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Investigation of Complex Ground Conditions at Sydney Park for the Sydney Metro City & Southwest Running Tunnels

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Abstract: The Sydney Metro City & Southwest (SMCSW) project will provide additional underground rail services between Chatswood and Marrickville. The two running tunnels pass close to Sydney Park, which was quarried in the 19th and 20th centuries for the manufacture of pottery and bricks and resulted in the excavation of large pits of up to 60 m depth. Quarrying ceased around 1948 with the pits progressively backfilled with municipal waste over the next three decades. The running tunnels were designed to be constructed through a long rock pillar formed by deep backfilled pits on either side. The site history posed numerous geotechnical risks to the design and tunnelling works. These risks included intersecting the waste in the pits, ground instability due to the proximity of the pit walls, and uncontrolled and potentially contaminated groundwater inflows into the tunnel during construction. To address the design and construction uncertainties the proposed tunnel alignment was initially verified by a detailed desktop study. Information on the geometry of the excavated pits was mostly limited to aerial photos from 1934 onwards. Comprehensive geotechnical investigations were subsequently undertaken to confirm that the rock pillar provided sufficient separation between the tunnel alignment and adjacent waste-filled pits. During the desktop study a reference to an abandoned tunnel was discovered on a survey plan dating from 1937, with the old tunnel shown crossing the SMCSW tunnel alignment. A targeted site investigation was undertaken using conventional geotechnical boreholes as well as a range of geophysical techniques to successfully locate the position, depth and condition of the abandoned tunnel. This paper presents the results of the desktop study and site investigation work used to define the extent of the backfilled pits and the abandoned tunnel and confirm that the tunnel alignment would avoid these hazards. This work provided critical input to managing the design and construction risk associated with the complex ground conditions caused by over 100 years of human activity and enabled successful construction of the running tunnels.

Keywords: Sydney Metro; Sydney Park; Brick pits; TBM Running tunnels.

1 Introduction

The SMCSW project includes major tunnelling and excavation works along the 15 km route between Chatswood and Marrickville. The Tunnels and Station Excavation works contract (TSE) was undertaken by the John Holland CPB Ghella (JHCPBG) joint venture as a design and construct project for Transport for New South Wales (TfNSW). Approximately 750 m of the alignment is located adjacent to Sydney Park. The twin running tunnels have an excavation diameter of 7.0 m with the centre of the tunnels separated by approximately 13.5 m. The tunnels, with an internal diameter of 6.17 m, were excavated with a hard rock double shield tunnel boring machine (TBM) and lined with a 0.26 m thick segmental concrete lining. Ground cover above the tunnel ranges between 35 m and 40 m along this portion of the alignment.

The area around Sydney Park was used to extract clay and shale for pottery and brick manufacturing during the 19th and 20th centuries. The large resources of relatively uniform thickness Triassic age Ashfield Shale had resulted in up to twenty pits operating over 80 years within the St Peters area (McNally and Branagan, 1998).

The pits were subsequently backfilled with municipal waste between 1960 and 1985 (Dupen, 1992), and capped with soil and building rubble. On the south side of Sydney Park Road, the reclaimed land was then reconfigured as parkland for public recreational use and on the north side for residential development (Figure 1). The total volume of waste in the pits is estimated to be at least 5,000,000 m^3, and includes a variety of materials including putrescible, non-putrescible and possibly liquid wastes (Dupen, 1992). Note that the pit crests shown in Figure 1 are inferred from historic maps and aerial photographs dating from 1890 to 1956, while the toe position of the steep slopes are schematic only.

Figure 1. SMCSW running tunnel alignment adjacent to Sydney Park, showing the inferred positions of backfilled brick pits, an abandoned haul tunnel and cable tunnel, overlaid on a 2015 aerial photo.

Given the age and nature of the original land use, there was extremely limited information on the geometry, plan extent and depth of the pits. This uncertainty led to a range of potential hazards to tunnel construction including:

- Intercepting waste material that the TBM could not tunnel through.
- Instability of the rock pillar between the tunnel excavation and adjacent pit walls.
- Uncontrolled groundwater inflows into the TBM excavation.
- Interception of explosive and/or toxic gases associated with the waste material (Wojcik and Hausmann, 1993).

The initial strategy was to route the running tunnels through a rock pillar formed by deep backfilled pits on either side. This alignment was firstly verified with a desktop study, followed by targeted geotechnical investigations. The work addressed the potential hazards to tunnel construction, as listed above.

2 Desktop Study

The desktop study was undertaken to obtain further information on the pit geometries, and involved obtaining information from various sources, including:

- Sydney 1:100,000 scale geological map produced by the Department of Mineral Resources NSW, 1983.
- Aerial photographs sourced from SIX Maps (the NSW Government online website service which provides access to cadastral and topographic information, satellite data and aerial photography for New South Wales).
- Aerial photographs sourced from Geoscience Australia, Land and Property Department NSW, and Sydney City Council.
- Published books, technical papers and an undergraduate thesis.
- Mine inspections reports from 1956 to 1979.
- Documents and survey plans retained by the Mitchell Library of the NSW State Library and Sydney City Council.
- Online information regarding the pits including news articles and historic photographs.
- Geotechnical borehole data from previous projects (provided by TfNSW).
- Information from building developments surrounding Sydney Park.

The first successful aerial photographs were taken in 1858 from a hot air balloon near Paris (Waxman, 2018). It was not until the late 1920s that aerial photographs were taken of parts of greater Sydney (RTA, 2005), though the earliest aerial photographs that could be found of the St Peters area were from 1930. The photographs provided useful details of the extent of the pits at the time that the aerial photographs were taken, however, they are blind to areas which may have been excavated and backfilled prior to the date of the photograph. Thus there is a period of roughly 50 years prior to the first aerial photographs in which the extent of pit excavations is largely unknown and the useful information was limited to a few relatively basic maps (Figure 2). The 1943 aerial photograph shows the extent of the brick pits at that time (Figure 3).

In the 1950s the City of Sydney Town Planning Branch produced a map entitled "Alexandria West" which showed numerous brickworks in the vicinity of Sydney Park, with each located adjacent to a large pit. The Austral Brick chimneys and kiln still stand adjacent to the intersection between the Princes Highway and Sydney Park Road (Figure 1).

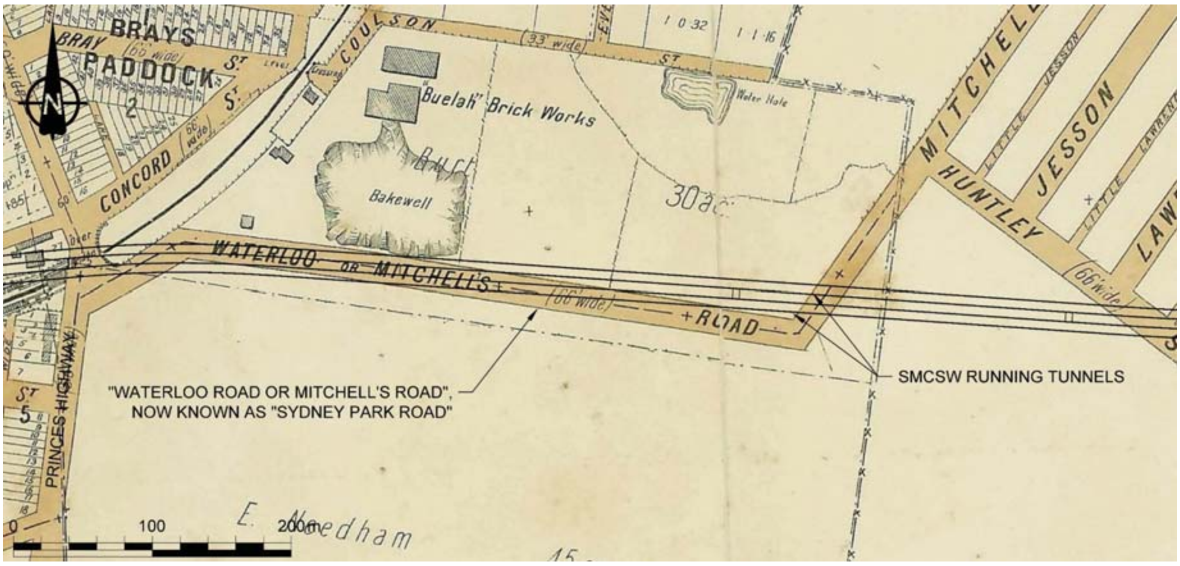

Figure 2. Extract from the 1886 map "Municipalities of the Glebe, Camperdown, Newtown, Macdonaldtown, and Darlington Parishes of Petersham and Alexandria", showing the original Bakewell pit located on the north side of Sydney Park Road. The pit formed part of the Buelah brick works.

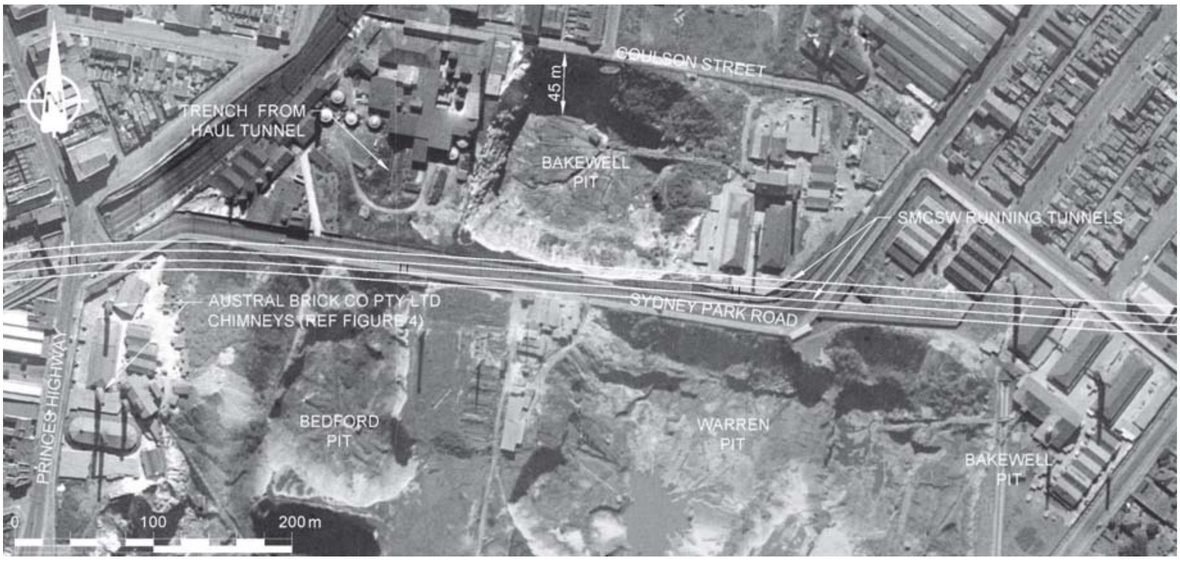

Figure 3. 1943 aerial photograph showing the extended Bakewell pit on the north side of Sydney Park Road, as well as shadows from the chimneys at the various kilns, with the length of the shadow within the Bakewell Pit also noted.

The current Sydney 1:100,000 scale geological map includes a unit for man-made fill (mf) in the Greater Sydney area. The presence of this unit is indicated around some of the foreshore areas of Sydney Harbour where land reclamation has occurred. However, this unit is not indicated on the map around Sydney Park despite the extensive anthropogenic activities that have taken place. Rather, the map shows the areas as comprising shale bedrock.

2.1 Pit depths

The desktop study was unable to locate detailed records of the geometry and depth of the backfilled pits. Inspection of the available historical photographs suggested that the pit batter angles ranged from approximately 45° to nearly vertical (~80°) with loose material evident along the base of the slopes.

The maximum pit depths are not reliably known. However, based on the other brick pits around Sydney it was likely that the pits were excavated down through the Ashfield shale bedrock (Dupen, 1992) until the resource was depleted and sandstone bedrock encountered (which is unsuitable for making bricks). McNally and Branagan (1998) noted that the pits within the St Peters area were worked to depths of around 40 m and that the Hawkesbury Sandstone typically lies a few metres below the pit floors.

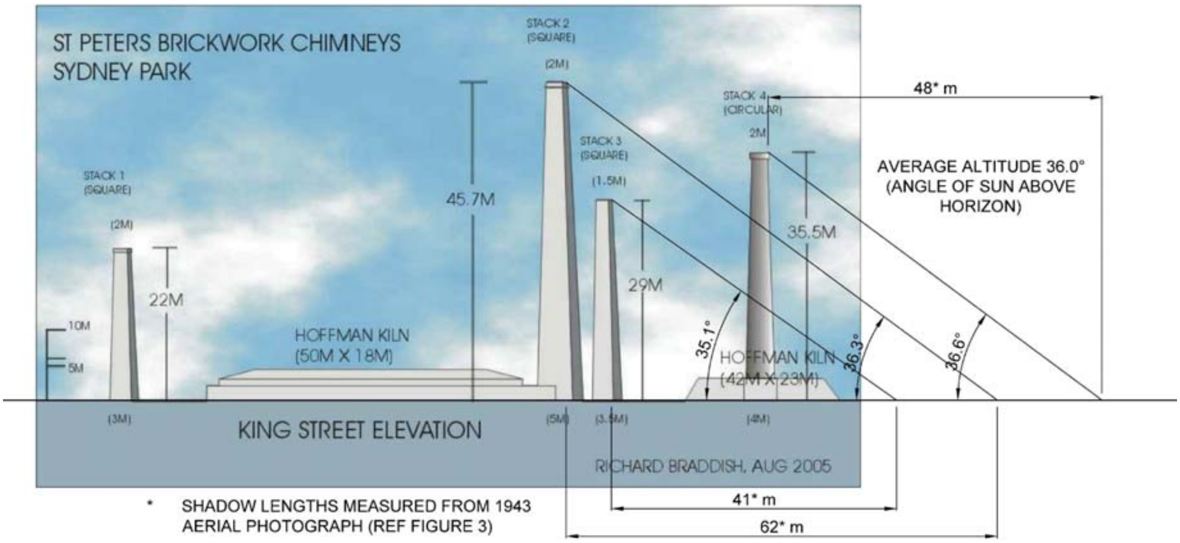

Figure 4. St Peters brickworks chimney height data used to estimate the depth of the pit shown in the 1943 aerial photograph presented in Figure 3.

A mine inspection report dated 1967 stated that the Bedford Pit face height varies from 65 ft to 110 ft (approximately 20 m to 34 m), though the location of the pit face was not given in the report. van Heeswyck (1976) noted that the pit was 18 m depth at that time with the pit being used as a refuse dump and was slowly being infilled, though it was unclear as to which pit he was referring to. From the available borehole information, the top of the sandstone unit (typically Mittagong Formation) is inferred to be at approximately RL -30 m, or 50 m below the current ground surface level.

Four chimneys of the former Austral brick works remain at the corner of Sydney Park adjacent to the Princes Highway (Figure 1). The height of the chimneys was assessed by Mr Richard Braddish in 2005 and summarised on a sketch (Figure 4). The chimney heights were obtained by counting the number of courses of bricks in each chimney and multiplying by the average course height (pers com Mr Braddish). These chimneys are also evident in a 1943 aerial photo (Figure 3), as are their shadows. The length of the shadows measured from the photo, combined with the chimney heights, was applied using simple trigonometry to determine the altitude of the sun at the time the photo was taken, and ranged from 35.1° to 36.6° (Figure 4). Figure 3 also shows a shadow length of 45 m from Coulson Street extending across the pit located on to the north side of Sydney Park Road. Based on the altitude of the sun obtained from the shadow lengths measured from the photo and the chimney heights it was determined that the deepest portion of the shadow extended approximately 33 m below Coulson Street.

2.2 Abandoned haul tunnel

A "possible tunnel" was mentioned in a geotechnical report undertaken for a development at 221 - 229 Sydney Park Road. The location of the tunnel could not be reliably determined in the report, and the borehole where tunnel backfill was thought to have been intercepted is more than 20 m from the tunnel alignment later confirmed during the SMCSW site investigation.

A hand-drawn survey plan (1:960 scale) of the Bedford Brickworks Pit originally dated 29 June 1937 and modified 29 March 1943 was found in the Mitchell Library. The plan shows magnetic north and several cadastral boundaries which include lengths and/or bearings. A few spot heights are given to an arbitrary site datum. The plan shows twin dashed lines labelled "Tunnel", which extend beneath Waterloo Road (now Sydney Park Road). Scaling from the plan indicates that lines representing the tunnel are approximately 60 m long, and are oriented perpendicular to Waterloo Road, though the plan does not extend sufficiently far north to show the location of the northern portal (i.e. the tunnel is longer than 60 m). Scaling from the plan suggests a tunnel span of about 1.5 m. There are no dimensions, coordinates or other details regarding the tunnel.

The tunnel was likely to have been used to haul excavated shale to the brickworks from the Bedford Pit to the south of Sydney Park Road. Based on rail tracks visible in some of the historic aerial photographs, it is surmised that the small tunnel may have housed tracks and rail carts pulled up the incline with a cable and winch.

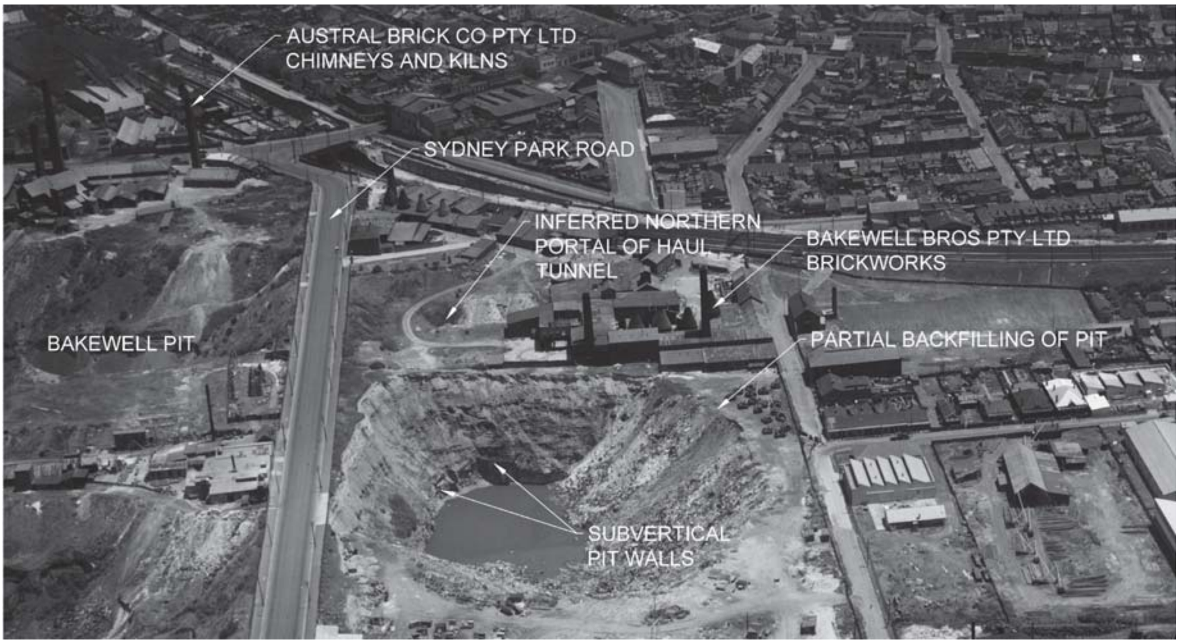

Figure 5. Aerial photograph looking west, dated between 1940 and 1955 (Mitchell Library of NSW State Library), showing the inferred location of the northern portal of the haul tunnel.

2.2.1 Georeferencing approach

Locating the plan position and depth of the abandoned tunnel was crucial to determine whether the SMCSW TBM alignment would intercept it. The location of the tunnel was georeferenced as accurately as possible relative to the SMCSW map grid (i.e. MGA). This involved scaling from the plan (both vertical and horizontal directions), rotation of the plan to align with the map grid and positioning it to align with cadastral boundaries.

Rotational adjustment of the plan required conversion from magnetic north to true north followed by true north to grid north (MGA). Based on the information obtained from Geoscience Australia, the magnetic declination in Sydney in 1940 was 10.15° (c.f. 12.58° in 2016). This advice was based on the International Geomagnetic Reference Field model (12th revision).

Due to the age and condition of the original paper plan and the fact that it was hand-drawn, precise georeferencing was not possible. The “best estimate” position of the south portal was assessed to an inferred accuracy of a few metres, with the tunnel axis alignment estimated to have a bearing of 11.0° (Figure 1).

2.2.2 Assessment of vertical alignment

Historical photographs of the Bakewell Pit did not clearly indicate the location of the haul tunnel portals (Figure 5). The tunnel length is inferred to be approximately 85 m based on the 1943 aerial photograph (Figure 3) with a track/trench evident heading towards the Bakewell Bros building.

Based on the topography shown in the photographs, the northern tunnel portal at the Bakewell Bros site appears to be in a localised trench estimated to extend approximately 10 m below Sydney Park Road.

The assessed elevation of the deepest point in the 1937 plan is approximately RL 18.7 m AHD. This elevation was obtained by comparing the relative level indicated on the plan for a point adjacent to Barwon Park Road with the level indicated for the same location from a more recent Lidar survey.

Prior to undertaking the geotechnical investigation, the level of the southern portal of the abandoned haul tunnel was uncertain. The deepest surveyed level of the adjacent pit is more than 200 m south of the portal. If this level also represents that of the tunnel portal, then a slope of approximately 16° is calculated, and the abandoned tunnel would pass over the TBM running tunnels with a vertical clearance of approximately 7 m. However, the abandoned tunnel portal could potentially be deeper and the tunnel steeper. If the invert level at the portal coincided with the top of the Mittagong Formation (which is inferred to be at about RL -30 m at the portal) a tunnel slope of approximately 20° is calculated and the abandoned tunnel would clear the running tunnels by less than 3 m.

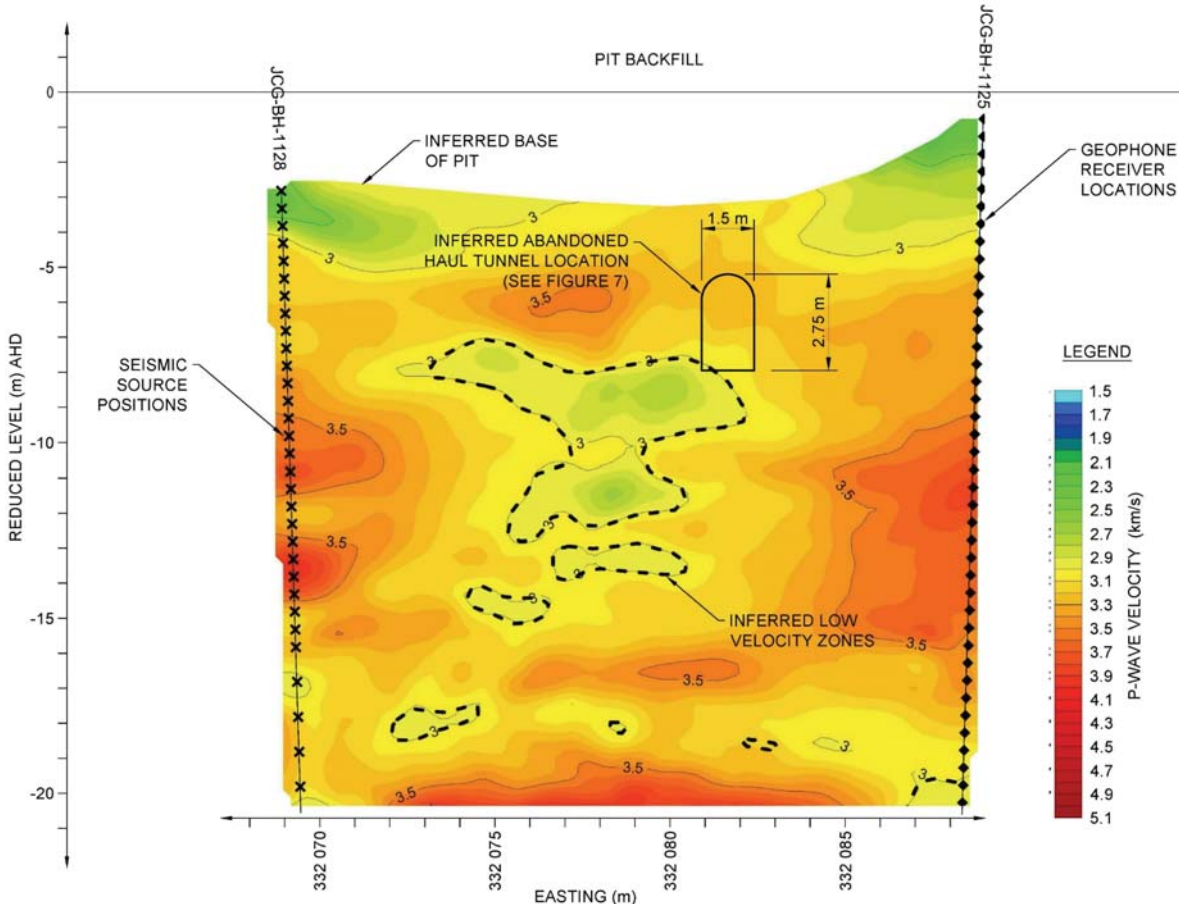

Figure 6. Cross section showing the cross-hole seismic survey results compared with the tunnel location as confirmed by interception by a borehole and inspection with a down-hole camera.

2.3 Groundwater conditions

The groundwater at this section of the SMCSW project was known to be influenced by the putrescible and non-putrescible wastes contained in the pit backfill material. Common influences include elevated concentrations of ammonia, nitrate and (to a lesser degree) metals. Other contaminants, including organic compounds, may also be present in leachates emanating from the site.

Groundwater monitoring reports made available for the SMCSW project indicated groundwater levels at Sydney Park ranging from approximately RL 15 m at the northwest corner of Sydney Park dropping to approximately RL 1 m at the southeast corner of the park.

Ground gas issues (associated with leachate migration) are also common for landfill areas. The risk of ground gas exposure in the running tunnels was addressed through the assessment of the ground conditions from the additional site investigations.

3 Additional Site Investigations

Based on the results of the desktop study, additional site investigations were undertaken to assess the ground conditions along the running tunnel alignment, in particular areas where the tunnels could potentially intersect the brick pit excavations. The site investigations included geophysical surveys, vertical and inclined geotechnical boreholes, and downhole camera inspections.

3.1 Geophysical surveys

The geophysical surveys consisted of:

- Electrical resistivity imaging (ERI) along three lines on Sydney Park Road.
- Micro-gravity testing along three surface lines located parallel to Sydney Park Road.
- Cross-hole seismic surveys between paired boreholes located approximately 20 m apart (Figure 6).

The ERI surveys presented a generalised profile of high electrical resistivity materials overlying moderate to low resistivity. This was inferred to indicate loose or dry fill, overlying saturated fill, over weathered shale. The location of the abandoned haul tunnel was not apparent from the ERI surveys.

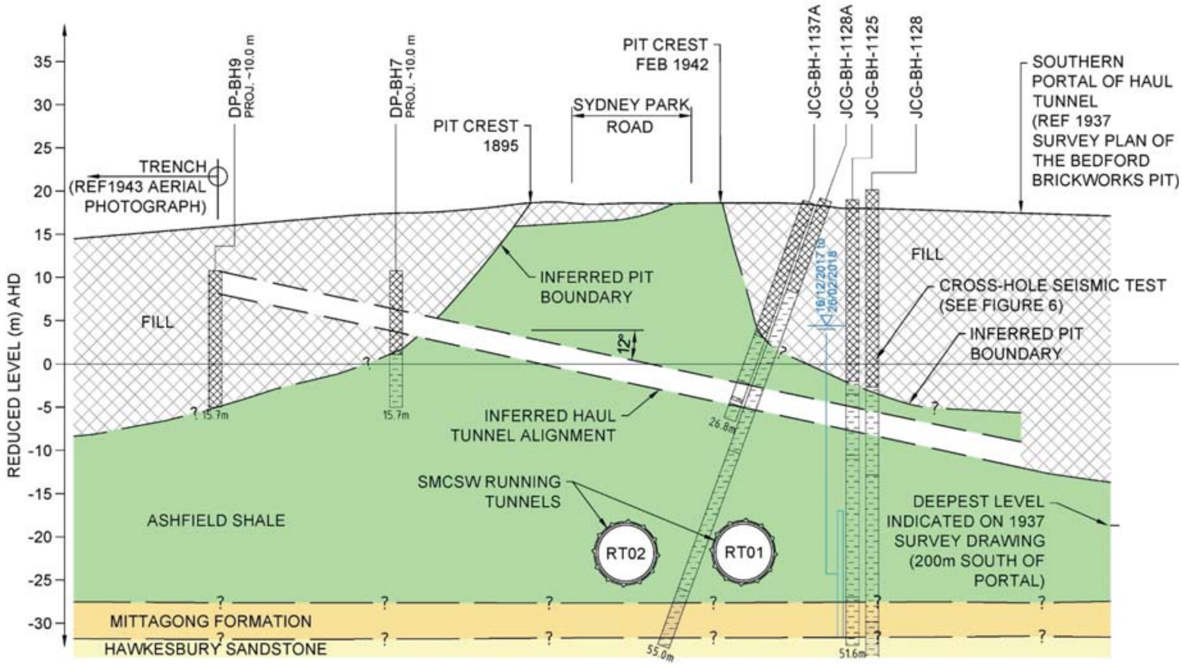

Figure 7. Inferred pit geometry and abandoned haul tunnel alignment at Sydney Park Road.

The micro-gravity testing indicated gravity lows inferred to be possibly associated with the abandoned tunnel. The location of the interpreted localised gravity low was in the general vicinity of the expected tunnel location.

The cross-hole seismic survey undertaken between one pair of the boreholes indicated possible anomalies (low velocity zones) associated with the abandoned tunnel (Figure 6). The tunnel was later found by the drilling a borehole at the position of the "best estimate" tunnel location described in Section 2. Comparison with the cross-hole seismic survey indicates no obvious correlation with the assessed low P-wave velocity zones and suggests that the tunnel was too small and the boreholes too far apart to allow the technique to be effective.

3.2 Geotechnical boreholes

A series of boreholes were drilled south of Sydney Park Road to confirm the ground conditions and extent of rock pillar between the proposed running tunnel excavation and pit walls. Nine boreholes (vertical and inclined) were drilled along Sydney Park Road with lengths ranging from 18.5 m to 56.5 m.

The position, orientation and length of each borehole was selected to target key areas where the extent of the pits was poorly understood from the desktop study, or where the remnant rock pillar between the tunnel excavation and pit walls was inferred to be relatively narrow. A rock pillar width of at least one tunnel diameter was targeted to provide an acceptable outcome for geotechnical stability.

Drilling methods included sonic drilling to advance through the pit infill materials to minimise landfill spoil and either sonic or HQ3 wireline rock coring in rock. Most of the boreholes intercepted municipal and domestic waste overlying Ashfield Shale at variable depths.

The borehole drilled along the "best estimate" tunnel alignment intercepted a void approximately 2.75 m in length within 1 m of the tunnel alignment assessed in Section 2.2.1. A downhole camera inspection was undertaken which indicated that the tunnel was full of turbid water, with some indistinct debris evident across the tunnel invert. The downhole camera inspection was undertaken using a bespoke arrangement including a high-definition waterproof video camera and LED lighting. The inspection captured an image that appeared to resemble two bricks and a central mortar joint in the crown of the tunnel, indicating that the tunnel was brick lined.

4 Ground Conditions

Based on the additional site investigations the inferred ground conditions comprised:

- Bedrock comprising Ashfield Shale (Class I/II as per the Pells et al 1998, classification system), Mittagong Formation and Hawkesbury Sandstone (Class I/II) along the alignment of the running tunnels.
- Cover above the running tunnel ranging between 35 m and 40 m and comprising:
- Fill: Pit infill material comprised a mixture of fines, sand, gravel, and waste of varying proportions and includes sandstone and shale gravel and rock fragments, concrete fragments, fabric, steel, timber, plastic and metal, with a landfill odour apparent.
- Residual soil from Ashfield Shale, (generally thin or absent).
- Ashfield Shale (Class I to V), and typically Class I/II at the level of the running tunnels.
- At least 10 m of rock cover between the abandoned haul tunnel and the crown of the running tunnels.

- Rock pillar width of at least one tunnel diameter (i.e. > 7 m).
- A standpipe piezometer was installed in one borehole (JCG-BH-1125, Figure 7). The measured groundwater level was at approximately RL 4.4 m, which was several metres lower than expected from the desktop study.

Figure 7 presents an example geotechnical section prepared during design. It shows the position of the pit crests as indicated by historical aerial images, together with the depth of waste material encountered in the boreholes (including historic boreholes where available), and stratigraphy of the various rock units encountered. Figure 7 represents the section where the abandoned haul tunnel was found and shows the inferred vertical alignment of the tunnel relative to the SMCSW running tunnels.

5 Conclusions

This paper demonstrates the importance of a comprehensive desktop study combined with targeted geotechnical site investigations to manage construction risks through a portion of the SMCSW tunnel alignment. These risks were complex and challenging and predominantly were the result of over 100 years of human activity.

The study comprised detailed interpretation of a range of historic documents, in particular maps and aerial photographs. Targeted geotechnical investigations included a range of geophysical techniques, as well as conventional geotechnical drilling to confirm that that the tunnel alignment would not intercept or pass too close to the backfilled pits. The position of an abandoned and poorly documented tunnel was confirmed to ensure that it did not pose a hazard to the construction of the TBM tunnels.

This work led to the successful uninterrupted advance of the TBM tunnels between the backfilled brick pits and tunnels around Sydney Park. The TBM tunnels were completed in 2019.

Acknowledgments

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