

# Design, construction and monitoring of connection between bored tunnel and drilled shafts in watercare's central interceptor New Zealand

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**ABSTRACT:** Watercare is building a 16.2 km-long underground wastewater tunnel called the Central Interceptor (CI) that will run from Māngere Wastewater Treatment Plant to Point Erin, Herne Bay. It is intersected by two link sewers, which capture flows from central and west Auckland suburbs. A range of major infrastructure such as a new pump station and confluence chamber has also been built at the Māngere site. The Central Interceptor project will significantly reduce wet weather overflows into waterways and Waitemata beaches, leaving a legacy of a cleaner environment for the people of Auckland. The project also involves the excavation of 18 shafts, where 3 of the smaller shafts (less than 4.5m internal diameter) are drilled shaft with Fibre Reinforced Polymer (FRP) as their permanent lining. The paper discusses the design development, construction and monitoring aspects of the structure connecting the main tunnel and drilled shafts.

Beginning from the tender design, safety in design was a key consideration for the connection design as it requires highly risky removal of main tunnel lining, rock excavation and subsequent working under confined space. Focus on minimising the amount of work required for the tunnel construction by reducing structural steel connections and large in-situ concrete pours offers reduction of safety accident risk, improved quality, less disruption with the standard activity, as well as reducing the material used and the associated carbon footprint. Through utilization of the existing structures of drilled shaft and bored tunnel, over 90% reduction in permanent concrete volume is achieved, resulting in significant risk reduction, time saving and carbon footprint reduction for the project.

## 1 INTRODUCTION

### 1.1 *Project background*

Watercare is building a 16.2 km-long underground wastewater tunnel called the Central Interceptor (CI) that will run from Māngere Wastewater Treatment Plant to Point Erin in Herne Bay. The 4.5m inner diameter main tunnel is being dug by a large tunnel boring machine named Hiwai-te-Rangi. Two smaller link sewers (2.4m and 2.1m diameters for Link Sewers B and C respectively) constructed as pipejacks will intersect the main tunnel to connect the current wastewater network to the main CI tunnel. The CI tunnel alignments are shown on a map of Auckland in Figure 1 along with the existing wastewater network and significant overflow locations.

Ghella Abergeldie JV is delivering the project for Watercare. The contractor's designer is Arup. Watercare's design team includes Jacobs, AECOM and Delve Underground. Construction is taking place at 17 sites across Auckland and involves the excavation of 18 shafts and associated infrastructure. Around 600 staff from the various project partners are working on the \$1.5b project, which is due for completion in 2026. It is the largest wastewater infrastructure project in New Zealand history and will leave a legacy of cleaner waterways by reducing around 80 per cent of

wet-weather overflows in central Auckland by capturing and storing combined stormwater and wastewater flows and sending them to the Māngere Wastewater Treatment Plant for processing at a controlled rate (Watercare, 2016).



Figure 1. Central interceptor alignment with existing wastewater network and significant overflow locations (Source: Watercare, 2016).

Among the 18 shafts constructed on the Central Interceptor, three (3) temporary shafts with internal diameter less than 4.5m are constructed as drilled shafts. The locations of these shafts are shown in Figure 1, where Keith Hay Park and Walmsey Park shafts are designed with 3m internal diameter, while PS23 is slightly larger at 4.5m internal diameter.

In essence, the drilled shafts are constructed using large drilling rigs, with similar construction methodology to big diameter bored piles. In areas of unstable bore, casings are provided until the bore reaches stable ECBF rock formation. After completion of drilling, permanent Fibre Reinforced Polymer (FRP) liners are lowered and grouted into place.

The construction method offers significant cost, time, carbon and safety benefits. With no personnel required inside the excavation, risks associated with working in confined space at depth are essentially eliminated. As the construction method does not require construction of temporary ERSS, significant cost, time and carbon savings were made.

After the completion of the shaft, the main tunnel is then driven under the completed shafts. The main tunnel consists of single pass segmental lining with inner HDPE lining as protection against the sewer environment (Surya, 2023 & Grace, 2019). Upon completion of the tunnel, the connection between the two structures is then constructed.

The construction of tunnel-shaft connections represents critical construction activity which is in the critical path of the construction program as it can only be constructed after completion of both the tunnel and shafts. In addition, with limited confined space working with exposure of the ground during construction, the connection represents a highly risky part of the construction. Combined with a desire to reduce the carbon footprint of the project as much as possible, opportunities for optimization of the tunnel-shaft connection have been identified from the tender design stage as one of the key initiatives in the design of the Central Interceptor project.

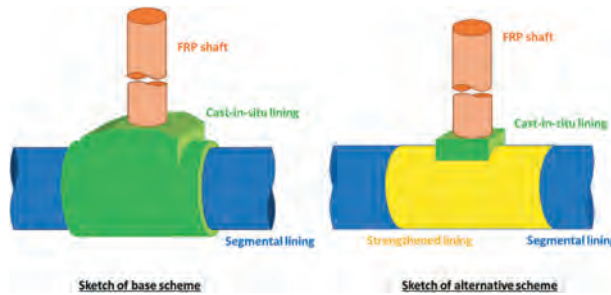


Figure 2. Initial concept sketch of tunnel-shaft connection optimization during tender design.

### 1.2 Tunnel-shaft connection

In the base scheme from the tender reference, the connection was to be constructed fully as cast in-situ lining as shown in Figure 2. After the completion of the tunnel drive, the main tunnel segments are to be excavated and enlarged to cast the connection. At the connection, a FRP saddle module is to be provided as shown in Figure 3 to ensure that the concrete at the connection is adequately protected from Microbially Induced Corrosion (MIC) from the sewer.

During the tender design, it was identified that alternative connection scheme making use of the main tunnel segments would offer significant safety, time, cost and carbon footprint benefit through significant reduction in the amount of additional excavation and cast in-situ concrete volume. By strengthening of the lining using rebar and shear dowels, the tunnel segments can be designed to accommodate the tunnel opening required for the connection.

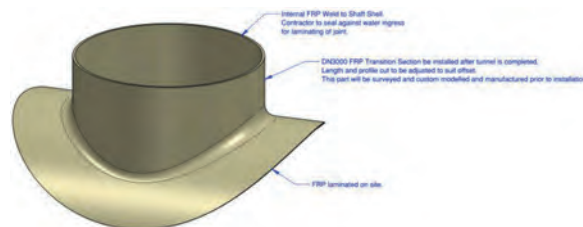


Figure 3. FRP transition section for tunnel connection from the reference design.

In the initial reference design, only 3m internal diameter shafts at Keith Hay Park and Walmsley Park are proposed to be constructed as drilled shafts. However, following tender award, GAJV has identified the potential of constructing 4.5m internal diameter PS23 shaft as a drilled shaft as well. Following discussions and reviews with Watercare and their design team, the proposal was eventually approved considering the multitude of benefits. As a consequence, similar tunnel connection scheme is also applied in PS23 shaft connection, albeit with several adjustments to cater for the larger connecting shaft.

### 1.3 Geology

As can be seen in Figure 4, the geology at the tunnel-shaft connection for all 3 shafts mainly consists of East Coast Bay Formation (ECBF) rock. The ECBF in this project generally consists of interbedded mudstones, siltstones, and sandstones with varying degrees of cementation. A subunit of ECBF known as Parnell Volcaniclastic Conglomerate (PVC) is also anticipated to be encountered at Walmsley Park. This is characterized by pebble to boulder sized conglomerate and can generally be very permeable.

As all the tunnel connections are constructed in similar geological conditions, similar design and construction methodology was applied to all 3 shaft connections. Some adjustments were made for the design and construction of PS23 shaft connection, to account for the larger shaft diameter at PS23 (4.5m).

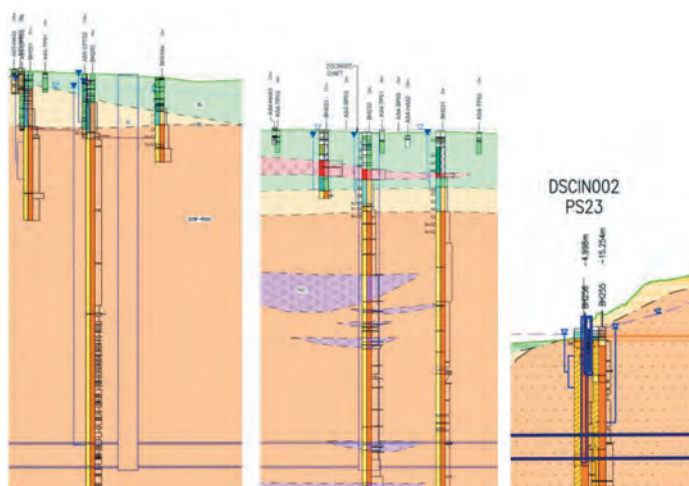


Figure 4. Geological sections at Keith Hay Park (left), Walmsley Park (middle) and PS23 (right).

## 2 DESIGN OF TUNNEL-SHAFT CONNECTION

### 2.1 *Permanent works design*

During the detailed design development, it was recognized that further improvement could be made to further reduce the amount of work at the tunnel opening. Considering the annulus between the temporary shaft and the FRP shafts are to be filled with flowable fill consisting of low strength cementitious material, it was recognized that part of the connection can be formed by replacing the cementitious grout at the bottom of the drilled hole with permanent concrete (see Figure 7), which will then be cut into shape by the incoming TBM. In order to avoid issues during the TBM drive, reinforcements for this part of permanent work are provided as FRP reinforcement instead of steel.

Afterwards, the remaining part of the permanent works will be constructed after the tunnel opening, as shown in Figure 5. The figure shows the concrete cast during the shaft drilling as yellow (1<sup>st</sup> collar), while the concrete cast during after the tunnel opening is shown as magenta (2<sup>nd</sup> collar). This results in further reduction in cast in-situ concrete required, as well as significantly reduces the amount of mining required.

To account for the eccentricity of the shaft with respect to the drilled hole, design was carried out based on minimum dimension derived from the shaft centralizer shown in Figure 6. FRP rebar cage was lowered with the shaft, before the hole was filled with concrete to form the 1<sup>st</sup> collar.

To connect between the two collars, post drilled rebars are specified. After the tunnel opening and excavation to expose the 1<sup>st</sup> collar, rebar cage for the 2<sup>nd</sup> collar is then assembled, with post drilled rebar installed to connect both collars structurally. The collars are designed to work together to resist the forces from the opened segmental lining.

For better clarity, construction sequence of the tunnel connection is shown in Figure 7.

At the PS23 shaft, as the internal diameter of the shaft is the same diameter as the shaft, a significant portion of the lining has to be removed to construct the connection as shown in Figure 8. Due to the larger opening, the permanent concrete is designed as reverse footing distributing the hoop force from opened segments into the surrounding ground instead of acting as frame. As such, it was decided that it's not possible to utilize the concrete from shaft drilling for this purpose as it is deemed too slender and complicates the connection works required.

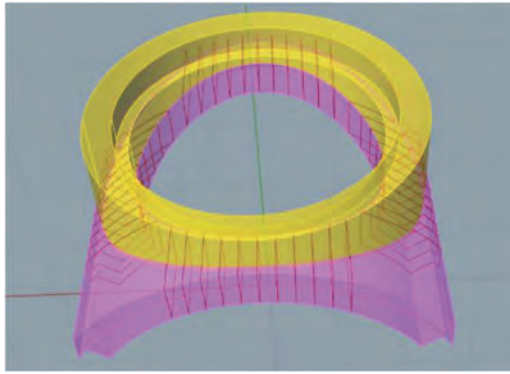


Figure 5. Geometry of permanent works for tunnel connections at Keith Hay Park and Walmsley Park, showing cross sections of the structural element extracted from the model.



Figure 6. Photo of FRP shaft, highlighting centralizer (red circle) located near the bottom of the shaft.

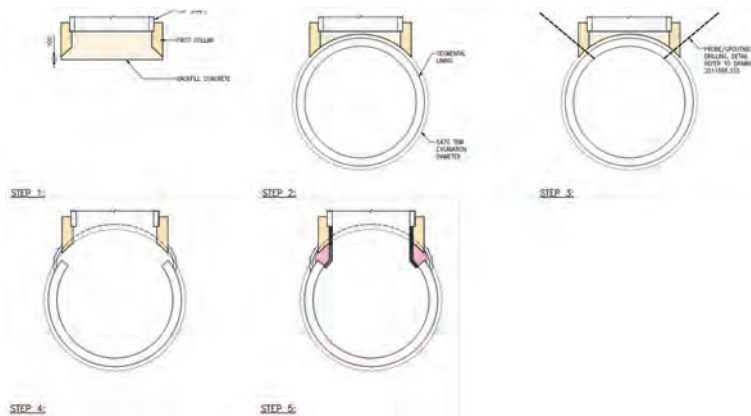


Figure 7. Construction sequence of the tunnel-shaft connection at Keith Hay Park and Walmsley Park.

### 2.1.1 Design analysis

Considering the complicated geometry and interaction between 1<sup>st</sup> and 2<sup>nd</sup> collar, also to facilitate the design optimization and subsequent finite element analysis, 3D parametric model of the collar was built using software Rhino with Grasshopper script.

This allows the design to be optimized and tweaked to simulate sensitivity analysis for different out-of-tolerance cases, for example when the TBM is driven out of tolerance with

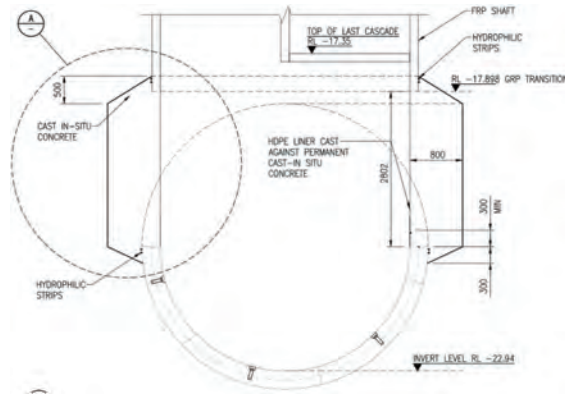


Figure 8. Drawing of tunnel connection permanent works at PS23 shaft.

respect to the shaft bottom. As the design is carried out using 3D finite element analysis (Plaxis 3D), the resulting geometry can also be directly imported for the analysis. The analysis is then carried out to obtain the forces in the collar during both static and seismic case. Temporary works are conservatively ignored in the permanent works analysis.

Due to the irregular geometry, forces in the collar are derived based on the stress output from Plaxis 3D, and converted into axial force, bending moment and shear using Grasshopper script. The reinforcement of the collar is then designed to ensure the design forces are within the section capacity in accordance with NZS 3101.

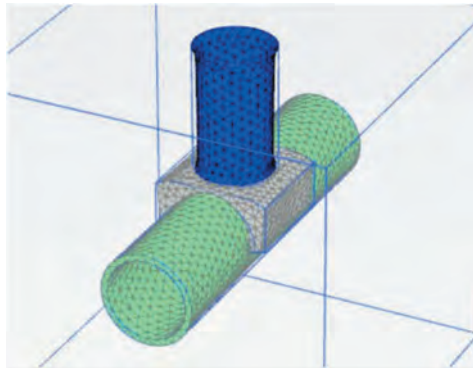


Figure 9. Screenshot of 3D analysis of tunnel-shaft connection at PS23 shaft.

## 2.2 Temporary works design

### 2.2.1 Design of tunnel opening

Considering the uncertainty in the exact segment locations with respect to the shaft bottom, design of tunnel opening was carried out based on the worst location of opening resulting in the highest number of opening segments.

In order to minimize the amount of temporary support inside the tunnel during the tunnel opening, high capacity shear dowels (FIP Biblock 84-46-274 M XP) were used. Furthermore, groundwater is specified to also be drained from the segments to reduce the groundwater pressure prior to opening the tunnel, which further reduces the forces acting on the segments.

The opening is modelled using structural software GSA, where the tunnel segments are modelled as shell elements and ground modelled as spring elements based on Duddeck & Erdmann (1985) and USACE (1997). Shear dowels are modelled as shear springs as shown



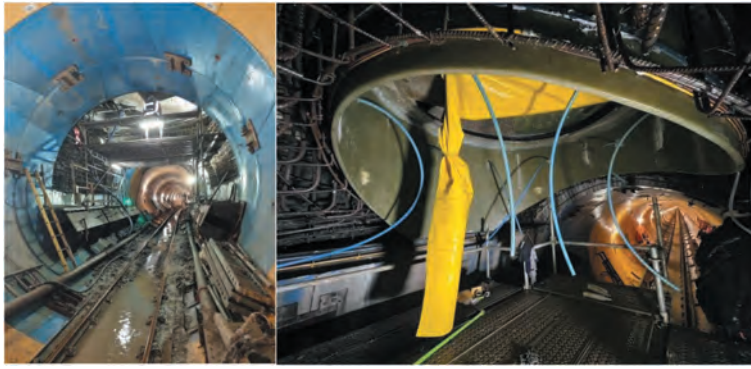


Figure 11. Photo of tunnel opening at PS23(left) and Keith Hay Park (right).

#### 4 CONCLUSION AND ACKNOWLEDGEMENTS

By recognizing the opportunity to make use of existing structures as much as possible, significant reductions in concrete volume (over 90%) was achieved in the tunnel-shaft connections. This also translates to significant risk, cost and carbon footprint reduction on the project through reduction of excavation volume, personnel exposure to unsupported ground and internal supports.

The authors would like to thank the different parties involved from design, review, construction and supervision of the tunnel-shaft connection. Through recognizing the common goal of achieving safe, economical and sustainable solution, open collaboration among the different project parties has allowed the design to be tweaked to suit the various constraints while also maximizing the opportunities available which allows the construction of the two tunnel-shaft connections to be completed successfully. This is testament to the hard work of all the parties involved, allowing the innovative solutions to be brought from conception to completion.

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