VSU PROPLESS CROSS PASSAGE CONSTRUCTION

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Ian Heath
Ian works for Bam Nuttall, and is on this job the contracting joint venture's tunnel manager

On Thursday 15 January, the British Tunnelling Society was treated to a lively presentation on techniques being used at Victoria Station to allow connections of new tunnels with existing platform and concourse tunnels . The three speakers were **Daniel Alston**, senior project manager for *London Underground (LU)* on the scheme, **Anmol Bedi**, senior SCL engineer for *Mott McDonald* and **Ian Heath** of *Bam Nuttall*, who is the contracting joint venture (TWBN)'s tunnel manager. The talk illustrated the innovative approach taken to forming connections with the operational station at VSU

LONDON'S VICTORIA Station is a major transport hub for the city. At a throughput of 82 million passengers a year, it has to deal with more passengers than London's Heathrow Airport. The underground station provides access to the District and Circle line at the high level, running roughly east-west and the Victoria Line, at the low level, running roughly north-south. The LUL are currently in the process of upgrading the station with the objective of relieving passenger congestion and allowing for future growth in use. A new northern ticket hall is being built, the existing southern ticket hall is being expanded, new connecting tunnels built, and escalators and lifts installed. The tunnelling comprises approximately 360m of SCL tunnels and 30m of traditional London Clay square work tunnelling.

One of LU's guiding principles in appointing a contractor was that the work should be carried out using the least number of closures and disruption

to the existing underground platforms and tunnels. The new expanded station would be constructed while keeping the existing station open.

THE CONTRACT

LU appointed the Taylor Woodrow / Bam Nuttall joint venture (TWBN JV) in May 2010 as their design and construct contractor on the scheme. The existing preliminary design was novated to the JV who were then responsible for completing the design with their designer Mott MacDonald (the Designer) from RIBA stage E through to achieving LU compliance.

The inherited design showed propping works to all existing tunnels where new connecting tunnels were to be joined. This approach could require the removal of finishes within existing tunnels, the loosening of ring bolts, and installation of massive steel props and barriers, all to be carried out in extremely limited engineering hours possessions. As part of the design development the JV were keen to amend these designs, with the aim of doing as much as possible behind hoardings, with minimal impact upon the existing operational tunnels. The JV's solution would ease logistics, with all resources being provided from within the site boundary, be simpler to build and would give better programme and risk certainty.

Consequently, the removal of props and intrusive works on the 'live' platform side would mean the station could remain fully operational during the construction works, with an insignificant reduction in platform width. This would ultimately increase passenger safety, especially during peak hours.

The JV had at the earliest stage of its tender identified that the design of the tunnel to tunnel connections was key to the success of the project. During their tender the JV tested a number of different designers to establish the strengths and weakness of that supply chain and establish a simple way forward for the connection works and other temporary works.

Alan Auld Engineering (AAE) were one of these designers who had provided a temporary works solution for an emergency services access tunnel between the Victoria Line platform tunnels relying solely upon square props installed within the new tunnel during construction and no props on the existing platform tunnels.

THE DESIGN

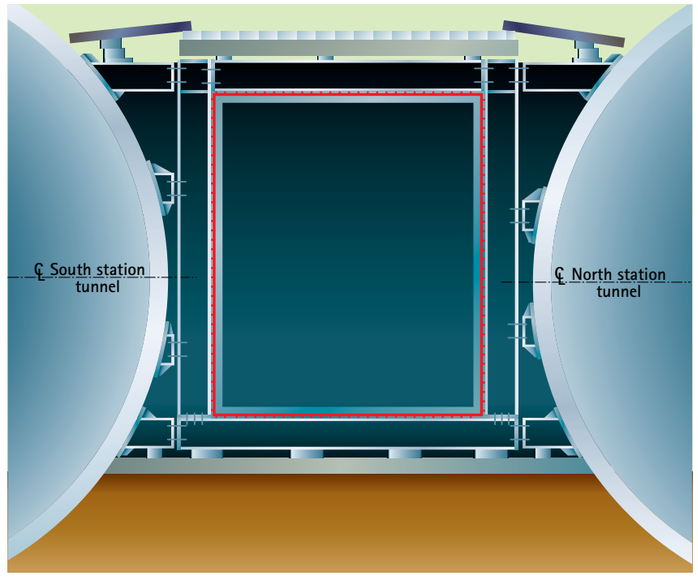
Although the task was relatively simple for the designers and construction team in its brief, it was not as simple in its execution. Many of the existing tunnels at Victoria are at a shallow depth, in water bearing ground and the site is in a confined area within a very busy part of London.

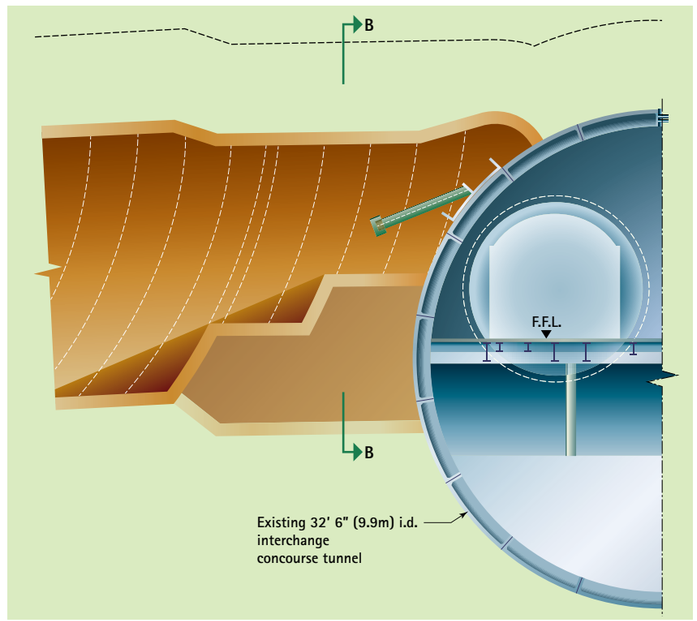
Propping within existing tunnels at connection locations has always been provided previously to counter the distortion of the exiting ring towards the area of excavation caused by the asymmetric unloading of the ring.

In order to prove the feasibility of the new solution the designer developed a novel model that would provide a more detailed assessment of joint segment behaviour than that based upon the Muir Wood1 Empirical Model.

Below, top: Frames between platform tunnels at 0.5m centres from the non-operational side

Bottom: Side elevation of SCL tunnel being advanced towards existing tunnel





Questions from the floor

John Elliot of Alan Auld Engineering, designer of the tunnel temporary works at VSU congratulated the team on an excellent presentation and asked what the team would do differently next time. He stressed in his own view that design development of permanent works, temporary works and methods should be run together to provide a robust solution.

Ian Heath answered that more work should be put into defining the various parties' scopes to prevent the overlap between temporary and permanent works design packages of that was experienced at Victoria.

John Elliot asked what deformations were experienced in the existing platform tunnels due to the construction of PAL 16 – the emergency services tunnel.

Anmol Bedi answered the measured deformations were in the order of 10mm – this was lower than the initial predictions undertaken by the designers as part of the potential damage assessment.

Alex Lowson of Mott McDonald and structural steel designer for the scheme asked what degree of stiffness did the jet grouted ground confer on the existing tunnel in practice.

Anmol Bedi answered that the team were unsure as no strain gauges or load cells were placed on the structural steel props, but what was clear was the braces and cross strut could have been done away with as the jet grout was much stiffer than expected.

Steve Parker of Ferrovial asked what temporary works was necessary to install the various steelwork temporary works.

Ian Heath answered that in most cases lifting was facilitated by air winches placed on purpose built tables bolted to the shotcrete and with hawsers running through snatch blocks again bolted to the shotcrete. In the case of Pal 16 the emergency services tunnel Specialist Plant designed a bespoke bogie mounted lifting system.

Colin Mackenzie, retired, commented that he had been section engineer on the Victoria Line at the station 50 years ago and again 20 years ago as director on the congestion relief scheme. He asked whether the hoop stress taken by the segments to be removed was designed to be taken out by through bolts in shear.

Anmol Bedi answered that this was correct and that additionally the top lintel of the frame was to be concreted in.

Colin Mackenzie further commented that in his experience bolt loosening at openings was not the correct way to secure an opening using the traditional method, and his practice was to tighten the bolts around an opening to stiffen the tunnel.

Ian Heath answered that this has not been the generally accepted view at the recent King's Cross Redevelopment works, which had led to the JV attempting to find a different approach.

The shallow tunnels and proximity of existing LUL assets required a more rigorous approach, and as the basis of the model the designer developed a closed form solution to assess joint stresses, based upon the D.J. Curtis Equations, to include rotational joint stiffness.

In order to provide ground stability, the water bearing ground around the existing tunnels had been jet grouted.

The proposed method for the connection was to advance a top heading in SCL to the top of the new opening and then use the combination of a bolted frame attached to the outer existing lining forming the opening and propping off the new SCL works.

The model had to recognise the extra stiffness conferred by the jet grouting in the upper half of the existing tunnel and be able to ascribe the effect of various degrees of existing lining joint opening so a contingency method could be put in place based upon a gradation of trigger levels.

The model also had to recognise any degree of ovality already built into the existing lining.

The model then had to identify which element of the existing ring was most likely to fail and the degree of ovalisation/joint rotation that this failure would occur at. In order to predict the existing level of stress in the lining, the JV carried out a detailed ring ovality survey in each location of a proposed opening.

The model was then developed to stipulate the deflection or joint rotation at which the ring component elements would distress and what level of stress would be likely caused by the JV's proposed excavation works.

The outcome of the model was a series of deflection and joint rotations of the existing ring that the joint venture could readily monitor as excavation proceeded using standard instrumentation and monitoring equipment installed on the cast iron segments of the tunnels.

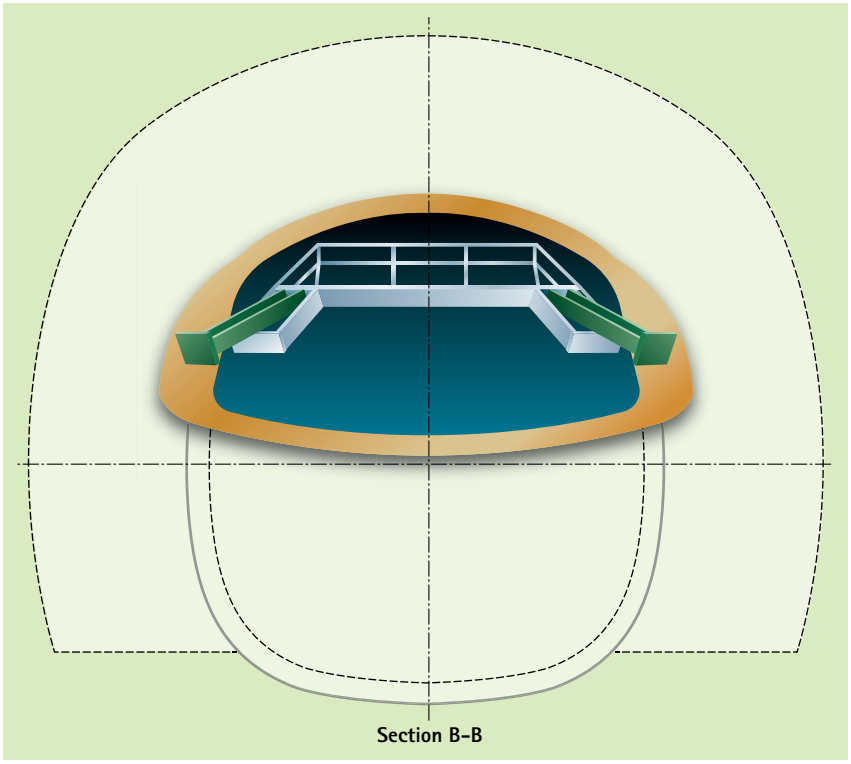
CONSTRUCTION OF JUNCTIONS

The presentation provided a number of case studies of the method of junction construction only two of which are mentioned here for brevity.

The opening at paid area link

The PAL 7 opening was a relatively simple example of the opening method in use and involved the connection of an SCL tunnel in to an extremely busy concourse tunnel providing a passenger connection between the District and Circle Line and underlying Victoria Line. The impact of the traditional style of propping into the concourse tunnel would have hindered the capacity of the tunnel to deal with peak passenger flows. The JV's method of forming the opening was to approach the back of the lining in an SCL top heading, form the top half of the opening steelwork behind the lining and prop forward off additional sprayed concrete footings.

The bench and invert were similarly constructed to allow for the completion of the remainder of the jamb frame. All steelwork was installed using air winches and snatch blocks with appropriate holding down bolts which were secured onto the shotcrete.



Above: A photo-montage of the works behind the existing tunnel with a superimposed photograph of the existing tunnel in use concurrently

Top right: Front elevation of propping of opening in top heading and bracing shedding load back onto SCL footings

Emergency access tunnel

PAL 16 involved the construction of a 28m-long emergency services access tunnel between the two platform tunnels of the Victoria Lining. Traditional methods would have involved propping over a significant length of each platform tunnel and the unwelcome restriction of passenger use on two very busy platforms. The JV's solution required no propping within the existing platform tunnels. The construction of the tunnel comprised the excavation of 500m^3 of tunnel muck and the installation of 72t of structural steel. The excavation was advanced in a series of timber headings with crown bars to support the timbering prior to installation of the steelwork frames which braced the existing tunnels. The JV underlined the importance of the marriage of the permanent works designer, temporary works designer, construction team and specialist suppliers in providing the final solution.

VALIDATION OF DESIGN

The presenters reported that the outcome of the works in terms of induced tunnel deformation was consistent with the model produced and movements in the existing tunnels using the external propping system were within the predictions and set trigger levels. As such, the construction progressed consistently and smoothly through-out the entirety of construction, without the need for any contingency or mitigation measures.

CONCLUSION

The team's approach to making connection works has been successful in preventing significant disruption to the passengers of London Underground using the station. Much had been gained by close liaison with London Underground's station manager and his team and this has helped ensure that the tunnel connection works were completed with no railway possessions and minimal impact to the operation of the station

Rapporteur: Ivor Thomas

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