IMPACTS OF TUNNELS IN THE UK
Non-technical summary

September 2013
High Speed Two (HS2) Limited has been tasked by the Department for Transport (DfT) with managing the delivery of a new national high speed rail network. It is a non-departmental public body wholly owned by the DfT.

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1 Introduction

1.1 Why we need HS2

1.1.1 The number of people travelling by train has doubled over the last 15 years. Demand for inter-city journeys, commuting and freight rail transport is rising and is expected to continue to do so in the future. This means that Britain’s railways are already overstretched and will get more and more overcrowded over the next 10 to 20 years.

1.1.2 High Speed Two (HS2) will tackle this problem by providing a new railway line – the first line north of London for 120 years. Phase One will run between London and Birmingham and tackle the congestion and overcrowding on the West Coast Main Line. Phase Two will do the same for the East Coast and Midland Main Lines from Birmingham to Manchester and Leeds.

1.1.3 HS2 will not only provide capacity for inter-city passenger services, but better connections between our major towns and cities. This improvement will make our railways fit for the next 50 years and beyond. It will also release capacity on the existing railway network for new regional, commuter and freight services.

1.1.4 With HS2, journeys will be shorter, our towns and cities will be closer together, there will be more regular and reliable services, our economy will benefit, and industry will get a boost from the construction of the new railway.

1.1.5 HS2 Ltd is the company responsible for developing a high speed rail route alignment to deliver the capacity we require, while also addressing the impacts of such a scheme on people, property and the environment. The proposed HS2 route connects London with the West Midlands and runs lines on to Manchester, Leeds and beyond. It would link much of the economic heart of England in an integrated, high speed rail network of 330 route miles (figure 1), connecting with the East and West Coast Main Lines to serve Liverpool, the North East and Scotland.

1.1.6 The requirements of the vertical alignment of railway lines in undulating ground often dictate that tunnels are necessary, and this is also the case for HS2. Additionally, some tunnels have been introduced for environmental reasons, especially to pass beneath built-up areas where disruption at the surface would be severe.

1.1.7 As part of the public consultation process, HS2 Ltd made a commitment to provide guidance on the likely effects on people and property from tunnel construction and from trains running in tunnels.

This document provides a summary of HS2’s main report – Impacts of tunnels in the UK – which can be found at www.hs2.org.uk.
Engineers have been constructing rail tunnels in the UK for over 150 years. From measuring settlement and recording noise and vibration levels on previous projects, they have a wealth of experience and technical understanding of the subject, which has been used to improve designs and construction methods. HS2 Ltd is using data from past and current tunnel projects to predict and mitigate the likely effects of tunnel construction and operation. This document (along with the main report) explains how people and property located over a tunnel are unlikely to be affected in any significant way.

In practice, modern technology and management ensure that the effects of tunnelling are generally small and typically go unnoticed. They are also well understood by engineers. As more tunnelled infrastructure is designed, built and operated, the knowledge of the likely effects increases further. This greater understanding, resulting from careful measurement and observation from projects, coupled with improvements in technology and practice, means that underground railways can be constructed and operated with less impact on people and buildings than ever before.

The vast majority of tunnelling projects are successful. The British Tunnelling Society (BTS), a learned society of the British Institution of Civil Engineers (ICE), produces guidance documents which are used internationally as standard, including methods for the control of ground settlement and ground stability during tunnelling, as well as a rigorous risk management approach in underground design and construction. Their guidance will be adopted by HS2 Ltd as the project develops and we are grateful for their and other experts’ comments on this evidence-based review of UK expertise, which constitutes the latest step of this ongoing process.

Managing the effects of tunnelling

Identifying effects

This document explains the causes of ground movement from tunnelling. It provides information on how buildings are affected by settlement, how damage is categorised and how it can be mitigated. It also explains the various sources of noise and vibration from tunnel construction and operation and how these can be reduced.

Putting a railway into a tunnel is one way to remove any direct impact of running it at the surface. However, tunnelling can have associated effects, principally:

- settlement (the movement of ground above and around the tunnel, generated during its construction); and
- noise and vibration generated by trains during operation, which can sometimes be perceptible at the surface, and can also be generated for short periods of time during construction.

People and buildings can be affected, but the impacts are small and often go unnoticed.

Most tunnel case histories investigated in the UK show that settlement did not cause any significant issues during tunnelling. Once tunnel construction is completed, some soils – such as clays or fine silts – can undergo further ground movement. This is termed ‘consolidation settlement’. Movements can sometimes be similar in
Impacts of tunnels in the UK | Ground movement

magnitude to those experienced from tunnel construction. However, consolidation occurs uniformly, over a longer period and a greater area; hence its effect on buildings and utilities is minimal – see section 3 for more details.

2.1.4 Rail technology has improved and modern railways produce far less noise and vibration than older systems. Recent projects, such as the Jubilee line extension and HS1, have shown that modern railways can run under large residential areas without noise and vibration affecting the people who live there or disturbing other highly sensitive non-residential land uses – see section 4 for more details.

3 Ground movement

3.1 Controlling ground movement

3.1.1 The majority of ground movements occur during tunnel excavation or shortly afterwards, but these ground movements can be controlled and managed. Excavating the tunnel causes a shallow depression – or ‘settlement trough’ – at the surface along the line of the tunnel (figure 3). The depth of this trough is termed the ‘maximum settlement’, and is dependent on:

- tunnel diameter and shape;
- depth of the tunnel;
- tunnel construction method;
- ground properties; and
- man-made structures.

3.1.2 The volume of the settlement trough can be expressed as a percentage of the excavated volume of the tunnel – this is termed the ‘volume loss’. There are well-documented case histories and research projects relating to tunnel construction and how ground has settled. Observed settlements have generally been lower than predicted maximum values, and have typically ranged between 5mm and 25mm, depending on the above factors.

3.1.3 Over the past few decades, ground movements have become smaller as tunnelling methods, equipment and engineering understanding have improved. The volume loss has reduced from values of between 2% and 3% in the 1990s to generally less than 1% today for tunnels constructed using modern tunnel boring machines (table 1).
3.1.4 Other tunnel case studies – namely Ramsgate Harbour tunnel, Abbey sewer, Southwick Hill tunnel, Bristol relief sewer, and Airdrie and Coatbridge sewer tunnel – show that settlement did not create significant issues during tunnelling.

3.2 How buildings are affected by ground movement

3.2.1 Buildings of different structural forms respond to ground movement in different ways and often this response goes unnoticed. This is because most buildings are generally good at tolerating small ground movements of the magnitude produced by modern tunnelling. The effect on a building depends on the amount of ground movement, the difference in this movement across the building and the building structure itself. For example, visible cracks in walls and ceilings may sometimes appear in older properties, and occasionally there may be minor damage, which can be easily repaired.

3.3 Tolerance of structures

3.3.1 In order to determine whether there is a risk of building damage from ground movement, engineers carry out assessments using an established three-stage process (figure 4).

3.3.2 Stage 1 is the most basic level of assessment, where a ‘greenfield’ settlement is calculated for the area influenced by tunnelling. This allows predicted ground movement to be conservatively calculated, without taking into account the building’s stiffness or behaviour. Where the predicted settlement is less than 10mm (or where the predicted ground slope is less than 1:500), experience shows that buildings and structures generally are not affected. Many buildings undergo similar magnitudes of movement as a result of seasonal ground variations.
3.3.3 Stage 2 involves carrying out potential damage assessments for buildings where:

- settlements are predicted to be greater than 10mm;
- the building is particularly sensitive or of historic significance; or
- the predicted ground slope is greater than 1:500.

3.3.4 The assessment allows buildings to be categorised on a scale of damage severity from zero to 5 (table 2). The construction of the London Underground Jubilee line extension and HS1 each required thousands of buildings and structures in London to be assessed. For the vast majority, damage was classified in the zero category, meaning there was a negligible risk of building damage from tunnelling.

3.3.5 Stage 3 requires detailed evaluations to be carried out for buildings in Category 3 or above. This process uses more detailed analysis and, if necessary, helps to determine appropriate protective measures to be employed during construction. Case studies from the Jubilee line extension show that even where actual settlements were close to the predicted values, building damage was in a lower category than the assessment suggested. This indicates that buildings are generally better at accommodating ground movements than the analysis suggests, leading to lower overall levels of damage.

3.4 Reducing impacts on buildings

3.4.1 A variety of methods can be used to reduce the impact of ground movement on buildings. The first stage is design, where key decisions are made on the tunnel’s alignment, depth and construction method. A good understanding of the ground conditions helps engineers to select the most appropriate tunnelling technique. However, it is virtually impossible to have an exact picture of the ground conditions at every point along a tunnel route. Variations in ground properties can be managed by the installation of ground support for the tunnel.

3.4.2 Further measures are available, one of which is the injection of material (usually cement grout) to wholly or partially replace the volume loss caused by tunnelling. By doing this between the tunnel and the foundations of a building, the movements affecting the building are significantly reduced. A notable example of these measures being employed successfully was in tunnelling close to the ‘Big Ben’ clock tower during the extension of the Jubilee line.

<table>
<thead>
<tr>
<th>Category</th>
<th>Severity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Negligible</td>
<td>Hairline cracks (&lt;0.1mm)</td>
</tr>
<tr>
<td>1</td>
<td>Very slight</td>
<td>Fine cracks covered by decoration (0.1mm to 1mm)</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
<td>Cracks easily filled (1mm to 5mm)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Cracks need opening up and repairing by mason (5mm to 15mm)</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Extensive repair (15mm to 25mm)</td>
</tr>
<tr>
<td>5</td>
<td>Very severe</td>
<td>Rebuilding required (&gt;25mm)</td>
</tr>
</tbody>
</table>

Table 2 | Settlement impact classification (developed for brickwork / blockwork / stone masonry buildings)
4 Noise and vibration from railways in tunnel

4.1 Impacts and improvements in practice

4.1.1 Noise and vibration may be perceptible for very short periods during construction, particularly as the tunnel boring machine passes a property. Once the railway is in operation, noise and vibration caused by trains may be perceptible to people living above and close to the tunnel, or may have an unacceptable impact in cases of highly sensitive non-residential land uses.

4.1.2 Any impact depends on several factors, including:

- the land use and its sensitivity to noise and vibration;
- the distance of the observer from the source; and
- the way in which the soil or the building itself transmits noise or vibration.

4.1.3 Impacts can occur because no matter how smooth a rail is, a steel wheel running along it produces some level of vibration. A proportion of this vibration will be transmitted through the track, the tunnel lining and then the surrounding ground – the ‘transmission path’ – where it can cause vibration in buildings (figure 5). Usually, the resulting vibration and noise levels are very low and may not even be noticeable. Where impacts could occur, modern low-vibration track systems are well proven as the principal means to avoid or reduce impacts.

4.1.4 Early rail tunnels often caused noise and vibration in buildings overhead and many of them still do. Since then, however, significant improvements have reduced the impact of noise and vibration. Many of these changes have been driven by the need to improve the running performance of the trains. The main improvements include:

- improved quality of the track;
- straighter rail alignments;
- smoother running surfaces on the rails;
- resilient rail support;
- fewer rail joints, which reduces the dynamic loads and consequently the wear and tear on the rolling stock; and
- better suspension on the trains, improving passenger comfort and reducing the impact forces on the track.
4.1.5 The most substantial improvements have been made over the past 30 years, as the development of proven low-vibration track systems has been combined with a requirement to provide such systems. For new projects, this requirement is created by the need to undertake an Environmental Impact Assessment (EIA) for a proposed scheme and, for HS2, the requirements imposed by decision makers when granting powers to construct and operate the new railway.

4.1.6 For high speed trains, the need for better performance ensures that the track is maintained to a very high level. The process of calculating the noise and vibration from rail tunnels is well understood and the effects can be accurately predicted. Where noise and vibration are considered to be an issue, proven mitigation measures are available. One method is to modify the track system that supports the rails. Such methods typically work by introducing ‘softer’ supports, such as resilient base plates or booted sleepers between the rails and the track bed (figure 6). This isolates the rail vibration from the structure of the tunnel, and hence the transmission path to the surface.

5 Requesting further information

5.1 Tunnelling in more detail

5.1.1 If you live or work near or above the line of the published HS2 tunnelled route, you may be interested in how tunnel construction and the operation of the railway may affect you. For Phase One, initial information is presented in the project’s draft Environmental Statement. Further, more detailed information will be provided in the Environmental Statement that will be included with the hybrid Bill deposited with Parliament before the end of 2013. Initial information for Phase Two is provided in the sustainability summary. An EIA will be undertaken for Phase Two if the Government decides to progress this phase of the project to the next stage.

5.1.2 If you would like further information on this subject, or would like to read the full report on tunnelling in the UK, please visit the HS2 Ltd website at www.hs2.org.uk; or contact our Public Enquiries team by email (enquiries@hs2.org.uk) or telephone (020 7944 4908; Mon-Fri, 9am-5pm).