

HIGH SPEED TWO PHASE 2a INFORMATION PAPER

F2: PHASE 2a TUNNELS

This paper outlines the range of proposed tunnelling methods to be deployed on the Proposed Scheme, the factors that influence the choice of method and the means of mitigating the construction and operational impacts associated with tunnelling.

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 High Speed Rail (West Midlands-Crewe) Bill which is now enacted. It was finalised at Royal Assent and no further changes will be made.

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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F2: PHASE 2a TUNNELS

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 phases: Phase One will connect London with Birmingham and the West Midlands. Phase 2a will extend the route to Crewe. Phase 2b will extend the route to Manchester, Leeds and beyond. The construction and operation of Phase One of HS2 is authorised by the High Speed Rail (London – West Midlands) Act 2017.
- 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 July 2017, the Government introduced a hybrid Bill¹ to Parliament to seek powers for the construction and operation of Phase 2a of HS2 (the Proposed Scheme). The Proposed Scheme is a railway starting at Fradley at its southern end. At the northern end it connects with the West Coast Main Line (WCML) south of Crewe to allow HS2 services to join the WCML and call at Crewe Station. North of this junction with the WCML, the Proposed Scheme continues to a tunnel portal south of Crewe.
- 1.4. The work to produce the Bill includes an Environmental Impact Assessment (EIA), the results of which are reported in an Environmental Statement (ES) submitted alongside the Bill. The Secretary of State has also published draft Environmental Minimum Requirements (EMRs)², which set out the environmental and sustainability commitments that will be observed in the construction of the Proposed Scheme.
- 1.5. The Secretary of State for Transport is the Promoter of the Bill through Parliament. The Promoter will also appoint a body responsible for delivering the Proposed Scheme under the powers granted by the Bill. This body is known as the 'nominated undertaker'. The nominated undertaker will be bound by the obligations contained in the Bill and the policies established in the EMRs. There may be more than one nominated undertaker.
- 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 Proposed Scheme have been reached.

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

² For more information on the EMRs, please see Information Paper E1: Control of Environmental Impacts.

2. Overview

- 2.1 This paper provides an overview of the range of proposed tunnelling methods to be employed on the Proposed Scheme and the means of mitigating the construction and operational impacts associated with tunnelling.
- 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, which are not compatible with railway operations. This is also the case for the Proposed Scheme.
- 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.

3. Tunnels on Phase 2a

- 3.1. A brief overview of the types of tunnel planned for the Proposed Scheme is as follows:
 - **cut-and-cover tunnel** (also referred to as green tunnel) – where a trench is excavated and a concrete structure with a base, roof and walls is constructed in the trench. Fill material and soil is then used to backfill the trench and cover the top. The ground above is then restored and graded to blend it into the surrounding landscape. A short length (about 200m) of the southern part of the Whitmore Tunnel will be in cut-and-cover. See Figure 1 below for the cross section of a typical cut-and-cover tunnel;

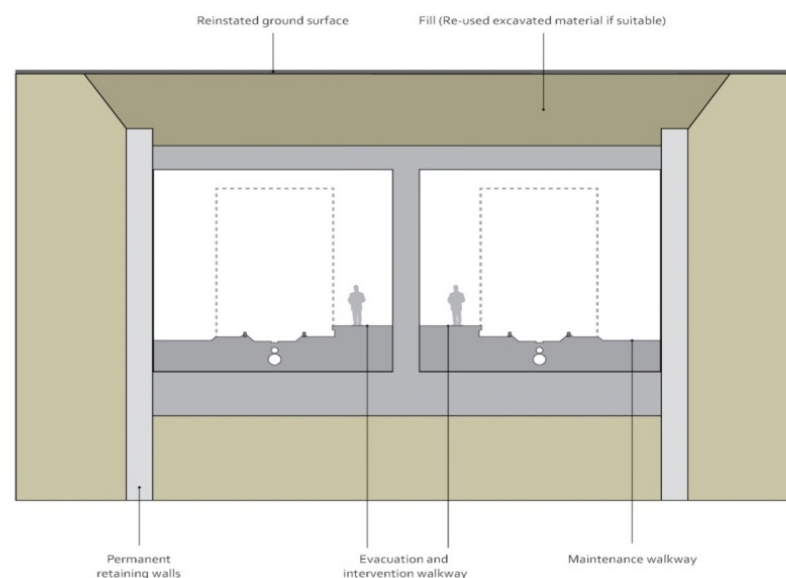


Figure 1: Cross section of a typical cut-and-cover tunnel

- **bored tunnels** – where two parallel tunnels, each containing a single rail track, are constructed. This can be done by either using tunnel boring machines (TBMs) or by excavation of a single-bore tunnel with mechanical

plant. The Proposed Scheme includes approximately 2km of twin-bore tunnels (Whitmore and Madeley tunnels). These are planned to have an internal diameter of 8.8m. See section 5 below for further information on tunnel construction.

- 3.2. For safety reasons, when bored tunnels exceed 500m in length, they are required to have cross passages to connect the two tunnel bores as well as escape routes that run the full length of the tunnel and are connected to the surface at tunnel portals. Cross passages and escape routes are required to provide safe exit routes and emergency services access in the event of an emergency. Figure 2 below for a typical cross-section of a twin-bored tunnel with cross passage.

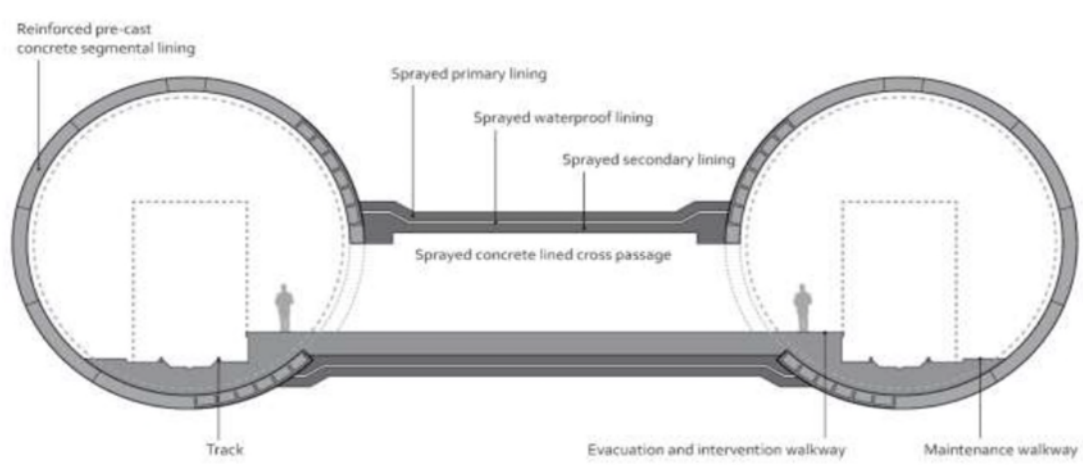


Figure 2: Cross section of a typical twin bore tunnel with cross passage escape route

- 3.3. On long tunnels, ventilation shafts may also be required at intermediate points along the tunnel to provide further emergency service access and evacuation points.

4. Tunnel Construction Methods

- 4.1. 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 entrance or entrances, based on:
 - distance from sensitive locations;
 - ease of access for logistics by road and rail;
 - impact on overall construction programme; and
 - economic use of plant and machinery.
- 4.2. At present, to construct the Whitmore and Madeley tunnels it is assumed that Tunnel Boring Machines (TBMs) will be launched from the main tunnelling

worksites at the southern portal of each tunnel. It is assumed that the tunnels will be bored in a south to north direction.

- 4.3. The main tunnel worksites are required for the removal of excavated material from the tunnel. They also form the main logistics area to take construction material and operatives into the tunnel. Depending on the construction method, the main worksite may also contain an area for casting concrete tunnel segments.
- 4.4. Cut-and-cover tunnels are constructed either in an open excavation or in a retained excavation.
- 4.5. The open excavation method involves excavating from the surface. Once the final depth is reached the tunnel floor is constructed, followed by the walls and roof to form a twin-cell box. Cut-and-cover tunnels in open excavation are generally constructed in shorter bays. The bays gradually advance over the full length of the tunnel section, with excavation being carried out from the ends of each box section. On shorter lengths of cut-and-cover tunnel the full tunnel length could be excavated at the same time.
- 4.6. The retained excavation method involves first constructing the walls using diaphragm walling or bored piling, followed by excavation and construction of the roof. Excavation of the tunnel is then undertaken beneath the roof slab from the open ends of the box. This method is likely to be adopted where space limitations restrict the width of an open excavation with side slopes.

5. Tunnel boring machines

- 5.1. HS2 Ltd has put together a high performance TBM specification that is specifically designed to limit both tunnel construction risk and ground movements to a practical minimum. The TBMs used to construct HS2 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 of performance, settlement control and to cope with the range of ground conditions expected along the Proposed Scheme.
- 5.2. 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, and similar to the ground conditions on some of the HS2 tunnels, proving the capability of modern construction techniques.
- 5.3. There are several types of TBM that employ different methods of supporting the tunnel face during excavation depending on the ground conditions, but they all involve essentially similar construction operations in terms of logistics.
- 5.4. The TBMs most likely to be used on the Whitmore and Madeley tunnels are Earth Pressure Balance Machines as shown in Figure 3 below.

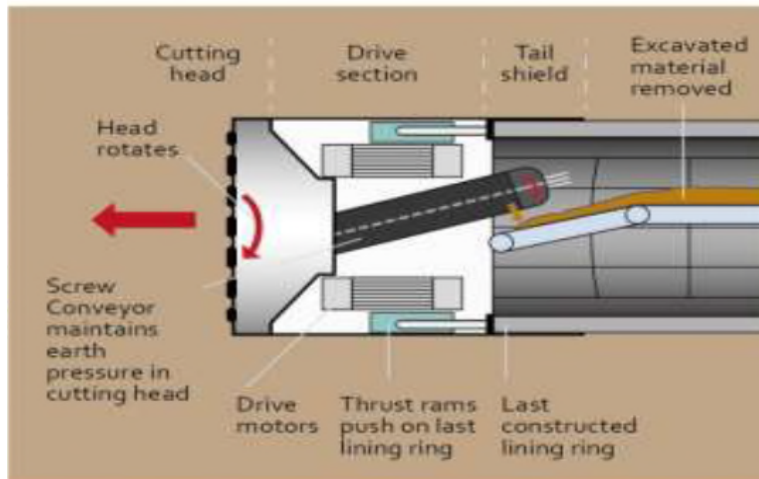


Figure 3: Earth Pressure Balance TBM

- 5.5. 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.
- 5.6. 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.

6. TBM operation

- 6.1. The TBMs will weigh over 1,000 tonnes when fully operational. They will be delivered in smaller components and assembled near the tunnel entrance.
- 6.2. 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.
- 6.3. 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.
- 6.4. Once the TBM is launched, the following tunnel construction cycle will begin:
 - excavation will be undertaken one tunnel lining ring³ at a time. First the TBM will excavate a short section of tunnel. Next, the tunnel lining ring segments will be built 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 previously erected tunnel lining ring; Figure 4 below shows the layout in a typical TBM.

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

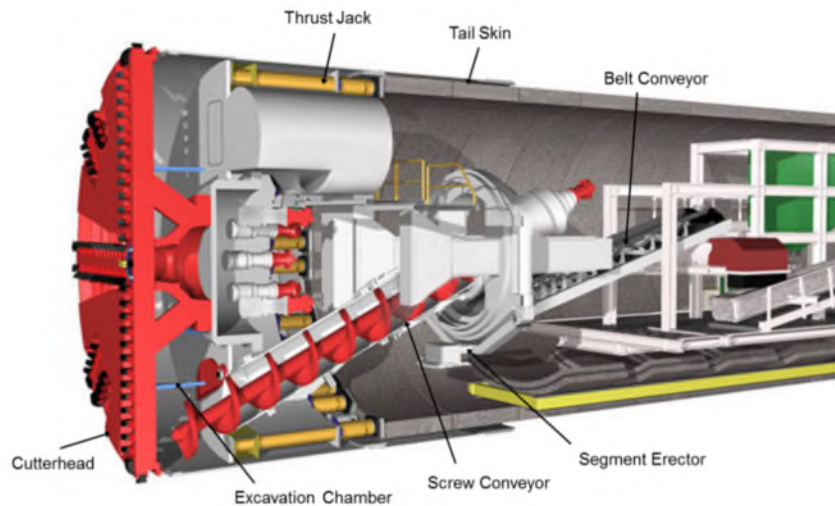


Figure 4: Sectional View of TBM Copyright Herrenknecht

- 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 other system such as pumping from the surface; and
 - excavated materials may be removed by railway, specially designed rubber tyre vehicles, conveyors or pumping, depending on the type of TBM and the length of the tunnel.
- 6.5. 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.
- 6.6. The tunnelling operation will be continuous, which will minimise ground movements. On completion of the tunnel drives, the TBMs will be dismantled and removed from the tunnels.

7. Tunnelling Construction Phase Impacts

- 7.1. Noise and vibration due to tunnel boring during construction have been assessed based on previous experience at the Dublin Port Tunnel, the Jubilee Line Extension, HS1 and Crossrail. In general, the levels are low and occur for a limited period only.
- 7.2. 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.

- 7.3. The impact of ground movements on buildings will be assessed through a well-established three-stage process to determine whether there is a risk of potential building damage. This process has been used successfully on both HS1 and Crossrail. Full details of this process are set out in Information Paper C14: Ground Settlement.
- 7.4. The environmental impacts of tunnelling are considered within the ES.

8. Tunnelling Operational Phase Impacts

- 8.1. Modern tunnelling methods mean the impact of ground-borne noise and vibration from railway operations are 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 and the use of continuously welded track (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).
- 8.2. For high speed trains, the need for better performance requires 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.
- 8.3. 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.
- 8.4. Further information on noise and vibration control, and mitigation is available in Information Papers: E10 Control of ground-borne noise and vibration from the operation of temporary and permanent railways; E11 Control of noise from the operation of stationary systems; and E13 Control of construction noise and vibration.

9. Tunnel lining design

- 9.1. Tunnel linings are required to;
- structurally retain the earth and water pressure; and
 - provide an internal space appropriate to the function of the operational railway.

- 9.2. 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.
- 9.3. The linings will be designed to withstand all foreseeable loading, including construction loads and those from the surrounding ground and groundwater. They will also meet fire resistance and durability requirements.
- 9.4. As well as the train itself, the internal diameters of the tunnels have been sized to accommodate the swaying movement of trains, the 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.
- 9.5. 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 and the openings for these formed 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.
- 9.6. 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 have been used successfully on the Crossrail project.
- 9.7. The lining of cut-and-cover tunnels will be conventional reinforced concrete.

10. Tunnel Porous Portals

- 10.1. A tunnel portal is the entry or exit section of a tunnel.
- 10.2. On high speed railways, the purpose of a porous portal at the entry of a tunnel is to ensure that the micro pressure waves produced by the 'piston effect' of the train moving through the tunnel, which can otherwise result in noise as the train exits the tunnel, are controlled and kept at a level which does not adversely affect the surrounding area.
- 10.3. A 'porous portal' is generally achieved by providing perforated structures, usually of concrete, at the tunnel portal. These structures have openings of increasing diameter, open to the outside air, running along their length.
- 10.4. Figure 5 and 6 below illustrate how porous portals on the Proposed Scheme could look:

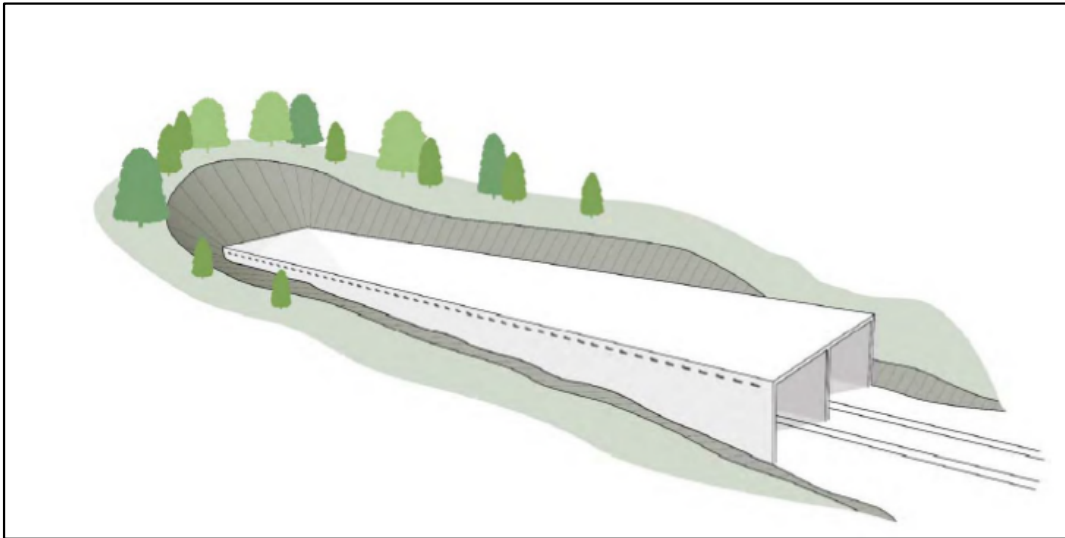


Figure 5: Example of porous portal (1)

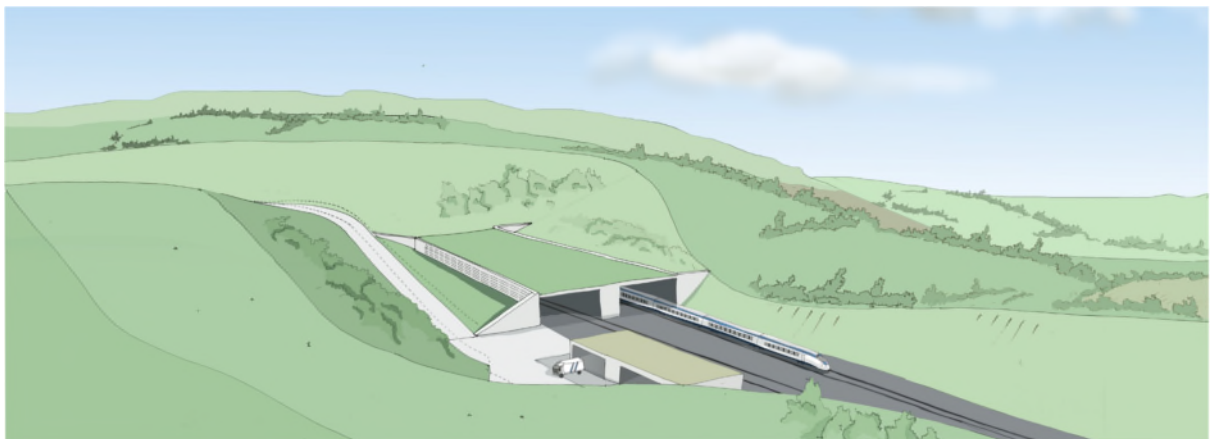


Figure 6: Example of porous portal (2)

11. Fit-Out of Tunnels

11.1. Once tunnels are excavated, lined and cleaned out, the following activities take place:

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

12. More information

12.1. More detail on the Bill and related documents can be found at: www.gov.uk/Hs2