



UNDERPINNING OF AUCKLAND'S CHIEF POST OFFICE BUILDING

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SUMMARY

The Chief Post Office (CPO) building was built in 1912 and occupied by the NZ Post Office until the early 1990s. It was later converted into Auckland's Britomart Transport Centre in 2001 where the city's commuter train services currently terminate. Two decades later, it has undergone another transformation as part of the city-changing City Rail Link (CRL) project.

Construction of twin rail tunnels beneath the Category 1 heritage CPO building in one of New Zealand's largest railway stations presented major challenges for CRL delivery. These challenges led to several NZ first innovations, including the underpinning of the CPO building.

The primary objective of the underpinning works was to take approximately half of the gravity load of the building from existing foundations and transfer it onto new concrete diaphragm walls (D-walls). This operation was necessary to allow the existing foundations to be removed for the construction of the rail tunnels themselves.

Once the tunnel was constructed, the building load was transferred off the temporary works and onto new foundations on the tunnel roof and back into the D-walls. Approximately 6,000 tonnes of building load (close to half the weight of the entire building) was incrementally transferred without impacting the building's structural or architectural integrity - a feat of delicate engineering not seen in this country before.

PROJECT DESCRIPTION

Auckland's top transport priority, the CRL project includes the design and construction of a 3.4km double-track underground rail line from Britomart Station through the CBD to connect with the existing western line at Mt Eden station.

In 2016, the Downer NZ and Soletanche Bachy JV (DSBJV) was awarded CRL Contract 1 (C1), an enabling works contract at Britomart. The design was managed by a team comprising CRL, Aurecon, Grimshaw, Mott Macdonald, Jasmex, and Arup, working very closely with DSBJV.

CRL C1 includes construction of tunnels from Britomart Station, westwards underneath the CPO building and lower Queen Street, connecting to cut and cover tunnels in Albert Street

delivered under Contract 2 (C2). However, the new tunnel clashed with the building’s existing foundations.

This article outlines the main steps that enabled the construction of these tunnels including:

- Construction of the diaphragm walls and jet grouting that served as new foundations for the building
- Construction of the permanent and temporary underpinning structures
- The load transfer from the existing to the new foundations
- The construction of the tunnels
- The release of the temporary underpinning structures

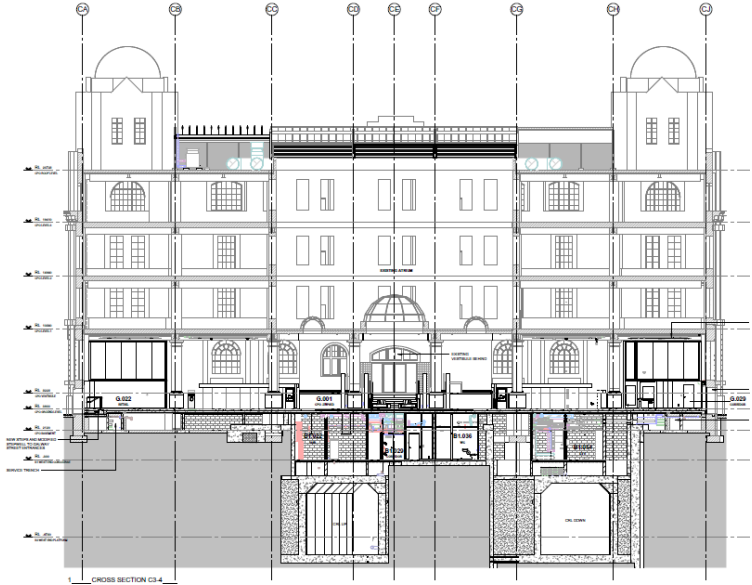


Figure 1: CPO Building with twin rail tunnels constructed underneath

During the works, the behaviour of the building was monitored very closely to ensure that the load transfer activity was conducted with precision, without impacting the building’s structural or architectural integrity. Monitoring prisms were installed throughout the building and continuously monitored over the duration of the project. Real time movement of the building during the load transfer was also monitored using traditional survey techniques to ensure that the building was not ‘lifted’ during the load transfer by more than 3 millimetres.

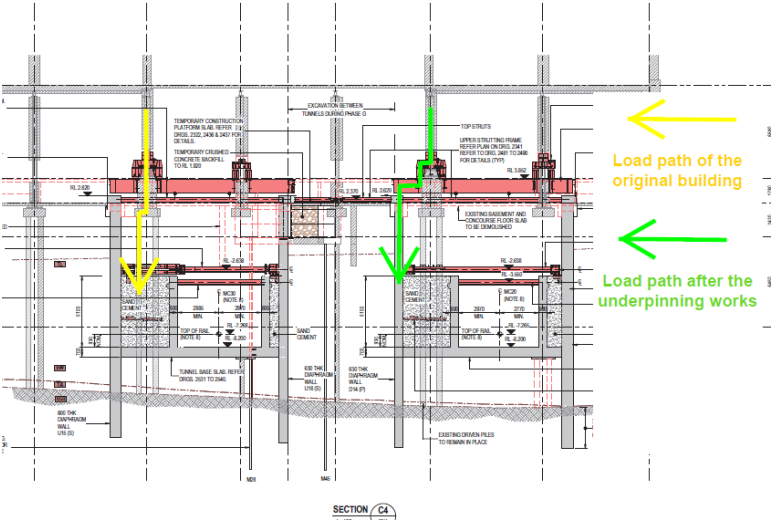


Figure 2: Original vs Underpinned Load Paths of CPO Building

DESIGN CONCEPT

Extending the railway from Britomart Station required the construction of two shallow tunnels below the CPO building. The tunnel alignment clashed with the driven piles supporting twenty building columns and the façade walls on the eastern and western sides. However, in recognition of the CPO building’s heritage value, the visible sections of the façades, upper floor levels and tiled vestibule had to remain undisturbed throughout construction. In addition, the high water-table and soft ground conditions on reclaimed land heightened the risk of ground movements affecting the CPO and surrounding properties during excavation.

To address these constraints, the tunnel design utilised a cut and cover sequence, whereby the building was first underpinned before excavating within a water-tight cofferdam. This required significant temporary works to be undertaken within the confines of the CPO building.

The construction sequence began with the demolition of the ground floor slab, followed by D-Wall installation from basement level. Subsequently, underpinning frames were installed to support the existing columns and walls and transfer loads onto the D-wall. During excavation, the existing foundations were demolished leaving the CPO structure suspended over the cofferdam. Two levels of steel strutting were installed to reduce wall deflections and internal forces. The top strutting level ran between the tunnels to prevent racking towards the central column of remaining ground.

Following excavation, the tunnel boxes were constructed bottom-up. The tunnel boxes re-supported the building columns and spanned the D-walls each side. This approach allowed the temporary underpinning frames to be removed, enabling re-construction of the ground floor and new basement space.

CONSTRUCTION OF PERMANENT STRUCTURES

The following sections of this paper describe the major phases of work required to tunnel under the CPO building, including D-wall construction, underpinning of the building foundations, and tunnel box construction.

Diaphragm walls (D-walls)

The overall D-wall is made of 64 panels, varying in width from 2.8m to 5.2m, approximately 17m in depth (3m socket into rock). These were drilled with two different thickness; 630mm and 800mm (approximately 50-50 difference in thickness).

Excavation and drilling of the D-walls was carried out using a Hydrofraise Compact HC05 last generation machine. The machine was equipped with a detachable power-pack which was positioned on a crawler and connected by an umbilical to the drill. This was due to the column orientation highly constraining the machines movement around the CPO ground floor.

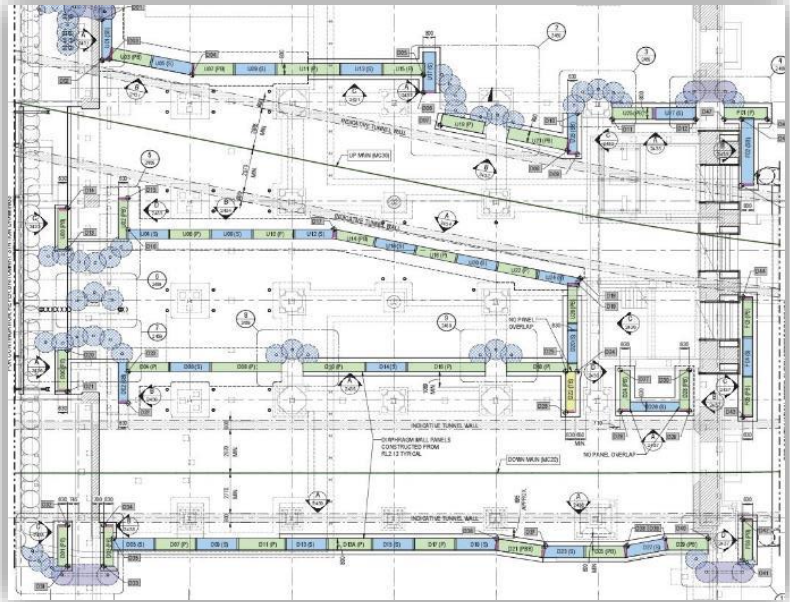


Figure 1: CPO D-wall panels



Figure 4: Hydrofraise D-wall machine (left). D-wall Power Pack detached (right). The Hydrofraise compact was the only machine capable of constructing the D-walls inside the building and was the first time this equipment was used in New Zealand

The 64 concrete panels were poured using a tremmie mix with design strength of 40 MPa at 28 days. The average concrete volume for each panel was 45 m³. Pours were completed in approximately 2- 3 hours. Given that most of the pours were constructed inside the CPO building, it was not possible to use the traditional D-Wall method of pouring straight out of the truck. Due to the limited 7 m headroom, DSBJV worked with Allied Concrete on a pumped tremmie concrete mix design with 3-4 hours workability.

The initial D-wall design included a double row of 40mm diameter longitudinal reinforcing steel. A construction review identified a bar congestion and constructability risk associated with the number of manual interventions inside suspended cages. This led to the design of a single row of high strength 50mm primary reinforcing bar, a first for New Zealand. New procedures for manufacture and testing were developed while keeping to programme and maintaining a minimal carbon footprint.

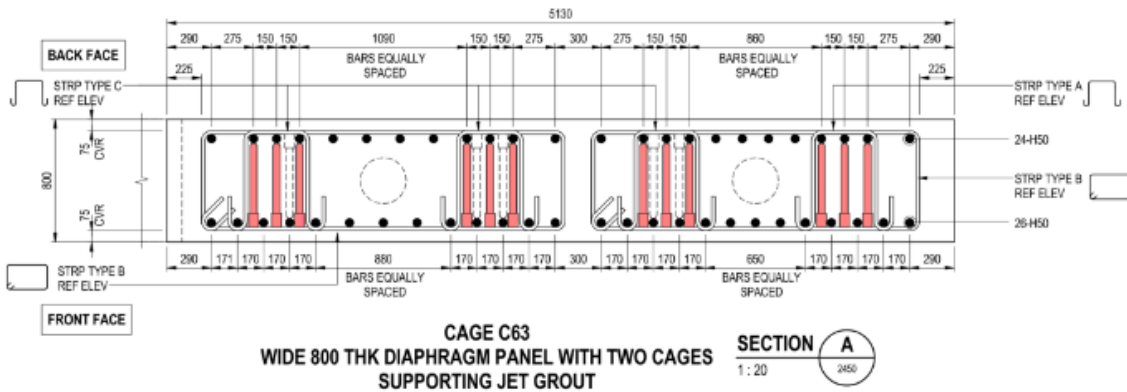


Figure 5: Section of D-wall showing single row H50 bars, each face.

Jet Grout Arches

To create the arches between the D-wall panels and complete the temporary retaining structures, DSBJV used a jet grouting method as the Hydrofraise was not able to access certain areas due to space restrictions. The overall jet grouting is made of 81 columns with a minimum diameter of 1.4m, approximately 17m deep.

A jet grout mix design was developed that achieves a minimum in-situ characteristic unconfined compressive strength of 5MPa. The jet grout mix used Holcim Ultracem type GP mixed with water and was pumped under high pressure using a jet grout piling machine.

The plant to undertake both the D-wall and jet grouting operations was built on site and maintained by the self-performing team throughout the works.



Figure 6: Bentonite D-wall and jet grout plant (left) Jet Grout Piling Machine (right)

Capping Beams

The D-wall capping beams had several objectives as part of the main works:

- Tie the D-wall panels together and distribute forces throughout the beam through the top level struts
- Provide temporary seating for the steel underpinning beams
- Provide a jacking surface for load transfer works (refer load transfer sequence)
- Provide permanent seating for the concrete underpinning beams
- Provide temporary seismic support for the front façade concrete underpinning beam
- Some capping beams included starters bars with couplers to enable permanent walls to be built above as part of the CPO rebuild works, following tunnel construction.

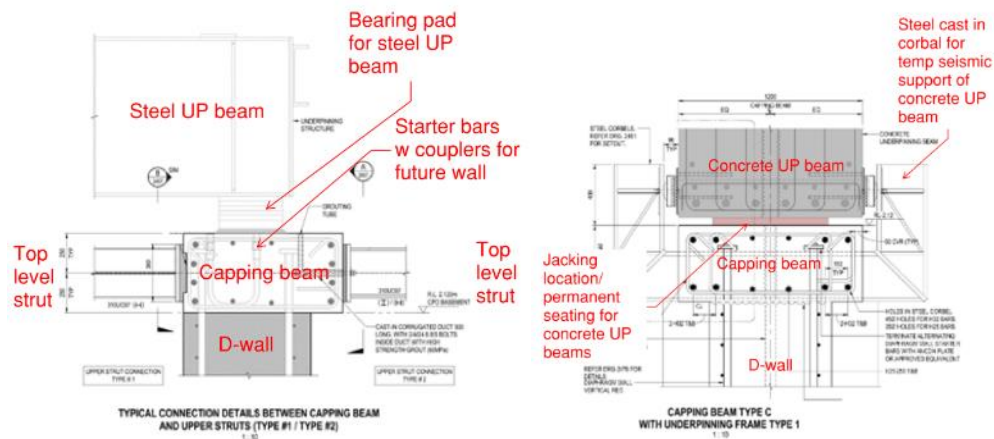


Figure 7: : Capping beams for steel and concrete underpinning works

Reinforced Concrete Underpinning Beams

Concrete underpinning beams consisted of approximately 830t of concrete structures comprising 38 reinforced concrete beams. 32 of these were post-tensioned using a series of stress bars and post-tensioning multi-strand tendons. The areas depicted below in plan and 3D were identified around the façade and vestibule area of the CPO where additional strengthening was required to stiffen the structure.

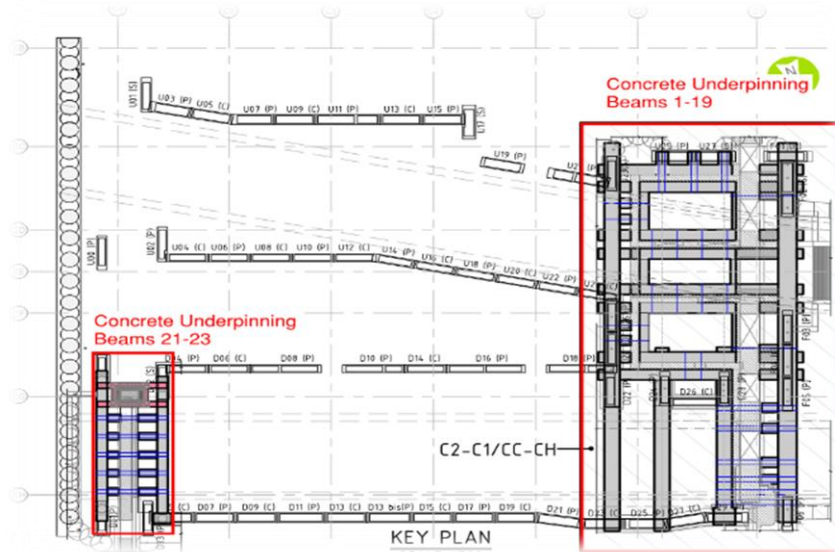


Figure 8 : Concrete underpinning beams layout

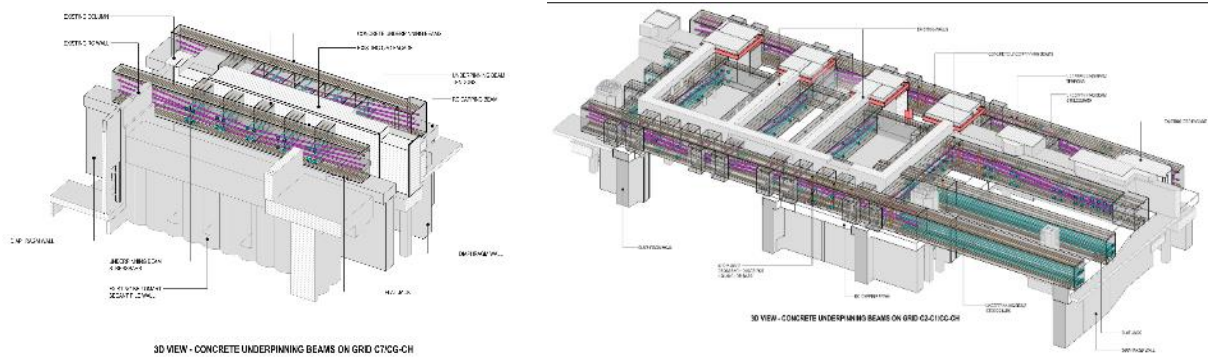
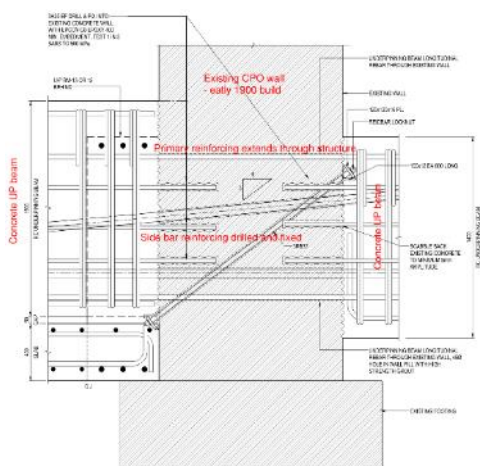


Figure 9 : Concrete underpinning beams layout

Post tensioned, reinforced concrete beams were located at the front and rear façade areas of the CPO building where it was imperative that the heritage elements were not compromised (Beam 22 shown below). The beams were cast against the existing concrete wall structures, many of which were unreinforced during the early 1900 build. Figure 10 below illustrates the typical details of concrete underpinning beams interfacing with existing walls.



TYPICAL UNDERPINNING BEAM REBAR THROUGH EXISTING WALL DETAIL



Figure 10: Typical Underpinning Beam through existing wall (left) Concrete Underpinning beam – North east façade (right)

The primary reinforcing and post tensioning in the beams extend through the existing walls and connect to adjacent beams in the particular group (using starter bars, couplers and corrugated ducts), effectively forming a grillage structure. The post tensioning enabled the loads to be transferred from the existing walls to the new concrete beams. Figure 11 below shows Beam 10 cast with PT ducts, side face bars and primary reinforcement couplers for transverse BM09. The left of the image shows holes cored for post tensioning elements between BM09 and BM10.

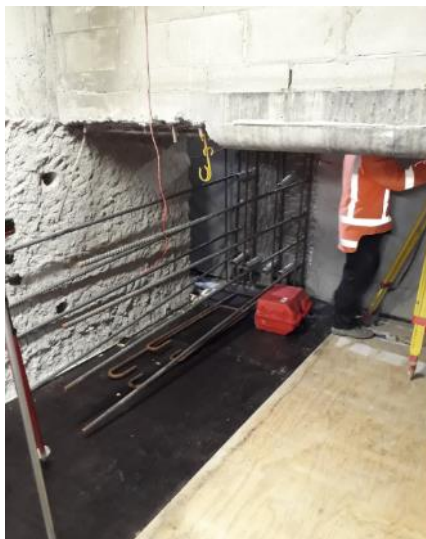


Figure 11: Concrete underpinning reinforcing and PT ducts through structures (left) Post tensioning works (right)

LOAD TRANSFER WORKS

Load transfer was conducted using Freyssinet's 'Flatjack' system. Flatjacks were used for their versatility and their load capacity. They require minimal clearance of 40-50mm and can be engaged using hydraulic fluid for temporary jacking or permanent grouts. They provide very high load capacity. Varying jack sizes with capacities from 62 ton to 585 ton per jack were utilized on this project efficiently and cost competitively.

Two distinct areas were identified for the load transfer works, which required specific methodologies to be developed:

1. Steel underpinning load transfer (internal columns)
2. Concrete underpinning load transfer (Eastern and Western facades)

The sequencing of the works involved the internal columns to be lifted before the western and eastern facades.

Steel Underpinning Load Transfer

The steel underpinning structures were constructed on top of the capping beams within the internal columns section of the building. This included fabrication and construction of nine steel frames and three standalone collar structures. These structures, totalling 350t, were all located within the CPO Building and positioned on the capping beams of the D-walls.

The primary function of the steel underpinning works was to support the internal columns of the CPO Building during excavation and tunnel construction and provide a suitable means of undertaking the load transfer works.

In the figure opposite, the steel structure can be seen in red and the concrete underpinning beams can be seen in grey.

Individual frames were constructed of welded beams, transverse steel beams, collar assemblies and shear boxes welded to the existing steel columns. Each collar assembly then had a specially designed low-shrink concrete poured inside the collar on a temporary falsework soffit. The collars were subsequently post tensioned.

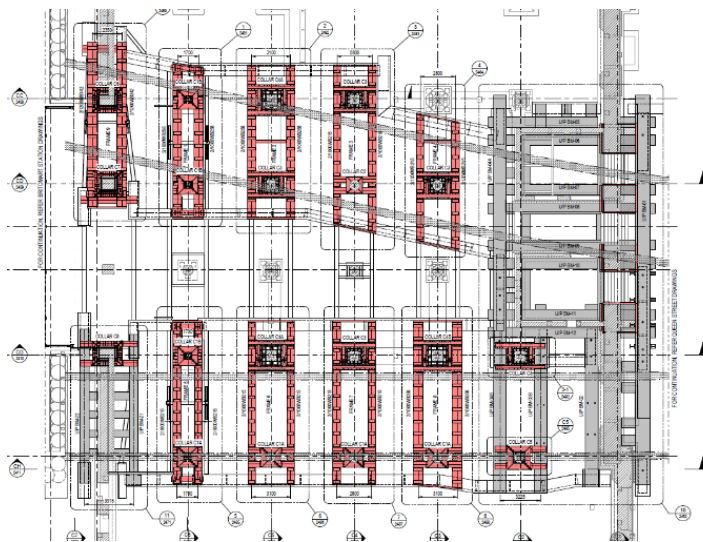


Figure 12: : Steel Underpinning Beams

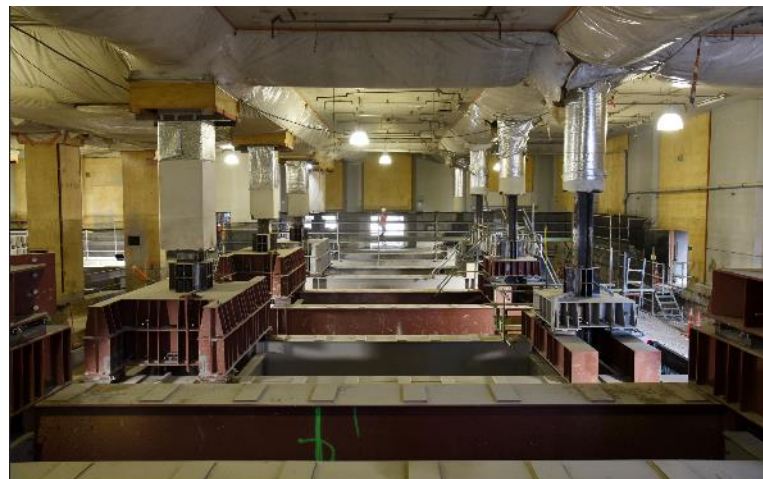
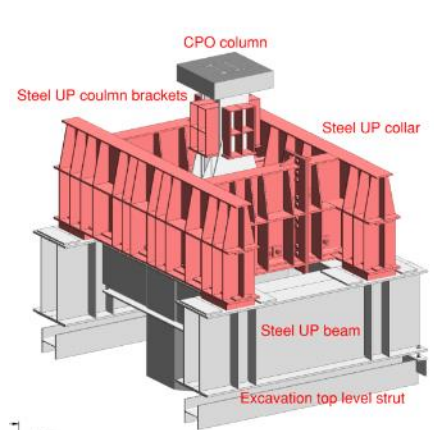


Figure 13: Steel Underpinning Collar (left) North Tunnel Trench from top of Underpinning Beams (right)

The internal column section was split into 9 zones. Each zone included a steel 'Frame' connected to the D-wall and two internal columns. Incremental load transfer in this section involved jacking up the columns one zone at a time.

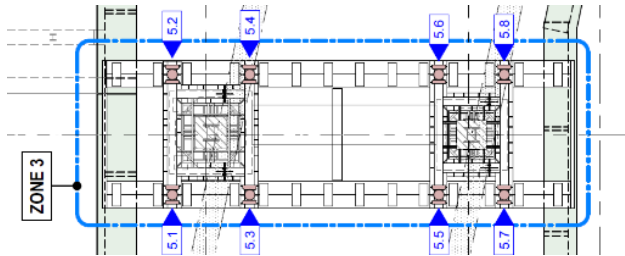


Figure 14: : Typical Flat Jack Zone

The critical features of these works:

- Flatjacks were positioned around each column to ensure the load applied was centred on the column to avoid imposing any bending moment on the column. This was achieved by surveying the position of each jack as well as designing a hydraulic circuit that enabled equal loading on all four corners.
- Maximum loads of up to 79 ton per flatjack. Total of 64 flatjacks between 270mm to 420mm were used.
- To minimise losses during the transfer of load between the flat jacks and adjacent shims, project specific design of a tapered shim was conducted to achieve the required accuracy
- Accounting for the unpredictable behaviour of the building and given its age, there was a degree uncertainty on the load carried by each column. Contingency was built into the load transfer methodology by applying a factor of safety on the capacity of the flat jacks. In addition to the load control, alert levels were set on displacements to avoid over-jacking of the building.
- In order to allow for accurate detection of column lift-off, a laser "dot" was shot on the column. This laser was also used to monitor any vertical movement of the column during jacking. The Surveyor was able to detect movement of the laser dot to 0.25mm. Allowing for normal background vibration, reliable detection of 1mm lift off was achieved.

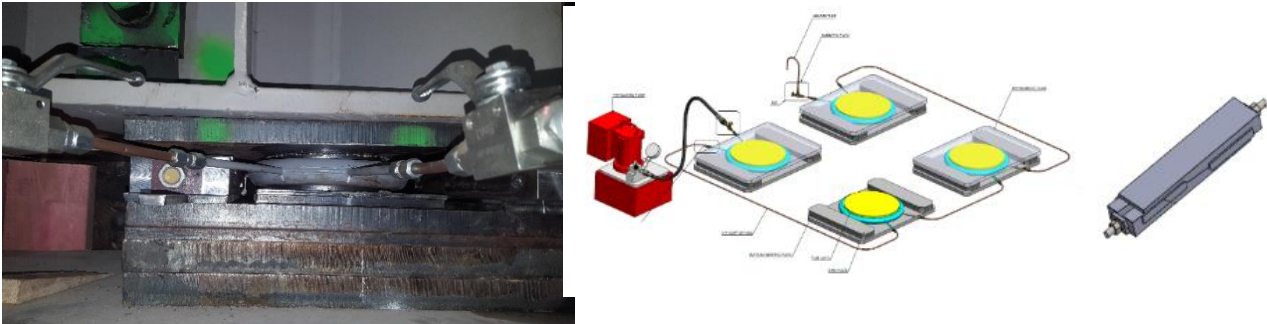


Figure 15: Hydraulically Linked Flatjacks (left), Flatjack circuit schematic (right)

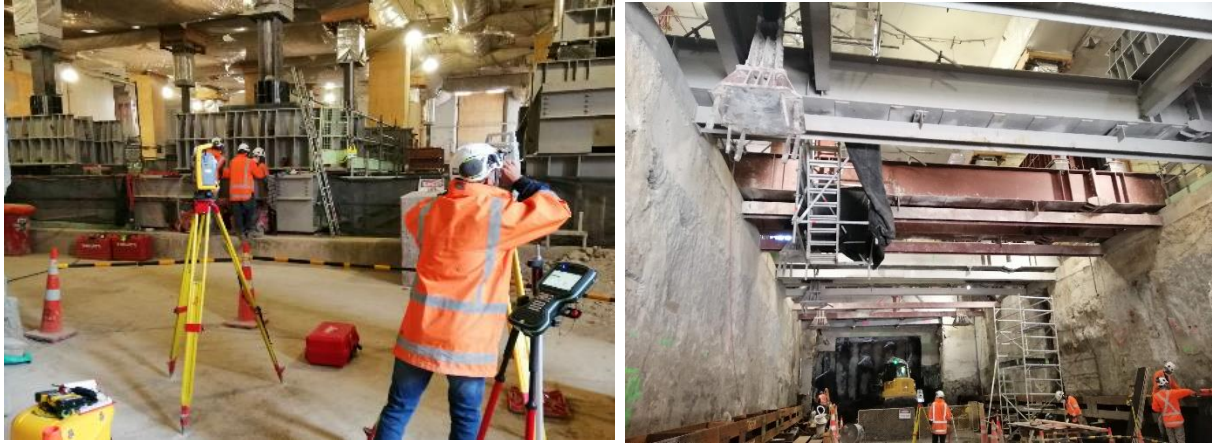


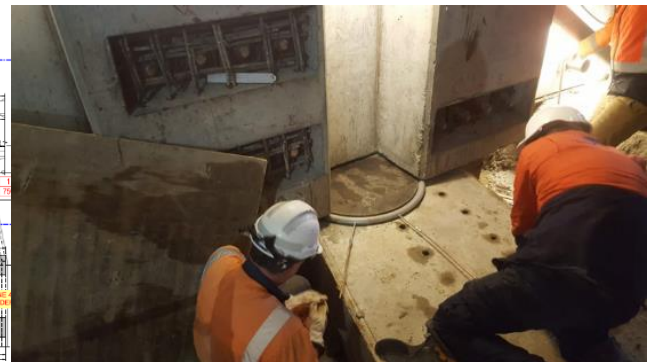
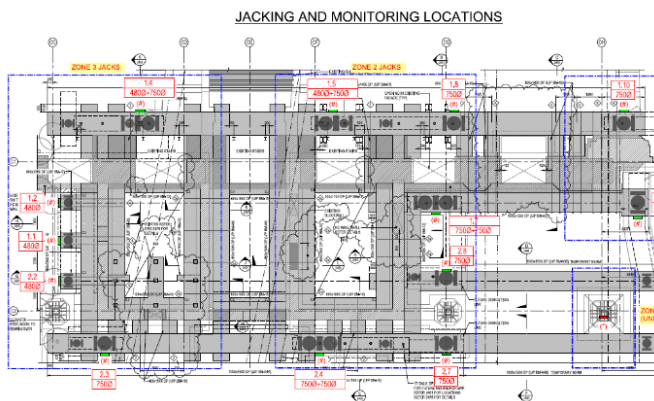
Figure 16: Multiple Survey Instruments to monitor the Load Transfer (left), Free hanging column footing after load transfer and partial excavation (right)

Concrete Underpinning Load Transfer

The eastern and western façade load transfer was also incrementally conducted in 4 zones.

The critical features of these works included:

- Much higher loads, with flat jack capacities up to 600 ton per jacking location. Total of 21 flatjacks between 350mm to 750mm were used.
- A much stiffer structure supporting a heritage structure including a mosaic floor, thus very sensitive to displacements. The façade load transfer was significantly more sensitive than internal columns as there was a significant risk of damage to the heritage façade and vestibule area. Additional monitoring locations were positioned during the load transfer of the façade.
- Flat jacks of varying sizes were used within a single zone, thus requiring a different setup to ensure proper sharing of the load between the different beams
- While all the jacks within a zone were required to be engaged simultaneously, they did not need to be linked in the same hydraulic circuit.



Jam and Capping Beam

Construction of Tunnel, Roof Beams and Columns Between the D-walls

Following excavation of the tunnel trench, work commenced to construct the rail tunnels.

The tunnel base slab itself had a blinding layer with an underlying drainage system to dissipate buoyancy forces on the tunnels and building. The base slab was cast on a fully bonded waterproofing membrane and was tied into the D-walls using couplers that were positioned accordingly in the D-wall cages at an early stage of construction.

Once the base slab was cast, side-wall infills were constructed. These consisted of mass flowable fill. This structure provided a smooth, fair face for the wall waterproofing membrane. Similarly to the base slab, the roof was also tied into the D-walls using couplers positioned in the D-walls.

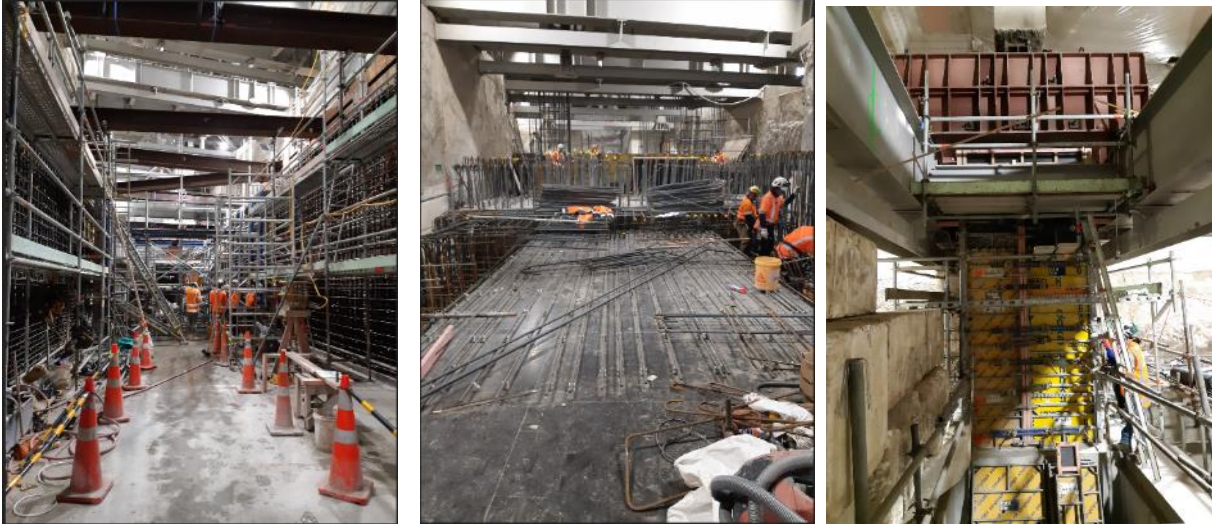


Figure 18: Tunnel Wall construction (left) tunnel roof construction (middle) CPO column construction while underpinned (right)

On top of the tunnel roof and in line with the overhead ‘hanging’ columns, DSBJV constructed the tunnel roof beams (typically 1.5m deep and 3.5m wide). These were constructed to support the new columns and spread the load across the tunnel roof and into the D-walls for the permanent state. Figure 19 below illustrates in detail the CPO tunnel construction works including roof beams and columns.

The tunnel box concrete design consisted of special grade concrete. In addition to meeting the requirements of normal concrete as specified in NZS 3104, the following was required:

- Blended cements were used (blended cement content: 35-50% fly ash / 50-65% Portland cement).
- The maximum drying shrinkage of concrete was 570 micro-strain at 3 weeks and 800 micro-strain at 8 weeks.
- Characteristic 28 day compressive strength, 40 MPa.
- Thermal expansion coefficient, 12 $\mu\epsilon/^\circ\text{C}$.
- Early-age concrete maximum temperature rise, 35 degrees.
- Permissible range of blended cement content: 370 kg/m³ – 445 kg/m³
- Maximum water / cementitious ratio, 0.45
- To mitigate spalling effects in the event of a fire, 2kg/m³ polypropylene monofilament fibres with a maximum of 32 micrometre diameter and 12mm length were added to the concrete mix.

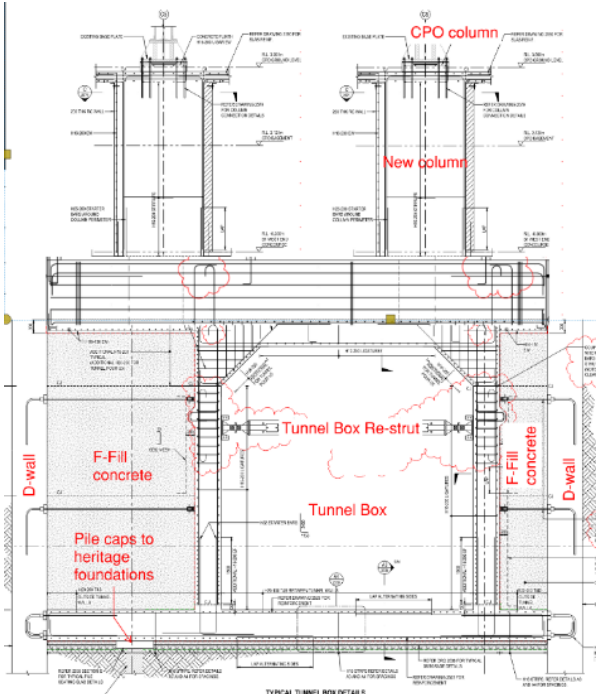


Figure 19: CPO Tunnel Construction details

During construction of the new columns, DSBJV worked closely with the architect to develop a concrete finish to the visible columns located on the B1 basement level as a departure to the specification and design. The columns were left exposed to assist in ‘telling the story’ of the recent construction works. Figure 20 shows the finished columns inside the public toilets, seen to the public on level B1.



Figure 20: CPO Columns exposed concrete appeal inside public toilets at B1 level

Load Transfer to Tunnel Roof

Once the tunnel roof was built, it was necessary for the building load path to be re-directed from the original column footings onto the tunnel roof. It was not desirable to leave the steel underpinning beams in place as they were occupying a large amount of space in what is now the Britomart Train Station foyer which thousands of people use for access daily. Controlled transfer was crucial as the steel underpinning beams had been storing large amounts of energy from the initial load transfer.

The works involved re-installing the flatjacks and hydraulic circuits and engaging the flatjacks to remove the tapered shims. The procedure was similar to the initial load transfer phase where specified loads were applied to each individual jacking zone. The columns and the facade were just sufficiently jacked up to loosen the tapered shims for removal.

CONCLUSION

The project required some 18 months of temporary works prior to any excavation, including the installation of underpinning structures to transfer approximately half the load of the 100-year-old CPO Building from its original piled concrete foundations - a feat of delicate engineering not seen in this country before.

Following the successful completion of the underpinning works, the tunnel construction and refurbishment activities were able to commence. Careful consideration of the CPO building's history and legacy resulted in successful reinstatement and refurbishment of the CPO basement level plant room, ground floor, rail ticketing facilities, station retail and all heritage features. Meticulous attention to detail was overseen by both client and contractor's appointed heritage architects to protect the heritage features.

DSBJV delivered this highly technical and challenging project, including specialist works and innovations new to New Zealand on time and on budget. DSB JV is proud to be part of a diverse and high-performing team. The power of collaboration between main contractor, specialist contractor, designer and client during early procurement phase through to contract execution phase has meant that what was once a challenging vision has now become a reality that will help to improve the quality of life for Auckland commuters.

ACKNOWLEDGEMENTS

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REFERENCES

Nil