through the Commercial Bay basement.

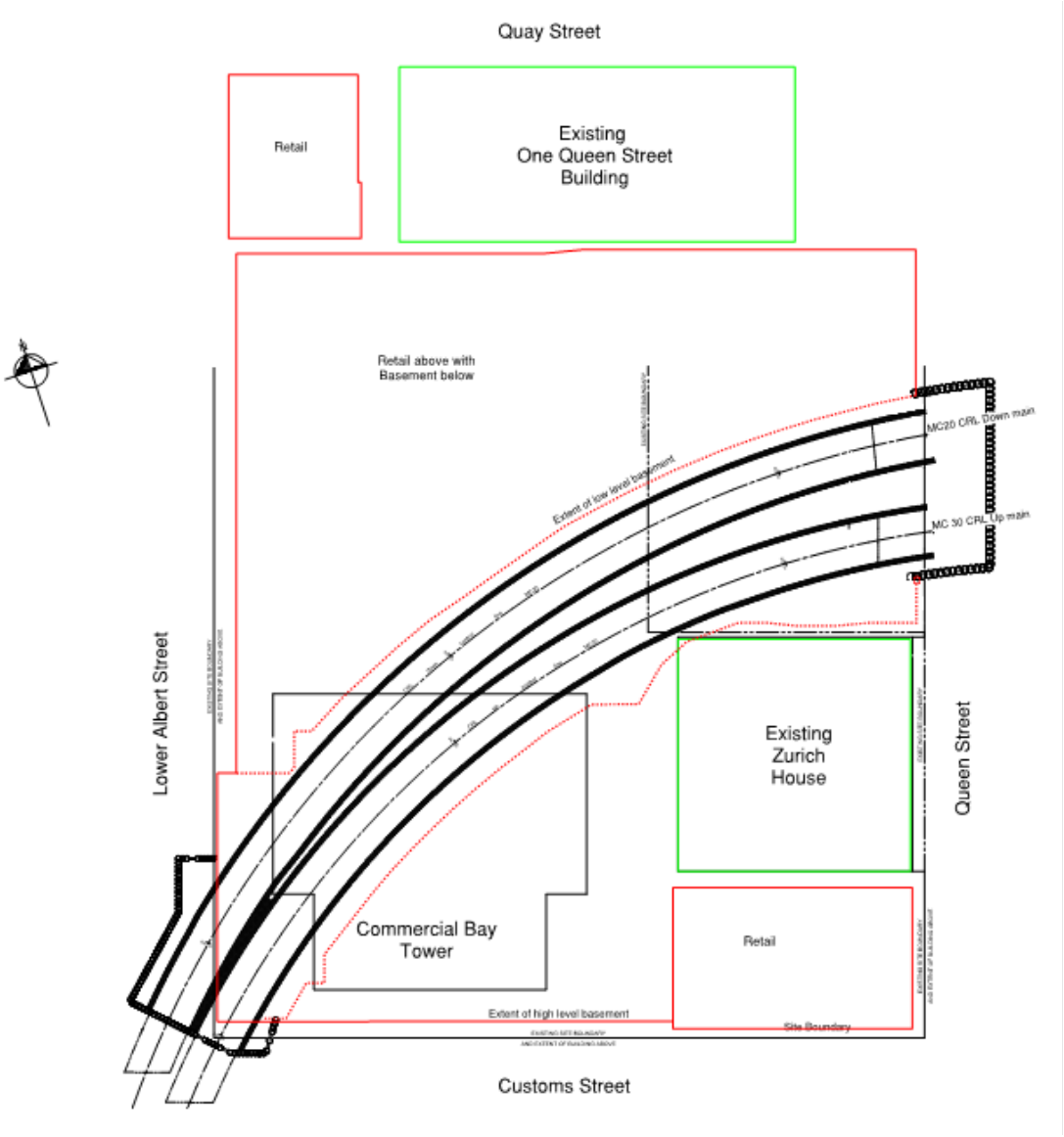


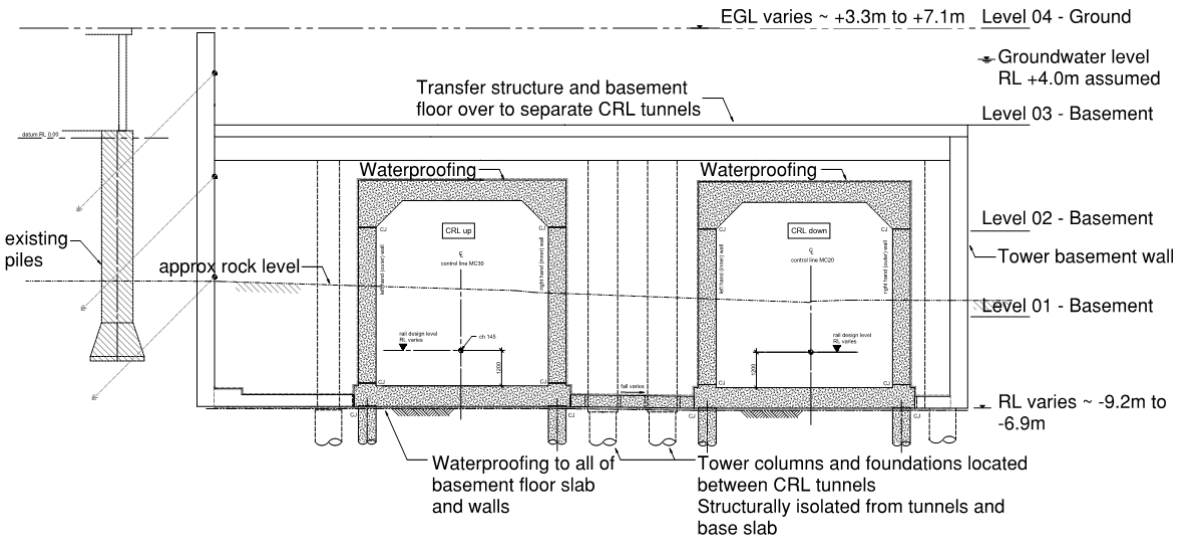
Figure 2 CRL alignment through the Commercial Bay development site

Coordination of the CRL tunnels with the structures above required coordination of column positions as they came down into the basement area. Columns from the Commercial Bay tower above had to be located between the tunnel structures, founded on piles positioned below the base of the CRL tunnels. In other areas, transfer beams and floor structure above were required to span over the CRL and transfer building loads to retaining and/or internal walls separating the CRL tunnels from the general basement areas.

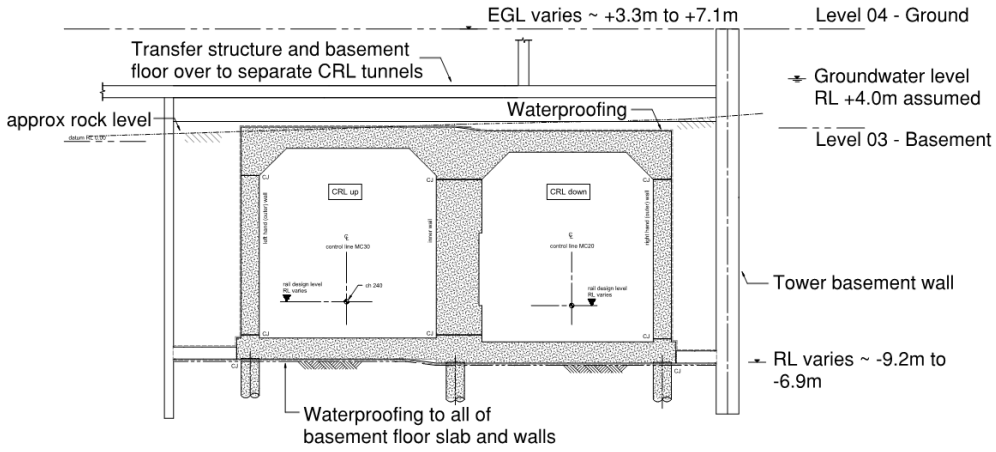
SIGNIFICANT DESIGN FEATURES

CRL Tunnels

Design and construction of the CRL tunnels within the Commercial Bay site was in accordance with the requirements of the Reference Design, originally prepared by Auckland Transport. The CRL rail alignments were fixed by the Reference Design, along with prescribed minimum internal space proofing requirements for the tunnel. The physical CRL tunnel structure outside this space proofing envelope was to be determined by the design team (noting the constraints of wanting to maximise the Commercial Bay development GFA, the proximity to Zurich House, and maintaining adequate noise and vibration separations).



a) CRL tunnels single box general arrangement



b) CRL tunnel double box general arrangement

Figure 3 CRL tunnel general arrangement

The tunnels were designed and constructed from reinforced insitu concrete typically comprising of 600mm thick walls with 700mm thick roof and floor slabs. Concrete hold down piles, 600mm diameter, at nominally 8 m centres to the outer walls and 4 m centres to the inner walls, were used along the tunnel length.

Significant design features of the CRL tunnels included:

- designing for high buoyancy effects on the CRL tunnel boxes, due to groundwater uplift pressures (especially considering the future rise in water table and potential storm surge effects)
- cast in-situ heavily reinforced concrete box construction methodology with the potential for concrete creep/shrinkage, heat of hydration issues with large/thick concrete pours and potential for long term concrete cracking
- constructability issues related to proximity, construction sequencing and coordination with over site development column/pile locations, transfer beams and walls.

- detailing of tension piles required to resist the uplift caused by buoyancy
- vibration and noise separation of the CRL from the adjacent structures
- waterproofing of the basement slab and tunnel boxes
- designing for a future backfill case in the event the surrounding development was demolished, and the site filled to existing ground level.

Commercial Bay Basement

The Commercial Bay development contains a three-level basement to the North of the tunnels, (up to 12 m below ground level) and a single storey basement to the South of the tunnels. The site contains a large portion of historically reclaimed ground, with rock located towards the top of the tunnel at the South-West corner of the site and towards the bottom of the tunnel on the East-side of the site. The site is tidal with the existing ground water level being approximately 2m below the existing ground level.

The basement provides three levels of carparking and interconnection between the adjacent existing building basements as part of the overall development. The basement also serves as a podium structure for six new retail buildings, typically 4-storeys tall located around the base of the tower. With the CRL tunnels passing through the basement volume, this impacted the usable space within basement area for the commercial development. The arrangement of vehicle access ramps and service areas such as the truck loading dock were configured within the available basement volume. Multiple levels were also required, within a single basement floor, to satisfy architectural and structural requirements which significantly complicated floor diaphragm design and details.

Deep excavations were required to form the basement for this development. Due to varying conditions around the perimeter of the site, different retaining solutions were required. Specific considerations were depth of rock, proximity to the boundary and adjacent structures, level of water cut-off, and final wall finishes.

Diaphragm walls are used to retain the north, east and south-east extents of the basement. Immediately to the north and to the south eastern corner of the basement, the diaphragm walls are constructed immediately adjacent to, and retain the existing foundations of One Queen Street (formerly HSBC House) and Zurich House. Temporary ground anchors were installed during excavation and later destressed as basement floor construction was completed which provided the permanent propping restraint to the wall. Permanent ground anchors remain in place adjacent Zurich House.

To the west, sheet piling was used to retain the reclaimed material above the bedrock, before construction of the permanent reinforced concrete basement wall. Sheet piling, through the reclaimed material was also used to support excavations and provide formwork for the reinforced concrete wall construction for shallow (single level) basement areas.

Secant piling was used at the heads of the tunnels to temporarily retain excavations and allow for the staged construction of the CRL tunnels. As the Commercial Bay construction programme was ahead of construction of the adjacent sections of the CRL, this temporary retaining had to be in place and allow for the adjacent sections to be constructed and subsequently broken through to link the tunnel sections.

GEOTECHNICAL CONDITIONS

Soil conditions vary across the site but are typically a mixture of weathered East Coast Bays (ECBF) soils or uncontrolled fill lying above the East Coast Bays formation layers.

The ground water varies across the site from sea level at the waterfront, to RL+1.0m across the centre of the site to RL+1.5m to RL+2.0m on Customs Street. The 100-year storm tide is RL+2.36m, and an allowance of 0.4m sea level rise over 50 years is included in the design. The Reference Design specified for uplift/buoyancy the water level shall be taken as the highest recorded ground water level i.e. RL+2.0m plus an additional 2m.

For the purpose of design of the CRL tunnels, through the Commercial Bay site, the ground water level was taken at RL +4.0m. The underside of the tunnel base slab was located at ~RL-9.2m at the Queen Street end, rising to ~RL-7.0m at the Albert Street end.

Large diameter bored reinforced concrete piles, up to 2.4 m diameter for the highest loaded office tower columns and 600 mm diameter for the CRL tunnels were used. All piles for the Commercial Bay development and the CRL tunnels were founded in the ECBF with a grooved rock socket to minimise pile embedment depths.

DESIGN STANDARDS AND REFERENCES

The CRL tunnel design was based on requirements from NZS 1170.5, NZS 3101 and the NZTA Bridge Manual (3rd Ed, amendment 2). Additional guidance was taken from the KiwiRail Rail Design Brief (for rail/rail impact loading), UK Highways Agency documents (for design of buried concrete box structures) and CIRIA C660 (for early age thermal crack control).

The CRL tunnel design is based on a 100-year design life, as is normal for infrastructure projects. The increased design life and corresponding loadings due to wind/earthquake etc required that the Commercial Bay Tower was designed for the equivalent level of loading. This effectively required an Importance Level 4 level of loading for the Tower's lateral load system, based on a 50-year design life. For the purposes of consideration of loading, the CRL tunnels were considered as Importance Level 3 in accordance with AS/NZS 1170.0:2002.

CRL DESIGN CASES

Case 1 – As developed case (within site boundaries)

Within the Commercial Bay site, the CRL tunnels are independent of the adjacent basement structure and foundations, as shown in Figure 3. The CRL tunnels contain their own foundation system, to resist imposed gravity loads and buoyancy uplift effects, and the box form of the tunnel structures forms their own lateral load resisting system.

All gravity loads from the Commercial Bay structures are transferred around the CRL tunnels, to independent foundations. The area surrounding the CRL tunnels is to remain unfilled and the basement structure directly adjacent the CRL tunnels is 400mm thick concrete, to mitigate against any noise or vibration transfer effects into the structures above. This design case scenario effectively results in independent reinforced concrete tunnel box structures.

Case 2 - Decommissioning case and sections beyond the site boundaries

As per the Reference Design requirements, the CRL tunnels through the Commercial Bay site were required to consider the potential de-commissioning of the structures above and surrounding the CRL, during the operational life of the CRL.

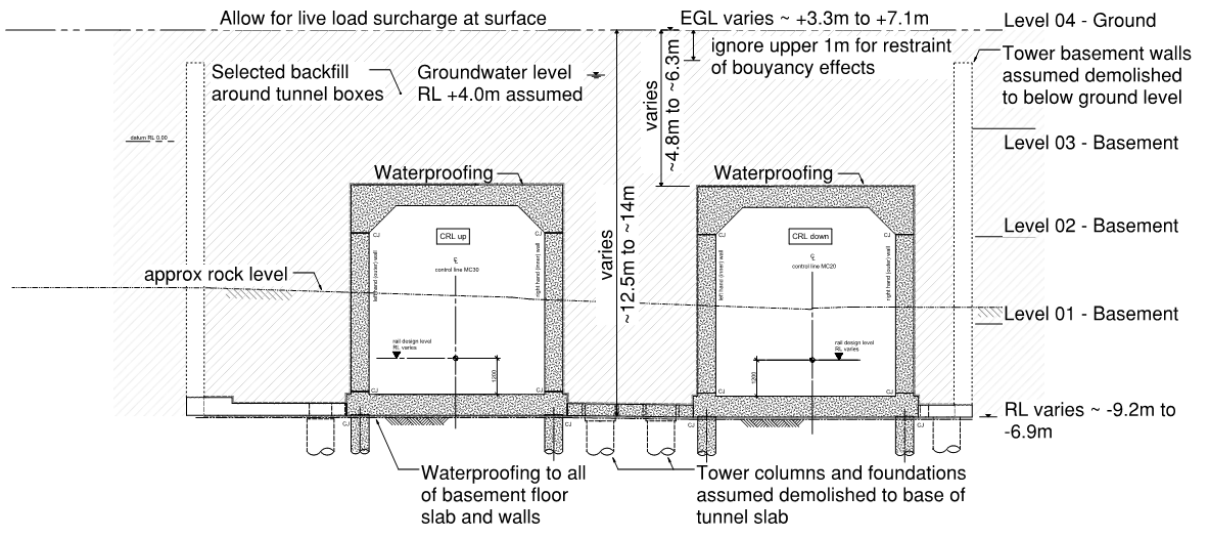


Figure 4 CRL tunnel schematic for Case 2 design scenario

This design scenario assumes the decommissioning and removal of the over site development structures and backfilling the area around and above the CRL tunnel structures to existing ground level as indicated in Figure 4. This design scenario does not include for construction of further superimposed building structures over or adjacent to the CRL tunnels – independent building foundations, to transfer loads and not impose these on the CRL tunnel structures, would be required.

Design allowance for a live load surcharge above the CRL tunnels was included in this design case, representing potential road traffic and/or loadings to general open public space.

This design scenario is also representative of parts of the structure to be permanently buried including portions of the CRL tunnels beyond the Commercial Bay site boundary at the interface with the adjacent sections.

FUNCTIONAL REQUIREMENTS

Internal Clearance Envelope

The tunnel internal clearance envelopes were prescribed in the Reference Design. The final design allowed for an additional nominal 20mm clearance all round, as an allowance for potential negative construction tolerance and any self-weight deflections of the CRL structure, outside of the Reference Design envelope.

Each running tunnel, as it passes through the Commercial Bay site, follows a constant horizontal radius curve, but they are different for each tunnel. The vertical alignment is also different for each tunnel and varies along the length. Further complicating this were required variations to the cross-sectional width of each tunnel box, to suit the rail clearance envelope and to minimise the impacts of the tunnel and tunnel construction on the existing foundations of Zurich House immediately adjacent.

It was desired to construct the tunnels using standardised formwork wherever possible. Segmented wall forms, to fit the required internal and external tunnel wall radii were made, with provision to adjust the set-out locations at the ends of the formwork modules to create the tapers and variations in the tunnel widths. This setout was checked and confirmed to ensure it complied with the internal clearance envelope and the construction tolerance allowance was not reduced.

Where the two tunnels merged to form the double box arrangement, polystyrene fill was used between the walls, where the spacing would not allow for placement and removal of the external wall forms.

Construction around Tower Columns

The transition between separate tunnel boxes to a combined double box arrangement occurs at a critical location for coordination of the CRL and setout of the Tower building above. Two Tower columns are positioned directly between the two tunnel boxes.

The Tower columns were constructed below the base of the CRL tunnels. Large fabricated steel box sections were plunged into the pile foundations to construct the Tower columns. Permanent steel forms were placed around the Tower columns to allow construction of the central tunnel wall and roof slab and create the necessary void around the building columns. The base and roof slab of the tunnels were constructed up to the face of the columns, with the necessary minimum structural clearance, allowing for waterproofing and separation for mitigating noise/vibration transfer.

Tie in-to adjacent Sections of Tunnel

The CRL tunnels adjacent to the Commercial Bay site have a similar design but with some minor cross-sectional differences. As design and construction of the Commercial Bay portion of the CRL tunnels was completed before the adjacent sections, allowance had to be made for connecting the sections together. Coordination of construction details, with the two adjacent sections being delivered by different parties. This included agreement as to the set-out of the transition point between the tunnel sections.

The Commercial Bay portion of the CRL tunnels have additional depth, compared to the adjacent sections of the tunnels, to allow for installation of potential vibration isolation measures, as the tunnel runs beneath the office/retail development. The base slab transition had been accommodated outside of the Commercial Bay section of the CRL tunnels. Reinforcing bar couplers were incorporated into the ends of the tunnel wall and slab sections to allow for the adjacent section of the CRL to connect into, once they had broken through the temporary secant pile retaining walls at each end.

Hold Down Piles

Adjacent sections of the CRL tunnels are buried beneath existing roads and/or building foundations. The portion of the CRL passing through the Commercial Bay development site was to be constructed within the basement area and would not be backfilled. The surcharge of fill material above the tunnel boxes was not available to counteract the significant uplift buoyancy pressures acting on the base of the tunnels. With the need to waterproof the volume around the CRL tunnels, as it passes through the Commercial Bay development site, the basement slab between the tunnel boxes also had to be designed for the uplift pressures.

Hold-down piles were provided to each of side of the tunnel boxes, and the basement slab between the tunnels was designed to span transversely between the tunnels. The piles had to transfer the tension loads from the piles up into the walls of the tunnel. Reinforcement had to extend up out of the piles and lap with wall vertical reinforcement.

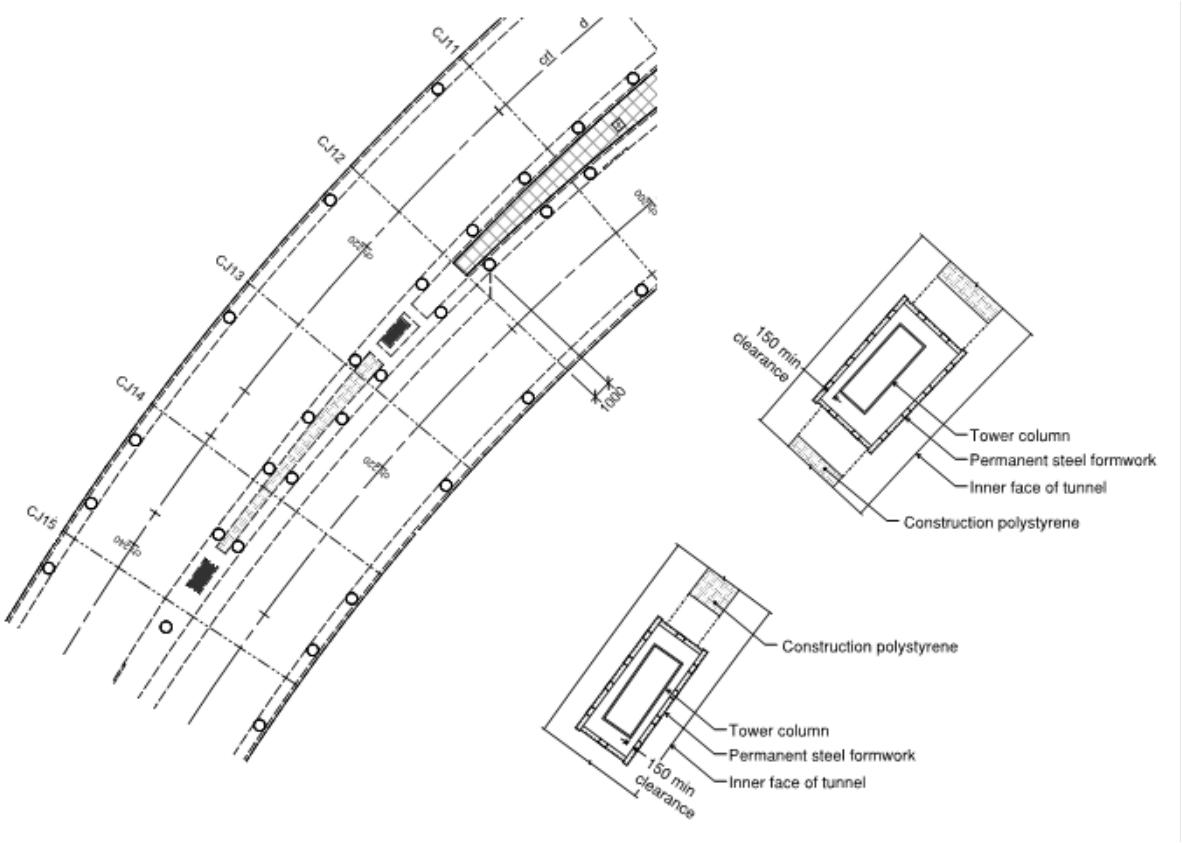


Figure 5 Transition to double box arangement and construction around OSD columns

As the piles and tunnel walls were the same dimension, there was the potential for reinforcement congestion and/or issues with piles being constructed out-of-position. A large diameter single central high tensile reinforcing bar was initially proposed to be positioned centrally in the pile and wall. It was proposed to stress this bar to counteract the tensile load in the pile and limit the potential for cracking across the pile to tunnel base connection.

An alternative detail, using six 40 mm diameter Grade 500 reinforcing bars was adopted in the final design, arranged such that they could be plunged into the tunnel pile, immediately after it was cast and positioned appropriately to match the tunnel wall set-out.

Construction Issues

Tunnel construction through the basement commenced at the Queen Street boundary progressing across the Commercial Bay site toward Albert Street. Tunnel and building pile foundations were constructed in advance of the tunnel and basement slabs. Starter bars from each pile into the tunnel wall were left projecting to be incorporated into the tunnel wall pours. Working space for the tunnels was very constrained, working within the building basement as both the tunnels, basement and tower construction was proceeding concurrently.

Extensive tanking and waterproofing details to the CRL tunnels were required to meet the Reference Design requirements, which had to be placed below the base slab and protected during construction. Waterproofing was also specified to the outside of the tunnel walls and roof slab, which was applied after the tunnel box cross section was complete.

The tunnel walls were cast in segments up to 8m in length. The tunnel wall forms were based on a series of straight lengths, to match the continuous radius. The design considered the

straight form, however on-site we found times where this meant there was difficulty in achieving the specified concrete cover and effectively preventing grout loss, especially where the alignment of the base nibs varied from the wall shutter lengths.

Complicated reinforcing detailing, particularly in the wall-roof junction, took some time to establish an appropriate fabrication sequence for the cages. The weight of reinforcing cages resulted in the use of long concrete strips in place of plastic chairs to support the base slab and roof cages. Where these were used in the internal roof areas of the tunnel this resulted in different colour concrete patches and some areas where grout had not penetrated requiring minor remedial work to achieve the required specified finish.

Concrete delivery issues were encountered throughout construction of the tunnels due to the stresses on the construction market. The consistency of the concrete mix varied, as indicated by variance in concrete slumps across pours and individual truck loads due to a range of mixing times resulting from delivery times / delays. This also led to some issues with pumping of the concrete into place on site. The tunnel concrete mix design also contained polypropylene fibres, to limit spalling of concrete in the event of a tunnel fire, further complicating concrete mix consistency issues.

With limited access to vibrate concrete, particularly in the wall forms, and difficulties in formwork fit-up/sealing at the base, resulted in some areas of grout loss requiring break-back and remedial work to meet design specification.

During construction some of the wall sections developed cracks (0.3-0.35mm) that were greater than the maximum limit of 0.2mm. This required attention during the construction phases and remedial work to meet design specification. The crack patterns were seen to closely match the theoretical crack patterns expected, however it varied as there were fewer, wider cracks at greater spacings than anticipated from the theoretical calculations. Cracking was evident in many of the wall sections, but not present in all. The cracking may have been exacerbated by many things, but it was hard to find a consistent reason (i.e. where ambient temperature differences were the most varied, the cracking wasn't seen to be any worse, despite unchanged concrete mix and reinforcing remaining the same). Additional reinforcing was added the walls, but it was found that this had little effect on the crack patterns and widths.

Despite the issues encountered during construction, these challenges were successfully addressed and overcome ensuring the completed structure meets all design specification requirements.

CONCLUSION

Commercial Bay and the City Rail Link (CRL) represent a significant investment in commercial property and public transport infrastructure development in downtown Auckland.

Redevelopment of an entire city block combined with the CRL tunnels passing directly through the Commercial Bay site created a number of design and construction issues to be resolved. The CRL tunnels pass immediately adjacent to existing building foundations, which had to be retained and supported and required the transfer of columns from the building above to position foundations clear of the tunnel alignment.

Challenges in the design, detailing and construction of the project have been successfully met. The CRL tunnels through the Commercial Bay site have been completed and joined into the adjacent sections of tunnel. The basement, retail buildings and tower are structurally complete, with most of the development due to open in early 2020.