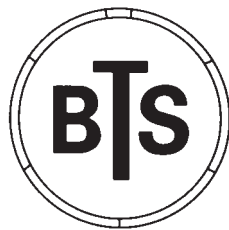

Closed-Face Tunnelling Machines and Ground Stability

A guideline for best practice

British Tunnelling Society
in association with the
Institution of Civil Engineers



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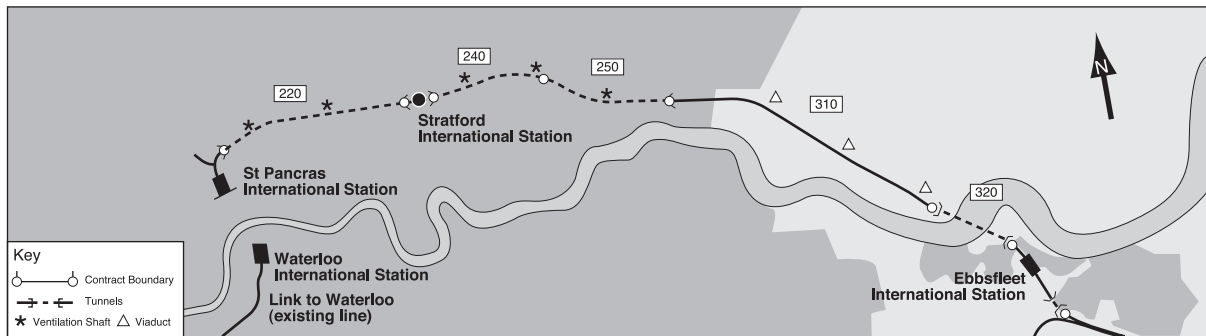
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Front cover illustration: Eight closed-face TBMs of the slurry and earth pressure balance (EPB) types were used between August 2002 and February 2004 to excavate a total 40 km (20 route km) of 8 m outer diameter twin running tunnels under the River Thames from Kent and beneath the suburbs of east London for the Channel Tunnel Rail Link project. The types of machines used were:

Kawasaki EPBM on Contract 220
Wirth EPBM on Contract 240
Lovat EPBM on Contract 250
Herrenknecht STM on Contract 320



Plan of the Channel Tunnel Rail Link Section 2 alignment

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Preface

This report is produced in response to a series of incidents of ground instability and collapse that have occurred on recent tunnelling projects in suburban and city centre environments on which closed-face tunnelling machines were used. In the UK these include events that occurred on the recently excavated tunnels for the Channel Tunnel Rail Link (CTRL) Project under the suburbs of east London and in particular to the event reported and referred to in the media and the technical trade press as the 'Lavender Street incident' that occurred in February 2003. It also relates to events that occurred on UK tunnel projects in Portsmouth in May 2000 and in Hull in November 1999, and draws on the experience of similar incidents of ground instability and collapse that have occurred on closed-face tunnelling machine projects in other countries during the past five years.

Compared to the many thousands of recorded kilometres of tunnels excavated in the world using closed-face tunnel boring machines since their introduction some 30 years ago, the incidence of ground instability and collapse is small. Nevertheless, events on tunnelling projects that come to the attention of the media and the general public are justifiable causes for concern. For the tunnelling industry, every incident is an event from which lessons are learned and guidelines for best practice are refined.

The purpose of this report is to examine the potential for ground instability or collapse when using closed-face tunnelling machines, to investigate the efficacy of various ground investigation techniques in urban areas, and to recommend management and operational guidelines to further minimise the risk when tunnelling beneath highly developed urban and city centre areas. This report does not aim to set out the details of particular incidents: there are official enquiry reports or media articles describing these events already in the public domain.

Tunnelling is a vital element in the full spectrum of civil engineering options available to city planners and developers of sustainable public infrastructure. The risks involved are also acknowledged by those engaged in the industry. The refining of best practice, together with rapidly advancing technological development, is a continuous process.

If anyone has any comments concerning the content of this report these can be directed to the Closed-Face Working Group of the British Tunnelling Society via the Secretary of the British Tunnelling Society (BTS) at the Institution of Civil Engineers, One Great George Street, London SW1P 3AA, UK or via the Society's e-mail at bts@ice.org.uk.

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5 Hazards associated with urban tunnelling

The most obvious generic hazard associated with all tunnelling works is the natural variability of the ground.

Such variations in ground types and behaviours can result in difficulties during construction. Similarly, the methodologies and plant associated with heavy civil engineering works inevitably have some construction process related hazards. Urban tunnelling is subject to these constraints just as is any other tunnelling operation. However, urban tunnelling differs in that it may also be affected by a series of other hazards that must be recognised and managed actively throughout the design and construction processes.

The most common specifically urban tunnelling hazards may be grouped broadly into those associated with the historical use of the land, those associated with physical constraints, and those associated with ground movement and environmental disturbance due to the tunnelling process.

5.1 Historical land use issues

Urban areas are generally characterised by a long history of development and change that inevitably involves extensive ground works including construction of basements, foundations and water extraction and supply systems in addition to extensive underground utility networks. Other human activities such as wartime bombing or the presence of burial grounds may pose particular problems. Many subsurface structures in urban areas extend to a depth below ground surface of up to 30 or 40 m, with bored wells, deep-piled building foundations and investigation borings extending deeper. Additionally many urban areas suffer from a degree of ground contamination as a remnant of past industrial land uses.

All of these features may present direct hazards to tunnelling via factors such as physical obstruction of the tunnel alignment, introduction of water at the tunnel horizon and modification of the natural soil properties because of earlier ground disturbance. At the very least, the possibility of such features means that finding anomalous conditions during tunnelling is more likely in an urban environment.

In addition to the direct physical problems created, the increased likelihood of encountering built features in urban areas also introduces uncertainty. Typically each successive generation of urban development obscures some or all of what was constructed on a site previously, and historic record-keeping is rarely completely adequate to identify all the features of significance to later planned tunnelling works. Nowadays clients will, where appropriate, incorporate time in the construction programme for an archaeological dig prior to the start of major excavation work. The result may be a need to carry a greater contingency allowance in the project budget than would be needed for similar works in a rural or undeveloped urban area.

5.2 Physical constraints on the works

The urban landscape commonly provides significant constraints on the location of surface works and therefore sometimes on the tunnel alignment itself. This may force a project into less than ideal working conditions regardless of the method of tunnelling employed.

Such problems may become apparent at the site investigation phase. A common hazard of urban schemes is the inability to gain access to

Figure 5.1 Surface installation of an STM slurry treatment plant



undertake investigations such as boreholes as close to the planned alignment as desired or at the preferred frequency. The result may be compromised data quality and greater uncertainty in the excavation phase.

During construction, hazards may include the need to use small and poorly accessible working shafts which may in turn compromise the ability to service efficiently the tunnelling process. Spoil handling in confined urban locations is also a potential problem and may influence the type of tunnelling machine used.

In most cases, STMs require a large site surface area to accommodate a surface slurry treatment plant. This can present a significant problem in urban areas. It is also a principle reason for selection of EPBMs in preference to STMs where both systems are equally applicable to the prevailing ground conditions.

5.3 Ground movements and environmental disturbance due to tunnelling

Aside from nuisance associated with surface works, the tunnelling process tends to give rise to two classes of potential environmental disturbance. These are tunnelling induced ground movements (typically settlements) and *reradiated* noise and vibration. Both represent particular hazards in an urban environment due to the proximity to existing buildings and infrastructure that may be disturbed. It is also important to prevent unintentional lowering of the groundwater table. This may cause undue settlement or deterioration or rotting of timber pile supports of older buildings in historical city centres.

Ground movement and its effects on existing overlying infrastructure is a major concern in developing an urban tunnelling scheme. Potential movements induced by closed-face tunnelling machines include both settlement and heave since both may be caused by normal operation. Certain types of infrastructure are also sensitive to the effects of horizontal ground movement. Examples of types of infrastructure that may pose a specific hazard include:

- structures on shallow foundations or piles
- bridges
- retaining structures
- existing tunnels (often railway tunnels with tight clearances and little tolerance of distortion)

- railway permanent way
- highway pavements
- river structures
- sewerage systems
- utility pipelines (especially cast iron pipelines in older cities)
- cable networks.

Furthermore in most cities the majority of these types of infrastructure are owned and operated by different parties thus presenting the tunnel promoter with potentially large and complex interface management tasks.

Ground-borne noise and vibration may also pose a problem. The levels reached during construction and operation of typical projects will rarely pose a threat of significant physical damage. Nevertheless, complaints of disturbance may have the potential to disrupt the execution of tunnelling works and should be considered as potential hazards.

5.4 Management of hazards associated with urban tunnelling

The challenge to the promoter of urban tunnelling projects is to develop suitable systems for identifying the risks and controlling them to an acceptable level. The process of risk management is addressed in more detail in Chapter 6 and a generic list of specific hazards that might form the starting point for a risk assessment is contained in Appendix A.

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