

Technical Specification

T0006

Deep Tube Tunnels Materials and Workmanship

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1 Purpose

- 1.1 The purpose of this Specification is to specify the materials and workmanship (M&W) to be used for deep tube tunnels and shafts on London Underground. The format of this M&W specification follows that of the British Tunnelling Society and Institution of Civil Engineers Specification for Tunnelling Third Edition 2010, highlighting only any differences, clarifications or omissions that are necessary when applying this specification to works on London Underground. The aim of this document is to avoid the need for bespoke specifications to be written for each project relating to London Underground deep tube tunnels and shafts and to assist in the development of generic products and methodologies that can be applied to provide a consistent approach to the construction and maintenance of these structures.
- 1.2 Throughout the remainder of this document the term “BTS Specification” shall be taken refer to the British Tunnelling Society and Institution of Civil Engineers Specification for Tunnelling Third Edition 2010.

2 Scope

- 2.1 This Specification applies to all work on London Underground that contains elements that will form part of, or interface with, the deep tube tunnel and shaft assets. The definition of which assets form part of the deep tube tunnel catalogue are provided in Section of London Underground Category 1 Standard S1055 Deep Tube Tunnels and Shafts and includes the following:
- a) Running tunnels
 - b) Cross passages between running tunnels
 - c) Step plate junctions
 - d) Crossover tunnels
 - e) Depot approach tunnels (e.g. London Road)
 - f) Overrun tunnels
 - g) Siding tunnels
 - h) Platform tunnels
 - j) Concourse tunnels
 - k) Station passageway tunnels
 - l) Tunnel headwalls
 - m) Tunnel ringwalls
 - n) Tunnel openings and junctions
 - o) Inclined shafts (e.g. escalator shafts)
 - p) Vertical shafts (e.g. ventilation, access, service, lift and substation shafts)
 - q) Cable shafts
 - r) Pump shafts
 - s) Disused tunnels
 - t) Disused shafts
 - u) Other tunnels and shafts constructed by mining methods

3 Specification

3.1 Preamble

- 3.1.1 Throughout this document reference is made to the BTS Specification and specific BTS Specification clause numbers are indicated in square brackets thus [BTS Clause

1]. Where clauses are added suggested numbering is provided following on from the BTS numbering. Where BTS Specification clauses are to be used without change then this is indicated by "No Changes" in this document.

- 3.1.2 Both this document and the BTS Specification contain references to the 'Client', 'Engineer' and 'Contractor'. It should be noted that in the context of this specification those terms shall be taken to have logical meaning in the broad senses of the words and shall be viewed as independent of the specific Conditions of Contract. Thus the term 'Client' shall be taken to mean Employer, Authority, Purchaser, etc; similarly 'Contractor' shall mean 'Contractor' in the traditional contractual sense if appropriate, or shall mean the relevant entity within other forms of contract such as alliancing and joint ventures, etc; and the term 'Engineer' shall also be construed in a generic sense to mean Contract Administrator, Engineer, etc. as appropriate to the contract.
- 3.1.3 All goods, materials, testing and other procedures not otherwise specified shall be in accordance with the latest edition of the appropriate London Underground Standards and M&W Specifications referenced in Section 6.

3.2 Requirements

[BTS Clause 1] General Requirements

101.13 (New Clause)

All new tunnel and shaft construction works shall be arranged and sequenced so as to be segregated to the greatest extent practicable from existing London Underground operational infrastructure.

101.14 (New Clause)

Notwithstanding any dimensional deviation clauses in any British Standard or other specification, where members are to be located or joined together by means of fixings or fittings positioned on or on members, the Contractor shall ensure that any dimensional deviations relating to the setting up of such or fixings or fittings are kept sufficiently small to allow satisfactory assembly of members.

101.15 (New Clause)

The Contractor shall develop and operate a Tunnel Management Plan for the works. The Tunnel Management Plan shall include:

- a) Organisation chart
- b) Roles and responsibilities:
 - i) Construction team
 - ii) Design team
 - iii) Designer supervision
 - iv) Tunnelling sub-contractors
- c) Competence
- d) Hazards and risk mitigation
- e) Contingency measures and emergency planning
- f) Readiness reviews
- g) Tunnelling Works - Management & Control
 - i) RESS process
 - ii) Settlement mitigation implementation
 - iii) Engineering Response
 - iv) Lessons Learnt Workshops
 - v) Survey / alignment
 - vi) Monitoring
 - vii) Shift patterns
- h) Methodology
 - i) Probing / face logging

- ii) Plant and equipment
- iii) Temporary works

[BTS Clause 102] Definitions

102.3 (New Clause)

Additional tunnelling definitions as encountered within the London Underground environment are given below:

Term	Definition
Admixtures	Materials which are added to the sprayed concrete such as accelerators, plasticisers and hydration control admixtures.
Dry method of sprayed concrete	A method in which the dry components of sprayed concrete are mixed with water and air at the nozzle immediately prior to application.
Emergency Preparedness Plan	A document outlining the plan with respect to impact on Third Party Assets resulting from ground movements etc. This will be owned by the Asset Owner.
Ground improvement	SCL tunnels driven through soils may deploy ground treatment measures to improve the properties of the ground in advance of tunnelling works
Grouting Exclusion Zone	A zone where compensation grouting shall not be carried out due to the proximity of tunnelling works, as defined in the works information and Specification section KC20.
Initial lining	Sprayed concrete applied as a thin layer protecting or priming the surface of the excavated face
Pass	The application of sprayed concrete to provide a given lining thickness is achieved in a continuous series of thinner passes, typically 50mm to 100mm thick.
Personnel Exclusion Zone	A zone where construction works are being carried out that shall be kept clear of all personnel for reasons of safety.
Pilot tunnel	For underground structures greater than approximately 9000mm span, the control of ground movements and improved face stability is provided by the construction of a pilot tunnel, followed by enlargement to the full profile.
Rebound	All material, typically aggregate and fibres, which does not adhere to the surface onto which sprayed concrete is being applied.
Regulating layer	A finer aggregate sprayed concrete layer used to regulate the substrate surface to receive a waterproofing system, or to provide an enhanced surface finish.
Safe Stop Procedure	A predetermined procedure for securing an excavation in the event that observed movements are exceeding a predetermined trigger value and the risk of damage or the actually level of damage to third party infrastructure is such that it is safer to stop the works than continue.
SCL Action Plan	A document that shall be prepared by the Contractor outlining the methods and procedures proposed in response to ground/tunnel movements (face instability and reaching/exceeding monitored deformation trigger limits) and encountering water. The document shall include procedures proposed in response to sudden events that must be dealt with urgently, such as fire, terrorism and discovery of unexploded ordnance. The programme of drills, including involvement of emergency services shall be included.
SFR Sprayed concrete	Sprayed concrete that includes structural fibre reinforcement.



Term	Definition
Sidewall drift	For wide span structures such as turnouts, the profile is sub-divided into smaller headings, referred to as single or double sidewall drifts, to control ground movements and promote face stability.
Sprayed concrete	Sprayed concrete is a mixture of cement, aggregate, admixtures, set accelerators and water projected at high velocity from a nozzle into place to produce a dense, homogeneous mass. Sprayed concrete shall be applied directly to the substrate in one or more layers to form the SCL structure.
Sprayed concrete layer	A discrete thickness of sprayed concrete, which is allowed to set and built up from a number of passes of the nozzle.
Temporary Measures	All ground treatment, ground water control, support and stabilisation (including the use of any of the “tool box items” indicated on the Works Information drawings) to uphold the excavated surfaces of all tunnels, shafts and other cavities.
Theoretical Excavation Line	Line that represents the minimum extents of the excavation in accordance with the design. The actual excavation may extend beyond this, but must not be within this line.
Trigger Limit	A predetermined value that can be measured from a stable Baseline, due to construction works such as a monitoring value used to assess the performance of a structure, corresponding to actions as identified in the SCL Action plan.
Wet method of sprayed concrete	A method in which a mixture of cement and aggregate is weigh-batched and mixed with water at a concrete batching equipment or in mixer trucks prior to being pumped through a pipeline to a nozzle where air and set accelerators, if necessary, are introduced to the mix which is projected without interruption into place.

[BTS Clause 103] References to Standards

No changes

[BTS Clause 104] Eurocodes and European and British Standards

No changes

[BTS Clause 105] Other standards and documents

No changes

[BTS Clause 106] General Provisions

No changes

[BTS Clause 107] Occupational health, safety and welfare

No changes

[BTS Clause 108] Quality Management and records

No changes

[BTS Clause 2] Materials**[BTS Clause 201] Standards**

No changes



[BTS Clause 202] Concrete

No changes

[BTS Clause 203] Reinforcement

No changes

[BTS Clause 204] Precast concrete linings

204.1.4 replace with:

Concrete shall be in accordance with Section 202, of minimum strength class C40/50.

204.1.5 replace with:

Reinforcement shall be in accordance with Section 203.

204.8 Substitute last sentence with:

The packing shall be in accordance with Section 215.

204.13.3 replace with:

Where grout holes will be used for segment handling then they should be designed accordingly. Calculations shall be carried out to demonstrate that they can withstand the applied forces including sufficient pull-out resistance.

204.13.4 (New Clause)

Where boltholes will be used for segment handling then they should be designed accordingly. Calculations shall be carried out to demonstrate that they can withstand the applied forces.

[BTS Clause 205] Spheroidal graphite cast iron (SGI) linings

205.3.4 replace with:

Corrosion protective coatings shall comply with System A2 as defined in LU Bridges and Structures M& W Specification clause 3.21.3.

[BTS Clause 206] Structural steelwork and steel linings

206.8.5 (New Clause)

Where boltholes will be used for segment handling then they should be designed accordingly. Calculations shall be carried out to demonstrate that they can withstand the applied forces.

[BTS Clause 207] Jacking pipes

No changes

[BTS Clause 208] Support arches and lattice girders

208.2 (b) – Delete Clause

[BTS Clause 209] Spiles and dowels

No changes

[BTS Clause 210] Sprayed concrete linings

No Changes

[BTS Clause 211] Sheet waterproof membranes

No changes

[BTS Clause 212] Spray applied waterproofing membrane

212.3.3 (New Clause)

To comply with the general requirements of COSHH Regulation 7(2) to avoid the use of materials hazardous to health in the workplace no part of any component of the system shall contain either substances classified as Category 1, 2 or 3 Carcinogens, Mutagens or Teratogens (substances toxic to reproduction) or substances classified as respiratory or skin sensitizers (potential occupational allergens) in accordance with Regulation 4 of the Chemicals (Hazard Information and Packaging for supply) (CHIP) Regulations 2009. Without prejudice to the above prohibitions, there exists a further requirement to use materials not classified as hazardous according to the CHIP Regulations so far as is reasonably practicable.

212.4.2 replace with:

The criteria for the acceptance of the applied waterproof membrane's performance shall be in accordance with the London Underground Standard S1055 clause 3.1.9.

[BTS Clause 213] Gaskets

213.1.4 (New Clause)

The use of hydrocarbon based gasket materials in particular (and any other materials in general) which fail to meet the requirements of the current version of LU Category 1 Standard 1-085 Fire Safety Performance of Materials, in respect of flammability, smoke emission and toxic fume emission in sub-surface railway (formerly referred to as "Section 12") areas (as defined in "The Fire Precautions (Sub-surface Railway Stations) (England) Regulations 2009"), shafts and tunnels (both bored tunnel and cut & cover tunnel forms), is not permitted unless a concession / fire waiver is obtained against the standard.

[BTS Clause 214] Cement for cavity grouting

214.2.5 replace with:

The Contractor shall propose details of the primary grout, including the required setting times and strength gain to prevent ring distortion and where necessary support the weight of the tunnel boring machine (TBM) and the backup. As a minimum the initial set of the grout shall be achieved within 45 minutes of injection at 20°C. The minimum strength requirement from the grout as measured from testing 100mm cubes shall be 1.5N/mm² in 24 hours. The proposals shall be submitted to the Engineer for agreement prior to commencement of the Works.

[BTS Clause 215] Packings

215.1.6 (New Clause)

The use of packing materials which fail to meet the requirements of the current version of LU Category 1 Standard 1-085 Fire Safety Performance of Materials, in respect of flammability, smoke emission and toxic fume emission in sub-surface railway (formerly referred to as "Section 12") areas (as defined in "The Fire Precautions (Sub-surface Railway Stations) (England) Regulations 2009"), shafts and tunnels (both bored tunnel and cut & cover tunnel forms), is not permitted unless a concession / fire waiver is obtained against the standard.

215.3.1 replace with:

Packings for jacking pipes are included in Section 207.

[BTS Clause 216] Grommets and bolts**216.1.2** replace with:

Grommets for cast iron, SGI or steel linings shall be either of low-density polyethylene or gel grommets

216.1.3 (New Clause)

The use of grommet materials which fail to meet the requirements of the current version of LU Category 1 Standard 1-085 Fire Safety Performance of Materials, in respect of flammability, smoke emission and toxic fume emission in sub-surface railway (formerly referred to as "Section 12") areas (as defined in "The Fire Precautions (Sub-surface Railway Stations) (England) Regulations 2009"), shafts and tunnels (both bored tunnel and cut & cover tunnel forms), is not permitted unless a concession / fire waiver is obtained against the standard.

[BTS Clause 217] Pointing and caulking material

No changes

[BTS Clause 218] Timber**218.1.8 (New Clause)**

The use of timber which fails to meet the requirements of the current version of LU Category 1 Standard 1-085 Fire Safety Performance of Materials, in respect of flammability, smoke emission and toxic fume emission in sub-surface railway (formerly referred to as "Section 12") areas (as defined in "The Fire Precautions (Sub-surface Railway Stations) (England) Regulations 2009"), shafts and tunnels (both bored tunnel and cut & cover tunnel forms), is not permitted unless a concession / fire waiver is obtained against the standard.

Clause 219 [NEW BTS CLAUSE] – Grout for compensation grouting**219.1 General**

219.1.1 Materials supplied in bulk shall be weigh batched, and the quantities per batch recorded. Water and other liquid admixtures used shall be measured to an accuracy of +2% of the target weight, and the records for each mix batch taken and maintained.

219.1.2 The final set product must be stable and must not deteriorate with time.

219.2 Fluid cementitious grouts

219.2.1 Fluid cementitious grouts are defined as those whose range of viscosity and shear resistance is best monitored for consistency by a flow trough, such as the Colcrete standard type.

219.2.2 Constituents of fluid cementitious grout shall be ordinary Portland cement to BS12 and clean potable water. Admixtures will be permitted to modify viscosity and shear strength and may include such materials as cellulose ethers, PFA or limestone dust.

219.2.3 Fluid cementitious grouts shall be prepared in a conventional stirred grout tank or high shear rate mixer, and stored until use in a tank with a continuous stirrer.

219.2.4 Flow trough tests shall be taken for each batch of fluid cementitious grout mixed and results recorded.

219.3 Cementitious mortar pastes

219.3.1 Cementitious mortar pastes are defined as those with shear strength range appropriate for monitoring by means of the concrete slump test defined in BS1881.

- 219.3.2 Cement mortar paste shall typically comprise ordinary Portland cement to BS EN 197-1:2011 with clean potable water, and combinations of PFA, GGBFS, sand bentonite and cellulose ethers. The design mix shall be set out in the Method Statement.
- 219.3.3 The mortar paste shall generally have a slump not exceeding 80mm.
- 219.3.4 Mortar pastes shall be mixed in a concrete mixer and transferred to a remixer for discharge to the pump.
- 219.3.5 Slump tests shall be taken for each batch of mortar mixed and the results recorded. All results shall be made available within 24 hours of the tests being completed. All such tests shall be carried out according to British Standard procedures, or if no such standard exists, according to the instructions of the specifier of the test method.

Clause 220 [NEW BTS CLAUSE] Maintenance - Grouting to control seepage in existing tunnels

220.1 General

- 220.1.1 Grouting must only be undertaken using materials on London Underground's Approved Product Register (www.lu-apr.co.uk). Where there is a case for using a material which is not on the Approved Product Register an application must be made to add the material to the register.
- 220.1.2 Grouting products must be approved prior to use.
- 220.1.3 All grout materials shall be used in accordance with manufacturer's guidelines and instructions.
- 220.1.4 All materials used for grouting must have a certificate of conformity.

220.2 Cementitious Grout

- 220.2.1 Cementitious grout shall consist of water and cement. The mixture and consistency shall be compatible with the contractors' equipment and the site conditions.

220.3 Mortar

- 220.3.1 Mortar shall be composed of cement and sand mixed in the proportions of 1:3 by volume. An addition of lime up to one quarter of the cement content will be permitted to improve the workability.
- 220.3.2 The quantity of water used shall not exceed that required to produce a mortar of sufficient workability to be placed where required.
- 220.3.3 The ingredients shall be mixed to produce a mortar of medium colour and consistency. Mortar shall be mixed in such quantities as can be used within one hour after mixing.
- 220.3.4 No mortar that has become hard or set shall be used or remixed for use in the Works.
- 220.3.5 No frozen materials or materials containing ice shall be used for making mortar.
- 220.3.6 Waterproofing mortar shall be the same as normal bricklaying mortar except that half the water shall be replaced by styrene butadiene rubber latex (SBR).

Clause 221 [NEW BTS CLAUSE] Hydraulic Oil

- 221.1 Only synthetic hydraulic fluids type HFDU (biodegradable, fire resistant, polyesters) shall be permitted within the TBM's hydraulic systems.
- 221.2 The Contractor shall obtain approval from the TBM manufacturer for all oils and grease and materials used on the TBM



- 221.3. The Contractor shall obtain approval from the Environmental Agency and acceptance from the Project manager for tail seal grease and materials in contact with the ground.

[BTS Clause 3] Methods

[BTS Clause 301] Excavation for tunnels

No changes

[BTS Clause 302] Drilling

No changes

[BTS Clause 303] Temporary works and ground support

No changes

[BTS Clause 304] Spiling and dowelling

No changes

[BTS Clause 305] Sprayed concrete

305.2.4 (New Clause)

The contractor shall submit an organisation chart and resumes of key personnel undertaking the ground works to the engineer for approval. The key personnel shall include: Underground Manager responsible for the works, Shift Engineers, Tunnel shift Foremen and Spray concrete nozzlemen.

305.3.4 (New Clause)

Full and complete records shall be kept available for inspection at the request of the Engineer of all constituent materials for the sprayed concrete.

305.4.20 replace with:

Where groundwater flow could interfere with the application of sprayed concrete or cause reduction in the quality of sprayed concrete the Contractor shall take all action necessary to control groundwater. Such action shall include the channelling of water by means of pipes and chases. On completion of spraying the pipes and chases shall be plugged to prevent further water ingress.

305.4.22 replace with:

All freshly sprayed concrete shall be adequately protected against the weather and other harmful effects. The temperature of the mix before placing shall not be below 5°C and shall not exceed 35°C unless special provisions are made. Spraying shall not be undertaken when ambient temperature is below 5°C unless special measures can be taken to provide protection against frost until the sprayed concrete has developed a compressive strength of at least 5 MPa.

305.4.24 replace with:

The Contractor shall verify the thickness of any sprayed concrete layer at any location requested by the Engineer. Any holes in the sprayed concrete should be backfilled with non-shrink mortar unless otherwise specified. The integrity of the waterproofing system shall be maintained at all times.

305.4.25 (New Clause)

Surfaces that are not to receive sprayed concrete shall be protected.

305.4.26 (New Clause)

Special care should be taken while spraying concrete around lattice reinforcement and embedded structural steel sections to ensure full and complete placement of concrete without voids caused by shadowing.

**305.10.1** replace with:

Tests to determine compressive strength shall be carried out on a routine basis as agreed with the Engineer on cores or other samples taken from sprayed concrete placed in the Works. The location of the cores shall be determined to give even distribution around the entire lining (i.e. samples from crown, axis and invert). The integrity of the waterproofing system shall be maintained at all times.

[BTS Clause 306] Ground support with arches

No changes

[BTS Clause 307] Forepoling

No changes

[BTS Clause 308] Explosives

No changes

[BTS Clause 309] Groundwater

No changes

[BTS Clause 310] Probing ahead

No changes

[BTS Clause 311] Break out from shafts and tunnels

No changes

[BTS Clause 312] Installation of sheeted waterproof membranes**312.4.9 (New Clause)**

Water bars encircling tunnels and shafts shall be welded to the sheet membrane to create isolated compartments not greater than 10m in length. At the interface between the superficial deposits and the London clay the barrier shall consist of at least three separate water bars.

[BTS Clause 313] Installation of spray-applied waterproof membranes**313.1.4** replace with:

Before application of the spray-applied waterproof membrane, the sprayed concrete surface shall be thoroughly cleaned to remove surface contamination, such as dust, oil, loose particles, etc.

313.1.5 – Delete Clause**313.1.6** replace with:

The substrate surface texture shall be adequately smooth to permit an even continuous spray membrane application. Where the surface texture roughness does not permit full coverage, or the consumption of spray-applied membrane is uneconomical, a regulating layer shall be applied to the sprayed concrete surface. The regulating layer shall consist of sprayed concrete and shall use an aggregate not exceeding 4mm. The regulating layer shall not encroach into the designed extrados of the secondary lining.

313.2.1 replace with:

During membrane application, the environmental conditions local to the spraying shall be in accordance with the membrane manufacturer's instructions. Substitute clause 313.5.1 with Areas of the spray-applied waterproof membrane which lack uniformity,

exhibit lamination or cracking, lack adequate bonding, lack watertightness, or fail to meet the specified strength and toughness requirements shall be regarded as defective. Where an area is deemed defective the section shall be resprayed with a minimum overlap of 200mm from the boundaries of the defect.

313.7 (New Clause) – Restriction of Groundwater Migration

313.7.1 (New Clause)

The provision of sufficient bond between the primary lining and the spray applied waterproofing membrane shall prevent the movement of groundwater between the primary lining and the waterproof membrane.

313.7.2 (New Clause)

The movement of water between the spray applied waterproofing membrane and the secondary lining shall be restricted to ensure leak sealing treatment can be effectively implemented. This shall be provided by:

- a) A bond, > 0.5MPa, between the spray applied membrane and the secondary lining concrete, tested in accordance with BS EN 1542:1999; or
- b) Systems to provide physical circumferential compartmentalisation of the lining, to prevent longitudinal migration of water.

[BTS Clause 314] Tunnel boring machines and shields

[BTS Clause 314.1] General

314.1.5 (New Clause)

This specification sets out the Minimum Requirements for the supply of Tunnel Boring Machines (TBM) for construction of the tunnels.

314.1.6 (New Clause)

The TBM diameter shall be sufficient to accommodate the Contractors segmental tunnel lining thickness to achieve internal diameter specified in the Employer's Works Information.

314.1.7 (New Clause)

The TBM shall be supplied new, be state-of-the-art and comply with all applicable Regulations, and relevant British and European Standards.

314.1.8 (New Clause)

The TBM shall be suitable for the ground conditions to be encountered and shall incorporate necessary soil conditioning.

314.1.9 (New Clause)

The Contractor shall be responsible for the design, specification, procurement, operation and performance of the TBM.

[BTS Clause 314.2] Machine Characteristics

314.2.5 replace with

Probing and ground treatment ahead of the face may be required. A sufficient number of sleeves fitted with shut off valves and stuffing boxes spaced around the periphery for angular ground treatment shall be provided. The arrangement direction and positioning of the sleeves shall allow for drilling the formation of a treated zone of sufficient diameter and dimensions at a suitable distance in front of the TBM cutter-head face to enable head intervention for inspection and maintenance. The design

shall ensure that the required drilling pattern can be accommodated through and beyond the arms of the cutter head.

314.2.9 replace with

The back-up system shall be fitted with Polyurethane or similar hydraulic adjustable steerable tyre bogies running tangentially on the tunnel lining or a rail system with mechanical handling facilities.

[BTS Clause 314.3] Guidance

314.3.4 (New Clause)

During forward movement of the shield or TBM, the guidance system shall provide "real-time" data for the TBM, with reference to the designed tunnel alignment at the machine head. The data listed below shall be presented in real time on displays in the TBM sub-surface Control Cabin, the TBM surface Control Room and in the Monitoring Control Area(s). The data shall be recorded in the Contractor's Monitoring Database.

- (a) Station (chainage).
- (b) Horizontal / line displacement.
- (c) Vertical / level / grade displacement.
- (d) Left or right lead / yaw at axis level.
- (e) Overhang or look-up / pitch at axis level.
- (f) Main axis rotation (roll).
- (g) This information shall be presented in numerical and graphical form, refreshed every 20 seconds or faster. The precision of each measurement shall be as stated in the table below.

Table of Precision of Position Measurements

Data	Accuracy
Station (chainage)	+/- 5mm.
Horizontal displacement	+/- 2mm.
Vertical displacement	+/- 2mm.
Left or right lead	+/- 0.1mm/m
Overhang or look-up	+/- 0.1mm/m
Main axis rotation (Roll)	+/- 0.1mm/m

314.3.5 (New Clause)

The tunnelling system shall be designed to maintain a clear space for the guidance system and laser beam and theodolite survey checks, irrespective of shield or TBM orientation.

314.3.6 (New Clause)

The system shall include the following functions:



- (a) The guidance system shall operate continuously with the position of the TBM cutter-head and tail skin ratified on an hourly basis by an independent non-manual method.
- (b) The guidance system shall alarm when the tunnel alignment is predicted to go out of tolerance.
- (c) An additional independent non-manual check should be initiated at the commencement of each shift.
- (d) TBM position relevant to surface topography and surface and subsurface infrastructure with real time movements indicated.
- (e) The guidance system shall be self-checking, with redundancy in essential components, and shall generate and record appropriate status messages for delivery when remotely or locally interrogated and to alert the TBM operator of fault conditions immediately they occur.
- (f) The guidance system shall have an uninterrupted power supply system to prevent data loss in the event of loss of primary power.
- (g) The guidance system, including cabling and connectors, shall be capable of sustained, safe operation within the onerous tunnel construction environment which includes dust, water, high humidity, large temperature ranges, varying quality of power supply and sustained vibration.
- (h) If guidance system stops working an interlock shall prevent the TBM advancing.
- (i) The Project Manager shall have access to the TBM Control Cabins, the TBM Control Room and the Monitoring Control Area(s).
- (j) The Contractor shall train the Project Manager's staff to use the system.
- (k) Facilities to download the data for electronic transmission and for obtaining hard copy paper printouts, independently of the current display, shall be provided.
- (l) The format of the electronic and hard copies shall be to the acceptance of the Project Manager.
- (m) The Contractor shall provide hard copies to the Project Manager.
- (n) Data shall be recorded in a medium unaffected by primary power loss in a store of sufficient capacity to hold the entire tunnels production records.
- (o) The Contractor shall provide a TBM guidance system that computes the correction curve required to return the TBM tangentially to the designed tunnel alignment throughout the forward movement of the TBM.
- (p) The guidance system shall compute and display the necessary corrections to attitude to be applied during the course of forward movement.
- (q) The correction curve re-alignment shall be designed by the Contractor and submitted to the Project Manager for acceptance.
- (r) The guidance system shall facilitate construction of the tunnel lining so that it follows, and does not bind into, the TBM tail-skin.
- (s) The system shall provide data defining the plane of the circumferential joint of the leading edge of the tunnel lining with respect to the Designed Tunnel Alignment (DTA) and actual TBM axis.

- (t) The guidance system shall predict the horizontal and vertical displacement of the TBM at intervals of 5, 10, 15 and 20m in front of the TBM to assist in understanding steering requirements.

[BTS Clause 314.4] Fire Protection

314.4.1 replace with

The Contractor and the TBM manufacturer shall jointly undertake a fire hazard assessment to identify and mitigate all potential fire sources. The assessment shall be included in the TBM Design Statement submitted to the Project Manager.

314.4.2 replace with

Subject to the conclusions of the hazard assessment, the TBM and back-up systems shall be provided with:

- (a) The fire suppression system which shall be suitable to mitigate the risks identified in the hazard assessment.
- (b) Emergency plunger buttons at suitable locations to activate a fire alarm.
- (c) Electrical cabinets and enclosures shall be fitted with fire suppression systems.
- (d) The TBM shall be equipped with manual fire suppression systems in areas identified to have a high fire risk.
- (e) Hand held extinguishers provided with colour coded covers in suitable locations.
- (f) A means of rapidly shutting off fresh air ventilation to the tunnel face, after the area has been evacuated.
- (g) Operation and training manuals for use by the Contractor.
- (h) Conveyor belting, rubber covered rollers and other similar parts to be manufactured in materials that reduce the fire risk, fire load, spread of flame and toxic fume risk.
- (i) Hydraulic hoses shall comply with BS EN 853 / ISO 1436. The hose covers shall be flame retardant and conform to the requirements of USMSHA. All hydraulic hoses shall be fitted with swaged end connections, re-usable fittings are not permitted.
- (j) Gas monitoring for oxygen deficiency and gasses including CO₂, CO, H₂S, NO, NO₂, SO₂ and CH₄.
- (k) Smoke detection and rate of temperature rise.
- (l) Low density foam generators shall be sited at high fire risk areas with either automatic or manual operation in the event of fire.
- (m) Spraying nozzles to be installed at the rear of the back-up system to create a water mist screen in case of fire in the tunnel.
- (n) Essential services shall be protected in the event of a fire so that they remain operable during all tunnelling operations for a period of 1 hour. The essential services are:
 - i. Emergency power supplies.
 - ii. All fire suppression systems



- iii. TBM emergency lighting.
- iv. Environmental monitoring systems
- v. All controls and tunnel communications.
- vi. The security of the air supply and control systems to the man lock shall remain operable in all emergencies including a fire.

[BTS Clause 314.5] Contractor's Submission

314.5.1 (New Clause)

The Contractor shall as soon as possible agree with the Engineer a programme for the design, provision, inspection, testing, transport, erection and commissioning of each TBM or shield.

314.5.2 (New clause)

A hazard and risk assessment shall be developed as part of the TBM design and submitted to the Project Manager addressing all risks related to the TBM operation and maintenance. As a minimum, the following elements of the TBMs shall be addressed:

- (a) A designed access walkway which is straight and level throughout the TBM and back up and lines up directly with the line and level of installed tunnel walkway. This walkway shall be extendable to the face of the machine, be bridgeable across the building area, kept clear of plant installation, designed to sufficient width and height to present no obstruction in an emergency evacuation and provide clear access for a stretcher to remove a casualty from the air lock and anywhere on the TBM backup to the shaft bottom.
- (b) The TBM electrical system including electrical shock and fire, electrical equipment fault and damage, loss of power supplies, fire suppression systems. Earth leakage protection shall be provided to a continuous earth cable separately installed as the machine advances.
- (c) The TBM Back-up system including leakage of high pressure fluids, risk of leakage in close proximity to heat and electrical sources, occurrence of naked flame and danger from moving machinery. All cables shall be laid clearly separate to hydraulic hoses within the TBM and its backup equipment.
- (d) Segment transport and erection including moving of tunnel lining segments through the TBM back-up to the segment erector, on the segment erector, the dangers to personnel arising from the segment erector and access for bolting segments.
- (e) The minimisation of ramps and changes of rail direction within the confines of the TBM backup equipment.
- (f) The provision of a traffic light system within the TBM equipment to ensure control of the trains through the TBM equipment by a designated banksman with a clear view of the track in front of the rolling stock. That light should fail to red should the operator drop the controller and green should indicate enter with amber indicating exit.
- (g) A powered Manchester Gate shall be provided to block all entry by rolling stock into the TBM backup and all rolling stock shall be stopped at the rear of the backup before the gate is powered open to enable rolling stock entry.



- (h) Spring shut Gates shall be provided at entry points from the walkway which shall have meshed guard and handrails to limit access to dedicated gates into the rolling stock area within the TBM Backup. These shall be clearly signed and are provided to stop entry of personnel into the area when the rolling stock is present or moving.
- (i) Start and operation of cutter head in maintenance mode and in normal operation.
- (j) Operation and maintenance of the TBM and back-up including surveying and provision of safe working platforms and access ways
- (k) Man entry into the mixing and bubble chambers and safe working methods for maintenance of the cutter head including its ventilation during free air entry.
- (l) The demarcation of personnel from tunnel trains and rolling stock servicing the tunnel advance.
- (m) For SPB machines the slurry system including all slurry pipe mechanical handling systems and all the pumps for operation and maintenance.
- (n) Compressed air system and working.
- (o) The grouting system.
- (p) The testing for gases, Oxygen levels, CO₂, Methane, CO, NO, NO₂, H₂S. The presence of Methane in any level should isolate the equipment immediately whilst maintaining ventilation and emergency lighting. All other abnormalities should alarm only with a clear indication on the TBM console that the anomaly exists. All gas anomalies should be recorded and should also alarm at the surface to alert management of the situation.
- (q) TBM Assembly, repair, servicing and maintenance and dismantling.
- (r) Lifting systems including all necessary anchor points shall be provided for all equipment that may need replacement or addition during the tunnel drives such as rail which cannot be safely manually handled
- (s) The operation of the TBM in normal, maintenance, degraded, accident and emergency modes.

314.5.3 (New Clause)

The Contractor shall submit a TBM Design Statement, for the acceptance of the Project Manager, prior to commencing the TBM design calculations. The TBM Design Statement shall include:

- (a) All design assumptions, loading conditions, elements of the TBM and back up to be covered in the calculations, the method(s) of analysis. The TBM Design Statement shall be accompanied by the Contractor's TBM specification.
- (b) The Contractor shall confirm the lead time for the supply of a replacement main bearing in the TBM Design Statement.
- (c) Details of where the Main bearing sealing system has previously been used, the tunnel drive lengths and the pressures encountered shall be submitted to the Project Manager for acceptance prior to manufacture and included in the TBM Design Statement.

314.5.4 (New Clause)

The Contractor shall prepare a Method Statement to demonstrate how the main bearing can be removed and replaced underground in the event of a main bearing failure during tunnelling operations together with a programme outlining the duration of each phase of the operation including the procurement and delivery of spare parts and submit this to the Project Manager for acceptance. The Contractor shall confirm the lead time for the supply of a replacement main bearing in the TBM Design Statement.

314.5.5 (New Clause)

The Contractor shall provide a method statement and associated risk assessment clearly showing the method of TBM dismantling including temporary works. The method statements shall demonstrate how the surrounding ground and the TBM components are supported at all stages and how damage to the permanent works is prevented.

314.5.6 (New Clause)

The Contractor shall prepare a method statement to demonstrate that the launch method is safe and efficient and submit to the Project Manager for acceptance before commencing TBM manufacture.

314.5.7 (New Clause)

The Contractor shall submit a method statement to the Project Manager demonstrating how cutter head interventions will be managed utilising the compressed air system if required. Particular attention should be paid to relevant Regulations and Health and Safety Executive Guidance. The Contractor shall ensure there is a sufficient air supply and reservoir to deal with a sudden loss of air into the ground during an intervention. The final entry door into the plenum/mixing chamber shall be fitted with a latch to keep it open during interventions and there shall be special consideration to safe man access within the chamber and to the ventilation of the chamber if free air entry is utilised.

314.5.8 (New Clause)

The Contractor shall undertake a hazard risk assessment and provide a refuge chamber sufficient to accommodate the number of persons identified to be at risk of fire or smoke hazards in the tunnel including the entire TBM crew, loco drivers, surveyors, fitters, electricians and six other persons. The chamber shall comply with the requirements of BS6164, the ITA guidelines for provision of refuge chambers in tunnels under construction and other relevant standards.

[BTS Clause 314.6] Inspection and testing

314.6.5 (New Clause)

Within four weeks of contract award the Contractor shall submit a preliminary TBM Quality Plan to the Project Manager for acceptance. This preliminary plan shall indicate the approach and structure of the detailed plan for the design and supply of the TBM and include:

- (a) All quality assurance and quality control procedures which are to be used for the design, manufacture, commissioning and maintenance of the TBM including design checks, inspection and test plans, and details of steel plate identification and testing, all weld testing and welding procedures.
- (b) A list of all the Codes of Practice, Standards and Specifications that the Contractor proposes and highlight any departures from this specification or the Employer's Works Information.
- (c) Quality assurance audit proposals.

- (d) A statement detailing the records that the Contractor proposes to keep and those that the Contractor proposes to supply, the time during which they will be prepared and the subsequent period and manner in which they will be stored.
- (e) Inspection and test plans for every activity requiring inspection including the level of inspection required and the person responsible for releasing an activity "Hold Point".

314.6.6 (New Clause)

Within 12 weeks from contract award the Contractor shall provide the detailed TBM Quality Plan to the Project Manager for acceptance.

314.6.7 (New Clause)

The Contractor shall update and maintain the detailed Quality Plan to incorporate all changes to the TBM related procedures.

314.8 (New Clause) Health and Safety

314.8.1 (New Clause)

The design and operation of the TBM shall comply with BS6164 2011 except where more onerous requirements are provided in this specification.

314.8.2 (New Clause)

The Contractor shall design and manufacture the TBMs in such a way to minimise the risks to the health, safety and welfare of personnel who manufacture, install and commission, operate, maintain and decommission the TBM, in accordance with the Construction (Design and Management) Regulations 2007 and all other applicable UK legislation relating to health and safety.

314.8.3 (New Clause)

A hazard and risk assessment shall be developed as part of the TBM design and submitted to the Project Manager addressing all risks related to the TBM operation and maintenance. As a minimum, the elements listed in cl.314.5.2 shall be considered.

314.9 (New Clause) Design

314.9.1 The TBM shall be designed in accordance with the requirements described below:

- (a) The TBM structural elements and back-up including, as a minimum, the cutter-head, main bearing, TBM shield body, screw conveyor, segment erection system, primary conveyor, back-up gantries, back-up sledges and chassis and rail crossings support systems shall be designed using Finite Element Methods (FEM) or other structural analysis software and verified by hand calculations.
- (b) The TBM design calculations shall consider loading conditions applicable during TBM launch, operation, retrieval and dismantling.
- (c) The design of each structural elements including the back up and rail systems shall be subject to an independent (Category 3) design check.
- (d) The TBM design calculations and Category 3 checks shall be undertaken by competent personnel who have previous experience of designing TBMs and associated elements thereof. The CVs of the proposed design engineers and the proposed Category 3 checking organisation shall be included in the TBM Design Statement submitted to the Project Manager for acceptance prior to the commencement of the TBM design.
- (e) The Contractor shall submit a Design Report with his calculations together with input and output of the calculations and fully annotated graphical output and the Design and Category 3 check certificates to the Project Manager for acceptance.