Makings Space In Urban Areas – The Bond Street Station Upgrade Project

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ABSTRACT

Urban areas are typically packed with buildings and busy traffic ways at the surface. Just below the surface, a multitude of utilities crowd the space and limit access to the ground below that. Making space at the surface in existing urban settings to accommodate new infrastructure or to improve and expand existing facilities either comes at a premium price or is virtually impossible. This leads to the need for the application of underground construction techniques in urban areas.

The theme for generating underground space in cities appears to be similar at every project: Cities are frequently built on poor ground with either deep piled foundations or settlement sensitive, shallow foundations. The latter applies primarily to historic buildings, which are per-se more settlement sensitive than modern buildings due to the nature of their structure. Space for laydown areas is restricted.

Where cut & cover techniques prevailed in the past, mining techniques are used these days, to minimize surface disruption and further traffic congestions. This is even applied for very shallow tunnels with minimal ground cover. Work access is provided through shafts built on small site areas.

The paper describes the challenges and constraints as well as implemented approaches for the upgrade project for the Bond Street Underground station located in London, UK, where solutions such as pre-support, various mined techniques and underpinning are being implemented and adjusted to the project-specific conditions to solve tough conditions.

1 INTRODUCTION

Bond Street station is in the heart of London's West End, on Oxford Street, the busiest shopping district in the UK - serving tourists, residents and businesses in the area. The station is currently served by the Central Line, built in the 1920's, and the deeper Jubilee Line built in 1975. With a capacity for 175,000 passengers per day, the lower levels of the station are already extremely busy at peak times on weekday mornings and evenings, a situation that is envisaged to get worse with the planned 2017 commissioning of an adjacent Crossrail station.

1.1 Existing station

Bond Street underground station consists of a sub-surface ticket hall serving two underground lines, the Central Line and the Jubilee Line. The station has street level access

through a shopping centre and through a separate subway entrance, but does not have in itself have a street level presence.

The Central and Jubilee Lines pass through the station with their platforms accommodated by 6.3m diameter and 105m long bored tunnels. The Central Line platforms are orientated in an east-west direction and the deeper Jubilee Line tunnels are orientated in a north-south direction. Access between the ticket hall and the platforms is facilitated by a series of escalators, passageways and concourses, all accommodated within inclined and horizontal hand mined tunnels. The lower levels of the station are ventilated through a series of vertical shafts and horizontal tunnels.

1.2 Project challenges

Historically, Stratford Place was build in the 1770's when it was on the edge of London and is on the site of the Tyburn River, one of London's lost rivers. Another technical challenge is the station's location within the Stratford Place Conservation Area, with many of these buildings considered Grade I, II and II* listed historical buildings as well as the Tanzania and the Botswana High Commissions.

A primary engineering consideration is to monitor and manage the vertical and lateral settlement of the area around the station and along the route of the tunnels so that the integrity of these buildings remains unaffected by the London Underground works.

Additionally the main area of Oxford Street also contains major utilities for London, with 2 main and 3 local sewers, a 30-, 24- and 21-inch water main from the 1830s, gas mains, as well telephone and power cabling. Also, the main passageway link to Crossrail has to be built within 2 meters of these services due to the congested nature of the ground.

Engineering and construction works have to take place while both underground lines remain operational. Short periods of station operation reductions will be provided to allow for construction of connections of new facilities to the existing tunnels.

Figure 1 Some utility mains exposed beneath street level

2 THE PRIMARY OBJECTIVES OF THE TUNNELLING WORKS

This project aims to deliver amongst other things improved access to the Central and Jubilee Line platforms. The tunnelling works will deliver this in two ways.

The first is a general capacity improvement to both sets of platforms in the form of additional escalators and stairways to/from street level and between the two lines. The positioning of the new stairs and escalators will spread the loading on the platforms, directing

users across a greater number of routes to/from street level and across a greater number of interchange routes between the lines.

The second is the provision of step-free access in the form of vertical lifts operating between street level and platform levels. Currently access to both the Central and Jubilee Lines is via staircases between street level and the ticket hall, and via escalators to the deep platform levels. This project will provide a passenger lift from the street level into the new satellite ticket hall, and separate lifts from the satellite ticket hall and the Central and Jubilee Line platforms.

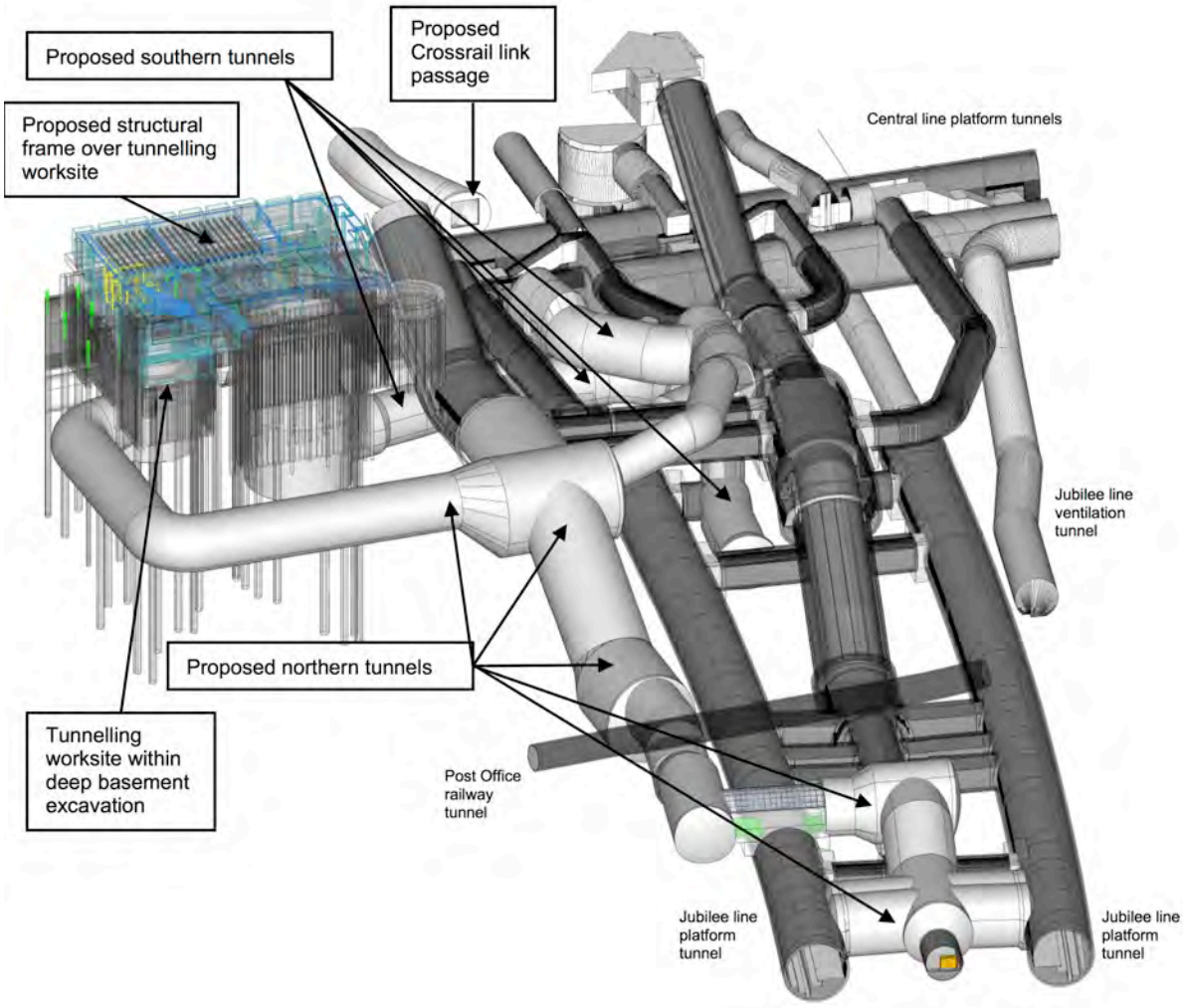

Figure 2 Overview of existing and new (light colour) underground structures

3 RAILWAY AND STATION OPERATIONAL CONSTRAINTS

Critical to the success of the Project has been the planning of the Works to minimise their impact on the day-to-day operation of the Central and Jubilee Lines and the station itself. Opportunities to temporarily reduce the capacity of the station are limited, and in some cases will have been agreed five years in advance. For example, the dates for short-term closure of existing platforms to facilitate the breakthroughs of new tunnels into the existing tunnels have been in place since July 2010, even though the associated works will not commence until 2015.

Some tasks that require access to passenger areas can be carried out during engineering hours when train services are halted, providing a 3-4 hour window of opportunity after midnight. These tasks include intrusive and non-intrusive surveys, and the erection or removal of temporary hoardings.

Some of the existing tunnels, although not directly impacted by the works, will be indirectly affected by the proposed tunnelling works and will require either short term propping or permanent strengthening. Where short term closures will occur, alternative routes and passenger diversions have been planned in advance.

The majority of the tunnelling works on this project will be serviced from the main worksite within the footprint of the new satellite ticket hall. All materials, plant, equipment and labour will access the tunnels from this site, minimising the impact on the operation of the station and the underground lines.

4 GEOLOGY

The majority of the tunnelling operations will be in the London Clay, which is divided into sub-units and it is anticipated that units A2, A3 and possibly unit B are present at Bond Street station.

The lowest unit A2 is anticipated to be 12m thick, consisting of alternating sandy clays and silty clays. This layer does not contain claystones. Unit A3 is also approximately 12m thick with a base layer of homogenous silty clay, followed by silty clay with three or four layers of claystones. Unit B usually comprises silty clays with silt and sand partings and numerous claystones. Its boundary with A3 is marked by a layer of sandy clay about 1m thick.

The Jubilee Line platform tunnels extend into the Upper Mottled Clay beds of the Lambeth Group which contains sand channels with the risk of perched water, and it is understood that sand was encountered during the construction of the Jubilee Line at Bond Street. Ground level varies across the site, with a consistent slope from northeast to southwest.

Two major aquifers exist within the vicinity of the site: the Upper Aquifer, within the Made Ground, Alluvium and River Terrace Gravels; and the Lower Aquifer, comprising the lower strata of the Lambeth Group, the Thanet Sand and Upper Chalk. The two aquifers are separated by the relatively impermeable London Clay and cohesive units of the Lambeth group.

The groundwater level recorded in nearby boreholes in the Upper Aquifer ranges between 5m and 6m below street level.

5. CONSTRUCTION LOGISTICS AND PASSENGER WORKFLOW

5.1. Construction Logistics

Oxford Street is one of the busiest shopping streets in the world, with land and property values being amongst the highest in the world. London Underground Limited (LUL) accepted that the worksite options would be very limited and they purchased an existing building adjacent to the station, with the intention of demolishing it, utilising the space as a worksite, and then redeveloping it afterwards to recoup its original purchase cost.

The demolition of the building (354-358 Oxford Street) is underway, and excavation of a deep basement to accommodate the new satellite ticket hall has commenced to make space for access shafts. The restricted space within the worksite is still insufficient to accommodate site accommodations or welfare facilities. A scheme has been implemented to construct the permanent structural frame for the future over site development to support material handling, craneage and site accommodation. This frame will be developed further, once the tunnelling works are completed.

Restrictions imposed on the delivery and removal of materials from site stipulates that there must be no direct access form Oxford Street, which led to the implementation of a controlled traffic management system with a single site entrance.

There is also very limited space on site for the storage of materials and transport in and out. Muck handling facility within the structural frame of the building can provide a storage buffer.

Figure 3 Busy Oxford Street with the building under demolition on the left hand for construction site area

Although the batching facilities for the tunnelling works will be housed within the worksite, the constituent materials for the SCL linings will be delivered to site in dry mix state for final mixing prior to delivery to the tunnelling works.

5.2 Passenger flow modelling

Extensive Legion modelling was commissioned by LUL from 2007 onwards to determine where passenger flow improvements could be made, and the outputs from the modelling led to the development in 2010 of a revised low level layout that could provide LUL with the required increased station capacity.

The end result has been the design of a system of new tunnels that will be excavated in the limited space available between existing tunnels to provide improved passenger access to and between the existing deep level platforms.

6. THE TUNNELLING WORKS

6.1 The proposed tunnel layout

The tunnelling works on the Project are split into three geographical areas. The northern tunnels relate to those serving the northern end of the Jubilee Line and will be excavated from a temporary vertical shaft in the main worksite. They consist of a temporary adit to a new inclined escalator barrel, a crossing under the Post Office railway tunnel, an over-bridge over the southbound Jubilee Line platform tunnel, an inclined stairway dropping between the Jubilee Line platform tunnels and a new binocular cross passage between the Jubilee Line platform tunnels.

The southern tunnels relate to those serving the Central Line and the southern end of the Jubilee Line platforms. These works will be excavated from a second ‘permanent’ shaft in the main worksite. They consist of a low level passage leading over the top of the Jubilee Line, new underpasses under the Central Line eastbound platform tunnel, a new stairway rising up

between the Central Line platform tunnels, a new lift shaft rising up between the Central Line platform tunnels, a new lift shaft dropping down to the Jubilee Line and a new stairway dropping down to the Jubilee Line. The last two connect into an existing cross passage between the Jubilee Line platform tunnels.

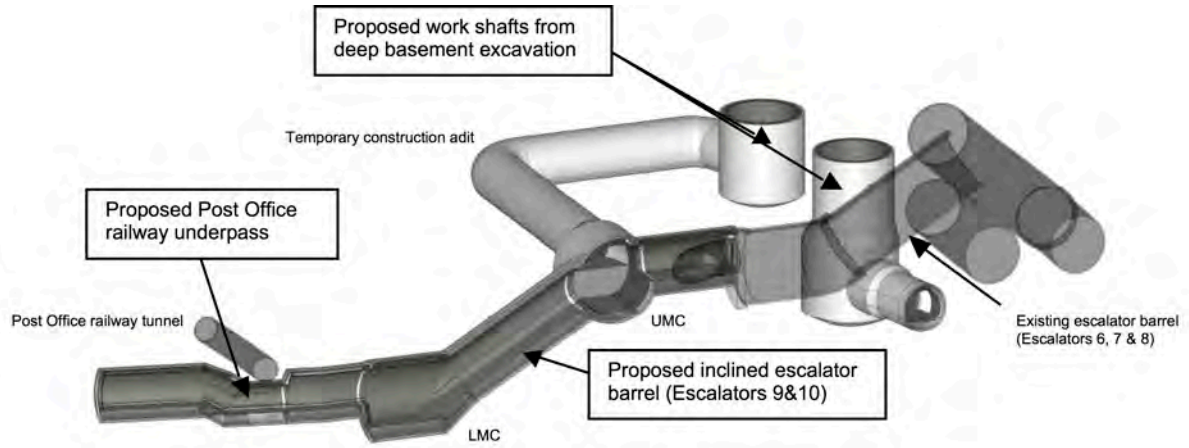

Figure 4 New northern tunnels with existing Post Office railway and Central Line platform tunnels

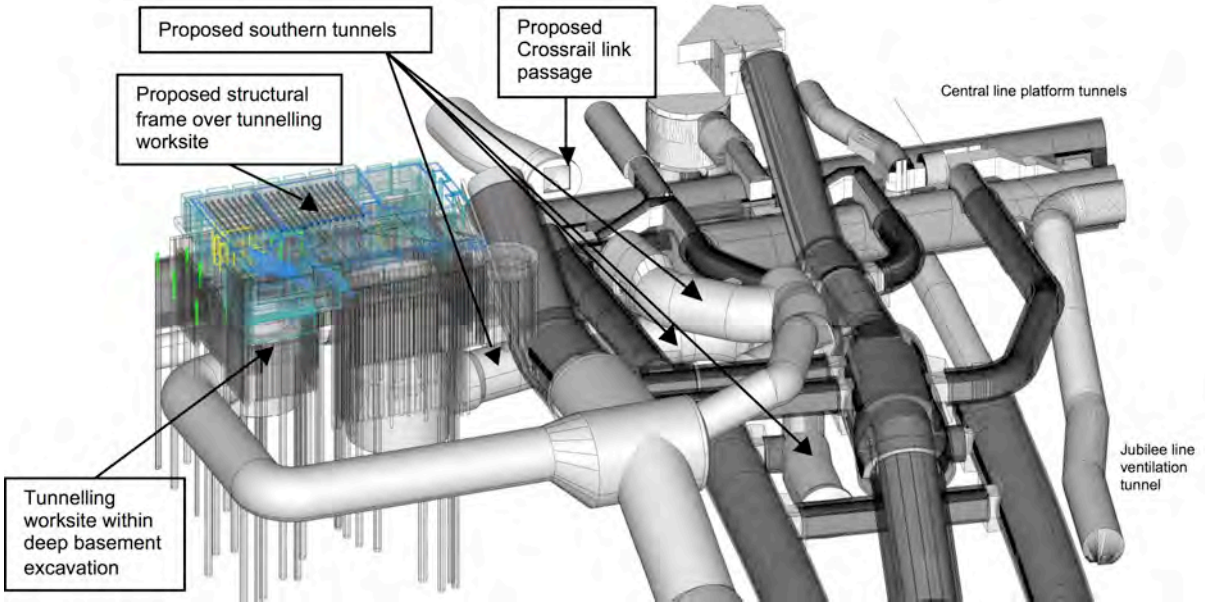

Figure 5 Southern tunnels Jubilee and Central Line access

The Crossrail link passage refers to the series of connecting tunnels linking the southern tunnels and the existing station passageways with the Crossrail station currently under construction south of Oxford Street.

The arrangement of the proposed tunnels is extremely complex, with their orientations dictated by the passenger flow requirements within the upgraded station, the need to avoid existing underground obstructions, the importance of minimising impacts on existing below-ground utilities and structures, and the pre-requisite of connecting into existing passageways at the appropriate locations.

6.2 Basic construction methods for the tunnelling works

To determine the most suitable tunnel excavation and construction methodologies, consideration has been given to:

- the spatial requirements of each of the new underground passageways

- the complex passageway, escalator, lift and stairway alignments
- the limited space to pass between underground obstructions
- the risks associated with working in close proximity to existing tunnels
- the minimisation of settlement effects on above-ground structures
- the minimisation of settlement effects on existing LU operations
- the minimisation of settlement effects on existing sub-surface utilities
- the limited space available at street level to serve tunnelling operations

Ultimately, the choice came down to a combination of 'traditional' hand work excavation (with timbering, insitu cast concrete and cast iron ground support) and the mechanised application of sprayed concrete lining (SCL) techniques.

Several of the tunnels will be excavated as traditional square-works, most notably the Jubilee Line over-bridge (over the southbound platform), the Crossrail link passage over-bridge (over the Central Line eastbound and westbound platforms), the Central Line underpasses and the lift shaft and stairway rising between the Central Line platform tunnels. Temporary support of the excavated surface will be by conventional timberwork. The majority of the permanent works will be constructed in structural steelwork encased in mass concrete. For the over-bridges the crown of the tunnels will be formed in bolted cast iron tunnel segments.

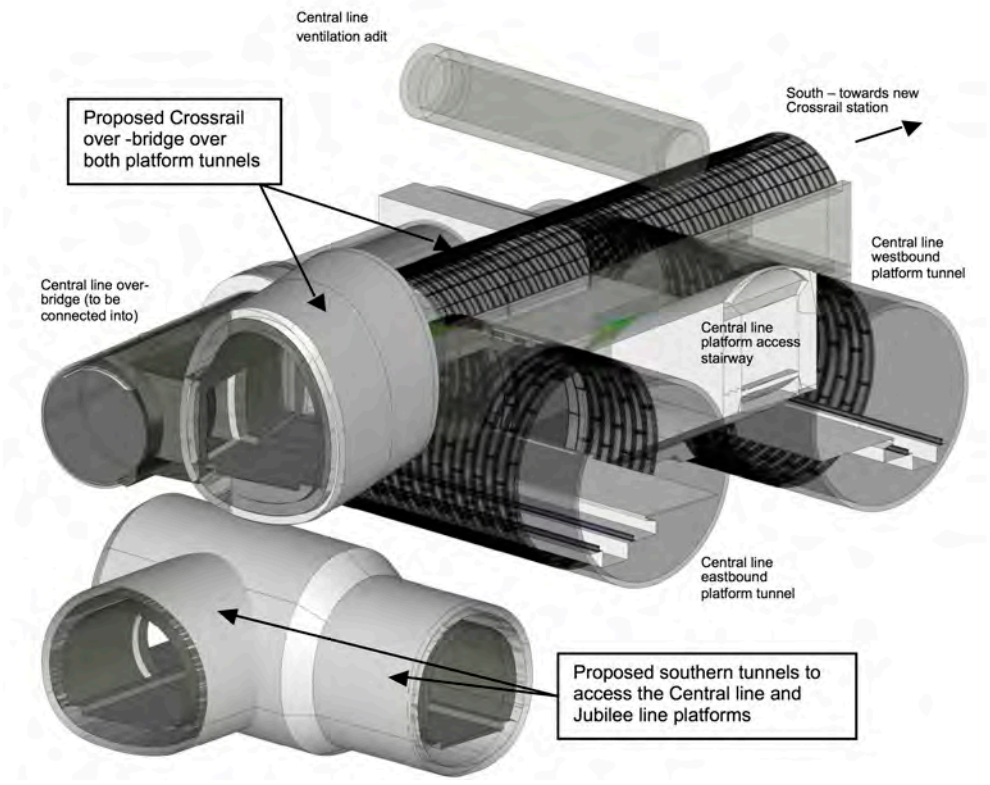

Figure 6 Crossrail Link Passage and Jubillee Line access underneath

The majority of tunnelling works, consisting of the temporary construction access, the inclined escalator barrel, the vertical shafts, the Post Office railway underpass and the connecting passageways will be mechanically excavated and lined with sprayed concrete. Reinforcement to the SCL will predominantly be by steel fibres with conventional rebar applied in high load areas.

Waterproofing membranes will be applied between the primary and secondary linings and will predominantly be of a spray applied type.

6.3 Specialist techniques

Specialist tunnelling techniques being utilised on the Project will include the installation of pipe arches at two locations to provide additional ground movement mitigation under existing operational escalator barrels. At a third location a pipe arch will be installed to ensure protection of the workforce and reduce the risk of progressive collapse of large diameter 1830s brick sewer.

Compensation grouting is also planned for implementation on the Project to control the impact of tunnelling induced ground movements on overhead buildings and sub-surface utilities. Temporary grouting shafts will be sunk at three locations and tube-a-manchette (TAM) arrays will cover the majority of the zone of influence of the tunnelling works.

Several of the vertical shafts on the Project will be excavated as 'blind' shafts i.e. excavated from below ground and not rising to ground level.

Many of the 19th century sewers and water mains have been assessed as being extremely sensitive to ground movements and have therefore been subject to a range of damage mitigation works including lining of the larger diameter pipes with modern materials.

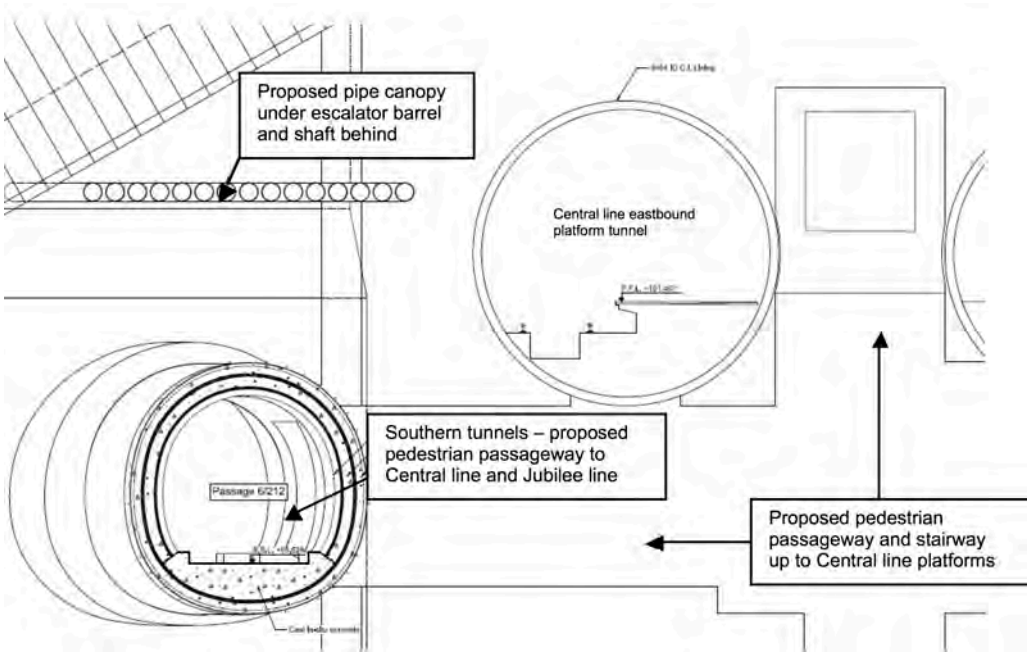

Figure 7 Southern tunnels – pipe canopy under existing escalator barrel (Escalators 6, 7 & 8)

6.4 Movement monitoring and mitigation

In anticipation that whatever tunnelling techniques are deployed tunnelling induced ground movements will be inevitable, systems for extensive ground, structure and utility movement monitoring have been installed across the site. Real-time monitoring systems have been installed inside the station, inside each of the escalator barrels and on each of the platforms. Monitoring points have also been installed on all of the buildings within the zone of influence of the tunnelling works, and remote monitoring systems are currently being installed in several of the large sewers under Oxford Street.

Baseline monitoring has been ongoing for a period of 12 months to gain sufficient background information ahead of the commencement of the tunnelling works. It is recognised that the existing above-ground and below-ground structures are subject to temperature induced movement on a seasonal and sometimes daily basis, and the intention is to build up sufficient information to allow this background movement to be isolated from the daily readings during the works implementation period.

The monitoring works have been designed to interface with the proposed settlement mitigation works, with the relay of real-time monitoring information expected to 'drive' the decision-making process for the compensation grouting.

6.5 Programme

The design and construction contract for the Bond Street Station Upgrade project was awarded in mid-2010 to the Costain Laing O'Rourke Joint Venture, who immediately commissioned their designers, the Halcrow Atkins Joint Venture to commence the detailed design of the Works. Dr Sauer & Partners Company are responsible to the Halcrow Atkins JV for the design of the SCL tunnels and Gall Zeidler Consultants are responsible for the independent checking of all tunnelling works designs.

The implementation works within the existing station commenced in November 2010 with modifications to an existing station entrance from Oxford Street, the closure of another entrance and the replacement of two 1930s escalators. These works are due for completion and hand-back to LUL in May 2012.

The building works, including the demolition of 354-358 Oxford Street and the underpinning of the 17th century residential property alongside it, commenced in early 2011 with the demolition due for completion and the piling around the new sub-surface ticket hall due to commence in May 2012. The excavation of the deep basement under the two buildings will then commence in late 2012 for completion ready for tunnelling operations to start in mid-2013.

The tunnelling works, from the deep basement excavation under 354-358 Oxford Street will commence in mid-2013 with a construction period stretching into 2017. The fit-out of the tunnels, the testing commissioning and hand-over will be completed in 2017, with the hand-back to LUL planned for late 2017.

7. CONCLUSION

The implementation of modern tunnelling techniques combined with state of the art logistic means for operating a construction site under extremely confined space conditions is being demonstrated at the Bond Street Station Upgrade Programme.

The preparations for the underground works are well under way including utility relocation, demolition of a building to make space for a small size site lay-down area and strengthening of existing underground structures.

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