



# CROSSRAIL INFORMATION PAPER

## D8 – TUNNEL CONSTRUCTION METHODOLOGY

This paper sets out the proposed Crossrail tunnel construction strategy and methodology.

It will be of particular relevance to those in the vicinity of the proposed Crossrail tunnels.

This is not intended to replace or alter the text of the paper itself and it is important that you read the paper in order to have a full understanding of the subject. If you have any queries about this paper, please contact either your regular Petition Negotiator at CLRL or the Crossrail helpdesk, who will be able to direct your query to the relevant person at CLRL. The helpdesk can be reached at:

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**APPROVED**

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## 1. Introduction

- 1.1 Crossrail requires the construction of 21km of twin bore running tunnels with an internal diameter of 6m.
- 1.2 The running tunnels in the central area link the Great Western Main Line surface rail at Royal Oak Portal with new sub-surface stations at Paddington, Bond Street, Tottenham Court Road, Farringdon, Liverpool Street, Whitechapel and the Isle of Dogs. From there they connect to the existing surface rail route at Victoria Dock Portal (just west of Custom House station) and via separate running tunnels connect to the Great Eastern Main Line surface rail at Pudding Mill Lane Portal (just west of Stratford station).
- 1.3 The other Crossrail tunnels run from the North Woolwich Portal under the River Thames to Plumstead Portal (“the Thames tunnel”).

## 2. Construction Strategy

- 2.1 The original tunnelling strategy developed for the hybrid Bill required sixteen tunnel drives to construct the central tunnels from five working sites in the central area. The longest tunnel drives planned were from the Royal Oak Portal to Fisher Street Shaft (5.10 km in length), Hanbury Street west to Fisher Street (3.70 km) and Pudding Mill Lane Portal to Whitechapel Station (3.70 km in length). The remaining drives were to be driven from Hanbury Street east to Whitechapel (0.60 km), from the Isle of Dogs east to Stepney Green (2.17 km) and on the Limmo Peninsula west to the Isle of Dogs (1.59 km) and east to Victoria Dock Portal (0.93 km). The Thames tunnels would start from the Plumstead portal and be driven to the North Woolwich Portal (2.64 km). These drives are shown in schematic form in Annex A.
- 2.2 The principal concerns regarding the impacts of this strategy were:
  - the environmental impact on the local area from using the Hanbury Street Shaft site as a launch site for tunnel boring machines (TBMs); and
  - the interface, in the area of Pudding Mill Lane Portal, between the tunnelling worksites and the 2012 Olympic construction works
- 2.3 These issues led Crossrail to carry out a fundamental review of the tunnelling strategy. Given the scale and complexity of the Crossrail project this took several months to complete.
- 2.4 This revised tunnelling strategy has been made possible following a major review of the proposed construction programme, which was started in mid-2005. In particular, it is no longer the case that pre-tunnelling enabling works will be carried out before Royal Assent. This has allowed a construction programme to be developed that integrates these enabling works with the main civil engineering works for the central area stations and at the TBM launch sites. This has allowed programme critical station works to commence at a relatively earlier time in the construction programme, taking them off the project critical path. It has also made it possible to gain access to start certain running tunnel drives earlier thereby

making longer drives possible. The longer drives in turn allow a modest increase in the average rate of tunnelling. This is supported by recent experience of tunnelling in London and the developments in the design, manufacture, reliability and performance of TBMs which can now deal with a greater range of ground conditions and drive longer tunnels. Taken together, the revised tunnelling strategy, with fewer longer drives, has been adopted without affecting the overall construction duration.

2.5 This revised tunnelling strategy increases the length of the central tunnel drives, reducing the number of running tunnel drives to ten and the number of construction sites located on the fringe of the central area to three (Royal Oak, Limmo Peninsula and Pudding Mill Lane). The revised strategy comprises driving the central tunnels from Royal Oak Portal to the west end of Farringdon Station (6.16 km), from the site on the Limmo Peninsula through the Isle of Dogs to the east end of Farringdon Station (8.30 km) and from Pudding Mill Lane Portal to the junction at Stepney Green or vice versa (2.72 km). The drives from Limmo Peninsula to Victoria Dock Portal are as before, as is construction of the Thames Tunnel. The revised tunnel drives proposed are shown in schematic form in Annex B.

2.6 The revised strategy has several advantages over the original strategy, including:

- it reduces the number of tunnel worksites and TBMs required to construct the project by increasing the length of the tunnels constructed from the Limmo Peninsula site and the Royal Oak Portal;
- it reduces the length of the tunnels driven from Pudding Mill Lane Portal and hence reduces the interface between the Crossrail and London Olympic worksites;
- it eliminates the need to use the Hanbury Street Shaft site to launch TBMs. This in turn removes the requirement for the temporary infrastructure associated with the removal of excavated material and supply of construction material from Pedley Street; and
- it reduces the size of the Hanbury Street shaft and eliminates the need to demolish Britannia House.

### **3. Tunnel Worksites**

3.1 TBMs will be launched from the four main tunnelling worksites as follows:

- two TBMs from Royal Oak Portal to the west end of Farringdon Station;
- two TBMs from the existing launch shaft site on the Limmo Peninsula to the east end of Farringdon Station. The current plan is to construct a section of the Isle of Dogs Station at the west end and use this to supply tunnel segments and provide logistic support for construction of the running tunnels. The excavated material will continue to be transported by conveyor through the Isle of Dogs Station and removed from the Limmo Peninsula Shaft site;

- the two tunnels from Limmo Peninsula Shaft to the Victoria Dock Portal will be constructed by one of the above TBMs;
- two TBMs from Pudding Mill Lane Portal to Stepney Green or vice versa; and
- two TBMs from Plumstead Portal under the River Thames to the North Woolwich Portal.

3.2 The above worksites are as included in the Bill and were selected to minimise the need for the removal of excavated material by road. The Royal Oak and Pudding Mill Lane Portal sites are served by rail. The Limmo Peninsula and Plumstead Portal sites are served by barge with a short highway transfer from Plumstead Portal to Manor Wharf.

#### **4. Environmental Impact**

4.1 The overall environmental impact of the revised tunnelling strategy is beneficial as compared to the original strategy. The revised environmental effects that have been identified are reported in Supplementary Environmental Statement 3 (SES3<sup>1</sup>) published in November 2006 and are summarised below.

##### *Pedley Street and Mile End*

4.2 The temporary construction tunnel from Hanbury Street to Pedley Street, the Pedley Street site, the conveyor, the Mile End Park excavated material facility and modifications to the Devonshire Street rail sidings are completely removed from the scheme eliminating all the impacts associated with these elements of the original strategy.

##### *Hanbury Street*

4.3 The site will no longer be used as a TBM launch site, removing the associated construction activities.

4.4 A shaft is still required for emergency intervention and ventilation during the operation of the railway. The size of the shaft and quantity of excavated material to be removed is estimated to be reduced by at least 50%. This has allowed a revised arrangement of the ventilation equipment, electrical and mechanical plant and intervention facilities to be developed and it is no longer necessary to demolish Britannia House (see Information Paper G3, Hanbury Street).

##### *Limmo Peninsula*

4.5 No significant impacts were identified with the original strategy.

4.6 Tunnelling activities here are the same as with the original strategy but the duration is increased. The lack of sensitive receptors in the area means the impacts are unlikely to be different from those of the original tunnelling strategy.

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<sup>1</sup> See

<http://billdocuments.crossrail.co.uk/80256FA10055060F/pages/supplementaryenvironmentalstatement3>

The use of barges from this site mitigates the impact of the removal of the increased quantities of tunnel excavated material.

#### *Isle of Dogs Station*

4.7 There will be a slight reduction in tunnelling activities at this site compared to the original strategy. Most of the excavated material generated by the tunnels will be removed from the Limmo Peninsula site by barge. The Isle of Dogs site will only be used to supply tunnelling materials and for personnel access.

#### *Royal Oak Portal*

4.8 The running tunnels constructed from the portal are longer than under the original strategy, which is offset by the higher progress rates planned for the high specification tunnel boring machines. It is estimated that this will result in a slight increase in the duration of tunnelling activities at this site. The delivery of segments and removal of excavated material are by rail so the impact on traffic and transport movements is considered to be slight. Where significant impacts have been identified on residential properties arising from construction noise and visual amenity then these impacts will occur for a longer duration.

#### *Pudding Mill Lane*

4.9 The running tunnels constructed from the portal are shorter thus reducing the duration of the tunnel construction impacts.

### **5. Ground Conditions**

5.1 The geological conditions along the route are indicated on the section shown in Annex C. The tunnels between Royal Oak Portal and Farringdon Station are generally within the Lower (sandier) section of the London Clay Formation. They may occasionally intersect the underlying Harwich Formation and Lambeth Group. Tunnelling technology through London Clay is well proven and most of the existing London Underground tunnels were successfully constructed in this ground.

5.2 The tunnels between Farringdon and the eastern portals will largely be driven along the interface between the Lower London Clay and the underlying Lambeth Group strata, though towards the east the geology rises relative to the alignment and the tunnels will be in Thanet Sands at the Isle of Dogs. Modern TBMs are able to construct tunnels very successfully in these ground conditions.

5.3 Between the North Woolwich and Plumstead Portals, the tunnel drives will be within the Chalk and Thanet Sand strata except for the sections at the tunnel portals where superficial deposits comprising alluvium and river gravels are expected. These ground conditions have similarities to the ground conditions encountered on the successful Thames tunnels on the Channel Tunnel Rail Link.

### **6. Tunnel Boring Machines (TBMs)**

6.1 High performance TBMs are essential for the successful construction of Crossrail. The TBMs will be purpose built machines using proven "state of the art"

technology and designed specifically for the project to a minimum specification to ensure their reliability in terms of performance and settlement control. They will be designed to cater for the range of ground conditions anticipated.

- 6.2 Advances in TBM technology and reliability have resulted in bored tunnels being successfully driven through ground conditions historically considered difficult including both the Lambeth Group and the Thanet Sands for the Jubilee Line Extension and the Channel Tunnel Rail Link.
- 6.3 The revised tunnelling strategy is based on using closed face earth pressure balance machines (EPBMs) for construction of all the running tunnels within the central London area and slurry machines for the Thames tunnel drives from Plumstead Portal to the North Woolwich Portal. These machines are considered best able to deal with the ground conditions expected as they allow a pressure to be exerted by the machine against the ground in front of the tunnel limiting ground movement and settlement.
- 6.4 To ensure that the tunnel boring machines are performing as required the TBM parameters together with the information from the ground movement monitoring will be relayed to the Crossrail tunnel monitoring and settlement control room. This will be in addition to the contractors' monitoring arrangements and will be in place and operated throughout the tunnelling activity. The control room will have displays of real time surface, subsurface and tunnel movement monitoring together with TBM tunnel progress and TBM parameters.
- 6.5 The operation of the control room and the supervision of tunnel construction will be carried out by experienced engineers representing the nominated undertaker who are independent from the contractor. Their role is to ensure that tunnel construction is being carried out in accordance with the tunnel specification and movements are controlled to acceptable limits. Green, amber and red triggers will be set for action levels with pre-planned contingency arrangements.

## **7. Tunnel Lining Design**

- 7.1 The tunnel linings will be designed in accordance with the Crossrail Design Standards Manual that references appropriate regulatory standards and guidelines and defines best practice. This is based on the well proven design and construction technology used successfully in London over many years including the Jubilee Line Extension (JLE) and the recent CTRL experience.
- 7.2 The linings will be designed to withstand temporary and permanent loading including loads from the surrounding ground, groundwater, a surcharge of 75kN/m<sup>2</sup>, and to meet fire and durability requirements.
- 7.3 The internal diameter of six metres is sufficient to accommodate the cross section of the train plus lateral movement tolerances, overhead power supply, evacuation and access walkways, resilient and floating track slab, signalling equipment, cables and cable brackets and construction tolerances.
- 7.4 The lining will be designed to provide a robust solution capable of dealing with the handling loads from construction and the permanent loads from the ground.

The majority of the tunnel will be formed using pre-cast concrete segments reinforced with traditional steel reinforcement or steel and polypropylene fibres.

7.5 The lining types will either be precast concrete expanded lining (in London Clay) or bolted segmental lining in other ground with the annulus between the lining and the excavated ground filled with a grout.

7.6 Openings may be formed using special spheroidal graphite iron linings or steel frames encased in concrete or sprayed concrete linings.

## **8. TBM Operation**

8.1 The TBMs will be designed, manufactured and operated in accordance with the Crossrail Materials and Workmanship Specification which will define “best practice” for the project.

8.2 The time required to procure, manufacture and deliver a TBM is approximately one year. Delivery of a second TBM, to the same worksite, can be expected two months after delivery of the first.

8.3 The TBMs, which can weigh over 1000 tonnes when fully operational, will be designed, manufactured and delivered to site in smaller components which will be assembled on site either adjacent to or within the launch chamber.

8.4 Where sufficient space is available the TBM will be fully commissioned prior to launch with all the back up plant installed. Where there is insufficient space the TBM will be advanced and a sufficient length of tunnel constructed to allow the support equipment to be assembled in the tunnel.

8.5 A shove frame will be erected within the launch chamber to provide the reaction to propel the TBM into the ground.

8.6 Where necessary ground treatment will be carried out around the tunnel to form a plug of stable ground behind the launch chamber structure to allow the TBM to be buried into the ground safely and the full stabilising effects of the closed faced tunnel machine brought into operation.

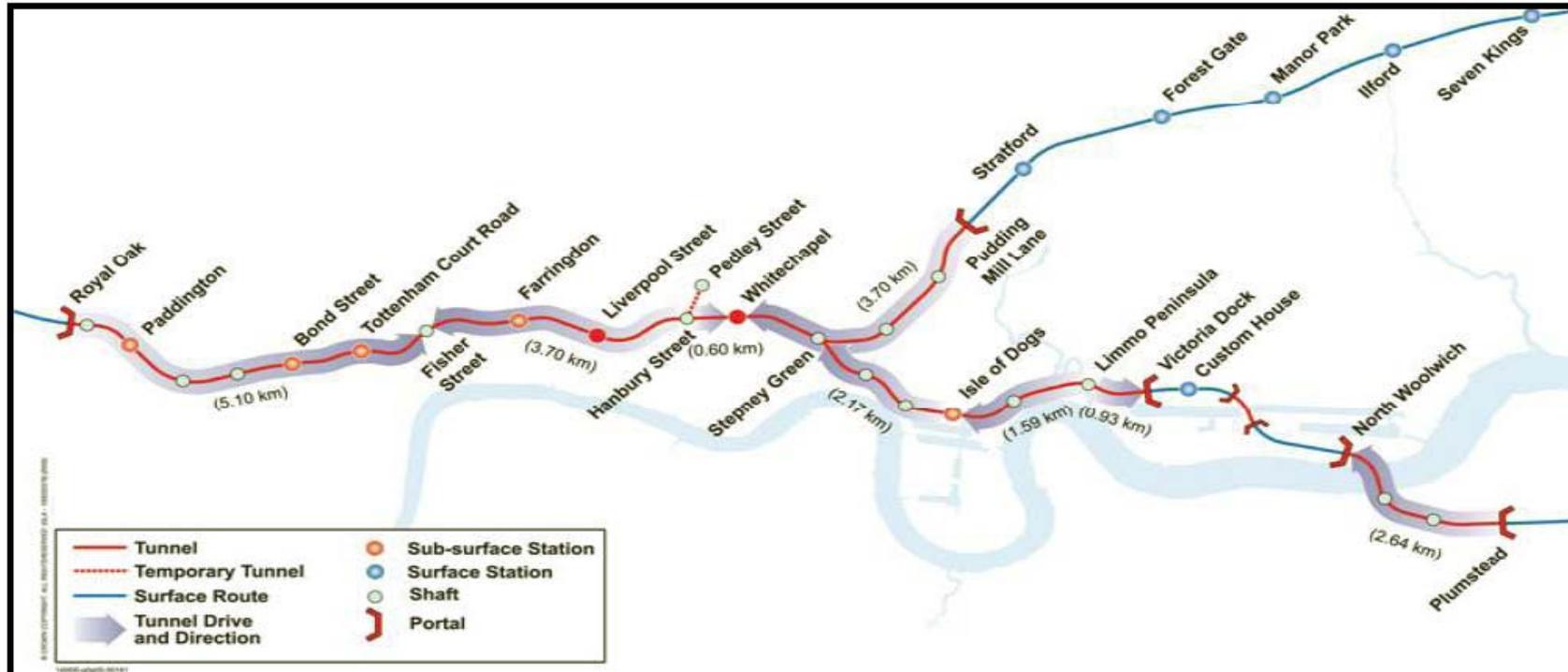
8.7 Following the launch of the TBM a regular construction cycle of excavation, advance of the TBM and ring erection, immediately after advancement of the shield is complete, will be established.

8.8 Excavation will be undertaken one ring at a time. On completion of the excavation cycle, the segments will be erected within the tailskin of the TBM using a mechanical erector to form a complete ring. The excavation cycle will then be repeated with the TBM propelled forwards by hydraulic jacks shoving off the ends of the previously erected tunnel lining ring.

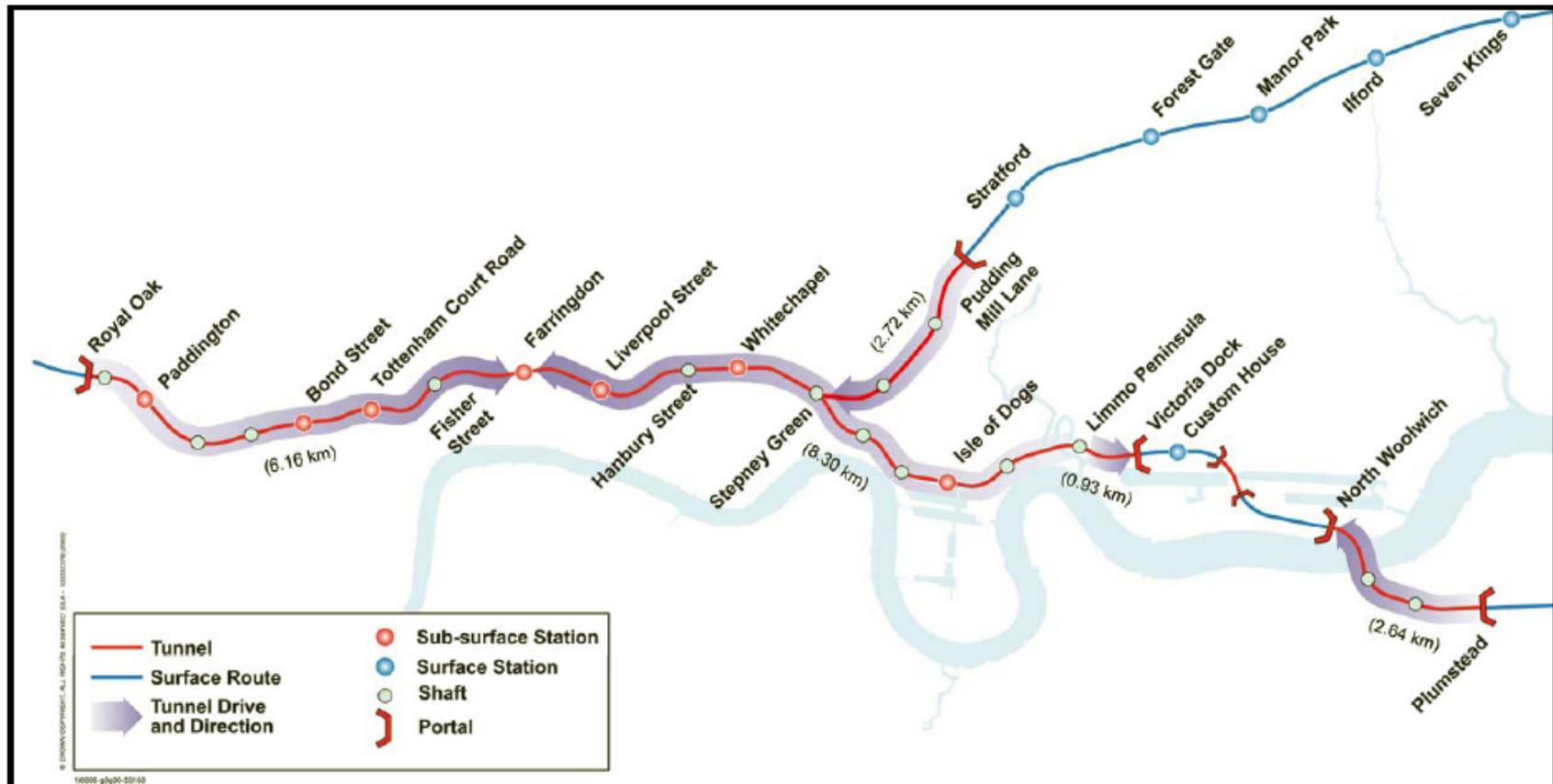
8.9 For non expanded linings grouting of rings will be undertaken as a continuous process through the tail-skin of the TBM to a predetermined pressure to fill the voids between the ring and the excavated surface of the ground. The injection pressure and volume of grout will be automatically recorded. Back grouting will be undertaken on a regular basis to ensure that any voids left behind the lining after excavation and erection are filled.

- 8.10 The delivery of materials (tunnel lining segments, grout etc) to the TBMs will be by a narrow gauge construction railway or similar system.
- 8.11 Removal of excavated material may be by railway, conveyors or by pumping dependent on the type of tunnelling machine selected and lengths of the tunnel drive.
- 8.12 TBM parameters will be monitored continuously both underground and within a Crossrail control room and a excavation/grout reconciliation carried out to ensure all voids have been filled to minimise the risk of settlement.
- 8.13 The tunnelling operation will be a continuous operation to ensure a steady state is achieved with the tunnel machine parameters and to enable any adverse trends to be identified and corrective actions taken to minimise ground movements and the risk of damage.
- 8.14 On completion of the tunnel drives the TBMs will be dismantled and removed either underground through the tunnel or lifted to the surface from the tunnel reception chamber.

Annex A Original tunnelling strategy showing drives and drive lengths



Annex B Revised tunnelling strategy showing drives and drive lengths



Annex C Tunnelling ground conditions

