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Challenges in design of retaining system for a deep underground station box in Sydney, Australia.

Bora Okumusoglu
Technical Leader, Geotech (ACCIONA), Australia, bora.okumusoglu@geotech.net.au

Sujatha Manoj
Principle Engineer, Tetra Tech Coffey, Australia

Pawel Kozak
Design Manager, Jacobs, Australia

Harry Poulos
Senior Consultant, Tetra Tech Coffey, Australia

ABSTRACT: Deep underground excavations often result in significant impact on the ground water regime and environment, within the influence zone of the excavation activity. Ground water seepage in a drained or undrained excavation can result in significant groundwater drawdown, resulting in large settlements. The resulting ground movements can also impact the existing assets and cause settlements and strains affecting structures around the excavation, which can be critical in an urban environment. This paper discusses the challenges involved in the design of a retaining system for a 31m deep and 230m long by 24m wide underground excavation for the station box at The Bays station and TBM launching area, as part of the Sydney Metro West project in Australia. The proximity of a settlement sensitive heritage building and other utilities and assets, combined with loose thick alluvial soils with the presence of a paleochannel and a high ground water table, presented great challenges in designing the retaining system. Significant ground water drawdown and settlements were predicted for this 31m deep excavation site. Diaphragm walls were proposed initially as part of tender design and this paper discusses how an alternative secant pile solution was successfully designed and implemented during the construction stage. Load and material factors considered in the design to arrive at a safe, sustainable and optimized design are also presented. Significant ground water drawdown and settlements were also predicted in this 31m deep excavation site. The paper also discusses how predicted impacts on important assets around the excavation were assessed and how remediation work was planned and implemented. The predicted ground movements were compared with the actual settlements measured and validate the successful design and implementation of the secant piled wall solution.

KEY WORDS: Retaining Walls, Underground, Excavation, Secant Piles, Drawdown

1 INTRODUCTION

Sydney Metro is Australia's biggest public transport project and is revolutionising how Australia's biggest city travels, connecting Sydney's northwest, west, southwest and greater west to fast, reliable turn-up-and-go metro services with fully accessible stations. The Sydney Metro West (SMW) project is a new 24 km underground metro railway which will double rail capacity between Parramatta and the Sydney Central Business District, transforming Sydney for generations to come. Construction started on SMW in late 2020.

The tunnelling and excavation work of SMW is currently being delivered under three construction packages: The Central Tunnelling Package (CTP), Western Tunnelling Package (WTP) and Eastern Tunnelling Package (ETP) as shown in Figure 1.

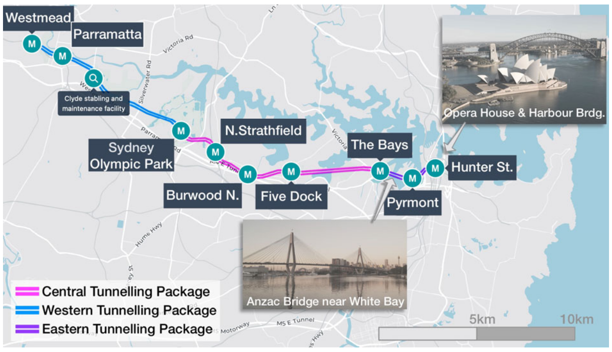

Figure 1. Sydney Metro West alignment and station locations.

2 PROJECT BACKGROUND

2.1 *Sydney Metro West - CTP*

A joint venture between Acciona and Ferrovial (AFJV) was awarded the design and construction contract for the Central Tunnelling Package (CTP) in July 2021, which consisted of twin 11 km tunnels using double shield hard rock TBMs and the excavation of five new station boxes (Figure 1) at Sydney Olympic Park, North Strathfield, Burwood North, Five Dock and The Bays.

The project specifications required that the construction activities including deep excavation and tunnelling should be designed and implemented without causing any adverse impact on the environment and on the surrounding structures. One of the most challenging aspects of the CTP was the deep excavation at The Bays Station where the proximity of a settlement sensitive heritage building and other utilities and assets, and the loose thick alluvial soils with presence of a paleochannel and high ground water table, presented great challenges in designing the retaining system.

This paper discusses the design of earth retaining systems at the deep excavation site at The Bays Station, located between Glebe Island and White Bay Power Station, where the first two Tunnel Boring Machines (TBMs) were launched in a westward direction. The initial design included diaphragm walls with anchors but with design optimisation and detailed assessment it was possible to change the retaining system to secant pile walls with anchors. The design of the retaining system and its optimisation, and the impact of construction on surrounding assets are discussed in this paper.

3 DESIGN CHALLENGES AT THE BAYS STATION

3.1 *The Bays Station*

The Bays Station (Figure 2) is located within the White Bay industrial area, in close proximity to the White Bay Power Station (WBPS) in an approximate East-West orientation. The station box minimum clear opening (MCO) was 230.5 m long x 24 m wide and 31 m deep. The existing ground levels varied between +2.7 to 4.3 m AHD (Australian Height Datum).

Figure 2. The Bays Station (highlighted in blue) and WBPS (yellow).

WBPS is a New South Wales (NSW) state heritage listed building built between 1912 to 1917. The 80 m tall chimney stacks stabilised by guy cables were added to it in early 1950s.

Presence of a palaeochannel near the Johnstons Bay area, with its floor about 36 m below sea level, along with the Great Sydney Dyke extending through the eastern and northern walls, and a high groundwater table, made the ground conditions challenging. One of the critical design objectives was to make sure that construction of The Bays Station and TBM tunnels would not cause any adverse and unacceptable impact on the existing assets. The following design challenges were identified and detailed mitigation measures were planned and implemented, to overcome these challenges.

3.1.1 *Geotechnical model and ground conditions*

A geotechnical ground model was developed by targeted geotechnical investigations, to capture the ground conditions with a reasonable level of confidence. Available historical boreholes together with Sydney Metro investigations within the Bays area are presented in Figure 3 showing the density of investigation points.

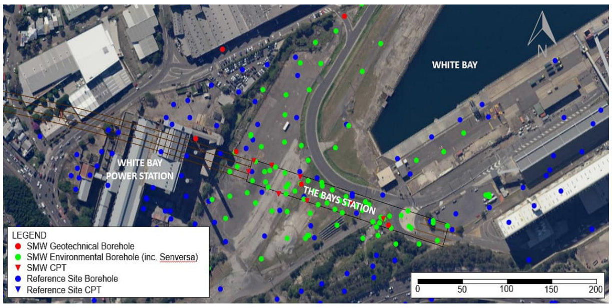

Figure 3. Distribution of investigation points in the Bays area.

Based on available geological information, the bedrock geology of the Bays area was characterized by a sub-horizontally lying Permo Triassic sedimentary sequence, approximately 230 million years old with stratigraphic units comprising of manmade fill (MMfill) materials followed by quaternary alluvium/estuarine sediments (Qa), residual soils (ResSoil) and the Hawkesbury Sandstone (HawkS) formation. A geological section across The Bays Station box is shown in Figure 4 below.

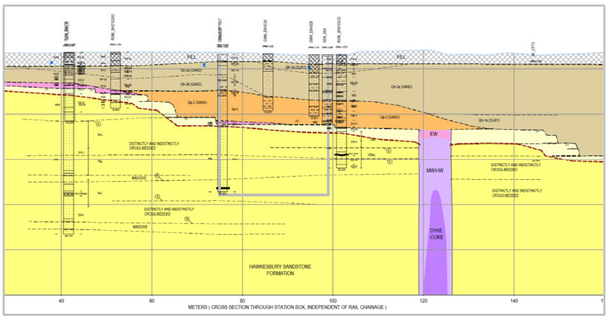

Figure 4. Cross section across The Bays Station (towards Five Dock).

Hawkesbury Sandstone generally consists of three distinct facies namely, massive sandstone facies, cross bedded or sheet facies and shale/siltstone interbed facies. The majority of the Hawkesbury Sandstone is made up of cross-bedded or sheet sandstone facies ranging in thickness from 0.5 m to greater than 5 m. The Great Sydney Dyke was intersected in several boreholes and in a rock cutting to the east, where it is exposed. It trends approximately northwest–southeast and extends through the station box.

3.1.2 *High groundwater and Paleochannel*

The groundwater table at the site was established to be between 1.7 m and 3.63 m below ground level (+0.58 and +1.44 m AHD) based on the readings from ground water monitoring wells. For design purposes, after accounting for the extreme rainfall event and rise due to a prolonged wet period, the water table was conservatively assumed at the ground surface for both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) design.

3.1.3 *The Great Sydney Dyke*

As the Great Sydney Dyke gradually moves away northward from the station box as seen in Figure 5, a narrow wedge of sandstone develops, and the shoring wall design had to account for this rock geometry. Due to the fractured nature and strongly defined subvertical rock structure, and the presence of a high groundwater table, systematic support of this material was required to maintain stability.

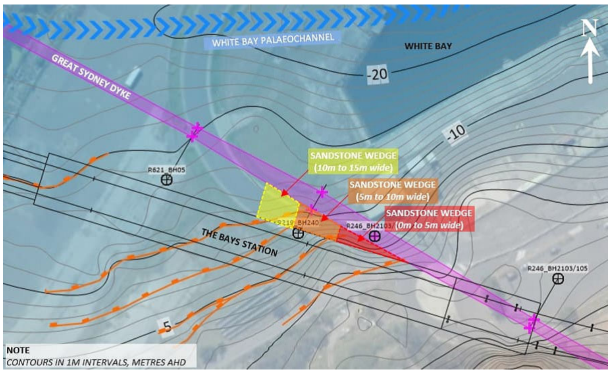

Figure 5. Great Sydney Dyke and narrow Sandstone wedges.

With targeted and detailed geotechnical investigations, it was possible to map the extent of the Dyke and identify locations where it intercepted the excavations. The eastern and northern excavation walls intercepted by the Dyke displayed different conditions and thus required different design considerations which were accounted for in the design. It was also proposed to grout the dyke zone to control ground water inflow.

3.1.4 *Proximity to sensitive structures*

The presence of the White Bay Power Station (WBPS) and other sensitive structures (Figure 6) posed another challenge due to strict project specifications requiring that the construction activities should cause no adverse impact on any surrounding assets. The WBPS location was underlain by deep alluvium over an irregular bedrock surface and its various buildings spanning over an inferred buried sandstone cliff. Some of the associated structures in the area were supported by timber piles, some of which were pulled out during initial enabling works. The exact details of the WBPS foundations were not known.

The top of the rock was deep at the power station site, indicating that the tunnel would have a thin rock cover above its crown. This posed a challenge due to the potential impact on the foundations of the WBPS. The tunnel ran shallow in this section with about 3 to 4 m of weathered sandstone above the crown of the tunnel. The risk of the saturated alluvium soils hydraulically connected to the fractured rock causing high groundwater inflows was assessed with well-informed ground profiles and models, assessing the potential of TBM tunnelling and excavations inducing surface deformation and settlement which would impact the heritage structure.

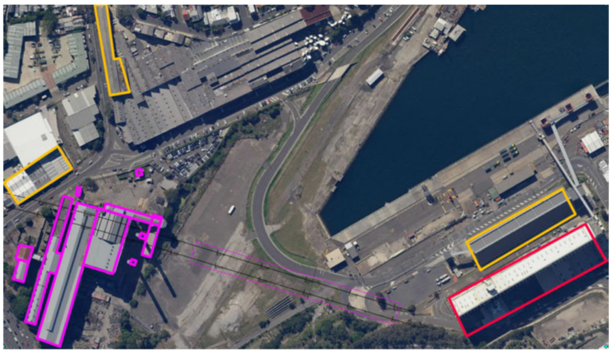

Figure 6. Sensitive buildings near The Bays Station excavation.

4 DESIGN OF RETAINING SYSTEM

4.1 *Initial design - Diaphragm Wall*

The retaining structure for the Bays Station box was designed based on a comprehensive review of all geotechnical data. This review established parameter ranges for use in various design sections of the retaining system:

Table 1. Typical Design Parameters.

Parameter (unit)	MM fill	Qa sandy	Qa clayey	Res Soil	HawkS Rock
γ (kN/m^3)	18-19	18-19	17-18	19-20	22-24
c' (kPa)	0	0	2-5	5	35-500
φ' (deg.)	23-30	28-33	28-30	32	35-37
E (MPa)	10-30	10-30	12-24	50	100-2500
k (m/s)	1x10^{-5}	1x10^{-5}	1x10^{-9}	1x10^{-7}	1x10^{-7}

The initial design was fully developed based on diaphragm walls (DWall) with a 10 year design life as the temporary retaining system, which consisted of cast in place reinforced concrete DWall with a minimum 1.5 m embedment into bedrock. The DWall was laterally restrained with rock anchors generally 4 m vertically and 1.5 m horizontally spaced. The retention system below the toe of the wall to the depth of excavation comprised of rock stabilisation by spot bolting combined with localized shotcrete to support potential unfavourable rock wedges or unstable discontinuities as depicted below in Figure 7.

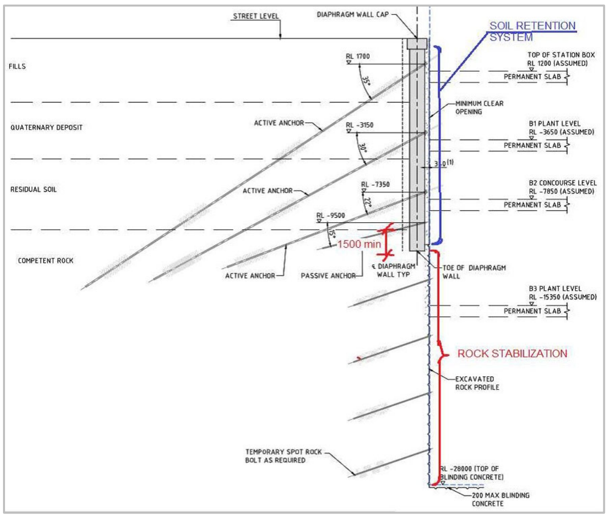

Figure 7. Initial design - DWall and anchor system.

The proposed retaining system extended from the ground surface to bedrock present at variable depth. Plaxis 2D FE model output is presented in Figure 8 which shows the computed accumulated horizontal displacements at the last stage of excavation.

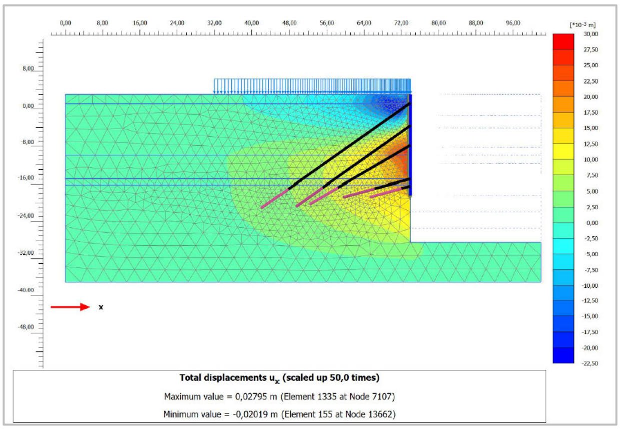

Figure 8. Horizontal displacements at The Bays Station DWall.

The 1000 mm thick D-walls, with panel lengths of 6.40 m, were to be constructed using a hydrofraise (hydromill) equipment to ensure adequate embedment in the sandstone. There would have been a risk that sufficient embedment could not be attained in sandstone and saturated soil remains below the Dwall. The DWall was required to be watertight, such that when the wall inner face is exposed by future works from the shaft, leakage is restricted to damp patches with no visible flow of water in any panel of the wall. Water seepage at panel joints was to be limited to a total inflow of 0.12 litres/linear meter per day overall, and 0.24 litres/day on any separate linear meter joint. It was anticipated that the shaft base would require grouting to achieve this water tightness.

An alternative option of a secant pile wall system was later proposed by the AFJV and Geotech Pty Ltd, an Australian specialist ground engineering contractor, in the final design stage of the work as a sustainable and safe retaining solution. Following a thorough review by the Sydney Metro Engineering Design Solutions (EDS) team and the Designer, this alternative was accepted as the retaining system at The Bays Station.

4.2 *Alternative - Secant Wall System*

The alternative design proposal of a Secant Pile Wall (SPWall) comprised of interlocking bored piles embedded into competent rock and laterally restrained with ground anchors. This hard/firm SPWall system utilised 1200 mm diameter piles, spaced at 750 mm intervals. Unreinforced primary piles were cast with 20 MPa concrete, while reinforced secondary piles, drilled down to the top of rock, used 50 MPa concrete. A capping beam would be formed on top of the SPWall and stepped to follow the existing ground profile.

Compared to DWall, SPWall's primary challenges were water tightness and verticality. Significant effort was invested to understand and control the risks of groundwater inflow and related ground settlement that could arise from switching the retaining system from DWall to secant pile wall (SPWall). Detailed site investigations, including packer and pump tests, were carried out to determine the permeability and hydraulic conductivity of the rock mass. These tests, combined with comprehensive hydrogeological modelling, helped predict potential inflow rates to the station box and assess the risk of settlement caused by water drawdown. Given these inflow risks, a complex curtain grouting system was designed around the excavation to further reduce groundwater ingress and minimise settlement. The integration of a shotcrete facing and targeted grouting measures provided additional watertightness for the SPWall, ultimately ensuring the retention system met strict project requirements.

The SPWall piles were designed in accordance with CIRIA C760 (Okumusoglu and Sentry, 2024). The design of the SPWall with a 10 year design life also followed the relevant Australian standards and the Transport for New South Wales (TfNSW) specification and project specific specifications. The design incorporated load factors, strength reduction factors and other design contingencies to reduce risk to an acceptable level.

4.3 *Load and Material factors in design*

The project specifications provided a set of load factors to be applied, which set out different load factors for the earth pressure, groundwater pressure and surcharge on the retaining walls. The specifications also allowed the use of AS 5100.3 which required that the retaining wall should be designed for all effects of actions, including water pressure, after factoring design action effects by a lumped load factor of 1.5. The project team further analysed this requirement (Figure 9) especially considering that the groundwater table is already at the ground surface and a factor of 1.5 on the water pressure seemed excessive.

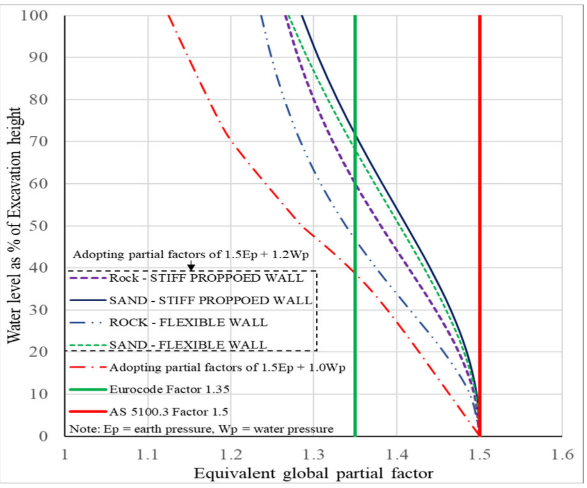

Figure 9. Lumped load factor achieved by various approaches for different ground conditions, with variation in water level.

The assessment presented in Fig.9 was made (Manoj et al., 2023) based on which a lumped factor of 1.35 was adopted in the SPWall design. It was also noteworthy that this fell in line with EC7 recommendations. The SPWall structural design was thus optimised based on the revised load factors. The ground displacements from the Plaxis finite element model are presented in Figure 10.

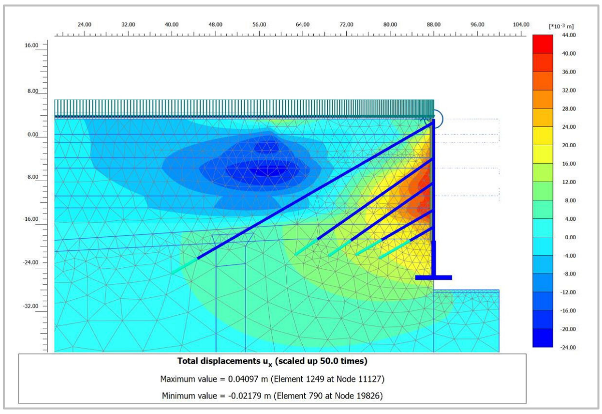

Figure 10. Computed accumulated ground displacements – SPWall.

4.3.1 *Hydro Geological Model and Settlements – Mitigated and Unmitigated scenarios*

The WBPS is sensitive to ground settlement, a significant component of which can potentially be induced by groundwater level drawdown. To prevent this, the project specifications required that the inflow into the station box should be limited to 5.15 l/s and a maximum of 445,000 litres in any 24 hours period. The Particular Specification also limited inflows to 50,000 litres in any 24 hour period (0.58 l/s), measured over any square with an area of 10 m², at all locations within the sides and bases of the excavation.

An initial hydrogeological model was developed for The Bays Station which was further modified to account for the SPWall design. Additional ground investigations were conducted to reduce uncertainty and reduce the risk due to unforeseen and unknown ground conditions. Based on the packer tests, pump-out tests, and pumping tests conducted at the site, it was expected that a typical horizontal hydraulic conductivity of the bulk rock mass across The Bays Station site was likely to range between approximately 10 Lugeons (8.6×10-2 m/day) and 30 Lugeons (2.5×10-1 m/day). An average value of 20 Lugeons was selected to reflect typical conditions. However, it was also possible that the bulk rock mass across The Bays Station site was much higher (up to 80 Lugeons). The elevated values of horizontal hydraulic conductivity were associated with sandstone beds that experienced buckling due to in-situ horizontal stresses. This buckling was triggered by unloading that occurred because of erosion of overlying sandstone layers during the formation of the palaeochannel. The buckling caused the bedding planes within the sandstone to open, increasing the pathways available for groundwater flow.

The SPWall design considered a worst-case groundwater level, and a three-dimensional numerical groundwater model was developed for The Bays Station site in the MODFLOW-USG software package. For the assessed typical permeability of the rock mass within the paleochannel (20 Lugeons), peak inflows to the station box were predicted to exceed 12 l/s. If the rock mass within the paleochannel was highly permeable (80 Lugeons), peak inflows to the station box were predicted to exceed 20 l/s.

A maximum groundwater drawdown of 4 m and 7 m, respectively, for the 20 Lugeon and 80 Lugeon paleochannel rock mass was estimated as the probable and worst scenarios. As presented in Figure 11, the predicted inflows indicated that grouting of the bulk rock mass to 1 Lugeon, and the weathered rock and identified bedding to 5 Lugeons, for the base case unmitigated scenario would not meet the inflow threshold. Furthermore, the modelling indicated that groundwater inflows to the station box excavation are likely to meet the inflow criteria of 5.15 l/s based on a grout curtain around the station box that would achieve 1 Lugeon permeability for the grouted rock. The curtain grouting combined with the plan to perform localized grouting under the WBPS and of significant water bearing features at the station during excavation, helped reduce ground water inflow and protected the WBPS from undergoing unacceptable levels of settlements. The inflows after mitigation scenario compared against the threshold/acceptable inflow of 5.15 l/s are also shown below in Figure 11.

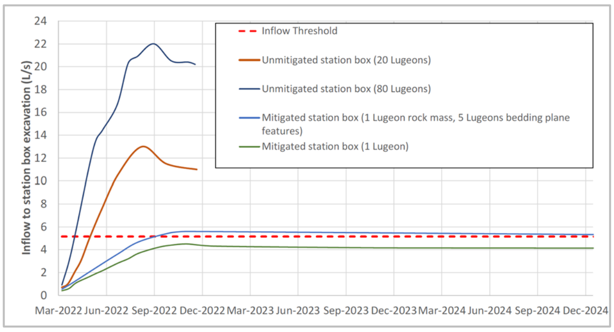

Figure 11. Predicted ground water inflows into station box – mitigated and unmitigated scenarios.

Grouting of the rock at the station box considered a temporary grout curtain around the full perimeter of the station box walls, with the curtain extending to -52 m AHD. With the grout curtain achieving a permeability of 1 Lugeon along its full depth, the model indicates that the inflow criterion would be met. Figure 12 shows the predicted water table drawdown in meters in December 2024 by the end of project works, for the mitigated scenario.

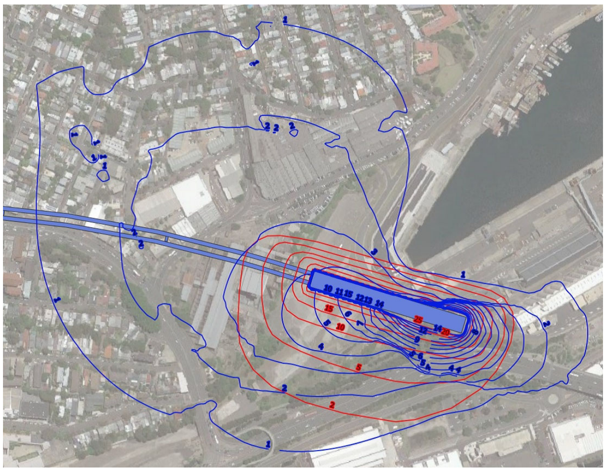

Figure 12. Predicted water table in meters Dec 2024 by end of project works (red) for mitigated station box and mitigated WBPS area with tunnelling scenario (blue).

For the fully mitigated scenario, using ground models with a grouted station box and grouting under the WBPS, the predicted inflows were 0.2 l/s in the grouted zone, increasing to 1.5 l/s outside the mitigated zone to the west of the WBPS. The controlled inflows into the excavation would mean that the groundwater drawdown at the WBPS was minimal and the resulting ground settlements remained within the acceptable levels that could be tolerated by the heritage structure.

4.4 *Settlement prediction for the WBPS*

Various scenarios and sensitivities were assessed to predict the impact of construction at the WBPS. Critical sections along and across the WBPS and different ground conditions for fully mitigated and no grout scenarios were analysed. Figure 13 presents settlement predictions at the south wall of the WBPS based on an upper bound pessimistic (red) scenario and a base case for grouted/mitigated case as most probable scenario (blue) for settlement impact.

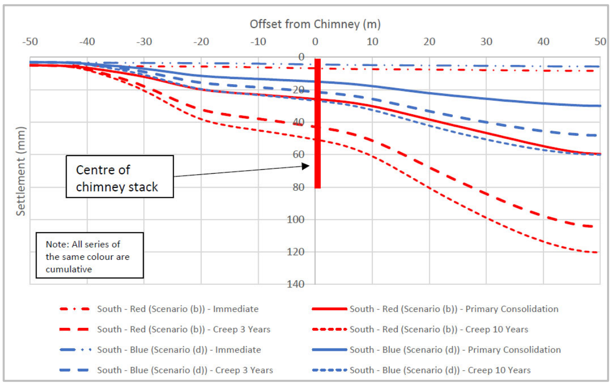

Figure 13. Settlement predictions North Wall of WBPS for upper bound (red) and most probable grouted (blue) scenarios.

This location was considered as the critical case scenario for the WBPS due to the presence of thick alluvium layer at this location.

5 SUCCESSFUL COMPLETION OF SPWALL SYSTEM

After receiving the final approval of the SPWall design, the installation of piles at The Bays Station commenced on February 9, 2022 (Figure 14). A total of 13114 m^3 of concrete and 1374 tonnes of steel cages were utilised for 524 piles with 8569 linear meters of piling works, completed over 6 months, followed by 811 active anchors installed and stressed over 9 months, with the final anchor completed on 7 February 2023. Piling and anchoring/excavation overlapped by about 3 months. TBMs Daphne and Beatrice, named in honour of Paralympian Daphne Hilton and Rozelle local Beatrice Bush, were launched on schedule in April and May 2023, respectively.

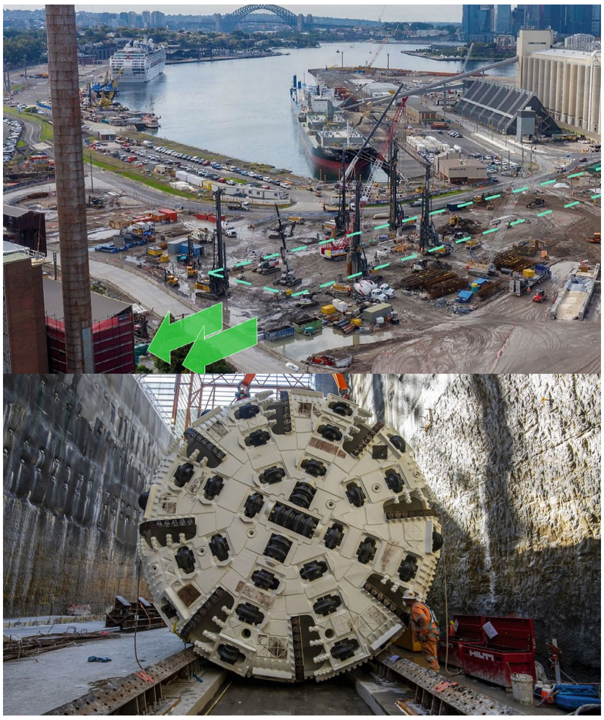

Figure 14. On the top, five piling rigs working to complete SPWall and on the bottom, TBM Daphne ready to launch from The Bays Station.

The actual ground conditions encountered during construction were more favourable than initially anticipated. This resulted in recorded surface settlements and wall movements to be well below the established monitoring thresholds, affirming the effectiveness of the design and construction methodologies implemented for the retaining system of the Bays Station box.

5.1 *Actual Settlements at the WBPS Chimney location*

The settlements beneath the centre of the chimney stack, as shown in Figure 15, measured less than 50 mm, which was both the most probable prediction scenario and within the permissible limit, with no remedial actions required. This confirmed that the excavation and tunnelling activities were completed without affecting the heritage structure.

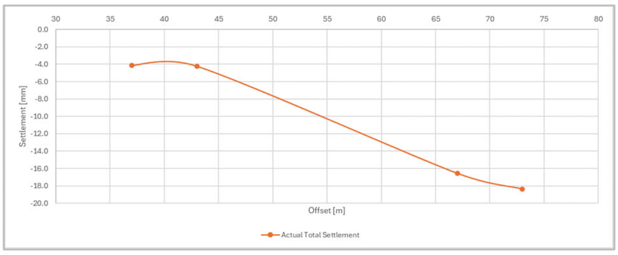

Figure 15. Actual settlements measured under the Chimney Stack.

5.2 *Recorded Performance of Retaining Wall*

Roper et al. (2025) conducted back-calculation analysis on the measured deflection of the retaining wall using available inclinometer data and found that some design parameters, such as the stiffness modulus (E) and cohesion (c'), could have been set higher. An example of their analysis is presented below in Figure 16.

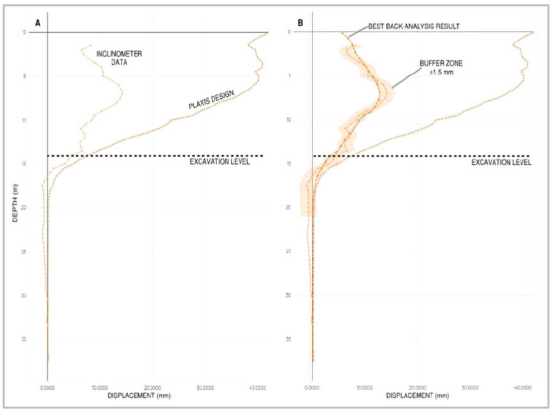

Figure 16. Design vs recorded and back-calculation of wall movement.

6 CONCLUSIONS

The successful delivery of the 31m deep excavation at The Bays Station demonstrates how comprehensive geotechnical investigation, combined with advanced numerical modelling, enabled an optimized retaining solution in a challenging urban environment.

The project's progression from an initial diaphragm wall design to the implemented secant pile wall system exemplifies the value of robust site characterization. The extensive investigation program, including targeted packer tests, pump-out tests, and detailed mapping of the Great Sydney Dyke and paleochannel, provided the confidence necessary to evaluate alternative retaining systems during construction. This investment in understanding complex subsurface conditions, particularly the interaction between loose alluvial soils, fractured rock masses with varying permeability up to 80 Lugeons, and elevated groundwater tables, proved instrumental in achieving a safe, economical, and sustainable design.

The refined hydrogeological modelling enabled accurate prediction of groundwater inflows and settlement impacts. Actual monitoring data showing settlements less than 50mm at the heritage-listed White Bay Power Station, along with wall movements well below established thresholds, validates this investigation-led design approach. Notably, the actual ground conditions and water flow parameters encountered during construction proved more favourable than anticipated, suggesting opportunity for further optimization while acknowledging the appropriateness of conservative assumptions when managing uncertainties in urban geotechnical projects.

This case history reinforces that in geotechnically challenging projects with stringent impact criteria on adjacent heritage structures, the investment in comprehensive investigation and sophisticated analysis enables design optimization that would otherwise be unattainable. The early collaborative involvement of specialist ground engineering contractors in the design process proved essential in developing innovative, constructible solutions that balanced technical requirements with practical execution, providing a valuable benchmark for future deep excavations in similar geological settings along Sydney Harbour.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Sydney Metro West Interactive Portal. https://caportal.com.au/tfnsw/sydmetrowest/map.

Gaba A, Hardy S, Doughty L, Powrie W, Selemetas D (2017), Guidance on embedded retaining wall design, C760. CIRIA, London.

ICE (2007) Specification for piling and embedded retaining walls (SPERWall), 2nd edn. Thomas Telford Publishing, London.

European Standard, EN 1997-1(2004), Eurocode 7 - Geotechnical design, Part 1: General rules, European Committee for Standardization, Brussels.

Manoj, S., Poulos, H., Dang, H.P. (2023), Hydro static pressure and load factors in retaining wall design - a review of provisions in Australian Standards in comparison with Eurocodes. Proceedings of 14th Australia and New Zealand Conference on Geomechanics, Cairns.

Okumusoglu, B., Sentry, M. (2024), Support of 30-m-Deep Excavation for TBM Launch and Future Underground Station of Sydney Metro West. Proceedings of the 5th International Conference on Transportation Geotechnics, Sydney.

Roper T.P., Gelonch, L., de Santos, C., Ali, M., Karlovšek, J. (2025), Reducing cost and carbon emissions through rapid design optimisation during construction. Proceedings of the 19th Australian Tunnelling Conference, Perth.

Standards Australia, AS 5100.3 (2017), Bridge Design Part 3.