

Guidance Document

G1417 Grouting to control seepage in tunnels and structures

Issue No.: A1

Issue date: April 2013
Review date: April 2016

MAYOR OF LONDON

 **Documents**
Document Sharing Hub



Contents

1	Purpose	3
2	Scope	3
3	Guidance	4
3.1	Introduction	4
3.2	Types of Grout materials	6
3.3	Pumps	8
3.4	Design of a Grouting Scheme to Control Seepage in structures and Tunnels	10
4	Responsibilities	16
5	Supporting information	16
5.1	Background	16
5.2	Safety considerations	17
5.3	Environmental considerations	17
6	Information References	17
6.1	References	17
6.2	Abbreviations	18
6.3	Definitions	18
6.4	Person accountable for the document	18
6.5	Document history	18
7	Attachments	19
7.1	Attachment A – Guidance on typical contents for a Grouting CDS	19
7.2	Attachment B – Template for Risk Assessment with commentary	23
7.3	Attachment C – Example drawing for grouting works	33
7.4	Attachment D – Example Template for a Grouting Shift Report	34
7.5	Attachment E – Example Competency matrix for grouting	36
7.6	Attachment F: Civil Engineering: Approved Product Register Guidelines	37



This preamble must be included where the document could be used by a supplier or contractor to London Underground;

This document must not form part of Contractual terms and conditions between London Underground and Suppliers.

Neither London Underground nor Suppliers are bound to provide any of the items or services or follow any processes described in this document unless they are also required to provide them explicitly by other, contractually binding, documents.

The information within this document must not be used by London Underground or Suppliers to raise or moderate expectations of delivery by Suppliers or London Underground over and above Contractual requirements.

1 Purpose

- 1.1 The purpose of this document is to provide guidance on established good practice solutions that meet the requirements for grouting to control seepage in tunnels and structures.

2 Scope

- 2.1 This guidance document has been produced following a Formal Investigation (LUSEA Reference 22005663) undertaken after an incident of trains striking a bulge in a non structural secondary tunnel lining between Embankment and Waterloo. The bulge in the lining was caused by grouting works, to seal seepage.
- 2.2 This guidance document will focus on London Underground's (LU) requirements for seepage control in Bridges and Structures (B&S) and Deep Tube Tunnel (DTT) assets.
- 2.3 Grouting processes may be used for other reasons including ground treatment to improve strength, compensation grouting for ground movement due to excavation and construction of new tunnel linings. These processes are not covered by this manual although elements of the advice may be relevant.
- 2.4 This guidance is not applicable to grouting wall or floor tiles and other non injection processes.

3 Guidance

3.1 Introduction

3.1.1 The majority of London Underground Bridges and Structures and all of the Deep Tube Tunnels assets are constructed below the ground surface and as a result are often susceptible to seepage, be it due to rainwater, groundwater or water from damaged water utilities percolating through the ground and finding a path into the structure or as a result of the structure being built below the groundwater table.

3.1.2 Subterranean structures are very rarely watertight, even though they may have been designed to be. Tunnels and structures tend to “weep and seep” and this is usually managed effectively through controlled diversion of seepage into drainage systems.

3.1.3 However there will be instances where the seepage, if left untreated, can cause structural deterioration of the asset itself and can cause damage and deterioration of ancillary structures and equipment. Additionally seepage can have a detrimental effect on the aesthetic appearances at stations. It could also have an impact on the operational railway as a result of seepage affecting track, signalling, and power and communication systems.

3.1.4 There are instances where grouting to control seepage is not normally permitted. One such instance is expanded pre cast concrete tunnel linings and flexible cast iron tunnel linings. These linings are readily identified by the absence of bolts connecting the segments together. They are designed to be flexible and if grouted could result in structural instability of the lining. In such cases it is recommended that the LU DTT Profession Head is consulted to agree mitigation measures to address any seepage.

3.1.5 If the tunnel/structure to be grouted is found to be damaged following a visual/defect survey, advice should be sought from the relevant LU Profession Head to agree a way forward.

3.1.6 There are a number of hazards associated with grouting works that need to be considered as part of the design process. The FIR on the Bakerloo line incident highlighted the root causes that led to the deformation of the secondary tunnel lining. These were:

- LU was exposed to a risk (expansive reaction between polyurethane and acrylic grout) that was not known to the supplier or LU
- The risk of grouting creating a closed system and distorting the secondary lining had not been explicitly risk assessed.
- The risk controls and project management systems applied to the trial stage of the project did not adequately reflect the uncertain and variable nature of the works.

3.1.7 In addition to the risks highlighted 3.1.6 other hazards that need to be considered are shown in table 1:

Hazard	Possible Causes
--------	-----------------

Structural damage to tunnel lining.	Drilling; pumping (excess pressure or volume); uncontrolled or unanticipated grout expansion; corrosive effects; lack of pressure relief; incorrect materials; incorrect design assumptions. Time delayed reaction of materials, unexpected effects due to interaction between newly injected grout and materials already present in the structure. CURRENTLY UNKNOWN MATERIAL BEHAVIOUR, GEOLOGICAL CONDITIONS etc.
Deformation of tunnel lining	Pumping (excess pressure or volume); uncontrolled or unanticipated grout expansion; corrosive effects; lack of pressure relief; incorrect materials; disturbance of caulking or packing; incorrect design assumptions. Time delayed reaction of materials, unexpected effects due to interaction between newly injected grout and materials already present in the structure. CURRENTLY UNKNOWN MATERIAL BEHAVIOUR, GEOLOGICAL CONDITIONS etc
Failure to rectify seepage.	The grouting works proved to be unsuccessful in sealing or controlling the seepage issue. Inappropriate materials; inappropriate method, quality in design or execution; incorrect design assumptions.
Fire	Flammability of grouting materials; incomplete encapsulation (at any stage of job); use of non approved materials. Spillage of grout materials in the railway environment particularly where materials with adhesive and expansive properties are used under time constraints.
Exposure to harmful substances.	Exposure of workforce in equipment failure (e.g. high pressure flexible hose failure); exposure of persons to noxious toxic carcinogen post work completion and handback; disturbance of asbestos. Spillage of grout materials
Flooding	Fluid accumulating within tunnels and structures from external source, or damage to asset such that fluid inflow causes damage or delays resumption of train services.
Contractor Competence	Inadequate experience or skills to implement grouting design satisfactorily; and/or lack of experience to identify major flaws in design.
Designer Competence	Inadequate experience or skills to develop a grouting design; and/or failure to develop a practicable design.

Table 1: Hazards related to grouting works for control of seepage

3.1.8 Consideration should be given to undertake physical verification of clearances (structure gauge and profile) using track gauges as part of the fit for traffic inspection where there is potential to infringe the kinematic envelope of vehicles already permitted over the route e.g. where secondary linings are present.

3.1.9 In some cases seepage into tunnel and structures assets could result in the ingress of ground (particularly with non-cohesive soils) as well as water. Such seepages have the potential to form voids behind the structure causing eccentric loading and instability. It could also cause ground settlement. It is possible that a single grouting solution may be able to treat both voids and seepage. This manual is applicable in such cases.

3.1.10 Generally three approaches are adopted in controlling seepage. These are:

1. Do nothing – If the seepage is only water and is not causing structural deterioration of the asset and is not affecting any other services (e.g. cable brackets, signals, track), then it may be feasible to do nothing and let the seepage find a path into the existing drainage system.
2. Passive – This is generally adopted if the seepage into the tunnel is only water, the rate of ingress is low, (i.e. drips) is not causing deterioration of the tunnel and structures asset but is affecting other services (e.g. signals, track, etc...). Passive measures involve controlled diversion of the seepage into a drainage system. This could be done by either using drip trays, weep pipes, channelling etc.

3. Active – This is adopted if the seepage is resulting in asset deterioration and affecting the structure and or other assets (signals, track etc) or where passive systems cannot be effectively employed (e.g. clearance issues). This involves sealing or reducing the seepage. Methods employed for active seepage control include:

- a. Caulking the joints of a bolted cast iron or concrete tunnel lining
- b. Installing new bolts and grummets of a bolted cast iron or concrete tunnel lining
- c. Surface sealing of a tunnel lining
- d. Installation of a secondary lining particularly in a station environment where ambience is a key issue
- e. Dewatering, but generally only in a temporary case
- f. Grouting

3.1.11 In some instances it may effective to use a combination of passive and active measures to control seepage.

3.1.12 Useful guidance on passive systems and on the other available active systems to control seepage is provided in CIRIA document C671 – Tunnels: Inspection, assessment and maintenance.

3.1.13 The guidance in this document will cover the type of grouts used for seepage control, the pumps used to inject grout, the requirements for getting products approved by LU prior to use and guidance on the process to be followed when designing grouting system for seepage control to tunnels and structures.

3.2 Types of Grout materials

3.2.1 Grouting should 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 should be made to add the material to the register.

3.2.2 Guidelines that outline the process, requirements and evidence needed for successful acceptance of products to the list of approved products is provided in Appendix F.

3.2.3 There are a number of different types of grouts used for sealing seepage through tunnels and structures assets. The table below provides a brief summary of the typical grout materials used for seepage control in the LU environment:

Grout Type	Description	Typical Use	Life expectancy
Polyurethane - Hydrophilic	Hydrophilic resins react when in contact with water and form a flexible gel or foam. These resins utilise a high percentage of water in	1. Suited to interstitial grouting into shallow and deep brick lined tunnels and passages where voids are present and the rate	Typically 50+years

	their reaction stage and generally generate low/medium expansive pressures during reaction phase.	of seepage is modest (damp, drips or slow trickle). - Also suited to injecting into B&S and DTT brick or concrete headwalls with areas of small to modest leakage and voids. - Where gaps in the joints of bolted cast iron tunnel linings are large (greater than 10mm)	
Polyurethane - Hydrophobic	Hydrophobic resins react when in contact with water but only require only a small amount of water to allow reaction and foam formation. These types of resins can expand up to 30 times their original volume and are known as foams rather than gels. These foams can be compressible or rigid types. Hydrophobic resin foams tend to exhibit much higher expansive forces during the reaction phase. These materials are typically two component systems.	- Injected into behind brick lined tunnels and passages (tunnels and structures) to cut off high flows of water. - Can be used to inject behind the structure where voids may be present.	Typically 50+years
Acrylic	Acrylics do not usually expand but can depending on their chemical characteristics exhibit swell (approximately 5%) in contact with water after full reaction of the acrylic has occurred. Acrylics, once reacted and cured, produce an impermeable and cohesive gel. Typically these are two component products.	- Effective in sealing fine cracks in brick tunnels and structures due to the resins ultra- low viscosity. - Could be used to seal joints in segmental lined tunnels where the gaps between the joints are up to 10mm.	Typically 10-15 years
Cementitious	Consist of water and cement mix with varying viscosity to penetrate fine cracks or bulk fill voids.	Highly viscous cementitious grouts can be injected behind cast iron,	100 + Years

	The viscosity of the grout can vary to be like slurry or like a watery liquid. These grouts have negligible expansion.	concrete and brick tunnels as a void filler and to provide some degree of structural strength. 2. Low and ultra low viscosity cementitious grouts (micro fine cements) can be as a void filler and injected into concrete linings and brick tunnels and passages to seal cracks and small voids.	
Colloidal Silicates	A mineral (sand particles) grout suspension. These are used to provide stability and strength	1. Can be injected into concrete linings, brick tunnels and passages and headwalls (brick and concrete) to seal cracks and small voids	100+Years

3.3 Pumps

3.3.1 The table provides details of a selection of typical pumps that are used for injecting grouts in LU tunnels and structures:

Pump Type	How they operate	Advantages	Disadvantages
Hand Pump	- Outlet pressure is generated manually by continuous manual action to operate the piston. - Pressures are controlled by gauge at the point of injection and resistance on the lever felt by the Operative - Maximum Pressures generated – could be in excess of 100bar	- Suitable for injecting single component polyurethanes of varying viscosity. - Pump is light, easy to handle, - No external power source required. - Suitable for grouting small volumes, - Simple to maintain, can be maintained on site.	- Only suitable for low volumes, - Operator fatigue. - Could have over enthusiastic pumping leading to excessive injection pressure
Single Piston Electric Pump	- Outlet pressure is generated by electrical motor. - Pressure set by using electronic gauge and this will be the outlet pressure.	- Suitable for injecting single component grouts. - Outlet pressure that is set to the pressure at which the grout is injected into the structure.	- Requires an electrical supply. - Requires workshop maintenance.



		3. Injecting high volumes	
Diaphragm Pump	1. A diaphragm pump uses the reciprocating action of a rubber, thermoplastic or Teflon diaphragm and suitable non-return check valves to pump fluid. 2. If inlet air pressure is 4bar, then the out let pressure at point of injection will be nominally 4bar. 3. Maximum Pressures generated: Depends on the air compressor and size of the pump. 4. Pressures controlled by regulating the air inlet pressure using a pressure gauge.	1. Suitable for injecting single component Polyurethane grouts and cementitious grouts. 2. Lightweight, 3. Generally low pressures generated 4. High grouting volumes can be achieved, sensitive to pressure increase	1. Requires external air supply, 2. can only be used for pre-mixed grouts
Twin Piston Pneumatic Pump	1. Uses an air compressor to generate air pressure. 2. The inlet air pressure is regulated and fixed by the user to a value which is appropriate for the grouting operation. 3. Due to the nature of the pump design, the outlet pressure at the point of injection could typically be 20 times the inlet air pressure. For example, if the inlet air pressure is set at 4bar, then at the point of injection it could be nominally 80bar in a closed system. If the outlet pressures in the line (hoses) become equal or greater than 20 times the fixed inlet air pressure, the pistons will stop working and the pumping will stop). However there will be a stored pressure of 80bar in the outlet hoses.	1. For two component Acrylic grouts 2. Maximum pressure is regulated, 3. Suitable for high flows; 4. No operator fatigue, 5. Precise grout mixes, 6. Reduced possibility of blockages.	1. Manual handling issues, requires compressed air, requires external power source, 2. Potential to trip the 110V tunnel supply 3. Excessive grout pressures possible if Inlet air pressure is incorrectly set, 4. Requires experienced operator 5. Requires workshop maintenance.
Peristaltic Pump	1. A peristaltic pump is a type of positive displacement pump. The fluid is contained within a flexible tube fitted inside a circular pump casing. A rotor with a number of "rollers" attached to the external circumference of the rotor compresses the flexible tube. As the rotor turns, the part of tube under compression is pinched closed thus forcing the fluid to be pumped to	1. Suitable for injecting cementitious grouts. 2. Low maintenance 3. Lightweight and compact	1. Unsuitable for polyurethane grouts 2. Unsuitable for twin component grouts. 3. Medium to low grout volumes



	move through the tube.		
--	------------------------	--	--

3.4 Design of a Grouting Scheme to Control Seepage in structures and Tunnels

3.4.1 Grouting works (maintenance or project work) to control seepage in structures or tunnels should follow an engineering design process to ensure a fully assured output is produced. The standard engineering practice of; designed, checked and approved should apply to the design of **all** grouting works. However the depth and breadth of the documentation produced in the design and implementation process should be commensurate to the size, scale, complexity and risk of the grouting works. The design process which involves a number of steps will however ensure the Grouting Designer establishes the purpose and extent of the works and to determine the most appropriate material and grouting technique to be used even in the simplest maintenance seepage control works. The following sections provide guidance to the Grouting Designer on what should be considered in designing the grout system.

3.4.2 Feasibility Stage

3.4.2.1 Site Reconnaissance

3.4.2.1.1 A site visit should be carried out to inspect the site conditions. A visual inspection of the affected structures or tunnels asset should be carried by a competent person and the findings recorded in a report. The inspection should highlight the condition of the asset and try to establish the source, nature and extent of the seepage(s). It should aid the Grouting Designer/Contractor in determining other assets that may be affected, assist in planning the access/egress arrangements and to understand the requirements and possible restrictions for size of plant and equipment that could be used for the works.

3.4.2.2 Desk Top Study

3.4.2.2.1 A comprehensive desk top study should be undertaken to inform the Grouting Designer /Contractor regarding the condition of the structure, ground conditions, the construction make up of the structures, adjacent structures that might be affected and potential hidden or buried services. A search should be carried out to locate Thames Water utilities (mains and sewers) near the affected asset to understand where the source of seepage may be originating from. If grouting is to be carried out behind a structure or tunnel that is shallow, a search for building basements and third party assets in the vicinity of the grouting location (gas, telecoms) should be considered.

3.4.2.2.2 The majority of LU structures and tunnels assets have been structurally assessed and inspected and this information should be reviewed as part of the desk top study. The assessment and inspection information for B & S and DTT assets can be accessed via LU's Core Asset Information database.

3.4.2.2.3 The desktop study should also search for records of previous grouting interventions undertaken on the assets.

3.4.2.2.4 The LU asbestos register should be reviewed to check for asbestos in the work area.

3.4.2.3 Intrusive Survey

3.4.2.3.1 The outcome of the desk top study should highlight areas where information on the asset and surrounding assets are deficient. In order to fill gaps of missing information, intrusive surveys should be considered as appropriate.

Asset	Test	Reason for test
Deep Tube Tunnels and Bridges and Structures assets	Obtain samples of the water seeping through the structure	To confirm the chemical composition of the water, e.g. the pH, whether the water is mains water, groundwater or sewage. If grouting is to be used, the soluble salts in the groundwater may have undesirable effects on some grouts. It is therefore necessary to know the chemical composition and pH values of the groundwater before choosing the type of grout to be used.
Masonry structure – Deep Tube Tunnels and Bridges and Structures assets	Endoscope survey	Establish the voiding within the structure and beyond the brickwork
Masonry structure – Deep Tube Tunnels and Bridges and Structures assets	Drill through the structure	Determine the thickness of the structure.
For tunnels in station platform tunnels where the construction make up is cast iron lining, concrete infill with a plaster and paint finish	Tests on the paint	To determine to confirm the paint type (oil based or water based) and to determine the adhesion to the substrate. This may be causing the deterioration of the aesthetic appearance of the structure
Deep Tube Tunnel assets	Asbestos tests should be carried out on the caulking in the joints between the tunnel rings	Confirm the presence of asbestos
Deep Tube Tunnels and Bridges and Structures assets	Hammer tap test	To aid the Grouting Designer in identifying drummy brickwork and the condition of the brick structure and or the secondary finishes
Deep Tube Tunnels and Bridges and Structures assets	Survey to confirm clearance	To aid the designer in confirming clearances and the potential need for special monitoring to detect change (e.g. detecting movements)

3.4.2.3.2 At the end of the feasibility stage, the Designer should be able to determine the nature of the problem and the potential treatments that could be implemented to arrest/manage the seepage.

3.4.3 Development Stage

3.4.3.1 Optioneering

3.4.3.1.1 With the information gathered from the site visit, desktop study and intrusive survey, the Designer should carry out an optioneering exercise to find solutions to resolve the seepage issue. The optioneering exercise should consider:

1. The methods that could be used to control the seepage issue, e.g. face sealing, drip trays, channels, caulking, replacing bolts and grummets, grouting etc.
2. The different grout materials available to use for grouting
3. The extent of the works

4. The plant and equipment that would be used
5. The affect on other assets by the grouting works
6. The effect on secondary structures

The pro's and cons for each option should be listed and eventually one option should be established and developed as a concept design.

3.4.3.2 Concept Design

3.4.3.2.1 Once the Feasibility and optioneering exercise has been completed, the Grouting Designer will be in a position to develop and produce a grouting conceptual design statement (CDS) for approval by the LU Profession Head. The grouting conceptual design statement must be completed in accordance with S1538 – Assurance and provide the details as required in the relevant LU Civil Engineering Cat 1 Civil Engineering Standards. Appendix A provides guidance on the contents requirements for a grouting CDS.

3.4.3.3 Grouting Designers Risk Assessment

3.4.3.3.1 The Grouting Designer should develop in conjunction with the Grouting CDS, a Designer Risk Assessment (DRA) at Concept Stage.

3.4.3.3.2 The purpose of the risk assessment process is to systematically identify significant risks associated with grouting and allow the prioritisation of mitigation and controls to manage and minimise them.

3.4.3.3.3 There are a number of potential hazards associated with grouting. These are listed in table 1.

3.4.3.3.4 The generic hazard list includes the requirement to consider currently unknown behaviours and conditions. On the basis that 'what is unknown is not known' this can only be a speculative exercise. However inclusion of this in guidance, together with the intention to use the DRA to build a history of previous hazards and mitigations, should provide the best attempt to consider and evaluate hazard mechanisms that are not currently known or have not been previously experienced.

3.4.3.3.5 It is the intention that the DRA at Concept Stage is then developed by the Grouting Designer during the detailed design phase which in turn is then developed by the Contractor as part of his risk assessment for construction.

3.4.3.3.6 The DRA template for grouting works (See Appendix B) has been developed to integrate with existing LU high level risk methods and also with civil engineering asset specific methods. This includes linkage with the civil engineering asset strategic and tactical risk assessment tool (STRATA); and through this to the LU Quantified Risk Assessment, and to service loss values as defined by the NACHs tables (for further information see guidance document G1299 - Guidance on Civil Engineering Asset Strategic and Tactical Risk Models).

3.4.3.3.7 The intention of the DRA is to provide a simple and consistent method to follow grouting works through the life cycle. This will allow the risk to be understood and managed, and appropriate mitigation measures developed, to match the project stage while taking into account previous knowledge and estimates. A key feature of the DRA is that each of the generic hazards that could arise must be evaluated for risk and mitigated if appropriate, or positively discounted from analysis and mitigation. Entries such as N/A or not relevant are not acceptable without supporting justification.

3.4.3.3.8 The DRA uses defined lists for the majority of inputs (e.g. hazards, risk evaluation scales etc) and uses pre defined rules for parameters such as the level and duration of service disruption that arise from particular asset behaviours. Freeform input is permitted in general only where the entries are for project specific items such as clarification of the way in which hazards attributable to grouting will be realised in