



CROSSRAIL INFORMATION PAPER

D23 – SPRAYED CONCRETE LINING

This paper sets out the proposals for the use of Sprayed Concrete Lining (SCL).

It will be of particular relevance to those in the vicinity of the proposed Crossrail tunnelled stations (such as Bond Street etc).

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:

Crossrail
FREEPOST
NAT6945
London
SW1H 0BR

Email: helpdesk@crossrail.co.uk
Telephone: 0845 602 3813

APPROVED

Version 3 – 20/11/07



D23 – SPRAYED CONCRETE LINING

1. Introduction

- 1.1 The design of the station tunnels and other underground passenger corridors and ventilation ducts at Bond Street, Tottenham Court Road, Farringdon, Liverpool Street and Whitechapel Stations, the Stepney Green junction tunnels, together with the lower portions of a number of the ventilation shafts is based on the use of Sprayed Concrete Linings (SCL) as the immediate and permanent ground support structure.
- 1.2 The long sections of tunnel between stations, the running tunnels, are designed to be constructed using Tunnel Boring Machines (TBMs) and use precast concrete or iron segments to form the structural lining and support to the tunnel. Information Paper D8, Tunnel Construction Methodology provides more information on the use of TBMs.

2. Description

- 2.1 The Sprayed Concrete Lining method is a safe and well established means of constructing underground structures using sprayed concrete to support the excavations as the work proceeds. As with all forms of construction there are associated risks that need to be managed and mitigated.
- 2.2 The approach outlined below is specifically designed to address the management requirements for the design and construction of the Crossrail SCL works.
- 2.3 The way in which SCL will be used on the Crossrail project builds upon the considerable experience of the use of the sprayed concrete as the means of forming tunnel linings and the following measures have been developed to specifically address and mitigate the risks to reduce these to As Low As Reasonably Practicable (ALARP). These include:
- The SCL design will, where applicable, comply with design codes and accommodate the full range of safety factors, load factors and material factors in accordance with the British reinforced concrete design code BS8110 or Eurocode equivalent.
 - The contract prequalification system, contract specifications and conditions, will ensure competent personnel design and construct the works.
 - Crossrail have prepared a design standards manual for tunneling, to ensure that SCL is designed and constructed to high standards across the project. This will cover issues including, how intermediate construction stages need to take into account, settlement mitigation measures and the impact of compensation grouting.
 - Crossrail have prepared a standard SCL implementation plan which details how the design and construction of SCL is to be managed. This will be adopted by all SCL designers and contractors.
 - Risk assessment and management will be central to the use of SCL on the project with monitoring and controls in place and contingency plans identified.
 - All SCL designs, both temporary and permanent linings, will have an independent check on the design.

- A working group has been established with the British Tunnelling Society to ensure that the tunneling industry is fully informed of the project's requirements and that appropriate and competent resources are identified.
- In addition to the tunnel contractor's monitoring arrangements an independent tunnel monitoring and settlement control room will be in place and operated throughout the tunneling activity. This will have displays of real time surface and subsurface ground movement monitoring, SCL and TBM tunnel progress data and TBM parameters. It will be manned by experienced engineers supported by the designer's representatives in the tunnel, plus supervisors from the nominated undertaker who are independent from the contractor, 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.
- The SCL designer will be required to provide 24/7 cover on site to ensure the construction of the works is in accordance with the design and that the assumptions made by the designer are appropriate for the actual conditions.
- Finally the Promoter has established a peer review panel, made up of appropriate industry experts, to review all safety critical tunneling works across the project, which include the SCL stations and crossover.

2.4 A key requirement is to apply the sprayed concrete lining as quickly as possible to minimize ground movements. The structural design of the sprayed concrete lining is undertaken with load factors applied in accordance with design codes to increase lining strength. This is then subjected to a check by an independent engineer.

2.5 Sprayed concrete lining has been used extensively on major underground works in London over a number of years. Notable examples include the Jubilee Line Extension (Waterloo and London Bridge stations), Heathrow Express (Terminal 4 station), the shafts and junctions for the Heathrow Baggage Transfer tunnel, shafts for London Electricity cable tunnels and on the Channel Tunnel Rail Link for the entire 3 km long North Downs tunnel and for the ventilation shaft connection in the London tunnels. These projects involved tunnelling through the range of ground conditions and urban environments expected on Crossrail. SCL is also proposed for the primary tunnel lining support for the construction of the passenger circulation tunnels for the redevelopment of Kings Cross Station for London Underground

2.6 All these projects benefited from the lessons learnt from the management failures that lead to the collapse of the tunnels at the Central Terminal Area of Heathrow airport on 21 October 1994. At Heathrow the method of construction employed sprayed concrete to support the tunnel excavations, but insufficient attention was paid to the management of the construction process. The causes of collapse are well understood following investigation by the Health & Safety Executive (HSE) and the Institution of Civil Engineers (ICE). The lessons learnt have been used, and management controls further developed, in the projects described in 2.5 above, all of which were carried out successfully.

2.7 For the construction of tunnel/shaft junctions and short lengths of tunnels, the SCL method has replaced most traditional hand excavation and segmental lining forms of construction. This is because the risk of Hand Arm Vibration (HAV) has made non-mechanized hand tunnelling very undesirable and therefore impractical in most circumstances. Owing to SCL's good record when correctly implemented, inherent safety features and recent technological developments, the use of SCL tunneling is increasing and is a proven method for constructing variable cross section tunnels such as station complexes in sensitive urban environments

3. Risk Management

3.1 In any major civil engineering project a review of available construction techniques is undertaken to determine the most appropriate design and construction solution, with the safety of the public, workers and adjacent property as the prime consideration. The nominated undertaker will be required to develop a rigorous risk management programme for the selected tunneling solution and to monitor the design and construction activities as the work progresses.

3.2 Drawing upon industry experience, published documents and lessons learned from other projects, SCL has been recommended by the engineering advisors to the Promoter, as the intended construction method for the locations listed in para.1.1 and adopted by the Promoter as the preferred solution.

3.3 the use of TBMs for station tunnel construction is not considered practical given the complex and varied geometry of the station tunnels and associated underground spaces and the difficulties of erection of TBMs within the work sites available.

4. Design and Construction

4.1 The SCL design is able to cater for all foreseeable ground conditions and temporary construction stages. A full engineering design and independent check will be carried out for all safety critical aspects of the tunnel design. This means that prior to construction, designs will be undertaken for all construction stages, expected ground conditions and the impact of adjacent excavations and settlement mitigation measures such as compensation grouting. Both the design and the check will be undertaken by companies with appropriate knowledge, skills and resources.

4.2 Monitoring of surface structures and subsurface ground movements is an integral part of the approach used to verify the predicted performance of the linings and ground movements during and after construction. Changes to the design and construction details would only be made, as with other forms of construction, on the basis of a full engineering assessment and design.

4.3 In SCL tunnels the excavation face can be sub-divided into small work areas and shorter advance lengths to take account of the behaviour of the ground and ensure its stability. These small sections are excavated in turn and stabilized with sprayed concrete. The excavation is then progressively enlarged to its full dimensions and the activity repeated to advance the tunnel. The sprayed concrete tunnel lining is completed to form a near circular concrete lined tunnel

that is able to support the ground and arrest ground movements thereby protecting the integrity of adjacent structures.

4.4 Sprayed concrete has been established as a safe and effective material for tunnel linings because:

- Sprayed concrete is a structural material which can be used to provide both temporary immediate ground support and a permanent tunnel lining.
- Sprayed concrete linings can be formed as and when required, and to a wide range of profiles. This enables the geometry of the tunnel and the timing of placement of the lining to be tailored to suit a wide range of ground conditions, thereby limiting ground movements. Sprayed concrete linings can be used for shafts, junctions, non-circular tunnels and tunnels with variable shapes.
- Sprayed concrete is soft when sprayed but rapidly increases in strength and stiffness, providing an increasing amount of support to the ground. The rate of gain of strength can be tailored to suit the ground conditions and the method of application.
- Overall SCL tunneling is safer and more effective than traditional methods for stations and tunnel junctions. For excavations with a variety of shapes the use of a free form structural concrete shell provides the most robust solution being placed directly against the excavated ground, following every contour and minimizing ground movement and the effects on adjacent structures.
- Modern SCL tunnelling lends itself to automation. This has health and safety benefits for the work force when compared with hand mining techniques which have risks of hand arm vibration

4.5 The Promoter will require the nominated undertaker to follow industry best practice in the use of SCL including design, procurement and construction and comply with the recommendations and guidance included within the following documents:

- The British Tunnelling Society / Association of Insurers' "Code of Practice for Risk Management of Tunnel Works in the UK";
- The Health and Safety Executive report "The Collapse of NATM tunnels at Heathrow Airport" (the SCL method was developed following the Heathrow collapse);
- The Institution of Civil Engineers guidance on "Sprayed Concrete Linings (NATAM) for tunnels in Soft Ground".

4.6 These requirements will involve independent checks of the design and construction methodology, monitoring and control of ground movements and the supervision of the construction of the works by suitably experienced representatives of the SCL designer and by the nominated undertaker's appointed engineer who will be independent of the contractor.

5. Conclusion

- 5.1 Modern SCL tunneling is safe and versatile and although, as with any form of construction, there are associated risks, these can be managed. Its flexibility of form permits tunnels and junctions of varying cross-sections and sizes to be built more efficiently and with a greater control over ground movements at least as good as other tunnelling methods.
- 5.2 The nominated undertaker will be required to develop a rigorous risk management programme for the selected tunnelling solution and to monitor the design and construction activities as the work progresses.