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Excavation directly beneath a heritage building with tight settlement limits, Sydney CBD

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ABSTRACT: The Wynyard Walk project was an extremely challenging design and construction project located in Sydney's Central Business District. Part of the project required excavation underneath a 12 storey heritage listed building with very little tolerance to movement, in order to deepen its existing basement by two levels. The excavation involved undermining of the building's existing shallow footings. The tight settlement criteria and geometric constraints of the site necessitated complete integration between structural and geotechnical design disciplines and the construction team, throughout the design and construction.

Site investigation was undertaken using a unique high quality downhole photography technique that allowed the geotechnical conditions beneath the site to be determined with precision. This provided a high degree of confidence in the design.

To control the building settlement at all stages during and after construction, an underpinning structure was designed comprising new piles installed from within the existing basement, and post-tensioned transfer walls founded on the piles and encompassing the existing basement columns. Large diameter flat jacks were included between the pile caps and the transfer walls, in order to transfer the building loads off the existing shallow footings and into the new piles prior to commencement of excavation. Ground-structure interaction and construction sequencing / constructability were primary considerations in the design.

1 INTRODUCTION

The Wynyard Walk project consists of a pedestrian walkway that connects the existing Wynyard Train Station to the Barangaroo waterfront precinct. The walkway is located just beneath the surface of the CBD surface and provides a safe, swift and efficient path for pedestrians. An overview plan of the Wynyard Walk project is presented in Figure 1. A project overview is also provided by Clarke et. al. (2018).

This paper presents the underpinning and excavation approach implemented for the design and construction for the portion of the walkway that was constructed beneath Railway House, a heritage listed building built in the 1920s.

2 THE RAILWAY HOUSE SITE

Railway House is a 12 storey building which had 3 basement levels prior to the Wynyard Walk project; B1, B2 and Concourse level. Whilst the entire B1 and B2 level consisted of working spaces, the Kent Street Tunnel (which was a tunnel providing pedestrian access between Kent Street and Wynyard Station) occupied part of the Concourse level as shown in Figure 2.

Railway House is a heritage listed building partly due to extensive use of terracotta tiles as part of the building façade as well as being one of the most intact art deco buildings in Sydney with cutting edge design features with the Wynyard Walk train station beneath the building.

Railway House is bounded by York Lane and York Street along its western and eastern boundaries respectively. The Wynyard Station train platforms are also located adjacent to the eastern boundary of Railway House, below York Street. There are two existing high-rise office buildings adjacent to the northern boundary (Transport House building) and southern boundary of Railway House. Access to the Kent Street tunnel was also possible from the Transport House building.

The Railway House footings were pad footings founded just below the B2 level floor slab. The footing base levels ranged between RL14.6m and RL14.9m with the column working loads ranging from 4.4MN to 9.5MN. The pedestrian walkway

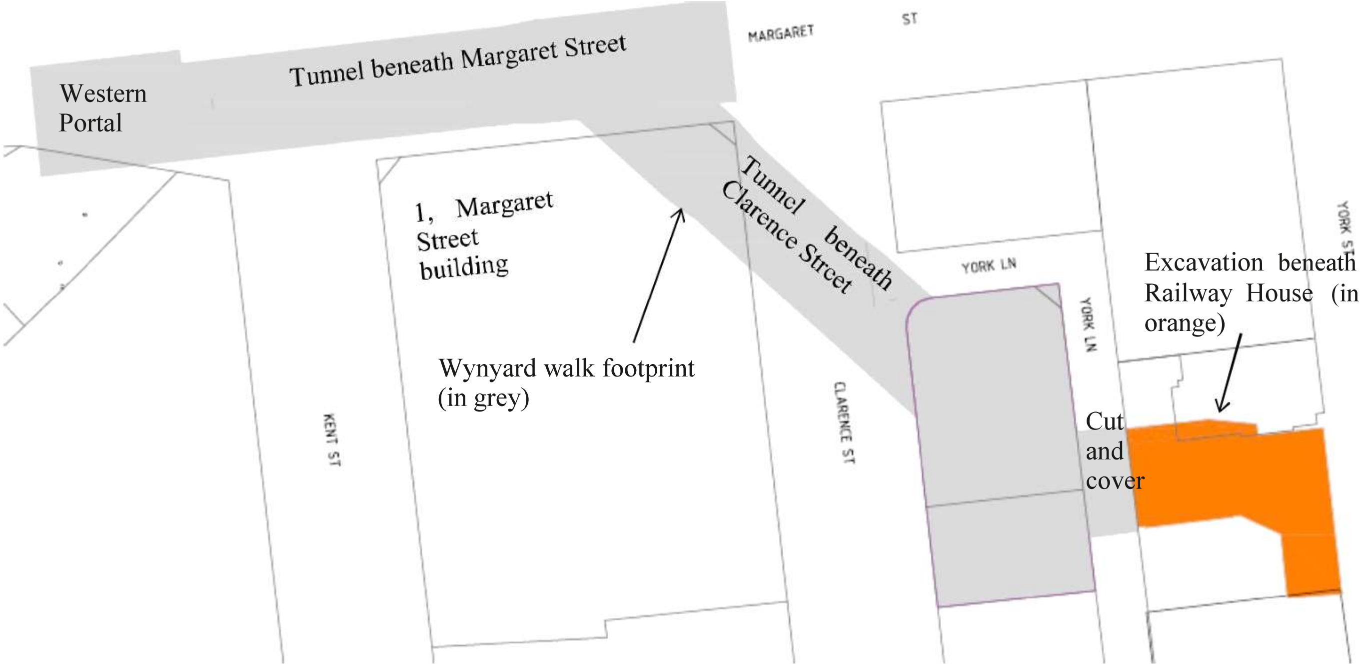

Figure 1: Wynyard Walk plan overview

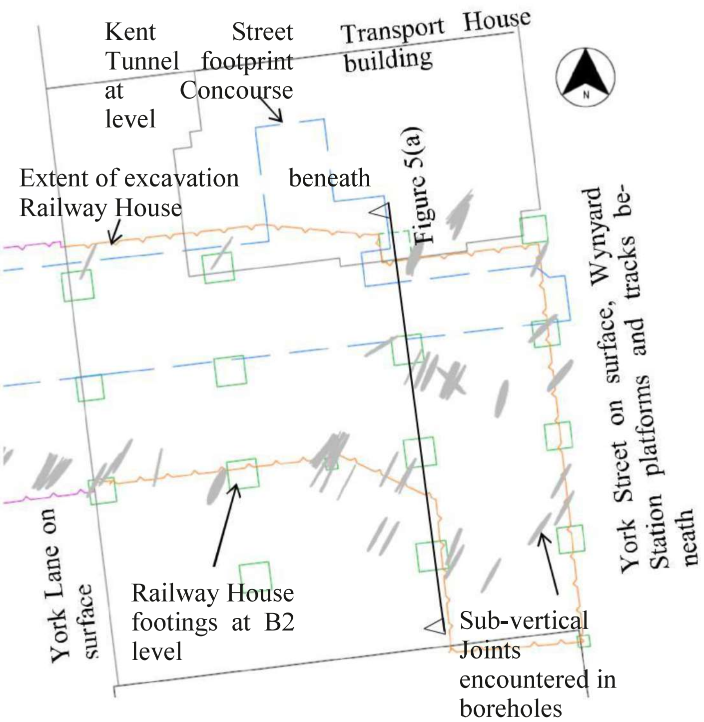

Figure 2: Railway House Plan

horizontal alignment required the walkway to pass beneath Railway House and many of its footings, and the vertical alignment required the existing B2 level at approximately RL15.3m to be excavated to the Concourse level at approximately RL9m. This meant that the some of the existing building footings would be undermined and some footings would be at the crest of a rock ledge or pedestal due to the excavation of the pedestrian walkway.

3 SITE CONSTRAINTS

Often, excavation and construction beneath an existing building is technically difficult and challenging.

The design and construction of the pedestrian walkway beneath Railway House was no exception. The site constraints included:

- Tight tolerance to movement at Railway House

The façade of Railway House is covered with fragile terracotta tiles and is heritage listed. Therefore, almost no ground movements from the excavation and underpinning works of the walkway were permitted, in order to prevent damage to the façade. This meant that the settlement of the underpinning structures had to be actively controlled to ensure that negligible ground and structure movements could be achieved, movement limits were as small as 3mm.

- Continuous operation of existing buildings

The excavation and underpinning works had to be undertaken without interrupting the operation of the offices above the basements and adjacent buildings. As a result of this constraint, there were noise and vibration levels which the project needed to comply with during the construction works beneath Railway House.

- Low headroom

The excavation and underpinning works had to be undertaken within the Railway House B2 level which had low headroom such that only small machines were able to access the site. Consideration was also given to the adopted underpinning design to ensure that construction was possible within the basement level.

- Excavation adjacent to rail tracks

The rail tracks immediately adjacent have minimal tolerance to movement. Considerations of the track movements were required during the excavation of the tunnel as stress relief from rock excavation might cause track movements, disrupting the train services.

• Existing Kent Street Tunnel

Design and construction of the pedestrian tunnel required consideration of the existing Kent Street Tunnel which provided pedestrian access between Kent Street, Transport House building and Wynyard Station. The tunnels demolition had to be accounted for in the design.

• Interface with adjacent project works

The walkway beneath Railway House extends beneath York Lane and through to Clarence Street Entry Building. The design and construction of the walkway beneath Railway House had to consider the interface of the adjacent project structures to ensure that the design and construction program at each site did not affect the adjacent sites.

• Geotechnical constraints

The geotechnical constraints are described in the following section.

4 GEOTECHNICAL CONDITIONS

The site is underlain by medium strength Hawkesbury Sandstone. The medium strength Hawkesbury Sandstone includes sub-horizontal bedding plane defects with some sub-vertical jointing (Bertuzzi and Pells, 2002). The existing pad footings were founded on this rock, Class III Sandstone based on Pells et. al. (1998). The rock at the final walkway invert was Class I/II Sandstone.

The extensive and detailed site investigations com-prised drilling of vertical and inclined boreholes from the B2 level to investigate the rock mass condition, including strength and defects within the vicinity of the existing pad footings that were to interact with the walkway excavation. The investigation was required to provide high confidence in the design approach, as the presence of adverse defects beneath these footings might compromise the structure of Railway House.

The downhole imaging was undertaken using a Slimline Optical Televiewer which provided a high resolution oriented photographs to precisely identify ground conditions surrounding the footings, almost entirely eliminating ground condition risks during construction and providing certainty of design and programme. The Slimline Optical Televiewer was different to the typical Optical Televiewer (OTV) and Acoustic Televiewer (ATV) imaging undertaken in the geotechnical industry as it provided a 360 degree high-resolution photograph of the borehole wall, removing the uncertainty that is often involved with interpretation of borehole imaging. Figure 4 presents the downhole imaging photograph for the same borehole for which the core photograph is presented in Figure 3. The sub-vertical joints and their orientation are clearly captured in the downhole imaging photograph, confirming the precise location of the sub-vertical joints beneath the Railway House site.

Based on the sub-vertical joints that were encountered in the boreholes, it was assessed that there was an extensive sub-vertical jointing beneath the site. As a result, leaving the existing pad footings found-ed on the edge of the excavation was not possible. Therefore, design and construction of new underpinning structures were required for the pedestrian walkway.

Figure 3: Typical sub-vertical joints encountered in an inclined borehole.

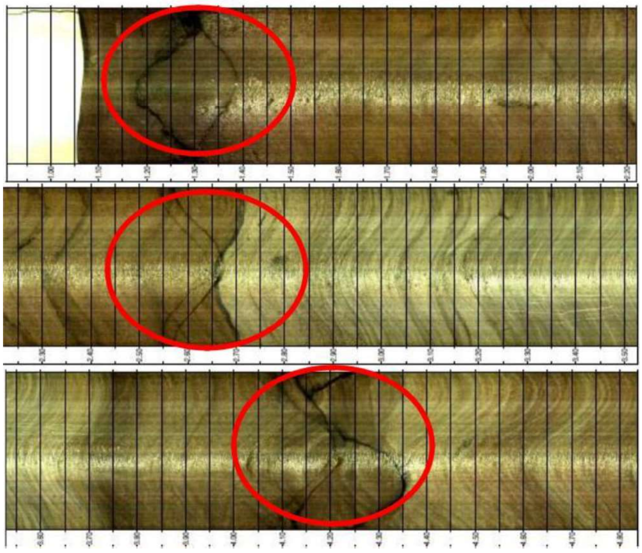

Figure 4: Downhole imaging photograph from the same borehole as the core photograph shown in Figure 3.

5 INTEGRATED GROUND-STRUCTURE UNDERPINNING DESIGN

The design and construction of the underpinning structures required a high degree of integration between the structural and geotechnical disciplines throughout the design and construction stages.

The underpinning design was based around a “transfer structure” across each row of columns, transfer-ring the existing column building loads away from the existing footings and onto new underpinning structures (temporary and permanent) to below the pedestrian walkway invert level. The “transfer structure” comprised post-tensioned tendons and reinforcement, forming concrete transfer beams and transfer walls within the B2 basement level, spanning across the width of pedestrian walkway.

The columns which were connected to the pad footings that were originally concrete encased steel for durability and protection, but the concrete was removed to expose the steel columns to allow for construction of the transfer wall encapsulating the steel columns. The rows of existing steel columns had steel studs welded along their length prior to encapsulation into the new transfer walls, allowing the loads from the buildings to be transferred as the rock below the column pad footings was removed. Each transfer wall spanned on to the new piles at each side of the pedestrian walkway and/ or the temporary underpinning piles adjacent to the new piles installed beyond each side of the pedestrian walkway and/ or the temporary underpinning piles adjacent to the existing pad footings. The existing building loads were introduced to the "transfer structure" prior to excavation of the basement by pressuring the flat jacks between the piles and the transfer walls. By loading the flat jacks, the settlement that might occur due to pile shortening or rock settlement was removed prior to excavation. At temporary pile locations, permanent steel underpinning columns were installed on pad footings and the load was transferred across from the temporary condition (on piles) to the permanent condition (on steel columns). By adjusting flat jacks, this load transferred occurred with negligible settlements. All flat jacks remaining in the transfer system had the jacking fluid replaced with grout under pressure to become a permanent bearing pad. The temporary underpinning piles situated within the tunnel zone were demolished at completion of the excavation to the Concourse level, after the loads were transferred to the permanent pad footings. The typical underpinning sequence is presented in Figures 5a to 5c although this varied between each row of columns. Figure 5d presents the condition beneath Railway House after excavation to Concourse level and the overall underpinning for Railway House is presented in Figure 6.

The piles were sleeved to ensure that the existing building loads were transferred through end bearing and not through skin friction within the rock that was to be removed. This was crucial to allow full control of the pile displacements due to the tight settlement criteria. The control of the basement settlement during excavation was not possible without the innovative system of large double diameter stacked flat jacks. The flat jacks were installed between the pile caps and transfer beams to control the effects of settlement of the underpinning piles during the excavation of the pedestrian walkway.

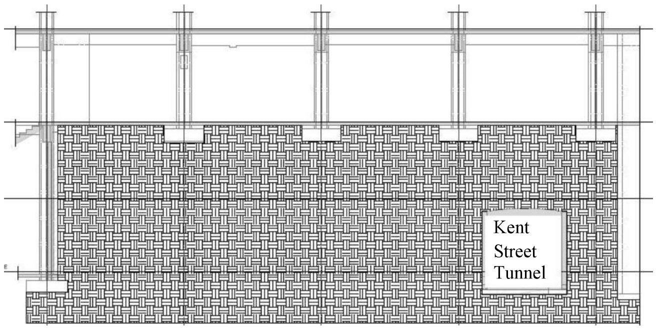

Figure 5a: Railway House existing condition.

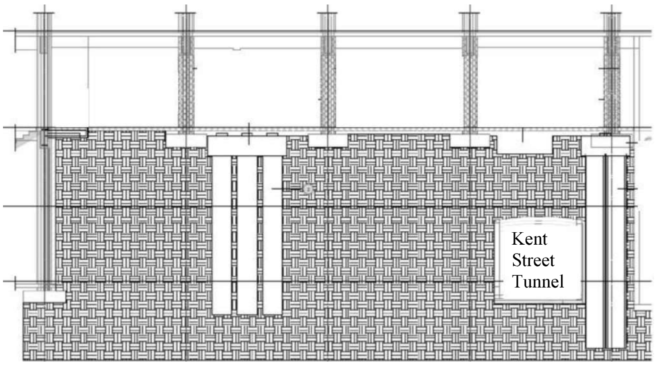

Figure 5b: Removal of concrete around the steel columns, installation of underpinning piles and flatjacks.

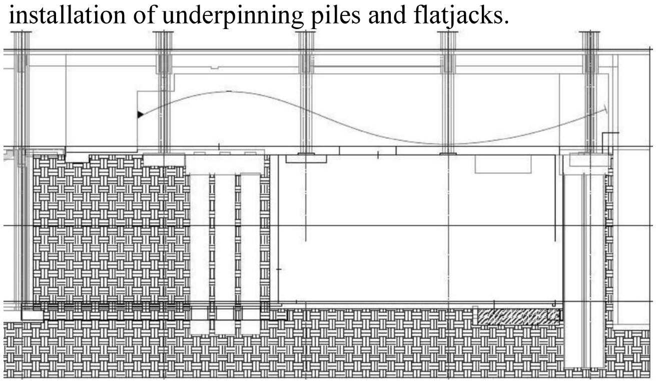

Figure 5c: Construction of "transfer structure", introduction of building loads to the "transfer structure" followed by excavation to Concourse level.

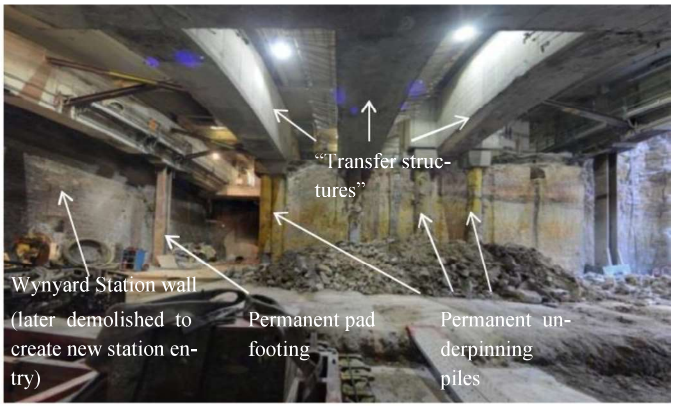

Figure 5d: Condition beneath Railway House after excavation to Concourse Level

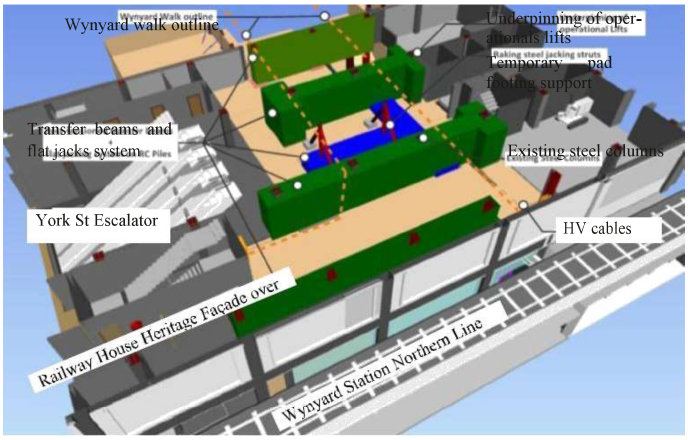

Figure 6: The Railway House underpinning design.

6 CONSTRUCTION AND MONITORING

The excavation and drilling of the piles were undertaken using small excavators and a low head height piling drill rig due to tight site access and low head room in the basement. Each underpinning pile was cleaned to ensure that the base and side walls were free of spoil after they were drilled. This was important to the design to meet the tight project settlement criteria. A brush was attached to the end of the auger to clean the side walls. The spoil at the base of the piles was removed using a cleaning bucket as well as being vacuumed to ensure that as much spoil as practical was removed. Inspection was undertaken of every pile base and side wall using a high-resolution custom built downhole camera to verify the cleanliness of the base and the side wall of the pile. The cleanliness of the pile base was crucial as the flat jacks had travel limits. Spoil at the base might have required additional flat jacks travel which may have impacted the settlement control. Figure 7 shows photographs of the pile base before and after the base was cleaned.

Figure 7: Photographs of pile base before and after being cleaned.

Monitoring of the underpinning piles was undertaken in real time during excavation beneath Railway House. The adopted real time automated settlement monitoring was a high precision system with accuracy better than 0.5mm. Flat jack pressure was continually adjusted to compensate for new pile settlements as load came on during excavation. Figure 8 presents an example of the real-time settlement monitoring at one of the Railway Houses (Grid B) during excavation. The real time settlement monitoring results were assessed in conjunction with the construction activities to allow the construction to respond to any movement that was observed. The settlement of the piles was controlled by adjusting the flat jack pressures as advised by the structural engineers.

The settlement data collected during construction essentially mimicked a series of full-scale pile load tests. The performance of the temporary and permanent piles and pad footings are summarised in Table 1.

Table 1. Summary of underpinning footings performance

Underpinning structure	Number of structures	Size	Range of working bearing pressure	Range of settlement	Range of settlement
			MPa	mm	(% of minimum pad or pile dimension)
Temporary piles	10	600mm and 750mm in diameter	5 to 10	0.5 to 3.5	0.07 to 0.6
Permanent piles	14	750mm in diameter	7	4 to 6.5	0.5 to 0.9
Permanent pad footings	5	1500mm x 1500mm	2 to 4	2 to 7	0.1 to 0.5

The "worst case" design expectation was that the pile settlements could be up to 1% of diameter at a bearing pressure of 3.5MPa and 3% at a bearing pressure of 10MPa based on Pells et. al. values for Class III Sandstone. The range of measured settlement was more comparable with expectations for Class I/II Sandstone based on Pells et. al. (1998), i.e. settlements up to 1% of diameter for bearing pressures up to 10MPa.

7 CONCLUSIONS

This paper describes the integrated ground-structure design of underpinning structures with active settlement control beneath the Railway House building that is sensitive to movement. The innovation in the design and construction of the underpinning structures led to:

- Settlements being within the criteria, demonstrated at all stages of construction by real time monitoring.
- Creation of a new underground space directly below existing buildings, ensuring the optimal pedestrian experience and linking the

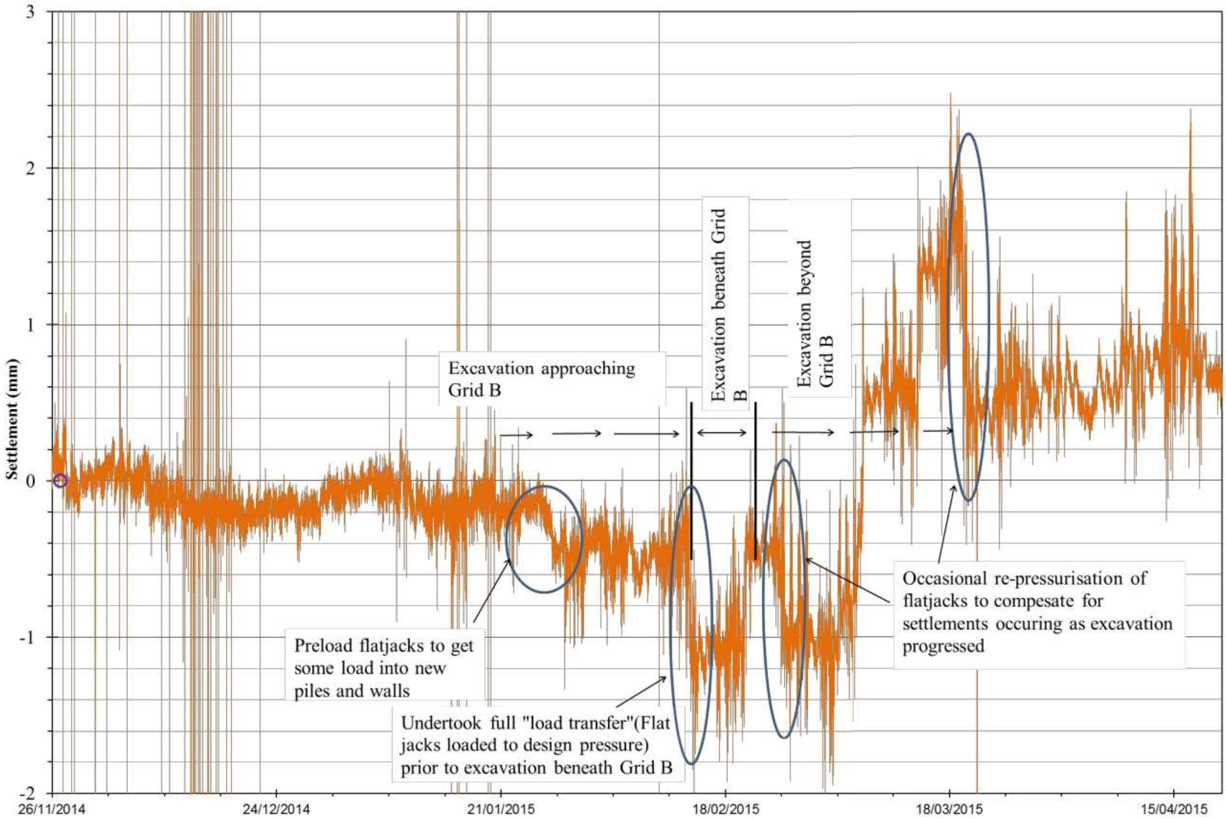

Figure 8: Settlement of the transfer wall at Grid B against time

new Wynyard Walk tunnel at grade with the existing Wynyard Station.

- No disruption to the adjacent rail operation or the users of Railway House above and adjacent buildings.

The design and construction approaches developed in solving the unique challenges of the Wynyard Walk project without affecting the structural integrity, or heritage aspects of the building is proof that excavation directly beneath buildings with tight settlement criteria is possible with collaborative effort between the structural and geotechnical engineers especially relevant for developments in CBD areas which have become increasingly congested and constrained.

8 ACKNOWLEDGEMENTS

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