

Category 1 Standard

S1055 Civil Engineering – Deep Tube Tunnels and Shafts



**Please read the Written Notices
attached to this standard**

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1 Purpose

- 1.1** The purpose of this Standard is to define the whole life cycle requirements for Deep Tube Tunnel and Shaft assets. These assets are collectively defined as “Deep Tube Tunnels” in the Deep Tube Tunnels Foundation Document which is contained in LU Standard S1042 (Asset Condition Reporting). Throughout this document the term “Deep Tube Tunnels” shall be taken to refer to all of the Deep Tube Tunnel asset types listed in the Deep Tube Tunnels Foundation Document (including Shaft assets).

Note: The Deep Tube Tunnel asset types are numbered and defined in the Foundation Document as follows:

- 101 Platform or Concourse Tunnels
- 102 Station Passageway Tunnels
- 103 Running Tunnels
- 104 Cross Passages Between Running Tunnels
- 105 Step Plate Junctions
- 106 Crossover Tunnels
- 107 Depot Approach Tunnels (e.g. London Road)
- 108 Overrun Tunnels
- 109 Siding Tunnels
- 110 Inclined Shafts (eg escalator shafts)
- 111 Vertical Shafts (eg ventilation, access, service, lift and substation shafts)
- 112 Disused Tunnels
- 113 Disused Shafts
- 114 Other Tunnels
- 115 Miscellaneous Structures (e.g. TTMS)

Category 115, Miscellaneous Structures was an interim classification introduced prior to complete cataloguing of the Deep Tube Tunnel assets. The category should not be required for future asset classification purposes.

Independent Structural components within a Deep Tube Tunnel e.g. escalator support steelwork, ladders, shaft landings, gratings etc. are included in LU Standard S1053 (Civil Engineering – Building and Station Structures)

Subsurface tunnels (i.e. cut and cover tunnels) and associated shafts constructed by surface methods (e.g. sheet piles or diaphragm walls) are included in LU Standard S1051 (Civil Engineering – Bridge Structures)

- 1.2** Tunnel Portal structures shall be designed as Earth Retaining Structures in accordance with LU Standard S1051 (Civil Engineering – Bridge Structures)
- 1.3** In defining requirements specifically applicable to Deep Tube Tunnel assets, this Standard complements LU Standard S1050 (Civil Engineering - Common Requirements) that defines mandatory requirements generally applicable to all Civil Engineering assets including the Deep Tube Tunnel assets.
- 1.4** Notes for guidance applicable to specific clauses are contained in grey boxes in this document. Supplementary guidance on Deep Tube Tunnels is contained in the Manuals of Good Practice given in clause 5.1.3 of this standard.

2 Scope

2.1 This Standard applies to Deep Tube Tunnel assets owned by, or being constructed for, LU.

2.2 This Standard defines the requirements for Deep Tube Tunnel assets through the following lifecycle stages:

- a) Inception and design;
- b) Construction, installation, testing and commissioning;
- c) Inspection;
- d) Analytical assessment;
- e) Condition assessment and certification;
- f) Maintenance;
- g) Modification;
- h) Strengthening and Renewal; and
- i) Decommissioning.

3 Requirements

3.1 Inception and design

3.1.1 General

3.1.1.1 The inception and design of new works including works of Strengthening and Renewal shall ensure that the Deep Tube Tunnel assets will satisfy their Required Duty.

Note:	The Required Duty for Deep Tube Tunnels is given in the current Foundation Documents as follows:
1	Meet railway operating requirements (within the performance specification at system installation or at the most recent system upgrade).
1.1	Maintain inherent structural integrity (support itself so as not to suffer complete or partial collapse).
1.2	Support static and dynamic design loads within acceptable stress limits.
1.3	Maintain the planned design envelope and adequate clearance to permit the safe passage of rail vehicles.
1.4	Provide appropriate access and egress for all planned uses (including Maintenance), and for reasonably anticipated emergency uses.
1.5	Sustain a Condition and state so as not to cause unplanned interruption to, or restriction of, any aspect of the operating railway; this includes externally sourced wear or damage which is greater than that currently accepted for the asset.
1.6	Sustain a Condition and state so as to maintain all interfacing non-railway services and facilities at full design capability.
2	Ensure support at asset interfaces without undue wear and tear.
2.1	Minimise the degradation of all interfacing assets (e.g. as evidenced through Maintenance cycles). This includes interfaces with the railway and adjacent infrastructure (e.g. track, structures and stations), and dynamic and static assets (e.g. not contributing to degradation of the signalling equipment).

- 2.2 Minimise the degradation of all interfacing assets which support non-railway services or facilities (e.g. as evidenced through Maintenance cycles). This includes interfaces with dynamic & static assets (e.g. roads, Outside Party buildings, etc).
- 3 **Match the LU policy in respect of realistic user perceptions.**
Ensure the asset does not cause undue degradation of interfacing assets, disruption to railway operations or unacceptable environmental nuisance, and that the asset provides acceptable appearance and general ambience. This includes visual evidence of seepage even where this is not a structural problem.
- 4 **Provide resistance against external interference and events.**
Asset minimises the likelihood and consequence of asset abuse. Asset abuse encompasses, vandalism, planned/unplanned work, damage due to external event (e.g. piling), etc. This applies primarily to new or refurbished assets.
- 5 **Present acceptable environmental impact.**
 - 5.1 Present an acceptable societal environmental impact (noise, vibrations, odours, ground borne contaminants, etc).
 - 5.2 Provide for ease of cleaning and support environmentally acceptable routes for disposal of cleaning residues.
 - 5.3 Support (intrinsically and at asset interfaces) appropriate temperature mechanisms to control temperatures within the range considered societally acceptable by LU policy.
- 6 **Minimise environmental impact throughout lifecycle.**
Minimise environmental impact and demands at all stages in the lifecycle; this includes effects now and into the future, including successive refurbishment, final decommissioning, and disposal routes.
- 7 **Function within the legal and standards framework.**
Ensure the asset functions within the framework defined by legislation (including environmental); regulatory guidance; LU, Infracore and applicable national and international standards; and LU and Infracore policies.
- 8 **Ensure safe operation as defined by LU.**
 - 8.1 Ensure safe operation and Condition as specified by LU requirements; this includes passengers, employees and members of the general public.
 - 8.2 Ensure safe ingress/egress by passengers, general public, employees, and emergency services in planned & reasonably anticipated emergency scenarios. This includes the means of transfer from the asset to the principal interfacing assets and transfer mediums (e.g. walking over trackbed or interaction with tunnel during evacuation).
 - 8.3 Safeguard the health and safety of passengers, employees and members of the general public.
- 9 **Provide above within reliability and availability targets.**
Provide all aspects of the Required Duty within the defined LU requirements.
- 10 **Ensure Required Duty is performed without incurring excessive or prohibitive costs to LU.**

Note: The designer should be aware of the best practice guidance on tunnelling published by the British Tunnelling Society and others referenced in Section 6.1

3.1.2 Inception

3.1.2.1 All proposals for new works, including Strengthening and Renewal, made by suppliers to LU shall be initiated and controlled in accordance with LU Standards S1538 (Assurance) and S1050 (Civil Engineering – Common Requirements).

3.1.2.2 The Technical Specification for Deep Tube Tunnels Materials and Workmanship shall be T0006. If a project requires modification to the Technical Specification the modification shall be approved by The Deep Tube Tunnels Engineer (LU).

Note: 'The Deep Tube Tunnels Engineer (LU)' refers throughout the clauses of this Standard to the owner of this Standard and anyone accredited to act on his behalf.

3.1.3 Geotechnical Baseline Report

3.1.3.1 A Geotechnical Baseline Report (GBR) shall be issued to tenderers bidding for contracts relating to the construction of tunnels, caverns, shafts and associated underground structures including the renovation or upgrade of existing underground structures (Tunnel Works) in accordance with the requirements of The Joint Code of Practice for Risk Management of Tunnel Works in the UK. The primary purpose of the GBR is to establish a single source document where contractual statements describe the geology and geotechnical conditions anticipated (or to be assumed) to be encountered by the Contractor during Tunnel Works. The contractual statement(s) are referred to as baseline statements.

Note: Additional guidance can be found in Attachment 2 to this Standard.
For further information on geotechnical baselines the reader is referred to the Underground Technology Research Council's (UTRC) guideline document titled Geotechnical Baseline Reports for Underground Construction (UTRC, 1997) and the updated version of this document (UTRC, 2007)

3.1.3.2 The GBR issued to the tenderers for Tunnel Works shall be approved by The Deep Tube Tunnels Engineer (LU). In the event of modifications prior to award of the contract, the modified version shall be approved by The Deep Tube Tunnels Engineer (LU).

Note: The intention of clause 3.1.3.2 is to ensure that the technical implications of the risk distribution implied by the GBR are recognised.

3.1.3.3 The designer shall not base the design of Tunnel Works on the GBR.

3.1.4 Design process

3.1.4.1 The design shall proceed in a staged manner in accordance with LU Standard S1538 (Assurance).

3.1.4.2 Conceptual Design Statements (CDS) shall be completed for all Deep Tube Tunnel permanent and Temporary Works in accordance with LU Standard S1538 (Assurance) and shall include as a minimum the information listed in Attachment 1 of this Standard.

3.1.5 Design compliance documents

3.1.5.1 A design compliance submission shall be prepared in accordance with LU Standard S1050 (Civil Engineering - Common Requirements). Approval shall be obtained from The Deep Tube Tunnel Engineer (LU) before the start of construction.

3.1.5.2 A Design Check shall be undertaken in accordance with LU Standard S1538. A written brief shall be provided to the Design Checker, which shall be included with the compliance submission.

- 3.1.5.3** Where temporary or permanent works support the ground a Category 3 Design Check shall be provided, as described in S1538 (Assurance).

Note: Works involving excavation are deemed high risk as per category 3 part a) from clause 3.16 of LU Standard S1538 (Assurance).
Further requirements for design documents and checking are given in LU Standard S1538 (Assurance).

- 3.1.5.4** Scope of the Category 3 Design Check:

- a) the Design Checker shall be provided with the design drawings and CDS as a minimum; **but shall not** be provided with the design reports and calculations. The Design Checker's analytical work shall be independent of the Designer and carried out without exchange of calculations or similar information.
- b) the scope of the Category 3 Design Check shall be defined in the written brief. The check shall confirm that the concept and detail of the design meet the intent described in the CDS.

3.1.6 Design life

- 3.1.6.1** The Design Life for Deep Tube Tunnel assets shall be a nominal 120 years.

- 3.1.6.2** Deep Tube Tunnels assets shall be designed, where practicable, to minimise the requirement for maintenance interventions other than visual inspections. To support this requirement the designer shall provide a statement of potential degradation modes identified during design and a schedule of the expected interventions during the design life.

Note: To prepare the schedules required under clause 3.1.6.2 the designer will need to consider all components including structural elements, gaskets and sealing materials and also the ability of all materials to resist degradation by soil, ground water and the environment through the Design Life.

- 3.1.6.3** All metal structures and steel reinforcement in concrete prone to corrosion shall be earthed in accordance with LU Standard 1-106 (Earthing and Bonding).

3.1.7 Structural design

- 3.1.7.1** All Deep Tube Tunnel assets shall have a structural lining.

- 3.1.7.2** Structural design for Deep Tube Tunnel linings shall be in accordance with the principles set out in BS EN 1990:2002 + A1:2005 (Eurocode – Basis of Structural Design).

Note: Eurocodes do not explicitly cover the design of tunnels. The designer may apply rules derived from appropriate Eurocodes but particular care must be taken to ensure that the application is appropriate to the context. This includes identification of appropriate limit states and selection of appropriate partial factors.

For the design of segmental concrete linings, the designer may wish to consider the use of PAS 8810 (Design of concrete segmental tunnel linings – code of practice).

- 3.1.7.3** No part of the lining or support shall encroach within the Structure Profile under any conditions of loading or deflection.

- 3.1.7.4** Structural analysis methods shall be justified and sensitivity analyses shall be undertaken.

- 3.1.7.5** The designer shall validate computer programs used for structural analysis.

3.1.7.6 Openings in tunnels may be designed as arches or beams. Both shall be considered and the most efficient adopted unless there are clear benefits to LU to do otherwise.

3.1.7.7 In structures formed using steel members encased in concrete consideration shall be given to the load carrying capacity of the concrete.

Note: Lifting and manoeuvring of large steel members may pose significant hazards in below ground works. Where such members are proposed it must be demonstrated that they are the optimum solution when construction issues are considered. The designer should also consider the use of bar reinforcement and steel fibres to reduce the need to lift large elements.

3.1.7.8 In new build segmental tunnels openings shall be designed to use an opening set with provision for the safe removal of temporary infill panels. The formation of openings into new build segmental tunnels by methods such as stitch drilling, cutting or breaking is not acceptable.

3.1.7.9 Where new openings are to be formed in existing tunnels the opening may be formed either from inside the tunnel by sequential replacement of the existing lining or from outside the lining by the use of a “bolt on the back” opening set. In the design of an opening into an existing tunnel consideration shall be given to the capacity of the existing lining to carry part, or all, of the load.

Note: In some situations it may be possible to enhance the capacity of the existing structure at an opening through measures such as the introduction of additional bolts or dowels.

3.1.7.10 Headwalls may be designed as either arches or beams. Both shall be considered and the most efficient adopted unless there are clear benefits to LU to do otherwise.

3.1.7.11 The assessment and impact of ground movement due to excavation is deemed to be part of the structural design of the works.

3.1.8 Loading

3.1.8.1 The designer shall establish the appropriate limit states and verify that none of these limit states is exceeded.

Notes: The Tables 1 and 2 present values of partial factors which have been found appropriate for the majority of London Underground tunnel design scenarios. The design loads QA, are determined from the nominal loads QK according to the equation $QA = \gamma_{fl} \cdot QK$ where γ_{fl} is the minimum partial factor for each type of loading as given in Table 1.

Nominal dead and superimposed Dead Loads shall be combined with the Live Loads using the minimum partial factors in Table 1. The calculated resistance, RA^* , determined from material strengths and measured section properties, shall be calculated from the following expression:

$$RA^* = \text{function}(f_k / \gamma_m)$$

where f_k is the characteristic strength of the lining materials and γ_m is the partial factor of safety on material strength. Minimum values of γ_m shall be as stated in Table 2.

Load		Ultimate (ULS)	Serviceability (SLS)
Dead	Construction materials	1.35	1.0
Super-imposed dead	Soil, overburden	1.35	1.0
	hydrostatic Pressure (beneficial effect)	1.0	1.0
	hydrostatic Pressure (adverse effect)	1.1	1.0
Grouting pressure (arising from adjacent works)		1.2	1.0

Horizontal earth pressure	horizontal pressure (adverse effect)	1.1	1.0
	horizontal pressure (beneficial effect)	1.4	1.0
Imposed loads		1.5	1.0
Table 1 - Partial factors for load			

Load	Ultimate (ULS)	Serviceability (SLS)
Concrete	1.5	1.0
Reinforcement	1.15	1.0
SGI	1.15	1.0
Bolts	1.15	1.0
Table 2 - Partial factors for materials		

3.1.8.2 The structure shall be designed to carry and transfer design loads and load effects for the Design Life.

Note:	Load combinations to be considered depend on structural form and construction sequence and may include the following:
a)	Superimposed loads based on traffic loading, loads due to existing buildings and foundations over and adjacent to the tunnel and any specified future loads;
b)	Short and long term soil and hydrostatic loads;
c)	The structural requirements for resisting buckling;
d)	Loads produced by long and short term ground yield or squeeze;
e)	Load from grouting operations planned as part of construction;
f)	Loads from adjacent tunnelling operations and excavations;
g)	Loads from openings and extensions to the linings;
h)	Long and short term loads induced by the construction procedure;
i)	Temperature and shrinkage;
k)	Long term variation in Groundwater levels;
l)	Handling, erection and TBM rams where applicable;
m)	Accidental (collision) load;
n)	Seismic;
o)	Compressed air;
p)	Mitigation of ground movement;
q)	Flotation;
r)	Internal loads; and
s)	Load effects created by construction tolerances, such as steps, lips, roll and broken joints for segmental linings.
This list is not exhaustive and other items may be required on a case by case basis.	

3.1.8.3 A loadcase combining a minimum surface surcharge of 75.0kN/m² with overburden and hydrostatic loads shall be included in the design.

Note: The maximum surface surcharge may not give rise to the most onerous load case.

- 3.1.8.4** The design shall include load from grouting carried out for construction, maintenance or repair including loads that may arise from the execution of ground improvement measures, or measures to control settlement.
- 3.1.8.5** The design shall take account of the following:
- a) changes in long-term Groundwater level as defined by LU; and
 - b) seasonal variation in Groundwater level
- 3.1.8.6** In Deep Tube Tunnel assets containing track all structures, cladding, cladding support frames and fixings of the same shall be designed to resist both pressures and suctions of 0.2kN/m^2 using a load factor γ_f or γ_{fl} as appropriate of 1.0.
- 3.1.8.7** Collision loading: any structure or support that is at risk of destruction or disproportionate damage from impact by a rail vehicle shall be designed for collision load.
- 3.1.8.8** The design shall specify measures to validate the design concept during construction.

Note: This requirement arises because soil structure interaction in tunnels is difficult to model reliably in design. Validation may be by means of monitoring to demonstrate that loading and deflections are in accordance with the designer's expectations.

3.1.9 Ground investigation information

- 3.1.9.1** Ground Investigations and desk top studies for Ground Investigations shall be carried out in accordance with LU Standard S1050 (Civil Engineering – Common Requirements).

3.1.10 Structure Gauge and space requirements

- 3.1.10.1** The design shall determine the minimum internal dimensions for Deep Tube Tunnels from the space requirements of:
- a) Structure Gauge in accordance with LU Standard S1156 (Gauging and Clearances);
 - b) Plant and services in accordance with LU Standard S1068 (Mechanical Building Services, Utility Provision and Energy Management);

Note: Plant and services include tunnel and shaft drainage, ventilation, internal finishes, fire safety installations and electrical installations (including power supply, emergency lighting, telecommunications and signalling). This will include the requirement for plant rooms e.g. lift equipment rooms, communication equipment rooms etc.

- c) Air flow and ventilation from LU Standard S1067 (Tunnel and Public Area Cooling and Ventilation);
- d) Passenger and personnel spatial requirements in accordance with LU Standard S1371 (Station Planning);
- e) Emergency evacuation in accordance with LU Standard S1371 (Station Planning);
- f) Platforms, architectural finishes and furniture in accordance with LU Standards S1131 (Premises – Station Platforms) and S1135 (Premises – Finishes);
- g) Construction equipment and operations as determined by the designer;
- h) Maintenance equipment and operations as determined by the designer;

Note: This will require liaison with the asset maintainer during the design.

- j) Construction tolerances as determined by the designer;



- k) Deformation tolerance as determined by the designer; and
- l) Cable requirements from LU Standard S1120 (Power Cable Route Design, Testing and Recovery Requirements).

3.1.10.2 Trackbed in running tunnels

- a) The structural design shall provide space and make provision for the trackbed and for the variation in position of the structure due to tolerances.

Note: The diameter of the tunnel may need to be enlarged where floating slab trackform is required. Specific consideration should be given to the load imposed on the tunnel lining and infill (stage 1) concrete by the support bearings for the floating slab.

- b) The structural design shall be coordinated with the track support design, LU Standards S1157 (Track – Performance, design and configuration), S1158 (Track – Inspection and Maintenance), S1162 (Conductor rail – Performance, design and configuration) and S1163 (Conductor rail – Inspection and maintenance).
- c) Where it is necessary for cables to cross tracks the design shall make suitable provision in a manner which does not encroach on the Structure Profile nor endangers cable function.

Note: The type of trackbed and required resilience may influence the tunnel design basis, for example dowels between the tunnel lining and trackbed may be required to restrict trackbed movement.

3.1.10.3 Drainage

- a) The structural design shall provide space for the drainage system and the variation in position of the structure due to tolerances.
- b) The structural design shall be coordinated with the drainage system design, LU Standard S1052 (Civil Engineering – Gravity Drainage Systems) and S1056 (Civil Engineering – Pump Drainage Systems).

3.1.10.4 Service fixings and connections

- a) The design shall comply with the requirements for service fixings and connections in accordance with LU Standard S1050 (Civil Engineering – Common Requirements).

3.1.10.5 Contained structural components

- a) The design shall provide space for structural components contained within the asset and for the variation in position of such structural components due to tolerances.
- b) Structural design shall be coordinated with the design of Contained Structural Components as defined in LU Standard S1053 (Civil Engineering – Building and Station Structures).

Note: Requirements for fixing and connection of internal structures are given in S1050 (Civil Engineering – Common Requirements).

Contained structural components include:

- a) Cable brackets;
- b) Cable bridges;
- c) Brackets for holding equipment such as water mains, signals ducts and fans;
- d) Noise reduction screens;
- e) Emergency and maintenance walkways; and

f) Access stairs and landings.

3.1.10.6 Finishes

- a) All finishes shall comply with LU Standard S1135 (Premises – Finishes);
- b) Where the function of the asset includes its use as a part of the ventilation system the finish shall be as required by LU Standard S1067 (Tunnel and Public Area Cooling and Ventilation);
- c) The structural design shall provide space for installation or application of finishing systems consistent with structure tolerances;
- d) The structural design shall be coordinated with the design of the finishing systems to ensure durability, water control and structural integrity of the asset;
- e) Finishing systems for new works shall allow inspection of the structure;
- f) Finishing systems for existing assets shall not diminish the inspectability of the structure; and
- g) Where no finishing systems are required, the structural elements shall have a surface finish compliant with Clauses 3.1.12 and 3.1.13 of this Standard.

Note: Requirements for fixing and connection of internal structures are given in S1050 (Civil Engineering – Common Requirements).

3.1.11 Alignment

- 3.1.11.1** Alignment of tunnels containing track shall be designed in accordance with the requirements of LU Standards S1157 (Track – Performance, design and configuration), S1158 (Track – Inspection and Maintenance), S1162 (Conductor rail – Performance, design and configuration) and S1163 (Conductor rail – Inspection and maintenance).

Note: The precise arrangements of tunnels, particularly around junctions, may have a significant impact on both constructability and structural efficiency. Further guidance on the layout of tunnel junctions is provided in G055 (Civil Engineering - Deep Tube Tunnels and Shafts).

3.1.12 Fire resistance

- 3.1.12.1** The design shall meet the requirements for fire performance in LU Standard S1085 (Fire Safety Performance of Materials).
- 3.1.12.2** The design shall meet the requirements for passive fire resistance to support the fire safety strategy for the asset in LU Standard 1-083 (Passive Fire Protection Systems).
- 3.1.12.3** The design shall ensure fire damage does not impact on the ability of Deep Tube Tunnels assets to fulfil their Required Duty.

Note: The designer demonstrates that a fire will not compromise the tunnel lining's structural stability. The designer proposes a fire load for agreement with The Deep Tube Tunnels Engineer (LU).

The purpose of this clause is to support life safety through other measures in addition to ensuring safe evacuation (which is dealt with elsewhere). The designer considers the effects of:

1. Spalling
2. Progressive Collapse
3. Inundation – By water and soil as a consequence of structural damage

4. Surface Disruption – In particular where non-cohesive soils are present which may run causing surface ground movement if the tunnel lining is damaged.

3.1.13 Water resistance

3.1.13.1 Deep Tube Tunnel assets shall be designed to be free from all leakage, seepage and damp patches. To achieve this the design shall include a continuous water barrier separating the soil from the internal environment of the tunnel.

Note: Whilst the design intent is for a completely dry tunnel it is recognised that this may be difficult to achieve both in initial construction and throughout the operational life of a tunnel or shaft. Therefore this standard includes further requirements to control the residual risk of water ingress.

For the design of assets to be placed within the tunnel it should be assumed that the performance of the tunnel waterproofing system should achieve the following levels:

- a) For tunnels containing track, above axis level shall be free from all leakage seepage and damp patches;
- b) For tunnels containing track, below axis level leakage shall be limited to damp patches minor weeping at joints with less than one litre/day/m² ingress;
- c) Shaft water ingress shall be limited to damp patches and minor weeping at joints with less than one litre/day/m²;
- d) Station, passenger and escalator tunnels shall be free from all leakage, seepage and damp patches; and
- e) Other non-track tunnels shall be assumed to have the same water-resistance performance as tunnels containing track.

The requirements for protection against flooding are given in LU Standard S1052 (Civil Engineering – Gravity Drainage Systems).

3.1.13.2 Where Deep Tube Tunnels have internal finishes that are distinct from the tunnel structural linings there shall be no leakage, seepage or damp patches in the space within the finishes. To remove residual risk of water ingress to these areas consideration shall be given to provision of a water management system between the structural lining and the internal finishes. The water management system should either be fully drained or, if there is evidence that the risk of water ingress is very small, evaporation based systems may be provided. Specific consideration shall also be given to maintenance of any water management system and also to protection of architectural finishes and their fixture from damage due to water ingress.

3.1.13.3 Where a water management system is not provided within the structural lining the design of the tunnel structure shall include design of generic repair techniques to seal any future leakage or seepage through the lining. This shall include the means to make good finishes within the structure.

3.1.13.4 At junctions between two different types of waterproofing or between new waterproofing systems and existing assets, water ingress shall be prevented by means of at least two separate systems. At least one of the systems shall provide the ability to repeatedly re-inject sealing material into areas where leakage may occur during the service life of the asset.

Note: The interfaces between waterproofing types and connections between new works and existing assets have been found to be particularly susceptible to water ingress. Therefore additional measures in these areas may be beneficial to ensure the structure meets its required duty.

Where concrete linings are used, the concrete itself should not be considered as one of the two types of water ingress prevention measures at the junction, even where they are designed as being “waterproof concrete”.

- 3.1.13.5** Materials specified for waterproofing shall meet the requirements of Clauses 3.1.12 and 3.1.13 of this Standard and LU Technical Specification T0006 (Deep Tube Tunnels Materials and Workmanship). They shall also be on LU's Products Register (<http://www.lu-apr.co.uk>). Should a supplier or contractor wish to use a product not on the register then special approval from The Deep Tube Tunnels Engineer (LU) shall be sought and granted before it can be incorporated in to the works. The product shall then be submitted for formal approval and entry on to the Products Register as soon as practicable thereafter.
- 3.1.13.6** The design of water resistance measures shall cater for the effects of long term ground movements and movements associated with the construction of adjacent structures, where such construction is reasonably foreseeable.
- 3.1.13.7** The designer of permanent linings shall state the maximum permitted depth of embedment for fixings.
- 3.1.13.8** Bolted linings shall be provided with a caulking groove and a gasket. Where linings are caulked the bolts shall be grommetted.
- 3.1.13.9** Bolted SGI and fabricated steel linings shall be machined on all joint faces and a groove shall be provided to accommodate a waterproof seal.
- 3.1.13.10** In-situ and sprayed concrete permanent linings shall be protected by an external water resistant membrane except in the cases described in clauses 3.1.13.13 and 3.1.13.14. Construction joints in the concrete lining on the inside of the membrane shall be provided with waterbars except where the membrane is fully bonded to that lining.

Note: The membrane may be applied as either a solid sheet form or as a sprayed or painted liquid. Different membrane types have different characteristics. In making a selection the designer will need to consider factors such as the potential for a bond to the structural lining, the potential creation of water paths and how the membrane may be repaired during its operational life.

- 3.1.13.11** Compartmentation is required on the outside of sheet membranes to control migration of water around the outside of the membrane.

- 3.1.13.12** When constructing a shaft with a sheet membrane, a grout collar shall be incorporated below the clay/gravel interface on the outside of the membrane to reduce flow paths as part of the installation. The grout collar shall allow for future reinjection.

Note: The requirements in clauses 3.1.13.11 and 3.1.13.12 are intended to stop water paths down the outside of newly constructed waterproof structures that then track along until they find a point of entry. This clause does not relax the requirement for a fully tanked waterproofing system and the designer shall describe how this requirement can be incorporated within such a system.

- 3.1.13.13** Where concrete-lined headings are used locally for structures, such as overbridges and openings into or between existing tunnels, space constraints may make it impractical to comply with the requirement to install an external water resistant membrane. In this circumstance the membrane may be omitted and waterproofing shall be by means of at least two separate systems in addition to the concrete itself. At least one of the systems shall provide the ability to repeatedly re-inject sealing material into areas where leakage may occur during the service life of the asset.

Note: Clause 3.1.13.13 is primarily applicable in cases where the ground around the excavation is supported by traditional timbering and where the installation of a membrane is therefore impractical. It is not applicable where the permanent structure is being constructed within a concrete temporary works structure. This is because a membrane is the preferred solution for tunnel waterproofing and it is deemed practical to install a membrane in a space in which either a sprayed concrete primary lining or cast in situ temporary lining has been installed.

A combination of waterbars, hydrophilic strips at joints and a reinjectable grout tube system has been found to be generally satisfactory in the circumstances described in clause 3.1.13.13. The use of concrete additives to enhance waterproofing is permitted but is not acceptable as one of the mandated “two separate systems in addition to the concrete itself”.

3.1.13.14 Where sprayed concrete linings are used there may be benefit to LU in using the concrete outside the membrane to carry a part of the permanent load. This solution is permitted subject to the designer providing evidence to LU that:

- a) the structure will satisfy its Required Duty (clause 3.1.1);
- b) that the structure, including permanent works outside a membrane, will be durable (clauses 3.1.6 and 3.1.12);
- c) that all possible cases for distribution of loads between different parts of the lining structures are addressed;
- d) that the structure will satisfy the water resistance requirement (clause 3.1.9); and
- e) that the structure and waterproofing system are sufficiently robust to withstand any likely movements.

Note: The requirement in clause 3.1.13.14 c) is driven by problems experienced with cracking developing in very lightly loaded secondary linings. This is believed to be due to the secondary lining gaining less load than anticipated as a result of the primary (notionally temporary) lining being capable of carrying a significant part of the long term load.

3.1.13.15 The design of junctions between two different types of waterproofing and between new waterproofing and existing assets shall allow sufficient space for the installation of future water management systems.

Note: Water ingress at junctions post construction is a common problem, often requiring remedial works and the installation of unsightly water management systems. This clause seeks to allocate space for the future installation of assets such as drip trays, pipework etc. without impacting on the passenger envelope, ambience or necessitating the diversion of other assets.

3.1.13.16 The designer shall design and specify a repair method to be employed where the waterproofing is compromised during the service life.

3.1.14 Impact on operational railway and adjacent structures

Note: The requirements for assessing impact and mitigation are given in LU Standard S1050 (Civil Engineering – Common Requirements).

3.1.14.1 The designer shall determine the potential ground movement associated with the construction method for the following purposes:

- a) to demonstrate that the environmental effects of the tunnelling-induced ground movement have been considered and taken account of in design;
- b) to draw attention to those zones where the implementation of the design is likely to cause ground movement;
- c) to assess the risks of damage associated with the design, to investigate alternatives, and modify the design as necessary;
- d) or, if avoidance is not possible, to design protective measures against the likely damage, which measures could include settlement mitigation such as compensation grouting that could themselves have effects requiring assessment; and

- e) to indicate where the purchase of property is required for demolition or structural modification.

3.1.14.2 The ground movement expected to arise from tunnelling activities shall be estimated by empirically calibrated methods.

Note: In most cases relatively simple forms of analysis are appropriate and preferred for reasons of simplicity and ease of validation. The use of complex numerical analyses may be appropriate for complex problems such as junctions but such tools should first be validated by comparison with other methods or case history data.

Case history evidence of particular value for current tunnel construction methods in London includes that from the King's Cross Station Upgrade (for sprayed concrete and timber supported headings) and the Channel Tunnel Rail Link (for tunnel boring machines). Further information on these projects is available in London Underground's Core Asset Information System (CAI).

The requirements for assessing impact and mitigation are given in LU Standard S1050 (Civil Engineering – Common Requirements). Reference may be made to CIRIA Special Publication 200, 2001: Volume 1 (of 2) Projects and Methods: Building Response to Tunnelling, Case Studies from Construction of the Jubilee Line Extension, London. Editors J B Burland, J R Standing, F M Jardine

3.1.15 Temporary works

3.1.15.1 Temporary works shall comply with S1062 (Temporary Works).

3.1.15.2 The temporary structure shall be designed to carry and transfer design loads and load effects for the design life.

3.1.15.3 The Temporary Works Designer (TWD) shall define the loads and load effects for each element of the design.

Note: Where redistribution of the overburden loads around structures, such as openings, can be demonstrated by the TWD, the TWD may reduce the overburden load to a proportion of the overburden or a value related to the time the TW will be loaded.

The TWD may consider it appropriate to design the installed support for stability of the excavation rather than a proportion of overburden (for example traditional design of timber headings to prevent wedge failures).

The TWD may find it useful to consider the historical approach to the design of traditional timber support. Guidance can be found in British Tunnelling Society publication Traditional Timbering in Soft Ground Tunnelling - A Historical Review by CNP Mackenzie.

LU Guidance document G055 provides information on time related loading in clay soils.

Where it is anticipated that loading is going to be less than full overburden, then steps should be taken install monitoring during construction, to monitor the actual loads imposed on the temporary works. This will aid the TWD in validating the design assumptions and also provide valuable data for other projects in similar ground.

3.1.15.4 Temporary Works required for the construction of the permanent works shall be fully compatible with the continuing safe and reliable operation of the adjacent facilities.

Note: Also refer to LU Standard S1354 (Customer Facing Aspects of Temporary Works at Stations) and for spatial constraints refer to LU Standard S1371 (Station Planning).

3.1.15.5 Where Temporary Works are left in place after construction, the impact of these shall be assessed as part of the permanent works design.

Note: This is to address the risk that residual temporary works (e.g. temporary SCL or timber headings) may influence the distribution of loads in the permanent structure. This will require coordination of the permanent and Temporary Works design.

3.1.15.6 Existing assets which will be required to sustain loads imposed by the Temporary Works associated with the construction of new assets shall be checked for their ability to do so and if necessary, additional support shall be designed.

3.1.15.7 Where there are separate temporary and permanent works designers for the tunnel lining, there shall be a clear statement describing whom is responsible for what in the CDS. The statement should also be clear on checking arrangements for the tunnel design through all stages of construction and in the permanent case.

Note: Where the delineation of design responsibility changes with time this should be made clear. Diagrams may be useful when illustrating the interface of design responsibility.

3.1.16 Sprayed concrete lining specific requirements

3.1.16.1 The designer shall state on the drawings:

- a) maximum sprayed concrete lining layer thickness per pass and,
- b) the minimum allowable time between the end of spraying one sprayed concrete lining pass and the start of the next pass and,
- c) criteria (including early age strength) that shall be met before any exclusion zones can be lifted.

Note: The requirement of clause 3.1.16.1 is to ensure the Designer considers the risk associated with fallouts. The Designer also considers how temperature and strength gain may affect fallouts and adjusts the implementation accordingly.

Further factors for the Designer to consider include the increased risk of debonding by allowing too much time between passes and the benefits from reducing the number of layers e.g. by swapping out steel fibres for polypropylene in the last pass, as opposed to having a separate layer.

3.1.17 Work sites, access and construction considerations

3.1.17.1 The Designer shall demonstrate a means by which to move the elements designed from delivery to erection into place. This shall include any specific measures required to ensure the safety of operatives.

3.1.17.2 The Designer shall demonstrate the location and size of the working sites required for the efficient and safe servicing of construction activity.

Note: Clauses 3.1.17.1 & 3.1.17.2 are driven in part by experience of lifting and manoeuvring hazards in underground works.

Factors to be considered includes safe personnel access and escape, safe materials and spoil access, separation from the operational railway. In the case of sprayed concrete tunnelling works particular consideration should be given to the proximity and adequacy of concrete batching facilities.

3.1.18 Ventilation during construction

3.1.18.1 Tunnel ventilation systems and dust suppression during construction shall be designed and subject to design compliance. The design shall include:

- a) minimum maintenance checks
- b) minimum monitoring requirements (including for the presence of dust and particulates)

Note: Particular attention shall be paid to the management of airflow where a supply feeds multiple faces. The design determines the frequency at which any filters shall be changed.

Additional guidance can be found in LU Guidance document G2108 Exposure to Occupational Dust.

3.1.19 Catastrophic Events

3.1.19.1 The risk management process for Tunnelling Works including Strengthening and Renewal shall assess the potential for Catastrophic Events during construction. Appropriate controls, mitigation and preventative action shall be implemented to manage the risk of Catastrophic Events during construction.

Note: The HSE commissioned report RR834 'Preventing Catastrophic Events in Construction' examines the risk of Catastrophic Events faced during construction and what can be done to prevent them. CIRIA have also published Guidance on Catastrophic Events in construction to help practitioners to respond practically to RR834.

3.1.20 Provision for maintenance

3.1.20.1 The design shall incorporate provisions to facilitate the inspection and Maintenance operations necessary for the achievement of the Required Duty for the Design Life.

3.1.20.2 As part of the design, the designer shall produce a plan for inspection, Maintenance and, if appropriate, instrumentation and monitoring of the asset to ensure serviceability throughout the Design Life.

3.1.20.3 The design shall demonstrate the asset can be cleaned:

- a) to reduce the risk of vermin infestation;
- b) to reduce the risk of fire;
- c) to reduce the environmental risk to system users and staff;
- d) to promote a positive customer perception of the underground environment;
- e) to remove obscuration of structural elements and so facilitate inspection; and
- f) to fulfill the requirements of LU Standard 1-160 (Cleaning of the track environment).

3.1.20.4 The designer shall produce specifications for anticipated concrete repairs.

Note: In general patch repairs to concrete shall be avoided where possible. In most locations repairs are only needed if the structural capacity, durability or fire resistance of the lining is compromised. In areas which are visible to the public, repairs for cosmetic purposes may also be required.

3.2 Construction, installation, testing and commissioning

3.2.1 General

3.2.1.1 General requirements for design, construction, commissioning and handover are given in LU Standards S1552 (Contract QUENSH Conditions), S1050 (Civil Engineering – Common Requirements) and S1538 (Assurance).

3.2.1.2 Any individual undertaking safety critical work or tasks as defined by ROGS shall demonstrate the required competence in accordance with LU Standards S1548 Safety

Critical Work and S1801 Competence Requirements for Undertaking Civil Engineering Safety Critical Work.

- 3.2.1.3** Procedures shall be implemented for controlling any changes to the design during the construction, installation, testing and commissioning phases. Such procedures shall ensure that the proposed design changes are not implemented until they have been designed, checked and approved.

Note: This applies equally to temporary and permanent works

- 3.2.1.4** At the end of construction as built drawings shall be produced. These shall include any temporary works left in situ and excavation profiles. These drawings shall include asset numbers for all new and any existing Deep Tube Tunnels assets affected by the works.

- 3.2.1.5** Adjacent buildings, structures, utilities and facilities shall be assessed for the effects of construction and the risks mitigated in accordance with LU Standard S1050 (Civil Engineering – Common Requirements).

Note: In complex situations it may be helpful to prepare a suite of documents to describe how this is done. Typically these would include:

- a) an Approval in Principle for the method of assessment;
- b) an assessment report;
- c) a mitigation proposals report; and
- d) an instrumentation and monitoring plan.

- 3.2.1.6** Mechanised excavation (including boring, coring and pipe jacking) shall not take place within 1m of existing LU Deep Tube Tunnels assets without written permission from The Deep Tube Tunnels Engineer (LU).

Note: This permission shall be sought via submission of drawings indicating the extent of the area to be mechanically excavated and how the risks to LU are to be mitigated.

The designer and contractor shall demonstrate that all practicable measures have been implemented to reduce the risk to LU, with special attention given to works likely to impact upon the running of the operational railway. Typically this will involve a risk based approach, the use of smaller plant or improved control measures, excavating during engineering hours and hand digging within close proximity of the tunnels (i.e. the last 500mm). Special care shall also be taken where it is expected that redundant temporary works may be found in the ground.

- 3.2.1.7** Sufficient testing of systems, sub-systems, materials and components shall be carried out to give assurance that they are in accordance with those specified in the approved design. This testing requirement shall be described in an Inspection and Test Plan.

- 3.2.1.8** All necessary attendance during site visits shall be afforded to LU to enable LU to discharge its responsibilities in respect of its duties including verification.

- 3.2.1.9** The Designer(s) shall be represented on site during excavation and the erection of ground support to ensure and certify implementation of the design intent. An exception is allowed where written agreement is obtained in advance of excavation from The Deep Tube Tunnels Engineer (LU).

Note: Ensuring implementation of the design intent includes interpretation of monitoring data and ground conditions and modification of the design if necessary.

An exception will generally be agreed for excavation by a TBM. It is not anticipated that an exception will be agreed where timber headings or SCL provide ground support.

- 3.2.1.10** The Designer's representative(s) during construction shall have a good understanding of the design intent, principles and underlying assumptions made during the design stage. They shall also be aware of any comments, issues or concerns raised by the Design Checker and how these were closed out prior to design compliance.

3.2.2 Tunnel Management

Note: Clause 3.2.2 is intended to set out minimum requirements for the management of Tunnel Works. The supplier retains responsibility to plan, manage and deliver their works.

- 3.2.2.1** A system to control and manage the construction process shall be maintained. This system shall comply with The Joint Code of Practice for Risk Management of Tunnel Works in the UK (JCOP).

Note: This system is to support LU:

- a) to discharge its responsibilities under ROGS and the Safety Certificate and Safety Authorisation;
- b) to discharge its responsibilities to maintain safe structures and operating railway systems during construction works;
- c) to satisfy itself that the construction is in accordance with the design; and
- d) to satisfy itself in respect of the adequacy of the system for the recording of construction data and information that may be relevant to the subsequent Maintenance, Strengthening and Renewal and eventual decommissioning.

- 3.2.2.2** A Tunnel Management Plan shall be prepared to describe the systems to be used to manage and control the construction process. The minimum requirements for the Tunnel Management Plan are provided in Attachment 7.3.

Note: The Tunnel Management Plan shall demonstrate compliance with JCOP. This in part satisfies the Construction Management Plan requirement in TFL Pathway.

- 3.2.2.3** An audit plan shall be provided to test compliance with each clause of The Joint Code of Practice for Risk Management of Tunnel Works in the UK.

- 3.2.2.4** The Tunnel Management Plan shall be approved by The Deep Tube Tunnels Engineer (LU) prior to the start of excavation.

- 3.2.2.5** A readiness review shall be undertaken by the Contractor and approved by The Deep Tube Tunnels Engineer (LU) prior to the start of excavation.

Note: An example of a suitable checklist is given in Attachment 7.6.

- 3.2.2.6** A review meeting shall be held at least daily whilst excavation or ground support works are being undertaken.

Note: More frequent review meetings may be required.

- 3.2.2.7** The review meeting shall review progress to date, interpreted monitoring results, ground conditions, results from the excavation and support works and any recent non-conformance reports relating to the tunnel construction. The required agenda of the review meeting and minimum requirements of the monitoring to be presented are given in Attachment 7.4.

- 3.2.2.8** The review meeting shall be attended as a minimum by representatives of the Contractor, Designer and The Deep Tube Tunnels Engineer (LU).

- 3.2.2.9** The output of the review meeting shall be a report which includes the Required Excavation and Support Sheet (RESS).



- 3.2.2.10** A RESS is required before any excavation commences. If no agreed RESS is available by a specified time each day then the work shall be made safe and stopped.

Note: There is no distinction whether the mining is by hand excavation or mechanised nor based on the ground support method; a RESS is always required.

- 3.2.2.11** The Designer shall be responsible for producing the RESS. The RESS shall be signed, as a minimum, by representatives of the Designer, Contractor and The Deep Tube Tunnels Engineer (LU).

Note: The RESS should adequately reflect the ground conditions, results of monitoring, progress to date and other factors likely to contribute to safety and production. For this reason the RESS should only capture a limited time period (typically 24 hours) before needing to be re-validated in a subsequent RESS.

- 3.2.2.12** The Contractor shall not undertake any excavation works unless they have the materials, plant and labour available to seal the face and make the worksite safe.

Note: The requirement of clause 3.2.2.12 is to ensure that works which cannot be safely stopped are not started. When considering how to comply with this clause the Contractor should consider the location of plant, materials and labour and the resilience of their operation should one or more elements become compromised. For example, how may the works be made safe should a crane or a spraying robot fail.

- 3.2.2.13** The minimum requirements of the RESS are presented in Attachment 7.5.

- 3.2.2.14** A copy of the RESS shall be provided to all key personnel and a copy shall be kept at each working face.

- 3.2.2.15** If for any reason an urgent change is required to the approved design and or the method, prior to the next scheduled review meeting, a special meeting shall be held with representatives of the Designer, Contractor and The Deep Tube Tunnels Engineer (LU). If the change is accepted a new RESS will be issued.

Note: The requirement of clause 3.2.2.15 is relevant primarily where events lead to changes being required to the RESS between scheduled review meetings. For example due to a change in ground condition, over/under excavation or lack of available material/plant/labour.

The requirement is for a special meeting to be held and a new RESS to be issued, signed and agreed by the required parties, prior to a change in work commencing.

- 3.2.2.16** Unsupported ground shall not be left unattended.

Note: The requirement of clause 3.2.2.16 is to ensure that any unsupported ground is kept under continuous observation.

- 3.2.2.17** Exclusion zones shall be implemented to restrict workforce access to high risk areas.

Note: Within tunnelling sites there are certain high risk areas where it is desirable to limit workforce access. Examples include areas with incomplete ground support, where fresh concrete is being placed at height, during the installation of lintels and in the vicinity of lifting operations (such as at shaft bottoms).

Information on exclusion zones (in relation to SCL works) can be found in the LU guidance document G2106 SCL Exclusion Zone Management, which will be issued shortly.

- 3.2.2.18** The Method Statement for all excavation works shall describe how to make the site safe at any stage if the work is stopped.

- 3.2.2.19** Where an excavation has been stopped temporarily, a competent face watch shall be established. The frequency of the face watch shall be risk based and approved by The Deep Tube Tunnels Engineer (LU).

Note: In determining the frequency, the following shall be considered:

- a) Design life of temporary support
- b) Ground conditions (especially presence of water and/or materials which can run)
- c) Data available from monitoring (including movement)
- d) Consequences of failure (risk to the works, risk to the railway, risk to third parties etc)
- e) Security of site
- f) Impact of any adjacent works

3.2.3 Independent Supervision

- 3.2.3.1** A Verification Activity Plan (VAP) is required for all tunnel works.

Note: The requirement of clause 3.2.3.1 is because excavation and ground support are deemed high risk activities.

- 3.2.3.2** Tunnel Works shall have supervision which is independent of responsibility for production. The supervision arrangements, including frequency of inspection, shall be approved by The Deep Tube Tunnels Engineer (LU) prior to the start of excavation.

Note: An example on recent projects has been LU Tunnel Engineers and Tunnel Inspectors reporting to the NEC contract Supervisor and acting with the Supervisor's delegated responsibility.

- 3.2.3.3** The independent supervision shall be provided by personnel accredited by The Deep Tube Tunnels Engineer (LU) as Tunnel Engineers or Tunnel Inspectors.

3.2.4 Materials

- 3.2.4.1** All construction materials supplied to the works shall comply with the requirements of LU Standard S1050 (Civil Engineering – Common Requirements) and LU Technical Specification T0006 (Deep Tube Tunnels Materials and Workmanship).

- 3.2.4.2** LU maintains a Products Register (<http://www.lu-apr.co.uk>). Products on that register are deemed approved for use on the Underground. Should a supplier or contractor wish to use a product not on the register then special approval from The Deep Tube Tunnels Engineer (LU) shall be sought and granted before it can be incorporated in to the works. The product shall then be submitted for formal approval and entry on to the Products Register as soon as practicable thereafter.

- 3.2.4.3** Conventionally reinforced concrete shall have cover as required in LU Standard S1050 (Civil Engineering – Common Requirements). The cover requirements of LU Standard S1050 do not apply to steel fibre reinforced concrete in Deep Tube Tunnel assets.

- 3.2.4.4** The use of polymer reinforcement for structural reinforcement of Deep Tube Tunnel structures is not permitted.

Note: This requirement is due to the potential for polymer fibre to creep and to become fire damaged. It does not prohibit the use of polymer fibres in concrete for other purposes such as fire protection.

- 3.2.4.5** The requirements of LU Standard S1050 with respect to the minimum reinforcement in each face for concrete below ground do not apply to Deep Tube Tunnel assets.
- 3.2.4.6** The requirements of LU Standard S1050 for a maximum crack width of 0.2mm only applies to Deep Tube Tunnel assets where the concrete forms part of the permanent works, is conventionally reinforced, in contact with the ground and not protected by a membrane.
- 3.2.4.7** Sprayed concrete (for primary lining, secondary lining & regulating layers etc.) shall be applied wet, unless written permission is obtained from The Deep Tube Tunnels Engineer (LU).

Note: It is expected that all sprayed primary, secondary and regulating layers will be applied using a wet mix, to reduce dust levels. Where this can be demonstrated to be impracticable, The Deep Tube Tunnels Engineer (LU) may allow the use of a dry mix where additional mitigations against dusty working for the workforce and others can be adequately demonstrated to be As Low As Reasonably Practicable. It is expected that this will consist of specifying additional dust mitigation and monitoring, minimum visibility requirements, etc.

- 3.2.4.8** Expanding polyurethane foam is permitted as part of a grouting process designed in accordance with the grouting guidance document G1417.
- 3.2.4.9** Where expanding polyurethane foam is proposed for purposes not covered by clause 3.2.4.8, written approval is required from The Deep Tube Tunnels Engineer (LU).

Note: Expanding polyurethane foam is not to be used as a general filler in temporary works, such as for sealing shutters etc.

- 3.2.4.10** There shall be a mechanical means of stopping bolts falling out of tunnel linings for the life of the tunnel structure. They shall not be susceptible to loosening caused by ground movements or vibration.

Note: Experience has shown that steel bolts into plastic sockets may present a safety hazard to the operational railway. An example of an acceptable connection is the use of banana bolts.

3.2.5 Instrumentation and monitoring

- 3.2.5.1** Where appropriate to the scope of work, instrumentation and monitoring shall be used:

- a)** to validate the design (to satisfy the requirement of clause 3.1.8.8);
- b)** to verify the predicted ground movement due to the work and to determine the effects which such ground movement will have on LU and adjacent assets;
- c)** to determine the impact of the work on third party assets;
- d)** to establish monitoring base readings sufficiently in advance of the work to ensure underlying and seasonal environmental trends are understood; and
- e)** to trigger the implementation of contingency plans if the results of monitoring so indicate.

Note: Further details on instrumentation and monitoring requirements can be found within S1050 and T0006. S1050 also mandates compliance with the British Tunnelling Society Monitoring Underground Construction best practice guide.