HIGH SPEED TWO PHASE ONE INFORMATION PAPER

D7: TUNNEL CONSTRUCTION AND METHODOLOGY

This paper outlines the proposed tunnelling methodology.

It will be of particular interest to those potentially affected by the Government's proposals for high speed rail.

This paper was prepared in relation to the promotion of the Bill for Phase One of the scheme which is now enacted. Although the contents were maintained and updated as considered appropriate during the passage of the Bill (including shortly prior to the enactment of the Bill in February 2017) the contents are now historic and are no longer maintained.

If you have any queries about this paper or about how it might apply to you, please contact the HS2 Helpdesk in the first instance.

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D7: TUNNEL CONSTRUCTION AND METHODOLOGY

1. Introduction

1.1. High Speed Two (HS2) is the Government's proposal for a new, high speed north-south railway. The proposal is being taken forward in two phases: Phase One will connect London with Birmingham and the West Midlands and Phase Two will extend the route to Manchester, Leeds and beyond.

1.2. HS2 Ltd is the non-departmental public body responsible for developing and promoting these proposals. The company works to a Development Agreement made with the Secretary of State for Transport.

1.3. In November 2013, HS2 Ltd deposited a hybrid Bill[1] with Parliament to seek powers for the construction and operation of Phase One of HS2 (sometimes referred to as 'the Proposed Scheme'). The Bill is the culmination of nearly six years of work, including an Environmental Impact Assessment (EIA), the results of which were reported in an Environmental Statement (ES) submitted alongside the Bill. The Secretary of State has also published draft Environmental Minimum Requirements (EMRs), which set out the environmental and sustainability commitments that will be observed in the construction of the Proposed Scheme.

1.4. The Bill is being promoted through Parliament by the Secretary of State for Transport (the 'Promoter'). The Secretary of State will also appoint a body responsible for delivering the Proposed Scheme under the powers granted by the Bill.

1.5. This body is known as the 'nominated undertaker'. There may well be more than one nominated undertaker – for example, HS2 Ltd could become the nominated undertaker for the main railway works, while Network Rail could become the nominated undertaker for works to an existing station such as Euston. But whoever they are, all nominated undertakers will be bound by the obligations contained in the Bill and the policies established in the EMRs.

1.6. These information papers have been produced to explain the commitments made in the Bill and the EMRs and how they will be applied to the design and construction of the Proposed Scheme. They also provide information about the Proposed Scheme itself, the powers contained in the Bill and how particular decisions about the project have been reached.

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[1] The High Speed Rail (London – West Midlands) Bill, hereafter 'the Bill'.

2. Overview

2.1. Tunnelling is often necessary on railway lines where, due to the rolling nature of the landscape, it would not be possible to align the track without steep inclines. This is also the case for HS2.

2.2. Tunnels have also been introduced into the Proposed Scheme for environmental reasons, for example, to pass beneath built-up areas where disruption at the surface would be severe.

2.3. This paper provides an overview of the proposed tunnelling methodology.

3. Impacts of Tunnelling

3.1. HS2 Ltd published a report on 'Impacts of Tunnels in the UK'[2] in September 2013 which fulfils an earlier promise by the Government to publish a clear, thorough and fully evidenced assessment of:

- the UK's recent history of building (tunnels beneath properties);
- the actual impacts that these have had on the properties and people above them; and
- the measures that will be taken to ensure that perceptible vibration impacts can be avoided.

Construction

3.2. Noise and vibration due to tunnel boring during construction have been assessed based on previous experience at Dublin Port Tunnel, HS1 and Crossrail. In general, the levels are low and occur for a limited period only.

3.3. As with any underground works, ground movements affecting buildings could occur during tunnel excavation or shortly thereafter. While the vast majority of tunnelling projects are successful, with very low recorded ground settlements, occasionally an incident occurs that results in higher localised ground settlements or subsidence.

3.4. The impact of ground movements on buildings will be assessed through an established three-stage process to determine whether there is a risk of building damage. Full details of this process are set out in Information Paper C3- Ground Settlement.

3.5. The environmental impacts of tunnelling are considered within the HS2 Phase One Environmental Statement and within the report 'Impacts of Tunnels in the UK'.

[2] http://assets.hs2.org.uk/sites/default/files/inserts/Impacts%20of%20tunnels%20in%20the%20UK.pdf

Operation

3.6. Modern tunnelling methods means the impact of noise and vibration is relatively low and may be effectively controlled. The main reasons for this are:

- better quality track;
- straighter track alignments;
- smoother running surfaces on the rails;
- fewer rail joints (reducing the dynamic loads and consequently the wear and tear on the rolling stock); and
- better suspension on the trains (which improves passenger comfort, as well as reducing the impact forces on the track).

3.7. For high speed trains, the need for better performance ensures that the track is maintained to a very high standard. The process of calculating noise and vibration from rail tunnels is well understood and the effects can be accurately predicted. Where noise and vibration levels are considered to be an issue, well-tried mitigation measures are available.

3.8. Further information on noise and vibration control and mitigation is available in the Information Papers: E21- Control of ground-borne noise and vibration from the operation of temporary and permanent railways; E22- Control of noise from the operation of stationary systems; and E23- Control of construction noise and vibration.

3.9. Recent projects, such as the Jubilee Line Extension and HS1 tunnels under London, have shown that modern railways can run in tunnels under large residential areas without noise and vibration affecting the people who live there or disturbing other highly sensitive non-residential uses.

4. Tunnelling on HS2 Phase One

4.1. A brief overview of the types of tunnels planned for HS2 Phase One is below:

- **cut-and-cover tunnel** (also referred to as green tunnel) – where a trench is excavated and roofed over, then the land on top of the tunnel is restored so it blends into the landscape. Six short tunnels (totalling 8.2km) consisting of two adjacent boxes will be constructed using a cut-and-cover method. See section 10 below for further information; and
- **twin bored tunnel** – where two parallel tunnels, each containing a single rail track, are constructed using tunnel boring machines (TBMs). HS2 Phase One will construct 39.1km of twin bore tunnels. These will have internal diameters from 7.55m to 8.8m. See section 8 below for further information.

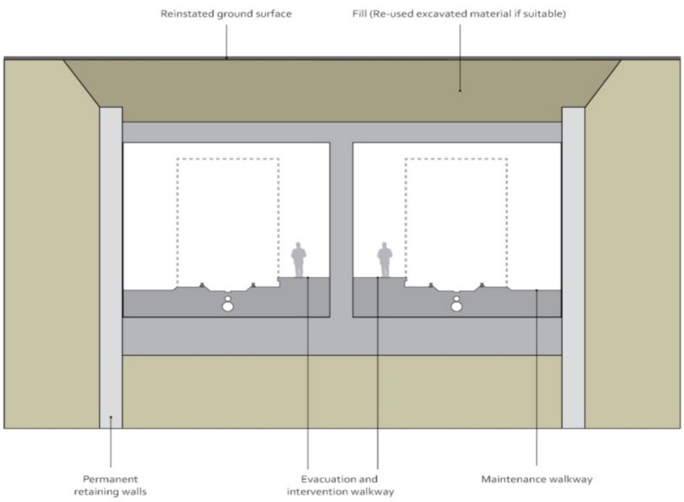


Figure 1: Cross Section of Typical Cut and cover Tunnel

4.2. For safety reasons, tunnels longer than 1km (0.6miles) are required to have cross-passage escape routes between individual bores and to the surface. Figure 2 below shows the cross section with cross passage escape route.

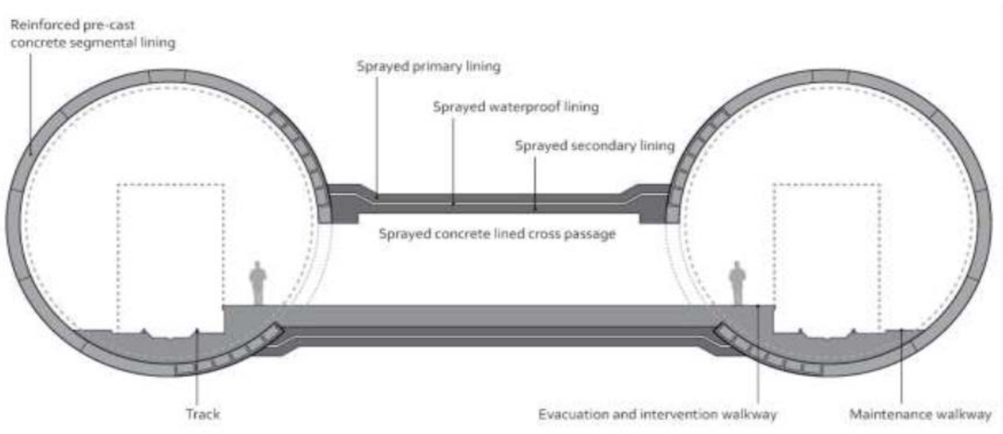


Figure 2: Cross Section of Typical Twin Bore Tunnel with cross passage escape route

5. Construction strategy

5.1. Bored tunnels are constructed either by starting from one entrance and constructing the whole tunnel or by starting at both entrances and meeting in the middle. The construction strategy will be to construct tunnels from the most suitable entrances, based on:

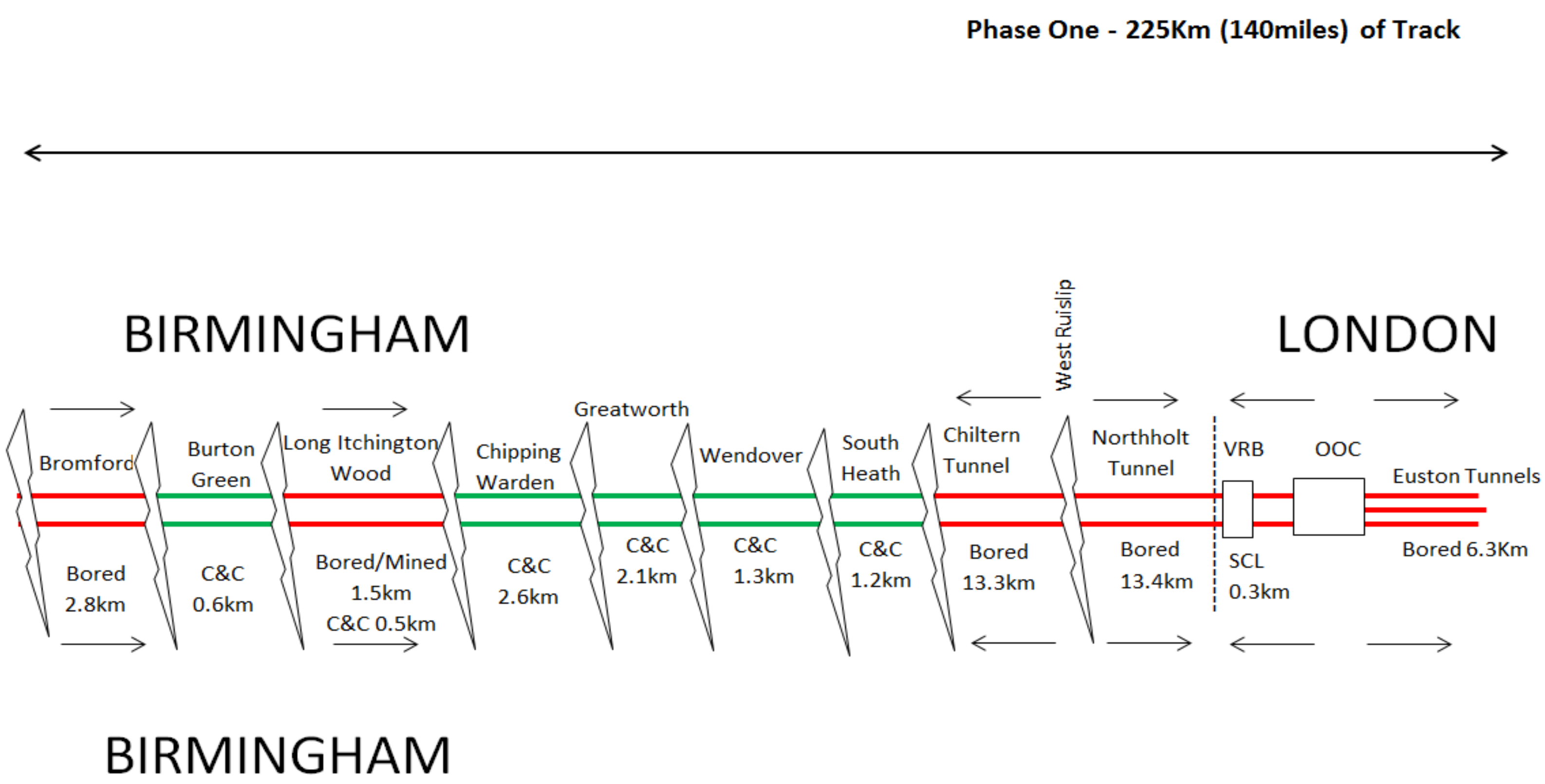
- distance from sensitive locations; and
- ease of access for logistics by road and rail.

6. Tunnel worksites for Bored Tunnels

6.1. TBMs will be launched from six main tunnelling worksites:

- two TBMs from the east end of the Old Oak Common site towards Euston;
- two TBMs from the west end of the Victoria Road box near Old Oak Common, heading west towards the Green Park Way shaft to construct the eastern portion of the Northolt Tunnel;
- two TBMs from the West Ruislip portal, east towards the Green Park Way shaft;
- two TBMs northwards from south of the M25 towards Mantle's Wood - the Chilterns tunnel site was chosen due to its proximity to the M25, allowing direct access to the M25 and so minimising traffic movements on local roads;
- one TBM south from the north portal of Long Itchington tunnel - on completion of the drive, the TBM will return to the north portal to drive the second bore; and
- one TBM eastwards from the west portal of Bromford tunnel - on completion of the drive, it will return to the west portal to drive the second bore - Bromford tunnel needs to be constructed from the west to utilise the area of land available for works area, minimising the amount of demolition.

HS2 PHASE ONE TUNNELS



VRB = Victoria Road Box

C&C = cut-and-cover tunnel

SCL = sprayed concrete lining

OOC = Old Oak Common Station Box

Figure 3: HS2 Phase One Tunnels

7. Tunnel boring machines

7.1. Advanced design TBMs are essential for the construction of HS2. The TBMs will be purpose-built machines, using proven state-of-the-art technology and will operate 24 hours a day, seven days a week. They will be designed specifically for the project to ensure their reliability in terms of performance and settlement control and to cope with the range of ground conditions expected to be encountered. Further information on settlement control can be found in the Information Paper C3- Ground Settlement.

7.2. During the Jubilee Line extension, HS1, and Crossrail projects, bored tunnels were driven successfully through ground conditions that would once have been considered extremely difficult, proving the capability of modern construction techniques.

7.3. Two types of TBM will be used during construction. The type of machine used depends on ground conditions and the amount of groundwater present but the TBM will be either:

- Earth Pressure Balance Machines, which will be used predominately. These are suitable for use in a wider range of soft ground types, as well as where the ground is more stable and self-supporting; or
- Slurry TBMs, which will be used if needed, where required by the prevailing ground conditions.

7.4. These types of machine have performed well on the Jubilee Line, HS1 and Crossrail projects. Volume 1 Section 6.12 of the Environmental Statement provides a fuller description of both types of TBMs.

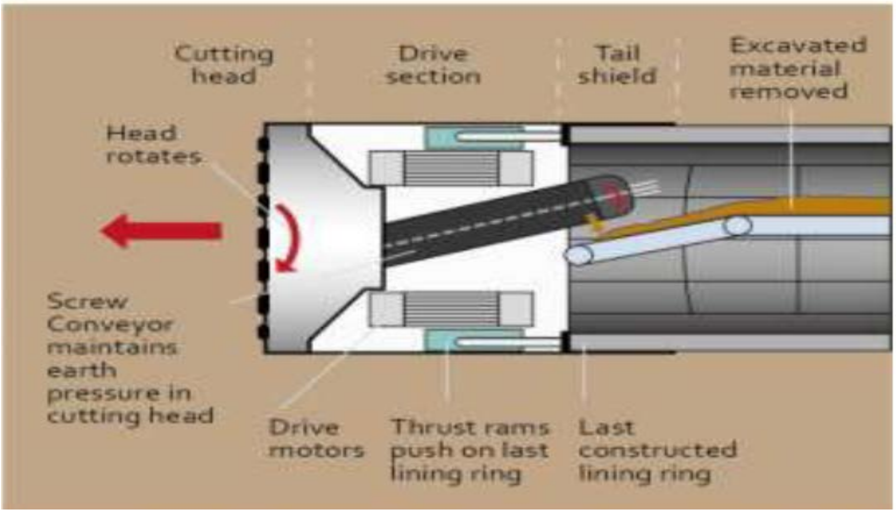


Figure 4: Earth Pressure Balance TBM

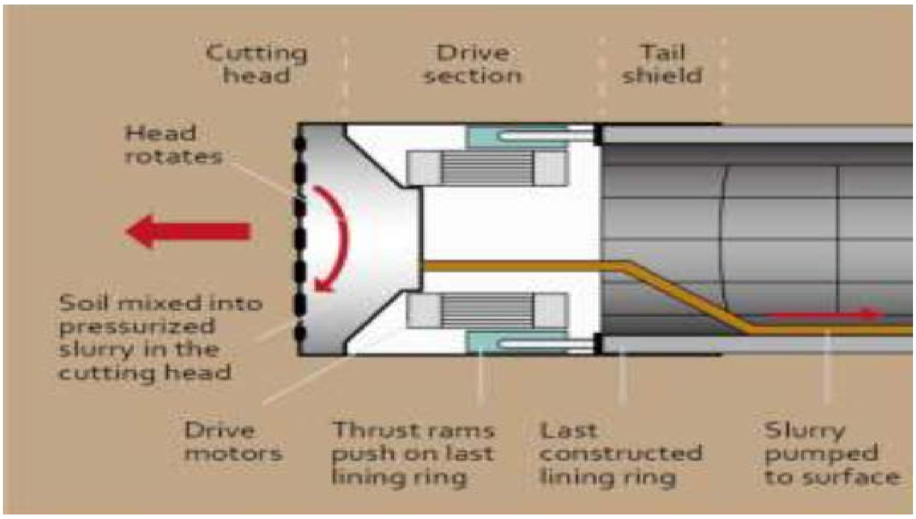


Figure 5: Slurry TBM

7.5. To ensure the TBMs are operating safely, information will be relayed to a dedicated monitoring room manned by suitably experienced engineers. The monitoring room will have displays of real-time surface, subsurface and tunnel movements, together with TBM tunnel progress and TBM parameters.

7.6. This will ensure that the tunnel construction is being carried out to specification and that ground movements and temporary vibration effects remain within acceptable limits.

8. TBM operation

8.1. The TBMs will weigh over 1,000 tonnes when fully operational. They will be delivered in smaller components and assembled near the tunnel entrance.

8.2. Where sufficient space is available, the TBM will be fully assembled before launch, with all back-up equipment installed. Otherwise, the TBM will be advanced and a sufficient length of tunnel constructed to allow the back-up equipment to be assembled in the tunnel.

8.3. Where necessary, ground treatment will be carried out around the TBM launch chamber structure to allow the TBM to be buried safely. This will also allow the full stabilising effects of the TBM to be brought into operation.

8.4. Once the TBM is launched, the following tunnel construction cycle will begin:

- excavation will be undertaken one tunnel lining ring[3] at a time. First the TBM will excavate a short section of tunnel. Next, the tunnel lining ring segments will be set up within the tail-skin of the TBM using a mechanical erector to form a complete ring. Following this the next short section of tunnel will be excavated, with the TBM propelled forwards by hydraulic jacks shoving off the ends of the previously erected tunnel lining ring;

[3] The tunnel will be built progressively through the building of joined 'rings' approximately 1.5 m in length.

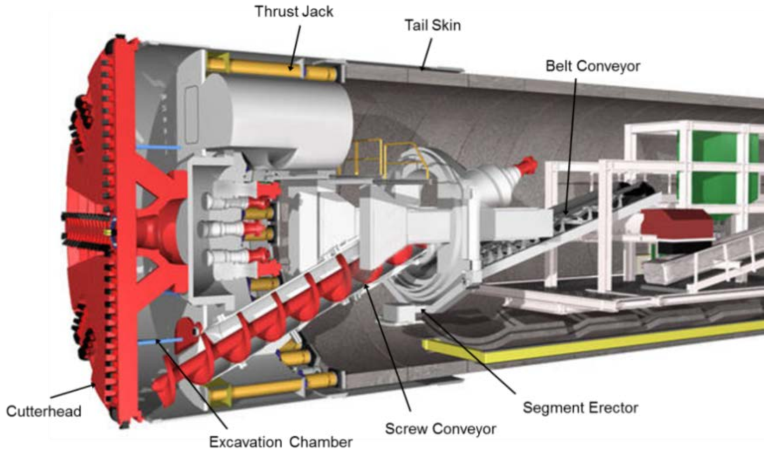


Figure 6: Sectional View of TBM Copyright Herrenknecht

- grouting of the tunnel lining rings will be undertaken as a continuous process through the tail-skin of the TBM to fill the voids between the tunnel lining rings and the excavated surface of the ground behind;
- materials (such as tunnel lining rings and grouts) will be delivered to the TBMs by a narrow-gauge construction railway or similar system;
- excavated materials may be removed by railway, conveyors or pumping, depending on the type of TBM and the length of the tunnel;
- TBM parameters will be monitored continuously both underground and within a dedicated tunnel monitoring control room. An excavation/grout check will be carried out to ensure all voids have been filled to minimise the risk of settlement;
- the tunnelling operation will be continuous. This will minimise ground movements; and
- on completion of the tunnel drives, the TBMs will be dismantled and removed from the tunnels.

9. Mined tunnels

9.1. In soft ground or fractured rock, tunnels may be mined using conventional methods. Tunnels may be mined using roadheaders (shown in Figure 7 below) and/or excavators, depending on the groundwater, ground conditions and length of drive.

9.2. Following a short initial excavation, the primary tunnel support is installed. This may consist of rock bolts and sprayed concrete in rock, or sprayed concrete in clays and soils.

9.3. This initial excavation is then enlarged by cyclic excavation and lining to form the required tunnel geometry. See Volume 1 of the Environmental Statement.

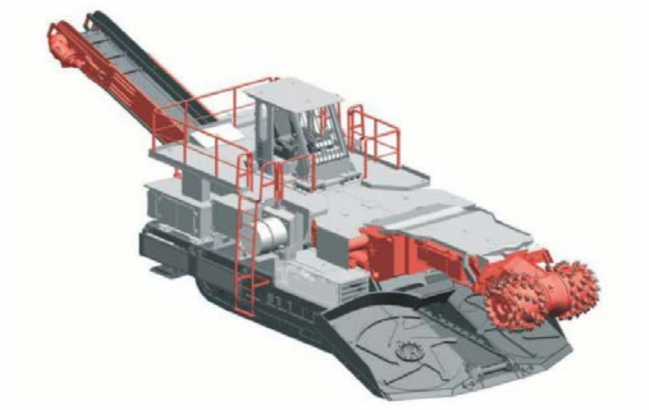


Figure 7: Typical Roadheader

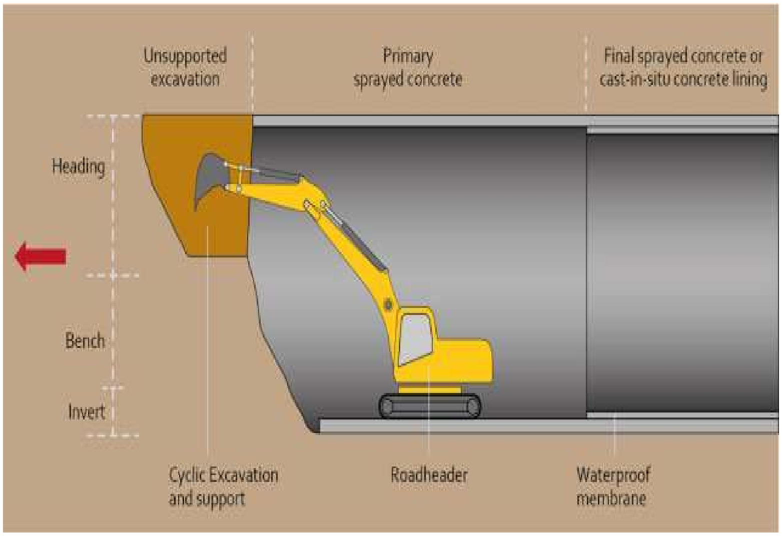


Figure 8: Mined excavation by conventional methods

9.4. Excavated material is removed from the tunnel either by conveyors or rubber-tyred loading shovels/dump trucks.

10. Cut-and-cover tunnels (Green tunnels)

10.1. Cut-and-cover tunnels are constructed either in an open excavation or a retained excavation. Examples of typical cut-and-cover tunnels are shown in Figure 9 below.

10.2. The open excavation method involves excavating from the surface, including the use of temporary support as required. Once the final depth is reached, the tunnel floor is constructed, followed by the walls and roof to form a twin-cell box to enable tracks to be separated for safety reasons. This box is then buried by back-filling with the previously excavated material and restoring the land so it blends into the landscape.

Figure 9: Typical cut-and-cover (green) tunnels

10.3. In the retained excavation method, first the walls are constructed using diaphragm walling or bored piling. Refer to Environmental Statement Volume 1 Chapter 6.12. Then the ground is excavated between the wall, down to the top of the roof of the box.

10.4. One option is then to form the roof and continue the excavation of the remainder of the tunnels, from the open ends of the box, and construct the floor slabs and dividing walls. The box is then backfilled to the surface.

10.5. The second option is to continue the excavation down to the floor slab, construct floor slab, walls and roof, and then backfill to the surface.

11. Tunnel lining design

11.1. Tunnel linings are required for two purposes:

- structurally - to retain the earth and water pressure; and
- operationally - to provide an internal surface appropriate to the function of the tunnel.

11.2. Tunnel linings will be designed in accordance with the relevant regulatory standards, guidelines and current practice. These are based on proven design and construction technology that has been used successfully worldwide.

11.3. The linings will be designed to withstand loading, including loads from the surrounding ground and groundwater. They will also meet fire prevention and durability requirements.

11.4. As well as the train itself, the internal diameters have been sized to accommodate the swaying movement of trains, overhead power supply, evacuation and access walkways, track slab, cables and associated furniture, and construction tolerances. Their sizing also takes account of the aerodynamic requirements of high speed trains.

11.5. The majority of the bored tunnels will be lined with pre-cast concrete tunnel lining segments, reinforced with steel fibres and polypropylene fibres. To enable connection between the twin bored tunnels, at intervals along the length of the route, cross-passages will be constructed using round graphite iron linings or steel frames encased in concrete alongside precast concrete tunnel linings. The linings are made up of a number of tunnel segments which are joined to form a ring.

11.6. The mined and cross passage tunnels, which are lined with sprayed concrete, will have a primary sprayed lining of fibre-reinforced concrete with a waterproof layer. A secondary lining of fibre-reinforced concrete will be either sprayed or cast in place. These construction techniques are currently being used successfully on the Crossrail project.

11.7. The lining of cut-and-cover tunnels will be conventional reinforced concrete.

12. Fit-Out of Tunnels

12.1. Once tunnels are excavated, lined and cleaned out then the following activities need constructing:

- construction of walkways;
- installation of rail track and formation;
- mechanical and electrical systems; and
- testing and commissioning.

13. More information

13.1. More detail on the Bill and related documents can be found at: www.gov.uk/HS2