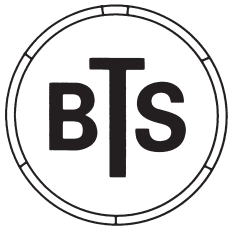
Specification for tunnelling third edition

The British Tunnelling Society and
The Institution of Civil Engineers



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100. Foreword

The *Model Specification for Tunnelling* was produced by the British Tunnelling Society in conjunction with the Ground Board of the Institution of Civil Engineers in order to establish a common standard for tunnelling and first published in 1997. It was revised in 2000, published as the *BTS Specification for Tunnelling* and has become the standard Specification referred to in the majority of tunnelling contracts in the UK and in many worldwide.

There have been many developments in construction technology and the way tunnelling contracts are arranged over recent years. The third edition seeks to include and incorporate changes which bring the specification up to date. Like the earlier editions it relies heavily on the experience of individual and corporate members of the BTS. There have been too many contributors to name individually here.

There are major changes in the section on sprayed concrete which reflect its growth in use and development of the technique. Sections dealing with new techniques such as sprayed applied waterproof membranes and jacked box tunnelling have been added. All sections have been updated to reflect best current practice, changes in national standards and the new Eurocodes. We trust that the third edition of the BTS Specification will become the standard for tunnelling contracts in coming years.

We recognise that change will continue to occur in the tunnelling industry and that it will always be possible to improve this specification. Any suggestions for improvements and amendments to future editions should be sent to the Secretary of the British Tunnelling Society at the Institution of Civil Engineers, Great George Street, London SW1P 3AA.

Third Edition Drafting Committee

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1. General requirements

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101. General notes

1. This Specification is a model document intended to serve as a basis for materials and workmanship quality requirements for tunnel projects including bored tunnels and shafts. In conjunction with the Specification component of the Institution of Civil Engineers Specification for Piling and Embedded Retaining Walls, the scope can be extended to include cut-and-cover tunnels and similar underground structures.

2. This Specification is written in modular form. It is intended that the whole document be incorporated into contract documents by reference, and additional, substituted or deleted clauses, particular to the Project included in a Particular Specification. References are made to the Particular Specification at various points in the text for the user to insert project-specific requirements. Where the Particular Specification is in conflict with the general text of the Specification, the Particular Specification shall take precedence.

3. The Specification indicates minimum standards of materials and workmanship, and is written so that the parties to the Contract are as a free as possible to agree on methods of carrying out the work.

4. Any clauses relating to work or materials not required in the project are deemed not to apply.

5. Whenever possible, reference has been made to other industry standards and accepted quasi-standards. Except where specific to the text, detailed references to Acts of Parliament and Statutory Instruments have not been made, as compliance with such documents is a legal requirement.

6. This Specification reflects tunnelling practice as practised by UK clients, contractors and designers, but has been written to allow it also to be used in an international context with the minimum of modification.

7. This Specification has been written so that it may be used with a range of procurement methods and Conditions of Contract. The title 'Engineer' has been used throughout this Specification as the person who is empowered to make decisions on design and technical matters and variations, but this title will vary between procurement methods and Conditions of Contract. The Contract Documents or Particular Specification should set out the roles and responsibilities for the particular project.

8. The title 'Designer' has been used for sprayed concrete lining works where it is essential that supervision is provided which fully understands the design basis. The 'Designer' may be

employed by the Employer or the Contractor depending on the particular project and procurement method.

9. Assessment of payment and sharing of financial risk have been specifically excluded from this Specification, this being deemed to be the province of other Contract Documents.

10. This Specification is written to be used in conjunction with other Specifications where several disciplines are involved in the works. The Particular Specification should establish the order of precedence where more than one Specification is referenced.

11. This Specification has been written on the basis that details of the Contractor's methods and temporary works will be submitted to the Engineer for agreement. The Particular Specification should clarify the requirements for the Engineer's agreement to methods and temporary works for the particular project, including timescales for review. Where the Engineer's agreement to methods and temporary works is not required, this shall be stated in the Particular Specification.

12. The planning and implementation of the works shall comply with the ABI/BTS Joint Code of Practice for Risk Management of Tunnel Works in the UK or the ITA Code of Practice for international projects.

102. Definitions

102.1. Where definitions are not provided within the specification they shall generally be those contained in BS 6100.

102.2. Definitions of tunnelling terms are contained in BS 6100: Part 2: Section 2.2: Subsection 2.2.3 (1990).

103. References to Standards

103.1. Standards and alternative standards

Standards referenced in this text are quoted with the current version as at date of publishing. Materials, equipment and methods shall comply with the Standards and Codes of Practice indicated using the versions that are current at the date for submission of tenders.

The Contractor may propose the adoption of alternative standards and shall provide explanations with any proposals. The use of such standards shall be subject to the agreement of the Engineer.

103.2. Alternative materials and equipment

The Contractor may propose alternative materials or equipment to those specified provided either:

(*a*) they are of at least equal quality and performance
or
(*b*) they are of like quality and performance and comply with approved alternative standards.

If alternative materials or equipment are proposed, the Contractor shall submit comprehensive details including technical descriptions, drawings and specifications to demonstrate that the alternative complies with either requirement of this clause. The adoption of such alternative materials or equipment shall be subject to the agreement of the Engineer.

104. Eurocodes and European and British Standards

104.1. Eurocodes

The following Eurocodes are relevant and are referred to in the text.

Eurocode 1	Basis of design and actions on structures
Eurocode 2	Design of concrete structures
Eurocode 3	Design of steel structures
Eurocode 5	Design of timber structures
Eurocode 7	Geotechnical design
Eurocode 8	Design of structures for earthquake resistance

104.2. European Standards

The following European Standards are relevant and are referred to in the text.

BS EN ISO 62:2008	Plastics. Determination of water absorption
BS EN 196:2005	Methods of testing cement
BS EN 197-1:2000	Cement. Composition, specifications and conformity criteria for common cements
BS EN 197-4:2004	Cement – Part 1: Composition, specifications and conformity criteria for common cements
BS EN 206-1:2000	Concrete – Part 1: Specification, performance, production and conformity
BS EN 295-7:1996	Requirements for vitrified clay pipes and joints for pipe jacking
BS EN 450-1:2005, A1:2007	Fly ash for concrete – Part 1: Definition, specifications and conformity criteria
BS EN 471:2003	Specification for high visibility warning clothing
BS EN 480:2006	Admixtures for concrete, mortar and grout. Test methods
BS EN ISO 527-3	Plastics. Determination of tensile properties. Test conditions for films and sheets
BS EN 681-2:2000	Elastomeric seals. Material requirements for pipe joint seals used in water and drainage applications. Thermoplastic elastomers
BS EN 771-3:12003	Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates)
BS EN 772-2:1998	Methods of test for masonry units. Determination of percentage area of voids in masonry units (by paper indentation)
BS EN 791:1996	Drill rigs – safety
BS EN 815:1997	Safety of unshielded tunnelling boring machines and rodless shaft boring machines for rock
BS EN 932-6:1999	Tests for general properties of aggregates. Definitions of repeatability and reproducibility

BS EN 933	Tests for geometrical properties of aggregates
BS EN 934-2	Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions and requirements, conformity, marking and labelling
BS EN 1008:2002	Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete
BS EN 1011-1:200	Welding. General guidance for arc welding
BS EN 1011-2:2001	Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels
BS EN 1062-7	Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete. Determination of crack bridging properties
BS EN 1097	Tests for mechanical and physical properties of aggregates
BS EN 1367:2007/8	Tests for thermal and weathering properties of aggregates
BS EN ISO 1461:2009	Hot dip galvanized coatings on fabricated iron and steel articles. Specifications and test methods
BS EN 1537:2000	Execution of special geotechnical work – rock anchors
BS EN 1542:1999	Products and systems for the protection and repair of concrete structures. Test methods. Measurement of bond strength by pull-off
BS EN 1562:1997	Specification for malleable cast iron
BS EN 1563:1997	Founding. Spheroidal graphite cast iron
BS EN 1744	Tests for chemical properties of aggregates
BS EN 1849-2:2001	Flexible sheets for waterproofing. Determination of thickness and mass per unit area. Plastic and rubber sheets for roof waterproofing
BS EN 1916:2009	Limits and fits for engineering. Guide to limits and tolerances
BS EN 1928:2000	Flexible sheets for waterproofing. Bitumen, plastic and rubber sheets for roof waterproofing. Determination of watertightness
BS EN ISO 3506-2: 1998	Mechanical properties of corrosion-resistant stainless-steel fasteners. Nuts
BS EN ISO 4624:2003	Paints and varnishes. Pull-off test for adhesion
BS EN ISO 9001	Quality management systems. Requirements
BS EN 10025:2004	Hot rolled products of structural steels. Technical delivery conditions
BS EN 10080:2005	Steel for the reinforcement of concrete. Weldable reinforcing steel. General
BS EN 10164:2004	Steel products with improved deformation properties perpendicular to the surface of the product – technical delivery conditions

BS EN ISO 11925-2: 2002	Reaction to fire tests. Ignitability of building products subjected to direct impingement of flame. Single-flame source test
BS EN 12110:2002	Tunnelling machines – Air locks – Safety requirements
BS EN 12111:2002	Tunnelling machines – Roadheaders, continuous miners and impact rippers – Safety requirements
BS EN 12310-2:2000	Flexible sheets for waterproofing. Determination of resistance to tearing (nail shank). Plastic and rubber sheets for roof waterproofing
BS EN 12317-2:2000	Flexible sheets for waterproofing. Plastic and rubber sheets for roof waterproofing
BS EN 12336:2005	Tunnelling machines – shield machines, thrustboring machines, lining erection equipment – Safety requirements
BS EN 12350	Testing fresh concrete
BS EN 12390	Testing hardened concrete
BS EN 12504-1	Testing concrete in structures – Part 1: Cored specimens – Testing, examining and testing in compression
BS EN 12588:1999	Lead and lead alloys. Rolled lead sheet for building purposes
BS EN 12620:2002	Aggregates for concrete
BS EN 12878:2005	Pigments for the colouring of building materials based on cement and/or lime. Specifications and methods of test
BS EN 12889:2000	Trenchless construction and testing of drains and sewers
BS EN 13055-1:2005	Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout
BS EN 13139:2002	Aggregates for mortar
BS EN 13263-1:2005	Silica fume for concrete – Part 1: Definitions, requirements and conformity criteria
BS EN 13492:2004 (E)	Geosynthetic barriers – Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures
ENV* 13670-1:2000	Execution of concrete structures
BS EN 13791	Assessment of in-situ compressive strength in structures and pre-cast concrete components
BS EN 14487-1	Sprayed concrete – Part 1: Definitions, specifications and conformity
BS EN 14487-2	Sprayed concrete – Part 2: Execution
BS EN 14488-1	Testing sprayed concrete – Part 1: Sampling fresh and hardened concrete
BS EN 14488-2	Testing sprayed concrete – Part 2: Compressive strength of young sprayed concrete
BS EN 14488-3	Testing sprayed concrete – Part 3: Flexural strengths (first peak, ultimate and residual) of fibre reinforced beam specimens
BS EN 14488-4	Testing sprayed concrete – Part 4: Bond strength of cores by direct tension

BS EN 14488-5	Testing sprayed concrete – Part 5: Determination of energy absorption capacity of fibre reinforced slab specimens
BS EN 14488-7	Testing sprayed concrete – Part 7: Fibre content of fibre reinforced concrete
BS EN 14889-1	Fibres for concrete – Part 1: Steel fibres. Definitions, specifications and conformity
BS EN 14889-2	Fibres for concrete – Part 2: Polymer fibres. Definitions, specifications and conformity
BS EN 15167-1:2006	Ground granulated blastfurnace slag for use in concrete, mortar and grout – definitions, specifications and conformity criteria
BS EN 60204:2006	Safety of machinery. Electrical equipment of machines
BS EN 61672-1:2003	Electroacoustics. Sound level meters. Specifications
DD CEN/TS 14416	Geosynthetic barriers. Test method for determining the resistance to roots
PD CLC/TR 50426: 2004	Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation. Guide
*ENV	Standards in draft for development. It is expected that full validated standards will be issued shortly

104.3. British Standards

The following British Standards are relevant and are referred to in the text.

Number	*Short title*
BS 21:1985	Pipe threads for tubes and fittings where pressure tight joints are made on threads
BS 143:1986	Threaded pipe fittings in malleable cast iron and cast copper alloy
BS 1134:1988	Method for the assessment of surface texture, Part 1
BS 1256:2006	Threaded pipe fittings in malleable cast iron and cast copper alloy
BS 4190:2001	ISO metric black hexagon bolts, screws and nuts. Specification
BS 4449:2005	Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product
BS 4482:2005	Steel wire for the reinforcement of concrete products. Specification
BS 4483:2005	Steel fabric for the reinforcement of concrete
BS 4921:1988	Specification for sherardized coatings on iron or steel
BS 5228-1:2009	Code of practice for noise and vibration control on construction and open sites. Noise

BS 5228-2:2009	Code of practice for noise and vibration control on construction and open sites. Vibration
BS 5268	Structural use of timber
BS 5400-6:1999	Steel, concrete and composite bridges. Specification for materials and workmanship, steel
BS 5607:1998	Code of practice for the safe use of explosives in the construction industry
BS 5911-1	Concrete pipes and ancillary concrete products. Specification for unreinforced and reinforced concrete pipes (including jacking pipes) and fittings with flexible joints (complementary to BS EN 1916:2002)
BS 5950-2:2001	Structural use of steelwork in building. Specification for materials, fabrication and erection – Rolled and welded sections
BS 5975:2008	Code of practice for temporary works procedures and the permissible stress design of falsework
BS 6100	Glossary of building and civil engineering items (various dates)
BS 6164:2001	Code of practice for safety in tunnelling in the construction industry
BS 6319	Testing of resin and polymer cement compositions for use in construction (various dates)
BS 6472:2008	Guide to evaluation of human exposure to vibration in buildings (1–80 Hz)
BS 7385-1:1990	Evaluation and measurement for vibration in buildings. Guide for measurement of vibrations and evaluation of their effects on buildings (Part 1)
BS 7385-2:1993	Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration (Part 2)
BS 7668:2004	Weldable structural steels. Hot finished structural hollow sections in weather resistant steels. Specification
BS 7671:2008	Requirements for electrical installations. IEE Wiring Regulations
BS 7973-1:2001	Spacers and chairs for steel reinforcement and their specification. Product performance requirements
BS 7973-2:2001	Spacers and chairs for steel reinforcement and their specification. Fixing and application of spacers and chairs and tying of reinforcement
BS 7979:2001	Specification for limestone fines for use with Portland cement
BS 8081:1989	Code of practice for rock anchors
BS 8102:1990	Code of practice for protection of structures against water from the ground
BS 8500-1:2006	Concrete – Complementary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier

BS 8500-2:2006	Concrete. Complementary British Standard to BS EN 206-1. Specification for constituent materials and concrete
BS 8666:2005	Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete. Specification

105. Other standards and documents

105.1. Standards referred to in the text

Swedish Standard

SIS 005900 SA 215 Grit blasting

German Standards: DIN

1048 Testing of concrete

4062 Cold processable plastic jointing materials for sewer-drains; jointing materials for prefabricated parts of concrete, requirements, testing and processing

16726 Plastic roofing felt and waterproofing sheet; testing

16776 Plastic moulding materials; polyethylene (PE) moulding materials; preparation of specimens and determination of their properties

53352 Testing of artificial leather and similar sheet materials; determination of mass per unit area

53363 Testing of plastic films; tear propagation test on trapezoidal specimens with a split

53370 Testing of plastic films; determination of the thickness by mechanical feeling

53377 Testing of plastic films; determination of dimensional stability

53387 Artificial weathering and ageing of plastics and elastomers by exposure to filtered xenon arc radiation

53455 Testing of plastics; tensile test

53457 Testing of plastics; determination of the elastic modulus by tensile, compression and bend testing

53479 Testing of plastics and elastomers; determination of density

53488 Testing of plastic sheets; hole test

53515 Determination of tear strength of rubber elastomers and plastic film using Graves angle test piece with nick

53521 Determination of the behaviour of rubber and elastomers when exposed to fluids and vapours

53532 Testing of elastomers; determination of permeability of elastomer sheetings to liquids

53739 Testing of plastics; influence of fungi and bacteria; visual evaluation; change in mass or physical properties

53861 Testing of textiles; vaulting test and bursting test; definitions of term

American Standards: ASTM

A820 A standard specification for steel fibers for fiber reinforced concrete

A569 Steel plate for liner plates

ACI 506R-05 Guide to shotcrete

D1693 Chemical resistance

105.2. Documents referred to in the text

1. Building Research Establishment Digest 330 *Alkali–silica reaction in concrete (2004 edition) – Simplified guidance for new construction using normal reactivity aggregates*, 2004

2. Concrete Society Technical Report No. 31 *Permeability of site concrete*, 2008

3. Health and Safety Executive Guidance Note EH 40 *Occupational exposure limits*

4. Pipe Jacking Association *Guide to best practice for the installation of pipe jacks and microtunnels*

5. Concrete Pipe Association *Concrete pipes for jacking small diameters (microtunnel) and unreinforced pipes*

6. CIRIA Report C515 *Groundwater control – design and practice*, London, 2000

7. International Society for Rock Mechanics – Document 2 Part 1 *Suggested methods of rockbolt testing*

8. German Concrete Association *Design principles of steel fibre reinforced concrete for tunnelling works 1992. Translation of DBV-Merblatter Faserbeton – Technologie des Stahlfaserbetons und Stahlfaser Spritzbetons –Bemessungrundlagen fur Stahlfaserbeton im Tunnelbau*

9. The Japan Society of Civil Engineers *SF4 Method of tests for flexural strength and flexural toughness of steel fiber reinforced concrete, Part 111-2 Method of tests for steel fiber reinforced concrete*, JSCE, 1984

10. The Concrete Society Technical Report No. 63, *Guidance for the design of Steel-Fibre-Reinforced Concrete*

11. Allenby, D. and Ropkins, J.W.T. IMechE lecture paper, 17 October 2007, London. *Jacked Box Tunnelling Using the Ropkins System™, a non-intrusive tunnelling technique for constructing new underbridges beneath existing traffic arteries*

12. BRE Special Digest 1 *Concrete in aggressive ground, 3rd edition*, London, 2006

13. British Constructional Steelwork Association *National Structural Steelwork Specification for Building Construction 5th Edition*, London, 2007

14. British Tunnelling Society *The Management of Hand–Arm Vibration in Tunnelling Guide to Good Practice*, London, 2006

15. British Tunnelling Society *Occupational Exposure to Nitrogen Monoxide in a Tunnel Environment by the BTS Best Practice Guide*, London, 2008

16. Institution of Civil Engineers *Specification for Piling and Embedded Retaining Walls 2nd edition*, The Federation of Piling Specialists in association with BGA and ICE, Thomas Telford, London, 2007

17. Association of British Insurers/International Tunnelling Association *The Joint Code of Practice for Risk Management of Tunnel Works in the UK* British Tunnelling Society, 2003

18. International Tunnel Insurance Group *A Code of Practice for Risk Management of Tunnel Works* 2006

19. Health and Safety Executive *Work in Compressed Air Regulations 1996* SI No. 1656, HMSO

20. Health and Safety Executive *A Guide to the Work in Compressed Air Regulations 1996*, HSE, Sudbury, 1996

21. Health and Safety Executive *Safe use of vehicles on construction sites: A guide for clients, designers, contractors, managers and workers involved with construction transport* Guidance booklet 144 HSE, Sudbury, 2009

22. Department for Transport Traffic safety measures and signs for road works and temporary situations. Design, In *Traffic Signs Manual*, Ch. 8-1, 2nd edition. DoT, London, 2009

106. General provisions

The general provisions of the Contract shall be as stated in the Particular Specification.

This would normally include at least the following items:

1. Health, safety and environment

2. Site areas

3. Survey

4. Fencing

5. Levels and reference points

6. Site accommodation

7. Public relations

8. Property interference

9. Protection against damage

10. Services

11. Traffic

12. Emergency arrangements

13. Publicity

14. Access to site

15. Environmental impact

16. Site working hours

17. Security arrangements

107. Occupational health, safety and welfare

107.1. The Contractor shall adopt safe systems of work which minimise the risk to health and safety. All persons working on the site shall be competent to carry out their tasks and duties safely and in a manner that will not endanger their own health nor the health of others. Persons, when first employed on the site, shall be subject to appropriate pre-employment occupational health checks, instructed on the hazards inherent in the site, precautions to be taken, the form of construction, and emergency procedures and fire safety. Such instructions shall be given whenever there is a material change in the working arrangements. The Contractor shall maintain a record of all persons instructed and each person shall be required to sign such record confirming that instruction has been received. No person shall be permitted on site without being inducted as set out above. The Contractor shall prepare a written statement of Safe Systems of Working which shall be issued to all persons at site.

107.2. All parties shall comply with the Health and Safety at Work etc. Act 1974, the Construction (Design and Management) Regulations 2007, the Work in Compressed Air Regulations 1996 and the other relevant statutory provisions as appropriate.

They shall also comply with the requirements and recommendations of:

BS 6164	Code of practice for safety in tunnelling in the construction industry
BS EN 815	Safety of unshielded tunnel boring machines and rodless shaft boring machines for rock
BS EN 12336	Tunnelling machines – Shield machines, thrust-boring machines, lining erection equipment – Safety requirements
BS EN 12110	Tunnelling machines – Air locks – Safety requirements
BS EN 12111	Tunnelling machines – roadheaders, continuous miners and impact hammers – safety requirements
BS 7671	Regulations for electrical installations (IEE Wiring Regulations)

107.3. The Contractor shall also comply with the requirements of the Employer's codes of practice for safe working and those of any authority or body where their services or property are affected by the works.

107.4. All safety and emergency procedure training shall be reinforced by regular practice drills.

107.5. A person responsible for Safety shall be appointed by the Contractor and this person shall be conversant with corporate policy,

management operational instructions, regulations, legislation and current best practice and how these relate to health, safety and welfare. Compliance with health and safety requirements is the responsibility of managers and individuals at each and every level.

107.6. The Contractor shall establish on site:

1. Welfare and first aid facilities with appropriately trained personnel, both on the surface and underground, as required by the scale of the Works. Welfare facilities shall include toilet and washing facilities. Where water washing facilities cannot be provided, appropriate alternative means of hand cleaning shall be provided. Barrier creams etc. for skin protection shall also be provided.

2. Occupational health facilities on the surface, staffed by appropriate occupational health professionals as required by the nature and scale of the Works.

3. Equipment for the rescue and evacuation of persons underground with persons instructed in its use.

4. All necessary equipment, safety barriers, notices and the like for the protection of persons.

5. Procedures to ensure that all plant and equipment underground is fitted with on-board fixed fire-extinguishing equipment covering fluid tanks, motors or engine compartments and tyres along with the use of reduced flammability (HFDU) hydraulic fluid.

6. Comprehensive fire detection and fire fighting facilities.

7. Sufficient chemical or compressed oxygen self-rescuer sets for all persons underground in accordance with HSE guidance.

8. A competent safety officer shall be appointed by the Contractor who shall be conversant with the hazards associated with the form of construction to be undertaken and who shall be responsible for ensuring compliance with all management directives, rules and regulations concerning occupational health and safety.

9. Subject to any legal requirement or requirement of the Employer and the size and nature of the Works, the Contractor may appoint a visiting competent safety officer under item (8) above. He shall visit the site at the start of operations and for changes in methods of working, but in any event his visits shall not be at greater intervals than one month.

108. Quality Management and records

108.1. Quality Management System

1. The project shall be administered using an accredited Quality Management System conforming to BS EN ISO 9001. The individual requirements for agreement by the Engineer of materials and workmanship throughout this Specification shall be incorporated into agreed self-certification procedures.

2. The agreed Quality Control arrangements, including hold points and submission of records for the Engineer's acceptance, shall be set out in agreed Inspection and Test Plans.

108.2. Engineer's agreement

1. References to the agreement of materials, workmanship, methods etc. throughout this Specification shall be interpreted as requiring the agreement of the Engineer.

108.3. Site records

1. The Contractor shall maintain all records necessary under this Specification, including quality records as appropriate.

2. Electronic records shall be maintained and backed up on a daily basis to prevent loss of data in the event of failure of electronic data storage.

3. Copies of all site records shall be available to the Engineer.

108.4. As-built records

1. The Contractor shall supply the Engineer with all information necessary for the Health and Safety File including as-built drawings and records, maintenance schedules, operation and maintenance manuals, within the time specified in the contract, after substantial completion of the Works. Information shall be provided in the agreed format. The Health and Safety File shall be prepared by the party identified in the Contract.

2. Materials

200. Standards

200.1. All materials supplied to the Works shall conform to all of the following:

(*a*) This Specification.
(*b*) The appropriate British or European Standard.
(*c*) Where an industry certification scheme is available, material supplied shall be supplied in accordance with that scheme.
(*d*) Materials shall be supplied from a quality assured source, operating a Quality Assurance system in compliance with the relevant part of BS EN ISO 9001.

200.2. Where required in the Particular Specification or were stated on the Drawings, samples should be supplied and the subsequent material shall conform to the samples.

200.3. Materials used on site shall be used in accordance with the manufacturer's recommendations and instructions.

200.4. All materials should be handled and stored in a way to maintain their integrity and to avoid damage and degradation.

200.5. Details of the level of inspection and testing to be adopted in respect of supplied materials shall be agreed with the Engineer prior to commencement of work. Individual submissions are then restricted to those required by the Quality System.

201. Concrete

201.1. General

1. All concrete shall be produced in accordance with BS EN 206 and BS 8500 unless where otherwise provided for in the Contract.

2. Where concrete is to be placed in aggressive ground, appropriate ground investigation shall be undertaken to identify the nature of the chemical composition of groundwater and ground. The concrete, cast in situ or precast, shall comply with BRE Special Digest 1.

201.2. Constituent materials – cement

1. Cement and cementitious materials shall comply with the relevant British Standards, as detailed in BS 8500-2 Table 1.

2. The Contractor shall submit cement and cementitious material manufacturers' certificates in accordance with the relevant British Standard. Details of all cements and cementitious materials shall be supplied including any alternative sources that might be used. The Contractor shall show that the quantity and quality required can be attained and maintained throughout the construction period.

3. CEM I will comply with BS EN 197.

4. Where Sulphate resistance is required, the selected cement will be appropriate to the required Design Chemical (DC) class.

5. Where specified or appropriate to use, blast furnace cements, Portland slag cements and blended ground granulated blast furnace slag (ggbs) cements will comply with the blending proportions specified in BS 8500-2.

6. Where specified or appropriate to use, Portland fly ash cements and blended fly ash cements will comply with the blending proportions specified in BS 8500-2.

7. Where specified or appropriate to use, Portland limestone cements and blended limestone cements will comply with the blending proportions specified in BS 8500-2.

8. Cementitious materials shall have a reactive alkali content not exceeding a value of 0.6% by mass and/or the total mass of reactive alkali in the mix shall be calculated and controlled to satisfy the requirements of BS 8500-2 and the British Research Establishment (BRE) Digest 330. Certification will be supplied by the producer to demonstrate compliance with BRE Digest 330.

9. Cementitious materials shall be delivered in bulk or in sealed and marked bags, and shall be protected from the weather by enclosed transfer systems or other approved coverings.

Cements which have exceeded the manufacturer's designated shelf life will not be used, and appropriate measures shall be taken for its safe disposal or return to the manufacturer.

201.3. Constituent materials – aggregates

1. Aggregates shall conform to BS 8500-2. The Contractor shall obtain the agreement of the Engineer for the proposed aggregate sources, and shall demonstrate compliance with laboratory tests that shall be made at regular intervals to confirm the suitability of aggregate.

(*a*) normal and heavyweight aggregates shall conform to BS EN 12620
(*b*) lightweight aggregates shall conform to BS EN 13055-1
(*c*) coarse recycled concrete aggregate (RCA) shall conform to BS 8500-2.

2. Aggregate shall be free from earth, clay, loam and soft, clayey, shaley or decomposed stone, organic matter and other impurities and shall be hard and dense.

3. Aggregates shall not contain any other matter likely to affect the long-term durability of the concrete. Reference is to be made to the BRE Digest 330 for guidance in reducing the risk of deleterious alkali–silica reaction to the absolute minimum.

4. Tests shall be carried out in accordance with British Standards, as appropriate, and the results shall comply with the limits given therein, or as otherwise specified. Testing will be carried out to BS EN 932, BS EN 933, BS EN 1097 and BS EN 1744 as appropriate.

5. Crushed sand may be added to natural sand in approved proportions in order to achieve the required grading. When tested, the resultant material will comply with BS EN 12620.

6. Sand for mortars and grouts shall comply with BS EN 13139.

7. Coarse aggregate shall be as defined in BS EN 12620.

8. Coarse aggregate shall be tested for drying shrinkage characteristics in accordance with BS EN 1367-4. The drying shrinkage shall not exceed 0.075%.

9. The acid-soluble sulphate (SO_3) level shall not exceed the values specified in BS EN 12620.

10. The maximum permitted level of equivalent acid-soluble chloride ions (Cl^-) for any single constituent or combination of the constituents of the concrete in the hardened mix shall not exceed the limits given in BS EN 206-1.

11. The total estimated sulphate content (SO_3) shall comply with the limits given in BS EN 206-1.

12. Hardness and abrasion characteristics of the aggregate will comply with BS EN 12620.

13. Water absorption shall not exceed the permitted value in BS EN 12620.

14. Where specific thermal characteristics of the mix are required, the aggregate will be appropriately selected and tested in accordance with BS EN 1367.

15. Each size of aggregate shall be stored separately in drained concrete-based bins or on stages to prevent intermixing and the inclusion of foreign materials.

201.4. Constituent materials – water

1. Water to be used for mixing and curing concrete and mortar shall be fresh and free from sediment and dissolved or suspended matter which may be harmful and shall comply with the requirements of BS EN 206.

2. Recycled water may be used provided controls are in place to demonstrate compliance with BS EN 206.

201.5. Constituent materials – admixtures

1. Water-reducing admixtures in liquid form shall comply with BS EN 206 and BS EN 934.

2. Unless specified in the Contract, the use of set-retarding and water-reducing admixtures shall be subject to the agreement of the Engineer.

3. Admixtures not covered by BS EN standards will not be used.

201.6. Constituent materials – fibres

1. Fibres are generally accepted for use in concrete conforming to BS EN 206-1 and BS 8500 if the fibre conforms to BS EN 14889, a European Technical Approval or British Board of Agrément (BBA) certification.

2. Fibre-reinforced concrete will be trialled and tested to ensure it meets the designers' requirements before inclusion in the works. Historical data of the same fibre and dosage will be accepted in place of trials provided the data are deemed appropriate.

201.7. Constituent materials – additions

1. General suitability as a Type II addition is established for the following:

   (*a*) fly ash conforming to BS EN 450-1
   (*b*) silica fume conforming to BS EN 13263-1
   (*c*) ggbs conforming to BS EN 15167-1
   (*d*) metakaolin with an appropriate Agrément certificate.

2. General suitability as a Type I addition is established for the following:

   (*a*) filler aggregate conforming to BS EN 12620 or BS EN 13055-1
   (*b*) pigments conforming to BS EN 12878.

   General suitability of limestone fines conforming to BS 7979 is established for use in combinations conforming to BS 8500-2 Annex A.

201.8. Concrete mixes

1. The grade and properties of the concrete used in each part of the work shall be as stated on the Drawings or in the Particular Specification and shall be in accordance with BS 8500.

2. The selection design and quality control of mixes shall be carried out by the Contractor or on his behalf by the manufacturer.

3. If the finish of the concrete is required to be of a controlled or superior standard then trial panels will be manufactured 35 days in advance of the Works starting and the finish achieved will be approved by the Engineer before commencing work. The panel will be retained during the course of the Works to use as a comparative measure for the Works.

4. If existing data on materials and properties of trial concrete mixes are not available, preliminary laboratory tests shall be carried out to establish the mixes to satisfy the Specification with the available materials.

5. Laboratory trial mixes shall be tested to determine compliance with BS 8500 for all the required properties of the mix.

6. Unless otherwise agreed with the Engineer, field trial mixes shall be prepared under full-scale site conditions at least 35 days before the commencement of concreting and tested in accordance with BS EN 12350 and BS EN 12390.

7. The field trial mixes shall be tested to determine compliance under statistical evaluation where required by BS EN 206. An acceptable value for the limits of the required properties shall be established during the trials which shall thereafter be used to monitor the Quality Control of the mixes and set the standard of compliance.

201.9. Ready-mixed concrete

1. Use of ready-mixed concrete and its source shall be subject to the prior agreement of the Engineer, and the Contractor shall use only third-party accredited Quality Assured Companies.

2. Water shall not be added to concrete in a truck mixer drum other than at the batching plant, unless approved by the Engineer in a controlled manner under the supervision of the producer's representative and recorded on the delivery note. The mix shall be continuously agitated during transportation.

3. The transportation and placing times of ready-mixed concrete shall be reviewed in relation to all the circumstances including travel distance and risk of traffic delays *en route*. Unless special measures are taken, the concrete will be placed in the works within 2 hours after addition of the water to the cement. The time between consecutive loads finishing placing and starting placing shall not exceed 30 minutes.

4. The Contractor shall provide certificates to demonstrate compliance of each component of the mix with the relevant clauses of the specification. The delivery note for each batch shall state the designation of the concrete mix, the type of cement and minimum cement content, the maximum aggregate size, the

workability class of the mix, the chemical exposure class of the concrete, the admixtures used, the time at which the concrete was mixed and the weight of the constituents of each mix along with any other specified requirements.

5. Concrete temperature at the time of delivery, when measured in accordance with BS 8500, shall not exceed any value specified by the Engineer in the contract, or 35°C.

201.10. Concrete batching

1. Production control of concrete will satisfy the requirements of BS EN 206 and BS 8500-2.

2. All constituents will be weighed or metered in accordance with the limits prescribed in BS EN 206.

3. Admixtures shall only be introduced using purpose-made equipment accurately calibrated. Where such equipment is unavailable, and where agreed with the Engineer, alternative dosing methods to the manufacturer's recommendations may be adopted.

4. Water shall not be added to concrete after it has left the mixer unless controlled, recorded and agreed with the Engineer.

5. Materials shall not be heated unless agreed with the Engineer.

6. Where fibre reinforcement is added to the concrete mix, this shall only be introduced using purpose-made equipment.

201.11. Quality control

1. The Contractor shall plan all concrete Quality Management procedures in accordance with Section 200.5.

2. The conformity control of strength parameters required, will be demonstrated in accordance with BS EN 206-1. Specimens tested to demonstrate compliance will be cubes, cylinders or prisms appropriate to the testing standards and BS EN 206-1.

3. Test samples shall be made, cured, stored, transported and tested to BS EN 12350 and BS EN 12390. Spot samples will not be used to evaluate strength parameters.

4. Concrete cube test results will be acceptable if statistical analysis of the results meets the requirements of BS EN 206-1.

5. Concrete shall be tested for durability properties by means of absorption and capillary suction (sorptivity) tests where appropriate. An appropriate test method will be agreed by all parties before testing is undertaken.

6. Compaction factor, slump, Vebe, flow table or other workability tests shall be carried out as required during concreting of permanent works to control workability at the batching plant and at the site of the pour. The degree of workability shall be as specified or as determined during the trial mixes; permitted tolerances shall be in accordance with BS EN 206. Samples tested will be either spot samples or composite samples taken in accordance with BS EN 12350-1 and the appropriate tolerances for compliance will be applied in each case.

202. Reinforcement

202.1. Bar reinforcement

1. Reinforcement for use in reinforced concrete shall comply where appropriate with BS 4449, 4482, 4483 and BS EN 10080.

2. Reinforcement shall be obtained from a Certificated Authority for Reinforcing Steels (CARES) Quality Assurance approved supplier and the Contractor shall provide copies of the manufacturer's certificates of test results relating to the steel reinforcement to be supplied.

3. Reinforcement shall be stored in an approved manner above ground under cover and racked as necessary for protection from aggressive elements.

4. Steel reinforcement shall be cut and bent in accordance with BS 8666.

5. Tying wire shall be 1.6 mm diameter soft annealed mild steel, and when fixed shall not project into the concrete cover.

6. Where the Contract so requires, the Contractor shall produce bending schedules, prepared in accordance with BS 8666.

202.2. Welded wire fabric

1. Welded wire fabric shall comprise hard-drawn wire in accordance with BS 4482 and BS 4483. It shall be firmly fixed in place using an agreed method. Overlap between adjacent sheets of welded wire fabric shall be a minimum of 2 squares.

202.3. Fibre reinforcement

1. Fibre reinforcement shall be obtained from a supplier meeting the requirements of BS EN ISO 9001 or similar.

2. Steel fibres can be deformed steel fibre in accordance with BS EN 14889-1 either from mild steel or cold-drawn steel. Fibres in accordance with ASTM A820 may be used with the approval of the Engineer.

3. Structural, macro-synthetic fibres shall be in accordance with BS EN 14889-2. Only Class II fibres shall be used where fibres are incorporated for structural purposes.

4. Alternative fibres may be utilised following successful completion of proving trials which meet the Designer's performance requirements.

5. Fibres shall be stored, handled and dosed in accordance with the manufacturer's recommendations. Generally this will require them to be stored in dry, sealed containers until ready for use and shall be free from corrosion, oil, grease, chlorides, and deleterious materials which may reduce the efficiency of mixing or spraying processes, or which may reduce bond between the fibres and the sprayed concrete.

6. Fibres shall have an aspect ratio in the range 30–150 for lengths of 12.7–63.5 mm. Tolerances shall be in accordance with BS EN 14889.

7. The minimum tensile strength for steel fibres is 800 MPa and for macro-synthetic fibres 500 MPa.

203. Precast concrete linings

203.1. General

1. Precast concrete segments for linings shall be supplied by the Contractor from an agreed manufacturer, or manufactured in a purpose-built factory, for erection in the Works in accordance with the Contract requirements.

2. Segments of the lining shall be designed to withstand handling, storing and erection stresses as well as permanent loads. The Contractor shall provide to the Engineer copies of calculations and drawings to demonstrate adequacy of the designs.

3. Lining segments may be cast in existing moulds and be a manufacturer's standard design or be a particular design to suit the requirements of the project and tunnelling plant.

4. Concrete shall be in accordance with Section 201, of minimum strength class C40/50.

5. Reinforcement shall be in accordance with Section 202. Cages may be formed by welding or tying.

203.2. Manufacture of segments

1. Manufacturing facilities for segmental lining systems will be required to show:

   (*a*) A certified Quality Assurance and control programme to BS EN ISO 9001 approved by the Engineer
   (*b*) compliance with British Standards regarding materials, mixing and placing, curing and storing of concrete constituents, concrete segments and fixings.

2. The manufacturer's premises and methods shall be open to inspection by the Engineer for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance is provided to the Engineer on each visit.

203.3. Moulds

1. Moulds shall be robustly constructed, tightly jointed and properly maintained such that the dimensions of the segments are always within the specified tolerances.

2. Where new moulds are being manufactured for the particular project, the fabrication drawings shall be submitted to the Engineer for agreement.

3. Details of the moulds to be used for casting concrete segments shall be supplied to the Engineer for his agreement before prototype segments are cast. Trial segments may be made for the Engineer's inspection. Samples shall be marked indelibly and set aside for reference purposes.

203.4. Tolerances for the manufacture of bolted segments

203.4.1. Segments

Dimensions of individual precast concrete special segments shall be within the following tolerances:

(*a*) circumferential length	±1 mm
(*b*) thickness	+3 mm, −1.5 mm
(*c*) width	±1 mm
(*d*) square	diagonal dimension ±1 mm from theoretical dimension
(*e*) bolt holes: size	+1 mm, −0.2 mm
(*f*) bolt holes and dowel position	1 mm
(*g*) sealing gasket groove: depth	+0.5 mm, −0.0 mm
(*h*) sealing gasket groove: width	±0.5 mm
(*i*) sealing gasket groove: position	±1.5 mm from specified position
(*j*) longitudinal joints	
in a plane generally along the axis of the tunnel (longitudinal)	0.3 mm from theoretical plane with rate of deviation not exceeding 0.6 mm/m
in a radial plane	0.1 mm from theoretical plane with rate of deviation not exceeding 0.6 mm/m
(*k*) circumferential faces	0.5 mm from theoretical plane with rate of deviation not exceeding 1 mm/m
(*l*) smoothness of other faces	
back face	smooth float ±1.5 mm
front face	formed face ±1 mm
(*m*) mismatch of sealing groove at corners	<0.5 mm

203.4.2. Rings

At least two test rings shall be erected on a flat and level base, in a form and sequence representative of the construction arrangement to be agreed with the Engineer. All designed longitudinal packings are to be removed from both rings. The following dimensions shall be checked:

(*a*) internal diameter (adjusted for packer removal where necessary)	±0.2% ID or 6 mm maximum
(*b*) lip between adjacent segments on internal diameter	<3 mm
(*c*) gap between longitudinal segment joints (packings removed and bolts tightened)	1 mm feeler gauge not passing

203.5. Tolerances for the manufacture of expanded segments

203.5.1. Segments

Dimensions of individual precast concrete segments shall be within the following tolerances:

(*a*)	circumferential length	±1.0 mm
(*b*)	segment thickness (on backs)	±1.5 mm
(*c*)	width	±1.5 mm
(*d*)	regularity of surfaces:	

straight edge applied in any position parallel to axis of ring on extrados, intrados and cross-joint faces, and normal to axis on longitudinal joint and cross-joint

joints:	0.25 mm feeler gauge not passing
extrados; intrados:	1.25 mm feeler gauge not passing

203.5.2. Rings

At least two test rings shall be erected on a flat and level base, in a form and sequence representative of the construction arrangement to be agreed with the Engineer. All designed longitudinal packings are to be removed from both rings. The following dimensions shall be checked:

(*a*)	internal diameter with key in its design location	0.2% ID or 6 mm maximum
(*b*)	lip between adjacent segments on internal diameter	1.5 mm
(*c*)	gap between longitudinal segment joints	0.5 mm feeler gauge not passing

203.6. Opening sets

Special rings and opening sets shall be built as a complete set to the tolerances specified in clause 203.6 unless agreed otherwise with the Engineer. The first ring of a special set shall also be built on the test ring.

203.7. Marking of segments

As a minimum all segments except solid key shall have marked with indented upper case lettering the following information on the inner face:

(*a*) internal diameter of lining
(*b*) type of segment referenced to the detailed drawings
(*c*) a unique mould identification any special information to indicate the position or orientation of the segment in the ring
(*d*) the weight of segment in kilograms
(*e*) date of casting.

203.8. Joint packing

Where shown on the drawings a minimum 2 mm thick strip of stress distribution packing is to be incorporated in each longitudinal joint covering at least 80% of the joint surface area. The packing shall be in accordance with Section 214.

203.9. Gasket grooves

Where shown on the Drawings, gasket grooves shall be provided around all joint faces of each segment and key in accordance with the dimensions recommended by the gasket manufacturer.

203.10. Concrete cover

1. Concrete cover shall be as stated on the Drawings or in the Particular Specification.

2. Precast segmental lining systems shall be designed in accordance with BS 8500-1 for cover and concrete mix requirements.

203.11. Grout holes

Where specified, grout holes shall be provided in every segment excluding the key, and shall be a nominal 50 mm diameter or greater. They shall be either plain or threaded, and provided with a non-return valve.

203.12. Curing

Segments shall be cured in accordance with the provisions of ENV 13670-1.

203.13. Handling stacking and transport

1. The method of lifting and handling, the type of equipment and method of transport shall not damage the segments. Segments are to be stacked in a manner approved by the Engineer.

2. Segments shall not be transported to site or incorporated into the works until they have achieved the 28-day compressive characteristic strength, and in the case of fibre-reinforced segments their flexural or tensile strengths.

3. If the grout hole is to be used for segment handling, the contractor shall ensure that this has been catered for in the design.

203.14. Segments reinforced with steel fibres

1. Steel fibre reinforcement shall comply with Section 202.3.

2. Steel-fibre-reinforced concrete shall generally be designed to Technical Report No. 63 *Guidance for the design of steel-fibre-reinforced concrete* (The Concrete Society).

3. Fibre type and dosage shall be selected such that the performance requirements specified on the Drawings or in the Particular Specification are achieved. This shall be demonstrated by laboratory trials undertaken and agreed with the Engineer prior to commencement of segment casting.

4. Fibre type and dosage shall be selected for ease of use in the batching, mixing and concrete placement processes proposed as demonstrated by site trials.

5. Fibres may be collated with a fast-acting water-soluble glue, or may be uncollated individual fibres.

6. Fibres which tend to form fibre balls during batching shall not be used.

7. Steel fibres shall be added during the production process in a manner which does not interrupt or disrupt the normal mixing cycle.

8. Automatic fibre dosing equipment shall be capable of monitoring and recording steel fibre usage during the production process.

9. Production testing shall continue throughout segment casting to demonstrate that the specified performance is being achieved.

10. Steel-fibre-reinforced concrete flexural performance shall be determined and monitored in accordance with ASTM C 1609/C 1609M or JSCE-SF4 as agreed with the Engineer.

11. Steel-fibre-reinforced concrete tensile performance shall be determined and monitored in accordance with ASTM C496 or BS EN 12350 as agreed with the Engineer.

12. Fibres shall be added and mixed in a manner to produce a homogeneous distribution within the concrete matrix, and compacted and finished to ensure that fibres do not protrude from non-formed surfaces. Testing of concrete shall demonstrate that the fibres are being uniformly distributed throughout the concrete mix.

204. Spheroidal graphite cast iron (SGI) linings

204.1. General

1. SGI linings shall be supplied by an approved manufacturer who will be required to show:

(*a*) a Quality Assurance and control programme approved by the Engineer
(*b*) a record of successful use of his linings
(*c*) a compliance with British Standards regarding materials, manufacture, testing and storing of materials, segments and fixings as described in BS EN 1563:1997 *Founding spheroidal graphite cast iron*.

2. The manufacturer's premises and methods shall be available for inspection by the Engineer prior to giving approval for use and at reasonable times during production for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance and testing facilities are provided to the Engineer on each visit.

3. The Contractor shall ensure that the segments are capable of sustaining, without damage, forces occasioned by handling, erection and other operations.

4. Castings shall be manufactured in accordance with the Drawings and Specification. The Contractor shall produce prototype or pre-production segments to enable tests to be carried out on at least two rings of each diameter. Where the Contractor submits evidence, acceptable to the Engineer, of manufacture by his proposed source, of rings of similar size and specification, he may at his sole risk carry out the required pre-production tests on rings from initial production.

5. The materials used for castings shall have material designation EN-GJS-600-3 complying with the requirements of BS EN 1563:1997. The minimum 0.2% proof stress shall be confirmed by testing and all test results shall be supported by the appropriate documentation.

6. Castings shall be sound, clean and free from defects which in the opinion of the Engineer may affect their serviceability. They shall be properly fettled and free from sand, flashes etc. before receiving any protective coating.

7. The designer shall specify an appropriate coating that meets all the safety requirements in terms of fire resistance, occupational health, environmental and smoke emissions as well as achieving the specified design life.

8. Segment lifting points shall be incorporated into the segment ribs for handling purposes.

9. Where the Contractor is responsible for the SGI segment design this shall be stated in the Contract and the design requirements shall be defined in the Particular Specification.

204.2. Testing

1. Tests required to ensure compliance with this Specification shall be carried out by the Contractor at times and in places stated in a programme of testing agreed with the Engineer. The Contractor shall provide certificates confirming the test results.

2. The Contractor shall afford access and facilities to the Engineer at all reasonable times to all places engaged in the manufacture of segments to allow inspection of the production at any stage, to witness the required tests and to reject any segment that does not comply with this Specification.

3. The Contractor shall replace or rectify any segments delivered to site which are defective or do not comply with the Specification.

4. The supplier shall carry out such additional tensile testing as may be required for proper correlation of hardness, strength and microstructure.

204.3. Production testing

204.3.1. The Contractor shall carry out the following tests on pre-production castings to determine the acceptance criteria:

1. Spectrographic examination of each pour to determine the percentage composition of materials.

2. Ultrasonic testing of all critical points on 5% of castings selected by the Engineer. The Contractor shall obtain the Engineer's agreement for the methods of testing to be employed. The degree of allowable defects shall then be agreed with the Engineer subject to the ultrasonic test results and the results of any testing described in the paragraphs below.

3. If there is any doubt as to the significance of any defects indicated by the ultrasonic tests, the Contractor shall carry out further examination by either X-ray or sectioning techniques.

4. Microstructure examinations of materials from at least 5% of castings selected by the Engineer.

5. Hardness tests on at least 5% of castings, including those subjected to microstructure examination.

6. Additional tensile tests as may be required to establish the proper correlation of strength, hardness and microstructure.

7. Where sonic or ultrasonic testing is to be used during production, preliminary tests shall be carried out as necessary to establish the mean characteristics of the material and to determine allowable deviations.

204.3.2. The following tests shall be carried out during production:

1. Spectrographic examination of each pour to determine the percentage composition of materials.

2. Ultrasonic testing at points selected by the Engineer on 5% of all production castings. In the event of significant defects occurring, the Engineer may order ultrasonic testing to be carried out on a greater number of castings, and in the case of doubt as to the significance of such defects the Engineer may order or may allow X-ray examination to be carried out.

3. Hardness tests on 5% of all production castings. The Engineer may, if in his opinion the methods of manufacture or Quality Control employed by the Supplier warrant it, order hardness tests to be carried out on a greater number of castings.

4. Castings not satisfying the stated quality standards shall be rejected, unless a programme of repairs is agreed to by the Engineer. Making good surface defects shall only be permitted where such defects are minor and then only with the Engineer's agreement. Welded repairs shall not normally be permitted.

5. The number of tensile tests shall be in accordance with BS EN 1563:1997. Sufficient samples shall be produced for testing including the extra number required in the event of a test failure.

6. If any individually tested ladle does not have a test sample made and a tensile test carried out then at least one casting from that ladle shall have sonic/ultrasonic and hardness tests and be subject to microstructure analysis.

7. All tests shall be subject to the Engineer's agreement and may be witnessed by the Engineer or his Representative, unless specifically agreed otherwise.

204.4. Marking segments

1. Marks indicated on the Drawings shall be distinct and shall be cast on the inner surface of the skin of each segment or key as follows:

(*a*) internal diameter of lining
(*b*) type of segment
'O' ordinary
'T' top, the 'T' shall be at the key end of the segment
'X' special or taper
(*c*) employer's mark as instructed
(*d*) mark of manufacturer
(*e*) date of casting and mark identifying the casting with the appropriate test sample
(*f*) weight of segment in kilograms.

2. The lettering on the skin of segments shall not be less than 50 mm high and shall project not less than 2 mm above the surface. On solid keys the lettering shall not be less than 20 mm high and may be incised.

204.5. Machining and drilling

1. Machining shall be carried out to a 250 mm centreline average (CLA) with a grade N10 finish as defined in Table 2 of BS 1134 Part 1. Machining shall be carried out before application of the protective coating system.

2. All castings shall have the radial flanges machined to correct form and dimensions as defined by the Drawings and the Specification. Where shown on the Drawings, the circumferential flanges shall also be machined in accordance with this Specification. All gasket grooves shall be machined.

3. The machined faces of segments shall normally be plane and the radial flanges shall be square to the circumferential flanges within the specified tolerances.

4. Machined surfaces shall be protected immediately after machining by the specified coating.

5. Where countersinks are required they shall be machined concentric with the bolt holes.

204.6. Dimensions and tolerances

1. The accuracy of drilling bolt holes and matching flanges shall allow all similar segments to be interchangeable not only within individual rings but also with similar segments in other rings. Prior to the commencement of bulk manufacture, as a check on the casting, machining, spacing of bolt holes and interchangeability the Contractor shall carry out the following trials for each size of ring and taper.

   (*a*) Assemble and bolt together on a flat level base approved by the Engineer, segments to form three rings.
   (*b*) The rings shall be built one above the other with the radial joints staggered by approximately half a segment.
   (*c*) The segments shall be bolted together with bolts 3 mm smaller in diameter than the bolt holes.

2. The lowest ring shall be maintained as a master ring for the duration of the Contract. The segments for the other two rings shall be selected at random.

3. From time to time segments selected by the Engineer shall be built to form rings on the master rings, to ensure that tolerances and interchangeability of segments are being maintained.

4. Every taper ring shall be built on the appropriate master ring unless agreed otherwise.

5. Substantial steel templates, made in accordance with the Drawings of a design agreed with the Engineer, shall be provided, fitted with plugs 3 mm smaller in diameter than the bolt holes shown on the Drawings and of a length sufficient to pass entirely through the bolt holes.

6. Until such times as the Engineer has agreed that the setting up of the segments for machining and drilling will produce consistently accurate segments, all segments shall be built, using a template.

7. When the Engineer has agreed these setting up arrangements, sample segments shall be built, using a template at such intervals as the Engineer may indicate, to ensure that the segments conform with the Drawings and this Specification. The pins of the templates shall pass freely through the bolt holes when the inner edge of the template corresponds with the inner edge of the flange and the ends of the template, both in length and angle, correspond with the ends or sides of the segment – subject to the specified casting or machining tolerances.

   Master templates shall be provided for checking the working templates. The working templates shall normally be checked with the master templates after every 2000 uses or every 3 months.

   The Engineer may require the templates to be checked at any time.

8. Dimensions of SGI segments shall be within the following tolerances:

Table 1. SGI segment dimensions – tolerances

Parameter	Tolerance	
Dimensions over a machined face	+1.0 mm	−0.0 mm
The thickness of any elemental part of the segment shall not deviate from the designed dimension	+3.0 mm	−0.0 mm
Internal diameter of a completed ring (as a percentage of the design diameter)	+0.15%	−0.0%
Bolt holes		
Drilled diameter	+0.5 mm	−0.0 mm
Drill centres	±1.0 mm	
Pitch circle diameter (PCD – as a percentage of the design diameter)	+0.15%	−0.0%
Bolt hole for services (M10 @25 mm deep)		
Drilled diameter	+0.5 mm	−0.0 mm
Drill centres	±1.0 mm	
Caulking groove		
Half width dimension	±0.5 mm	
Depth	±0.5 mm	
Sealing groove		
Depth	±0.5 mm	
Width	±0.5 mm	
Grout plug holes		
Thread	$1\frac{1}{4}$ inch BSP	
Segment lifting point holes		
Diameter	±3.0	
Deviation from pitch circle diameter (PCD – as a percentage of the design diameter)	+0.15%	−0.0%

Dimensions of completed rings shall be within the following tolerances:

internal diameter up to 6.0 m: 40 mm maximum
internal diameter over 6.0 m: 60 mm maximum

Master ring segments shall fulfil the above tolerances.

204.7. Segment weights

1. The weight of segments shall be computed from the Drawings based on one cubic metre of metal having a weight of 7.17 tonnes.

2. Segments weighing less than the weight, computed in accordance with this clause, shall be rejected.

3. The Contractor shall make available to the Engineer copies of all delivery notes for the linings showing the weighbridge weights of each type of casting.

204.8. Grout holes

1. Grout holes shall be either cored or drilled, perpendicular to the internal face of the casting.

2. Unless otherwise specified, grout holes shall be threaded throughout their length in the segments and for a minimum depth of 25 mm in the inner face of solid key with 32 mm (1.25 inch, BSP) parallel pipe thread. When grout plugs complying with the Specification are engaged by hand, the large end of the threaded part shall protrude from the holes by between two and four threads. An internal boss shall be provided as detailed, to give the minimum thread length detailed on the Drawings. The Contractor supplying the SGI segments shall also supply the screw grout plugs.

3. As soon as the grout hole is tapped it shall be greased and the plug shall be screwed in from the concave side sufficiently tightly to prevent it becoming loosened or lost in transit.

204.9. Grout plugs

1. Grout plugs shall conform to BS 143 and BS 1256. They shall be made from malleable iron complying with BS EN 1562:1997 grade B 30-06 and shall have 32 mm (1.25 inch BSP) taper heads to BS 21.

2. The thread of the plugs shall be coated with grease after manufacture.

3. The segments shall be delivered to site complete with all grout plugs fitted in position.

204.10. Casting details

1. Washer pads, where required, shall be formed with faces perpendicular to the bolt holes.

2. All fillets shall be to the radius shown on the Drawings. Sharp corners resulting from the repair of damaged fillets in the moulds, shall not be accepted.

3. Grommet recesses may be cored or machined.

4. Bolt holes may be cored or drilled. Cored, circumferential bolt holes only shall be elongated by 5 mm.

204.11. Corrosion protection

1. Castings shall be fettled by shot blasting equivalent to Swedish Standard SSA 2.5. The castings shall then be machined to the specified tolerances and cleaned to the original SSA 2.5 immediately prior to application of the protective coating. Machined surfaces shall be protected with a coating meeting the requirements of the Particular Specification and approved by the Engineer.

2. Grit blasting of machined faces shall be subject to the agreement of the Engineer.

3. Prior to applying the protective coating, the segments shall be pre-cleaned with water-based cleaner, thoroughly rinsed to remove all residue and allowed to dry fully.

4. The protective coating shall be applied strictly in accordance with the manufacturer's written instructions. The finished thickness of the coating shall be within the limits specified. Should this coating be removed or deteriorate during the period of storage within the control or responsibility of the Contractor or his supplier, it shall be replaced or repaired as agreed with the Engineer.

204.12. Damaged segments

Segments which are damaged or defective shall be indelibly marked and shall be removed from site. No damaged or defective segments shall be delivered to the Works.

204.13. Ring removal

Where SGI segmental rings are intended to be removed under the Contract, they shall be designed and supplied with means for safe removal.

205. Structural steelwork and steel linings

205.1. General

1. Structural steelwork shall be in accordance with the *National Structural Steelwork Specification for Building Construction 5th Edition* (NSSSBC) published by the BCSA and the specific requirements set out in this Specification and on the Drawings.

2. Reference to the Steelwork Contractor in the NSSSBA shall be read as a reference to the Contractor.

205.2. Fatigue and dynamic loading

1. This Specification is applicable to structural steelwork subject to static loads only. Particular requirements in respect of dynamic loads or fatigue resistance shall be specified on the Design Drawings or in the Particular Specification.

205.3. Connection design

1. For the purpose of connection design the following details shall be as stated on the Drawings or in the Particular Specification:

   (*a*) The design standards to be used for connection design.
   (*b*) Unfactored and factored values of the forces and their combinations at each connection.
   (*c*) Movements to be accommodated by each connection.
   (*d*) Details of the design submissions to be provided by the Contractor for acceptance.

2. Types of connection detail shall be as shown on the Drawings.

3. 'Industry standard' connection details (as noted in the NSSSBC) are not applicable.

205.4. Materials

1. The steel material to be used including material grade, Standard number and impact quality shall be as stated on the Drawings or in the Particular Specification.

2. Steel materials shall be tested for through-thickness properties to the specified quality class in accordance with BS EN 10164:2004 where shown on the Drawings or stated in the Particular Specification.

3. Internal defects shall not exceed the limits set out in the Particular Specification.

4. The grades of bolt assemblies and their protective coatings shall be as stated on the Drawings or in the Particular Specification.

5. Individual components shall be traceable to their inspection and certification documents.

205.5. Fabrication

1. Fabrication details shall be as shown on the Drawings.

2. Thermal cutting shall not be used in areas identified on the Drawings or where stated in the Particular Specification.

3. Flame cut edges and ends shall be treated in accordance with Clause 4.3.3 of BS 5400 Part 6:1999.

4. Welding consumables shall be such that the mechanical properties of the deposited weld metal are not less than the specified minimum values in the product standard for the parent metal being welded.

5. Where noted on the Drawings or in the Particular Specification, special welding procedures shall be submitted for acceptance prior to fabrication work commencing.

6. Particular requirements for non-destructive testing of welds, in addition to those required by the NSSSBC, shall be as shown on the Drawings or as stated in the Particular Specification.

7. Full-size punching of holes shall not be used in areas identified on the Drawings or where stated in the Particular Specification.

8. Surfaces shall be machined as stated on the Drawings.

9. Arrises shall be smoothed by grinding or filing as necessary to allow the required thickness of protective coating to edges.

10. Flatness for full contact bearing shall be as stated in Clause 7.2.3 of BS 5950 Part 2:2001.

205.6. Protective treatment

1. Grades of preparation for protective treatment shall be as stated on the Drawings or in the Particular Specification.

2. Galvanised coatings shall be applied in accordance with BS EN ISO 1461.

3. The thickness and composition of any metal coating shall be as stated on the Drawings or in the Particular Specification.

4. Post-galvanising inspection shall be as stated on the Drawings or in the Particular Specification.

5. Paint treatments shall be as stated on the Drawings or in the Particular Specification. Stripe coats shall be applied to all edges. Materials used for paint treatment of structural steelwork shall be non-flammable, shall prevent the spread of flame and shall not give off harmful gases in a fire.

205.7. Steelwork erection

1. Hard stamping or other permanent identification marks shall not be used in areas identified on the Drawings as being unmarked.

2. The Contractor shall provide details of holes and attachments necessary for safety, lifting or erection to the Engineer for acceptance. Where required by the Engineer such attachments shall be removed on completion of steelwork erection.

3. Lubrication of threads for tightening of preloaded assemblies shall be in accordance with the bolt supplier's recommendations.

4. Steelwork members shall be marked, showing the weight in kilograms.

205.8. Bolt assemblies

1. The grades of bolt assemblies and their protective coatings shall be as stated on the Drawings or in the Particular Specification.

2. Where preloaded assemblies are required, the applicable Standard and type of system shall be as stated on the Drawings or in the Particular Specification.

3. The minimum number of clear threads protruding beyond the end of the nut, and remaining between the bearing surface of the nut and unthreaded part of the shank shall be as stated in BS 5950 Part 2:2001.

4. Washers shall be used unless specified or shown on the Drawings.

205.9. Fabricated steel segments

1. The procedures to be adopted for the fabrication of steel segments shall be agreed with the Engineer. Fabrication methods shall make due allowance for weld shrinkage, control of distortion, accuracy, ease of welding and avoidance of stress concentration. Preheating and stress relieving will be allowed but the Engineer may require procedural trials for the more complex joints. Templates and jigs shall be made of steel.

2. Fabrication drawings for fabricated steel segments shall be provided to the Engineer for agreement.

3. Marking, testing, machining and drilling, dimensions, tolerances and trial rings grout holes and grout plugs, and caulking shall follow the same general provisions as for SGI segments (refer to Section 204 of this Specification).

205.10. Cold-formed pressed steel segments

1. Steel segments made by a cold-forming process (liner plates) shall be obtained from an approved manufacturer who can demonstrate:

   (*a*) a satisfactory Quality Assurance and control programme
   (*b*) a record of successful production of such linings.

2. Steel used in the production of liner plates shall conform to ASTM A569, with a minimum yield strength of 190 MPa.

3. Design calculations for liner plates shall be provided by the Contractor and shall prove the suitability of the chosen section in respect of:

   (*a*) deflection
   (*b*) buckling
   (*c*) stiffness
   (*d*) joint strength.

4. Any damaged or distorted segments shall be discarded.

206. Jacking pipes

206.1. General

1. Concrete jacking pipes shall comply with the provisions of BS EN 1916 and BS 5911-1.

2. Vitrified clay jacking pipes shall comply with the provision of BS EN 295-7 and BS EN 12889:2000.

3. Manufacturers of jacking pipes will be required to show a third-party certified Quality Assurance and control programme to ISO 9000.

4. When requested a certificate shall be provided to the Engineer to confirm that the jacking pipes comply in all respects with the relevant standards.

5. The packing material shall be resilient and shall distribute pipe stresses arising from jacking loads. The packing material dimensions and installation shall be agreed with the Engineer prior to commencement of jacking operations.

6. The manufacturer shall provide, on request, a statement of the allowable distributed and deflected jacking loads. Details of the characteristics used in the assessment of the allowable jacking loads shall be included in the statement.

7. Provision shall be made for the injection of lubricating fluid or grout through pre-formed holes in the pipe walls. Lubrication holes shall be fitted with non-return valves.

8. All pipes shall be handled, unloaded and stacked in such a manner as to prevent damage to the pipes, in accordance with the manufacturer's recommendations.

9. Jointing shall be carried out in accordance with the manufacturer's instructions.

10. The manufacturer's premises and methods shall be open to inspection by the Engineer for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance is provided to the Engineer on each visit.

207. Support arches and lattice girders

207.1. General

1. Steel arches or lattice girders shall be installed to maintain the designed shape of the opening and if necessary provide an immediate support at the working face over the length of the last excavation completed. If necessary the installation of steel arches or lattice girders shall also prevent ground loss and shall improve load distribution.

2. For the design of support arches and lattice girders the following shall be taken into account:

   (*a*) axial stress and bending moment in the steel arch ribs induced by the ground loads
   (*b*) lateral stability and bracing of steel arches or lattice girders
   (*c*) method of installing the steel arches or lattice girders
   (*d*) method of blocking and spacing of blocking points
   (*e*) bearing capacity of the ground at the toe of the arch ribs
   (*f*) the stand-up time of the unsupported part of the excavation
   (*g*) the groundwater regime and permeability of the ground.

207.2. Arches/ribs

1. Arches, base plates, ties and connections shall be formed from steel conforming to BS 7668. Arches shall be rolled to suit the dimensional requirements of the Contract. Welding shall conform with BS EN 1011-1. Holes for ties, struts and any bolted connections shall be drilled. No burning will be allowed whether for temporary Works items or permanent elements.

2. Threaded tie rods and struts shall be of adequate length to suit arch centres and allow 25 mm projection each end beyond the nut.

3. Bolts for bolted connections shall be black bolts to BS 4190.

4. Where arches are to be provided as part of the Contractor's obligation for support the Contractor shall provide dimensional details of the arches, calculations regarding imposed loads and design and such other information that the Engineer may reasonably request.

5. Galvanised arches, where required, shall be treated in accordance with BS EN ISO 1461. All components, including the rods, fish plates, nuts and bolts shall be galvanised.

207.3. Lattice girders

1. Lattice girders shall consist of three primary bars, connected by stiffening elements to the manufacturer's design or as shown on the Drawings. They shall be designed so as to:

   (*a*) facilitate sprayed concrete penetration into and behind the girder, thereby minimising the creation of projection shadows and/or voids

(*b*) provide good-quality bonding between the steel and sprayed concrete, to form a composite structure acting as a continuous reinforced concrete lining
(*c*) make allowance for the specified tolerances including convergence.

2. Stiffening elements. A minimum 5% of the total moment of inertia shall be provided by the stiffening elements. This percentage is calculated as an average along the repeatable lengths of the lattice girder. To ensure stability against buckling, the maximum spacing between the stiffening elements shall be less than three times the cross-sectional height of the girder.

3. Dimensions and tolerances. The lattice girders shall be fabricated to meet minimum clearances and tolerances shown under consideration of accuracy of placement during construction, manufacturing tolerances, and of lining deflection following installation. Prior to installation, each girder shall be inspected as specified below and all measurements taken shall be recorded along with any comments. Any changes in the inspection frequency must be authorised by the Designer's SCL Engineer following a review of previous inspection results.

4. Each girder inspection shall check the following criteria:

(*a*) That the girder is fully identified with the girder type and the unique traceability reference.
(*b*) That the girder chord length ($\pm$25 mm) and height ($\pm$15 mm) is in accordance with the appropriate drawing detail subject to the specified tolerances.
(*c*) That the girder links and sinusoidals are in the correct positions and are adequately welded.
(*d*) That the reinforcement and plate types and sizes are as specified on the Drawings.

5. When inspecting weld quality, the following criteria shall be used:

(*a*) The reinforcement shall be free from undercut in excess of 1 mm.
(*b*) The weld metal deposition shall be even and blend smoothly with the bars.
(*c*) The weld metal shall be free from cracks and porosity.

6. The chord length shall be checked by measuring the distance from the outer edge of the connection plate to the corresponding point on the connection plate at the other end of the girder. The measurement shall be taken to the nearest millimetre.

7. The chord height shall be checked by placing a tight cord across the centreline of the girder between the outer edges of the end plates then measuring the height from the chord to the inside edge of the lower main bar. The measurement shall be taken to the nearest millmetre. Where the girder consists of a double radius the chord lines shall be taken along the outer edge of the connection plates to the point at which the radius changes.

8. Lattice girders shall also comply with the following tolerances:

(*a*) The erected lattice girders shall not deviate from the design shape and position by more than −0, +50 mm.
(*b*) Lattice girders shall be fabricated to include an allowance for 10 mm of convergence.

9. Fabrication. Each of the primary bars of the lattice girder segment shall be composed of only one piece of high-yield steel to BS 4449:2005 (minimum grade 500). Secondary bars are either plain round profile or deformed high yield to BS 4449:2005 (minimum grade 500). In addition all steel is to conform with Specification Series 1800 Structural Steelwork.

10. The connection elements at the end of the girder segments shall be constructed of flat or angle steel to BS EN 10025:2004, grade S275JR. Connections between lattice girder segments shall be bolted as shown on the Drawings; welded connections between segments shall not be permitted. Nuts and bolts supplied are to be grade 8.8 or higher.

11. All welding shall be carried out in accordance with BS EN 1011-1:2009, with welding personnel and fabrication facility UK Certification Authority for Reinforcing Steels (CARES) approved.

208. Spiles, dowels and rockbolts

208.1. Spiles

1. Spiles shall be either:

(*a*) steel bars or tubes with wall thicknesses not less than that specified and constructed from steel to BS 4449, or
(*b*) glass-reinforced plastic (GRP) bars or tubes with wall thicknesses not less than that specified.

2. The spile diameter shall not be less than that specified.

3. Pre-drilled and self-drilled spiles shall be grouted. If grout is to be used for spile installation it shall be commensurate with the ground conditions and angle of spile inclination.

4. If grout is used, Specification and methods should comply with those given in Section 208.2.

208.2. Rock dowels

1. Rock dowels shall be either:

(*a*) untensioned steel bars threaded at one end and provided with a face plate, shim plates and a conical seated washer and nut
(*b*) split or deformed steel tubes, or
(*c*) glass-fibre-reinforced resin rods.

2. Steel bars shall be grade 460, deformed type 2 bars complying with BS 4449. Threaded parts of bars, nuts and seatings shall comply with the requirements of BS 4190. Face plates shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralised slot to suit dimensions of the rock dowels.

3. Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

4. Cement for grouting in rock dowels shall conform to the requirements of British Standards as detailed in BS 8500-2 Table 1 as appropriate to the circumstances. Cement grout shall have a water/cement ratio commensurate with the product, either thixotropic grouts or pumpable grouts and shall achieve the characteristic strength as described in Section 304. Admixtures containing chlorides shall not be used. Other admixtures including plasticisers and expanding agents to BS EN 480 shall be used only with the Engineer's agreement.

5. Full details of resin-based grouts shall be agreed with the Engineer. Resin grouts shall be tested in accordance with BS 6319.

208.3. Rockbolts

1. Rockbolts are typically passive (non-tensioned) installations. In specialist circumstances they may be active (stressed, with

a debonded free length), to provide immediate support and prevent further unravelling. The bolt may be one of the following:

(*a*) solid steel bar (deformed) to BS 4449, or threaded bar of steel grades 500/600 N/mm^2 or 670/800 N/mm^2
(*b*) hollow steel bar of the self-drilling type, grade 500/600 N/mm^2
(*c*) slit steel tube with a tapered distal end, or folded steel tube which is expanded upon installation using high-pressure water injection
(*d*) glass-fibre-reinforced resin rods, solid or hollow.

Only item (*a*) can be debonded effectively for active support applications.

Alternative materials shall be subject to agreement with the Engineer.

2. Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

3. Rockbolts shall have face plates which shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralised slot to suit the dimensions of the rockbolts.

4. Cement for grout for rockbolts where required shall conform to the requirements of British Standards as detailed in BS 8500-2 Table 1 as appropriate to the circumstances. Cement grout shall have a water/cement ratio commensurate with the product, either thixotropic grouts or pumpable grouts and shall achieve the characteristic strength as described in Section 304. Admixtures containing chlorides shall not be used. Other admixtures including plasticisers and expanding agents to BS EN 480 shall be used only with the Engineer's agreement.

5. Full details of resin-based grouts where required shall be submitted to the Engineer for his approval. Resin grouts shall be tested in accordance with BS 6319.

208.4. Rock anchors

1. Rock anchors are specialised installations and are generally only required in localised areas of high load, where restraint is required, such as for stabilisation of a rock wedge.

2. Rock anchors feature a fixed length (bonded in a stable zone) and a free length (fully debonded). They are often heavily loaded and typically feature lengths of 10–30 m.

3. The anchor tendon may be:

(*a*) steel bar of grades 950/1050 N/mm^2 (prestressing steel), 670/800 N/mm^2 (high-strength rebar grade steel) or 500/600 N/mm^2 (rebar grade steel)
(*b*) steel strand of grades 1770/1500 N/mm^2, 1820/1545 N/mm^2 or 1860/1600 N/mm^2.

4. Corrosion protection for rock anchors shall be considered in the context of design life and aggressivity of the environment.

In general terms a design life of up to 5 years is classified as temporary. For temporary anchors an assessment of durability shall be made in line with procedures in BS EN 1537 and provided assessed corrosion does not lead to failure, no corrosion protection is necessary.

5. If design life exceeds 5 years or the aggressivity of the ground is deemed to present a high risk of failure, suitable corrosion protection (as outlined below) shall be provided.

6. Corrosion protection measures shall ensure the provision of a physical barrier between all areas of the stressed anchor tendon, including the head termination, and the ground/environment. The integrity of the protection barrier must be comprehensive, even after installation. Particular attention shall be paid to the section of the tendon at the underside of the bearing plate that is subjected to the highest risk of corrosion.

7. Corrosion protection options include:

(*a*) Double corrosion protection in accordance with BS 8081 – suitable for permanent works.
(*b*) Single corrosion protection – suitable for temporary works, where additional protection to overcome local aggressivity is required. Single corrosion protection will only provide a limited degree of protection and its use should be carefully assessed by the Engineer.
(*c*) Epoxy coating. This coating when comprehensive is highly effective; however, the coating is highly susceptible to damage and the anchors must be handled with extreme care.

8. Galvanising and sacrificial corrosion allowance only offer limited life spans in respect of corrosion protection. Furthermore, borehole grout, while beneficial where cover to the tendon is present, cannot be relied upon as a comprehensive corrosion protection mechanism as its integrity and degree of encapsulation cannot be assured.

9. Ground anchors shall be assessed and tested as prototypes and after installation according to a programme agreed with the Engineer following procedures and recommendations given in BS EN 1537.

209. Sprayed concrete constituent materials

1. The sprayed concrete shall comply with the BS EN 14487-1 *Sprayed concrete*, except as noted otherwise below.

2. The requirements listed below generally refer to high-quality temporary or permanent sprayed concrete.

3. This specification is primarily for the use of wet-mix sprayed concrete but in certain circumstances dry-mix sprayed concrete may be suitable.

209.1. Cement

1. Portland cement shall conform to the requirements of BS EN 197-1 or National Standards and must be suitable for sprayed concrete application.

2. As a minimum, Portland cement shall be CEM I, strength class 42.5; class N and R are both appropriate.

3. The Portland cement fineness shall not be less than 350 m^2/kg and C3A content not less than 5%.

4. The minimum Portland cement content shall be 360 kg/m^3.

5. The minimum total binder content shall be 400 kg/m^3.

Table 2. Maximum level of additions (by weight of binder)

Cementitious material	Maximum addition
Silica fume (solids)	15% of Portland cement
Pulverised Fuel Ash	30% of Portland cement
GGBS	30% of Portland cement

209.2. Pulverised fuel ash (PFA) and ground granulated blastfurnace slag (GGBS)

1. Pulverised fuel ash and ground granulated blast furnace slag shall conform to BS EN 450-1 and BS EN 15167 respectively and may also be included in the mix provided (see Table 2).

209.3. Silica fume

1. Silica fume shall be in the form of water slurry and shall comply with BS EN 13263-1.

2. Silica fume (microsilica) shall comply with the following requirements:

   (*a*) The content of SiO_2 by weight of dry mass shall be not less than 85%.
   (*b*) The silica fume shall not contain more than 0.4% elemental silica (by weight of dry mass) or any deleterious materials such as quartz, rust, and/or cellulose fibres.
   (*c*) The specific surface area shall not be less than 15 000 m^2/kg.
   (*d*) The carbon content shall not exceed 2% and the total alkali content as Na_2O equivalent shall not exceed 2%.

(*e*) SO_3 content (by weight of dry mass) shall be less than 2%.
(*f*) pH shall be 5.5 ± 1.0.
(*g*) The viscosity shall be 20 seconds with a 4 mm viscosity cup in accordance with British Board of Agrément Certificate 85/1568 and the relative density shall be between 1.3 and 1.4.
(*h*) The activity index shall at least 100% after 28 days.

3. Testing to establish compliance with item (2) above shall be carried out on a monthly basis.

4. Storage and handling: silica fume shall be regularly agitated by circulation pumps prior to use.

5. The compatibility of silica fume and liquid admixtures shall be established by carrying out appropriate accelerated testing procedures agreed with the Engineer.

6. The optimum content of silica fume shall be determined during site trials.

209.4. Aggregates

1. Aggregates for sprayed concrete shall comply with BS EN 12620 and the Section 201 of this Specification.

2. The maximum nominal particle size shall be 10 mm unless otherwise agreed with the Engineer and the grading shall lie within the envelope given in Table 3 and Figure 1 unless otherwise approved or specified elsewhere.

Table 3. Recommended aggregate gradation zone

Sieve	Min %	Max %
0.125	4	12
0.25	11	26
0.5	22	50
1.0	37	72
2.0	55	90
4.0	73	100
8.0	90	100
16.0	100	100

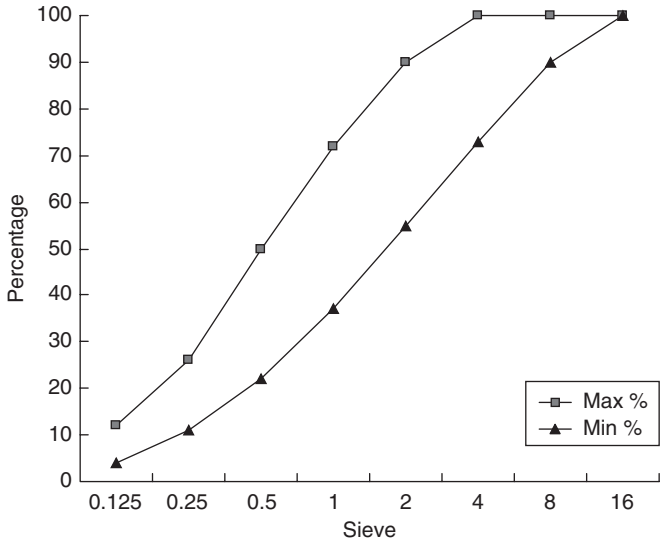

Figure 1. Recommended aggregate gradation zone

3. The aggregate shall be checked for chemical reactions, such as alkali–aggregate reaction, with latent hydraulic binders and admixtures, especially accelerators.

4. The grading and moisture content of the individual fractions of the aggregate shall be checked and recorded daily.

209.5. Water

1. Water shall comply with the main specification Section 201.4.

2. The water/cement ratio range for permanent sprayed concrete shall be not more than 0.50.

209.6. Admixtures

1. Admixtures may be used in sprayed concrete, subject to agreement with the Engineer.

2. Admixtures shall be free of chlorides such that the percentage of chlorides shall not exceed 0.1% by weight.

3. The required characteristic values and consistency of delivery to the site shall be agreed in writing with the manufacturer of each admixture before commencement of concrete spraying. Storage conditions and usage of admixtures shall comply with the manufacturer's recommendations.

4. Written confirmation of the stability of admixtures with the mix water shall be provided prior to commencement of site trials.

5. The content of SO_3 shall not exceed 4.8% by weight of total binder content.

6. Only liquid alkali-free accelerators (pH 3.0–8.0 and having alkali content less than 1% by weight Na_2O equivalent) shall be used unless pre-bagged dry mix is used where powdered accelerator has already been mixed in. Only the minimum quantity of accelerator necessary shall be permitted in normal concrete spraying operations. The quantity shall be determined by site trials, subject to maximum dosage of 8% by weight of cementitious materials. Higher dosages of accelerator can be considered subject to establishing the effect of the dosage rate on the medium and long-term strength development on the in situ concrete. At no stage in the strength development should the strength of the accelerated mix drop below 0.7 times the strength of the unaccelerated concrete mix.

7. Testing of accelerators and the base mix with respect to acceleration of setting, early strength and decrease of strength at a later age (28 days), shall take place in due time before commencement of concrete spraying.

8. Setting time of the Portland cement and accelerator shall be determined in accordance with BS EN 196-1 and 196-3. The results should be:

   (*a*) initial set <3 min
   (*b*) final set <10 min.

9. Laboratory testing of the selected type(s) of accelerator shall be carried out at dosages as recommended by the manufacturer, to

establish the variability of the above properties with dosage. Accelerators showing excessive variability with dosage will not be permitted.

10. Accelerators shall be selected so that, at the dosage chosen for use in the Works, the characteristic compressive strength of any sprayed concrete at an age of 28 days can be achieved. Compliance with this clause shall be demonstrated by site trials.

11. Accelerators delivered to site shall be tested at least once every two months for their reaction with the Portland cement used, with particular reference to the setting behaviour and strength decrease after 28 days. The stability of accelerators during storage shall be visually inspected at similar intervals. Storage times and working temperature ranges shall be in accordance with the manufacturer's recommendations. The manufacturer's safety instructions shall be observed.

12. Plasticisers and retarders complying with BS EN 934-2 may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects and optimum dosages of plasticisers and retarders shall be determined by site trials.

13. The influence of the plasticisers and retarders within the concrete mix shall be checked regularly for setting time, water reduction, and development of strength. These values shall be compared with the results from the pre-commencement trials.

14. Compatibility of plasticisers and retarders with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials.

15. Hydration control admixtures may be used to control the hydration of the mix as appropriate to expedite construction of the Works. The effects and optimum dosages of hydration control admixtures shall be determined by site trials.

16. Compatibility of hydration control admixtures with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials. Hydration control admixtures shall be used in accordance with the manufacturer's instructions.

209.7. Consistency

1. Flow shall be determined in accordance with BS EN 12350-5. The flow range should be set to ensure that the pump filling efficiency is greater than 80% at all times. The flow range for a mix should be set during the trial mix development. Generally flow values of 50 cm and 68 cm will give acceptable performance.

2. The temperature of the plastic concrete should be between 5°C and 35°C at all times during batching delivery and application.

209.8. Strength and quality

1. The compressive strength of the sprayed concrete in the short and long term shall be specified by the designer. Where early-age support is crucial to support unstable ground or minimise

ground movements, higher early-age strength will need to be specified.

2. The compressive strength of sprayed concrete at the age of 28 days shall be in accordance with BS EN 206-1, with minimum concrete strength class C32/40.

3. The early-strength development shall conform to Table 4, unless otherwise specified by the Designer.

Table 4. Sprayed concrete early strength development

Age	Test method	In situ strength: MPa
1 hour		0.5
3 hours	Penetration gun	1.0
9 hours	HILTI Tester,	2.0
12 hours	BS EN 14488-2	2.5
24 hours		5.0
28 days	BS EN 12504-1	27.2*

* For a C32/40 mix, with the reduction factor of 0.85 for cores from in situ concrete as per BS EN 13791 Table 1

4. The concrete should not show any decrease in strength with time.

5. For permanent sprayed concrete, durability is strongly influenced by concrete permeability. Accordingly the coefficient of water permeability should be less than $1 \times 10–11$ m/s at 28 days according to the test method described in Concrete Society Technical Note 31 *Permeability of site concrete*, or the penetration depth should be less then 50 mm at 28 days according to BS EN 12390-8.

209.9. Fibres

1. The structural performance of fibre-reinforced sprayed concrete shall be clearly established by the Designer. The Designer shall also specify an appropriate testing regime to determine the minimum fibre content and to establish compliance with the prescribed criteria. As a minimum, equivalent flexural strength values shall be specified.

2. Fibre reinforcement shall comply with Section 202.3.

210. Sheet waterproof membranes

210.1. Sheet waterproofing membrane systems

1. Sheet waterproofing membrane systems for tunnels should comprise a geotextile fleece fixed to the primary lining substrate, with a sheet waterproofing membrane fastened to this; see Section 312 for details of installation.

210.2. Materials – geotextile fleece

1. The purpose of the geotextile fleece is to protect the sheet membrane against mechanical puncture.

2. The geotextile, when used with a sheet waterproof membrane, provides a drainage path for any water seepage around the tunnel structure.

3. The geotextile fleece will also create a sliding surface to minimise tension and stress forming in the membrane and allow dissipation of the stresses, such as those generated via early-age thermal behaviour and settlement, generated in a secondary lining.

4. The geotextile fleece shall be a non-woven fleece and conform to the performance requirements shown in Table 5.

5. The geotextile is to provide adequate protection from chemical aggression caused in the curing processes of concrete.

Table 5. Performance requirements for geotextile fleece

Property	Test method	Requirement
Weight	DIN 53352	Not less than 700 g/m^2

6. Water transmissivity of the geotextile fleece should be designed to suit expected volume of water ingress.

210.3. Materials – fixing elements for sheet waterproofing membrane

1. The geotextile is fixed onto the substrate with non-projecting disks. The disks are secured through the geotextile and into the substrate with shot-fired nails.

2. The disks should be made of a compound that allows the sheet waterproofing membrane to be fully welded to the surface.

3. In order to prevent stresses being transferred from the secondary lining to the sheet waterproofing membrane, the resistance to failure in shear of the nails and disks must be less than the shear resistance of the sheet membrane itself.

210.4. Materials – sheet waterproof membrane

1. The sheet waterproof membrane shall consist of a continuous impermeable heat-welded sheet of one of the following materials:

   (*a*) soft polyvinyl chloride (PVC) unreinforced
   (*b*) flexible polyolefin (FPO/TPO) unreinforced

(*c*) high-density polyethylene (HDPE) in accordance with DIN 16776 Parts l and 2
(*d*) ethylene copolymerical bitumen (ECB).

2. The membrane as supplied shall be of such dimensions and shape as will result in the minimum of on-site seam welds.

3. Unless otherwise stated in the contract, the membrane shall conform to performance requirements and have properties shown in Table 6.

Table 6. Performance requirements of sheet waterproof membranes

Property	Test method	Requirement
Thickness	BS EN 1849-2	2.0 mm ±10%
Tensile strength	BS EN ISO 527-3	16 MPa
Elongation at break	BS EN ISO 527-3	Not less than 300% (−10%/+20%)
Resistance under water pressure	BS EN 1928 method B	5 bars at 1 hour
Root resistance	DD CEN/TS 14416	No penetration
Tear resistance	BS EN 12310-2	80 N/mm
Tensile strength of welded seam	BS EN 12317-2	Cracks occur next to the seam
Water absorption	BS EN ISO 62	<4.0%
Fire Rating	BS EN ISO 11925-2	Self-extinguishing
Smoke class	BS EN ISO 11925	E

4. Further guidance on test methods and requirements for mechanical properties and durability can be found in BS EN 13492:2004 (E) *Geosynthetic barriers – Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures*.

5. Where reinforced concrete is to be placed against the sheet waterproofing membrane a signalling layer, to give a visual indication of any mechanical damage, shall be provided on the exposed surface of the waterproofing membrane. The signalling layer shall be such that it does not adversely affect the seam welds.

210.5. Additional Items – sheet waterproofing systems

1. Where the waterproofing system is to be divided into sectors, the waterstops should be formed of material that can be welded to the sheet waterproofing membrane.

2. Additional drainage capacity can be provided by studded drainage membrane made from thermoplastic material attached prior to installation of the geotextile fleece.

3. Double-sleeved reinjectable hoses with offset openings and/or slots to dispense compressed injection material can be used to seal joints and fill the cavity formed during the casting of the secondary lining. The hose should be made of a material compatible to attachment to the sheet waterproofing membrane. The openings in the interior hose are to be offset from the openings in the outer hose to prevent the entry of any injection material.

211. Sprayed-applied waterproofing membrane

211.1. General

1. Spray-applied waterproofing systems include waterproofing linings formed in situ and cured in place.

2. Selected spray membrane systems must permit the safe construction of the secondary lining (cast-in-situ or sprayed) without reduction in waterproofing properties.

211.2. Materials

1. The materials will be prepared in accordance with the manufacturer's instructions. No site batching variations from these instructions will be permitted without written agreement from all parties including Designer and Manufacturer.

2. The product shall conform to the performance requirements shown in Table 7.

Table 7. Material performance criteria

Property	Requirements
Bond to substrate	Failure shown to be in substrate or bond >0.5 MPa
Permeability	Zero penetration of water through membrane
Crack bridging	Capable of bridging a 2 mm gap without diminishment of resistance to water permeation

3. Storage conditions of the product shall comply with the manufacturer's recommendations.

4. The manufacturer shall demonstrate the durability of the product for the design life of the project.

211.3. Materials – health and safety during application

1. Where the application of a particular product presents fire and Control of Substances Hazardous to Health Regulations (COSHH)-related hazards, notably in respect to the confined space environment, then measures shall be put in place to control these hazards. Appropriate measures could include:

   (*a*) adequate ventilation
   (*b*) fire detection
   (*c*) fire suppression
   (*d*) specialised personal protective equipment
   (*e*) exclusion zones
   (*f*) specific trained operatives
   (*g*) remote application
   (*h*) eye wash and first aid facilities.

2. For a particular product, where some or all of the identified hazards are adequately covered by a manufacturer's recommended application method, then when this product is used it shall be applied strictly in accordance with those recommendations.

211.4. Selection of spray-applied membrane systems – from track record or appropriate trials

1. The capability of the equipment, workmanship, materials and application methods under field conditions should be demonstrated by either:

   (*a*) previous relevant performance in similar conditions for projects with equivalent acceptance criteria
   (*b*) appropriate trials.

2. The criteria for the acceptance of the applied waterproof membrane's performance shall be in accordance with the project-specific requirements for degree of watertightness (please refer to Section 508 – or BS 8102 *Code of practice for protection of structures against water from the ground*).

3. The testing programme shall be started sufficiently early prior to installing the membrane to allow verification that the required watertightness can be achieved and allow repetition of the trials should the initial results prove unsatisfactory. All trials and acceptance tests shall be completed satisfactorily by the time installation commences.

4. Evidence must be available to demonstrate safe application of the proposed secondary lining within the chosen spray-applied waterproofing system. For a sprayed concrete secondary lining this evidence shall demonstrate that a sprayed lining can be applied to a fully cured spray membrane test section in the main tunnel crown with no observed instability of the freshly applied sprayed concrete, such as sagging or sprayed concrete fallout.

211.5. Quality assurance and requirements during trials

1. Trials, as required by the engineer to validate previous data, shall be carried out within the tunnel to assess the performance of the spray-applied waterproofing system in all conditions to be encountered during the permanent works, including where appropriate:

   (*a*) a dry area
   (*b*) a damp area
   (*c*) an area with active groundwater ingress.

2. The waterproofing system can include integrated water management measures as appropriate, including:

   (*a*) locally applied grout/injection systems
   (*b*) faster curing mix solutions
   (*c*) active drainage such as strips or pipes.

3. The test area shall be sufficiently large to adequately represent the permanent situation.

4. During trials the membrane and waterproofing shall be applied using the same equipment and methods, and by the same approved personnel, as those intended for the permanent Works.

5. Substrate surface roughness – the trials shall be carried out on the full range of surface roughness to be encountered during application of the permanent Works. This trial shall confirm

the requirement or otherwise for smoothing layers additional to those required as part of the standard waterproofing system.

6. A visual inspection of the spray-applied waterproof membrane shall be carried out. Areas in which the substrate is still visible, the spray-applied membrane is not sufficiently opaque (for opaque coloured membranes) or where the spray-applied waterproofing membrane is damaged, shall be marked up and an additional layer of spray-applied waterproof membrane applied with a minimum lap of 200 mm around the area.

7. Where the trials are carried out in the tunnel the spray-applied waterproofing membrane shall be repaired as for a defect, as detailed in clause 6.

8. Manufacturers shall detail post-application non-destructive testing to identify the integrity (in accordance with the specified dryness criteria) of the lining. These tests shall be carried out at a frequency and spacing as identified by the manufacturer. Where the integrity of the lining is shown to be insufficient, repairs shall be carried out in accordance with clause 6.

9. In order to provide an additional reference during full-scale application, the quantity of spray-applied waterproofing membrane applied to achieve the required thickness per metre squared (over the given substrate condition) shall be assessed and recorded.

Table 8. Trial criteria for spray-applied waterproof membranes

Property	Test method	Requirements
Bond to substrate	BS EN ISO 4624:2003 – Pull off test for adhesion, for resin-based materials (using a 50 mm dolly) or BS EN 1542:1999 – Pull off test, for all other materials	Failure of the substrate or bond >0.5 MPa at 28 days (as evidence of long-term water path obstruction)
Permeability	BS EN 12390-8:2000 (but sealed and tested for 28 days with spray-applied waterproof membrane located <25 mm from tested face of the specimen, within the primary and secondary layers) or Taywood Testing/similar appropriate where the lining is put to a 10 bar test for 28 days	Zero penetration of water through membrane
Crack bridging static test	BS EN 1062-7:2004 Part 7	Capable of bridging a 2 mm gap without diminishment of resistance to water permeation

10. Cores (concrete–membrane–concrete sandwich) and patches shall be taken from test panels or the testing area as required by the specification, in order to demonstrate the properties of the combined system specified in Table 8.

211.6. Quality Assurance construction testing

1. Coverage/continuity. A visual inspection of the spray-applied waterproof membrane shall be carried out. In addition manufacturers shall detail post-application non-destructive testing to identify the integrity of the lining. These tests shall be carried out as specified in Table 9 below. Areas in which the substrate is still visible, or where the spray-applied waterproof membrane's integrity is impaired, shall be marked up and an additional layer of spray-applied waterproof membrane applied with a minimum lap of 200 mm around the area.

2. Thickness. Product allowing, thickness measurements shall be carried out, as specified in Table 9, using a simple depth gauge. The equipment used shall be approved by the Engineer, with the thickness and location of the test recorded as appropriate. Adequate applied thickness may be additionally cross-referenced to the quantities per metre squared identified during trials.

3. The location of the thickness and coverage tests shall be determined to give even distribution around the entire lining (i.e. samples from the crown, axis and invert).

Table 9. Construction testing for spray-applied waterproof membranes

Parameter	Test method	Frequency	Pass/fail criteria
Coverage/ continuity	Visual	A visual inspection to be carried out continuously while the membrane is applied	100% coverage Where appropriate: lining should be 100% opaque
Thickness	Wet film thickness – depth gauge	As required in the Particular Specification but minimum 10 tests per 100 m^2	As per manufacturer's recommendations in given conditions, verified by site trials
	Application quantity measurement	Per batch	kg/m^2 to match minimum applied quantity determined during field trials
	Patch test	As required in the Particular Specification but minimum 1 test per 200 m^2	As per manufacturer's recommendations in given conditions, verified by site trials

212. Gaskets

212.1. Compression gaskets – general

1. Gaskets for precast concrete segmental lining shall be supplied by a specialist supplier certified to ISO 9001 or equivalent quality standard.

2. The gasket cross-section shall be dimensioned as detailed for the mating surfaces of the segmental tunnel linings. Gasket manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness. Prototype gaskets shall be fit-tested to assess stretch characteristics.

3. The material from which gaskets are to be manufactured shall withstand any aggressive response from the ground or groundwater and, where the tunnel is to carry effluents or liquids, the medium contained in the tunnel. In particular the gasket material shall withstand chemical attack and biological degradation such that the gasket functions properly for the design life of the facility.

212.2. Compression gaskets – testing

1. Gaskets shall be tested in accordance with the agreed quality procedure.

2. The test rig for assessing watertightness shall simulate a range of conditions of displacement and joint gap, including the worst combination to be encountered in the completed structure, and the type of joints to be constructed in the tunnel. In each test the water pressure shall be increased in increments of 0.5 bar and held at each value for 5 minutes. The final test pressure shall be as stated on the Drawings, or the maximum of:

   (*a*) at least 1 bar in excess of the maximum hydrostatic pressure to which the structure may be subjected
   (*b*) two times the maximum hydrostatic pressure to which the structure may be subjected.

3. This pressure shall be maintained for 72 hours during which no leakage shall occur at the gasketed faces. Tests shall be carried out at normal ambient temperature.

4. The gasket shall function under all combinations of packing and displacement encountered in the completed structure including permissible tolerances.

5. Based on accelerated aging tests, the projected residual compressive stress in the gasket material at the end of the design life shall not be less than 65% of the short-term compressive force for the fresh material. Where the residual compressive stress is less than this value, the test pressures in the watertightness test shall be reassessed.

6. The manufacturer shall provide details of the maximum load to fully compress the gasket in the groove.

212.3. Hydrophilic gaskets

1. Hydrophilic sealing material shall perform to the same effect as elastomeric gaskets. The composition and properties of the proposed material shall be agreed with the Engineer and sealing strips and joints shall be subjected to the same testing regime as set out for elastomeric gaskets.

2. Hydrophilic gasket material shall take into account the chemical composition of the groundwater.

3. Hydrophilic gaskets shall be of an extruded hydrophilic rubber of an appropriate profile and size to fit preformed grooves in concrete segments. The gasket shall be treated with a coating to delay the onset of swelling during erection of segments.

4. Hydrophilic gaskets shall be protected from contact with water, including rainwater, prior to erection.

212.4. Elastomeric gaskets

1. Elastomeric gaskets shall comply with the requirements of BS EN 681-2 and have an IRHD (international rubber hardness degrees) between 60 and 75. The material shall consist of a compound able to withstand the long-term stresses and strains, groundwater and internal chemical conditions without detriment to the specified performance.

2. The gasket cross-section shall be dimensioned to suit the groove as detailed for the mating faces of the segmental tunnel linings. Manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness unless specified otherwise on the Drawings.

3. The extruded section shall be joined to form a rectangular gasket that is a stretch fit into the grooves of the concrete segments. The corner joint shall be shot moulded and the comer pieces shall be of a different section from the extruded lengths in order that the watertightness characteristics described in this specification may be achieved and to avoid excessive load on the comers of the concrete segments.

4. Gaskets shall be fixed into the groove cast in the segmental tunnel linings prior to erection. The adhesive shall be as recommended by the manufacturer of the gasket.

5. Gasket faces shall be lubricated prior to erection with a product recommended by the gasket manufacturer and agreed with the Engineer.

212.5. Composite gaskets

1. Composite elastomeric and hydrophilic gaskets shall be tested to the same requirements as elastomeric gaskets. A time allowance for the expansion of the hydrophilic portion of the gasket shall be allowed for in the test where appropriate.

2. The gasket cross-section shall be dimensioned to suit the groove as detailed for the mating surfaces of the segmental tunnel linings. Manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness unless specified otherwise on the drawings.

3. Gaskets shall be manufactured from extruded solid sections with appropriate spaces within the section to enable the gasket to be fully compressible within the groove formed in the concrete segments. The gasket shall still be capable of further compression when its top surface is level with the top of the groove.

4. The extruded section shall be joined to form a rectangular gasket that is a stretch fit into the grooves of the concrete segments. The corner joint shall be shot moulded and the comer pieces shall be of a different section from the extruded lengths in order that the watertightness characteristics described in this specification may be achieved and to avoid excessive load on the comers of the concrete segments.

5. Gaskets shall be fixed into the groove cast in the segmental tunnel linings prior to erection. The adhesive shall be as recommended by the manufacturer of the gasket.

6. Gasket faces shall be lubricated prior to erection with a product recommended by the gasket manufacturer and agreed with the Engineer.

212.6. Gaskets for pipejack joints

1. Gaskets for pipejack joints shall provide a seal against the ingress of groundwater during jacking and in the permanent condition. Gasket material shall comply with the requirements of BS EN 681-2, including resistance to chemical attack and microbiological degradation.

2. The gasket shall be lubricated with a product recommended by the manufacturer and agreed with the Engineer.

213. Cement grout for cavity grouting

213.1. General

1. General-purpose cement grout shall be mixed in accordance with the proportions given in Table 10. The water content shall be kept to the minimum required to ensure a smooth, fluid mix.

Table 10. Mix proportions for cement grout

	Proportion by mass		
Class	**Cement**	**Sand**	**PFA**
G1	1	–	–
G2	1	3	–
G3	1	10	–
G4	1	–	10
G5	1	–	4
G6	1	–	0.5

2. Pulverised fuel ash (PFA) shall not be used as a constituent of grouts which contain sulphate-resisting cement.

3. Grout shall be used within 1 hour of mixing.

213.2. Special grouts

1. Where necessary due to the nature of the ground conditions or where adverse water conditions are anticipated then the requirements for the use of special grouts shall be stated in the Contract.

2. Special grouts supplied by proprietary manufacturers may be used subject to agreement with the Engineer.

3. Details of accelerating and retarding agents for proposed inclusion within the grout mix shall be submitted to the Engineer for agreement. Any such proposal shall be submitted in conjunction with a statement which outlines the Contractor's interpretation of ground behaviour during tunnel construction.

4. Primary grout for machine-driven tunnels shall be special grout injected through the tail skin of the machine as it advances.

5. The Contractor shall propose details of the primary grout, including the required setting times and strength gain to support the weight of the tunnel boring machine (TBM) and the backup and prevent ring distortion. 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 100 mm cubes shall be 1.5 N/mm^2 in 24 hours. The proposals shall be submitted to the Engineer for agreement prior to commencement of the Works.

6. Preconstruction grout trials shall be undertaken to demonstrate that the required setting times and strength gains will be

achieved. Details of the trials and results shall be submitted to the Engineer.

7. Records of batching and batcher calibration shall be maintained to demonstrate that grout batching is in accordance with the design mix. Alternatively, grout strength tests may be used.

213.3. Mixing

1. Grouts containing polymer additives shall only be mixed in a colloidal-type mixer.

2. Special grouts from proprietary manufacturers shall be mixed and used in accordance with the manufacturers' instructions.

213.4. Storage and delivery

1. Bagged grouts shall be stored under cover in dry surroundings and on a suitable platform, clear of the ground.

2. Bulk deliveries of grout constituents shall be stored in appropriate silos with suitable dust control and batch weighing equipment.

214. Packings

214.1. Packings for segmental linings

1. All forms of packing shall be of a shape commensurate with the lining, provided with bolt holes where required and of a width which does not prevent the proper operation of any gasket or seal included in the joint.

2. Timber packings shall be knot-free softwood, or plywood, sawn to shape with bolt holes where applicable. They shall be treated to retard rot and fire, and shall be available in all necessary thicknesses.

3. Stress distribution packing for longitudinal joints in concrete-rings shall be cut from an approved bituminous felt fibre based sheet to the thickness defined on the drawings to the shape required with bolt holes where applicable. Alternative materials to bituminous felt shall be agreed with the Engineer.

4. Steel packings shall be machined and provided in thicknesses of not less than 2 mm. They shall be protected from corrosion in the manner specified for mild steel segments.

5. Packings shall only be used where detailed on the drawings or agreed with the Engineer.

214.2. Packings for opening frames

1. Packings and folding wedges for opening frames shall be as detailed on the Drawings and shall be made of mild steel.

2. To prevent buckling, all packings and folding wedges shall be located at circumferential joints of the tunnel lining segments and at stiffeners in opening frames.

214.3. Packings for jacking pipes

1. Packings for jacking pipes are included in Section 206.

215. Grommets and bolts

215.1. Grommets

1. Grommets for precast concrete linings shall be polyethylene.
2. Grommets for cast iron or steel linings shall be of low-density polyethylene.

215.2. Bolts

1. Bolts shall generally be black bolts to BS 4190.
2. Sherardised bolts, where required, shall be treated to BS 4921 Class 2.
3. Galvanised bolts shall be hot-dip spun to BS EN ISO 1461.
4. Stainless steel bolts, where required, shall be to BS EN ISO 3506-2.

216. Pointing and caulking material

216.1. Caulking

1. Lead for caulking shall comply with BS EN 12588:1999.

2. Lead shall be supplied in rod or strip of widths appropriate to the segment joints, or as lead wool.

3. Cementitious caulking compound cord shall be asbestos free.

216.2. Pointing

1. Mortar for pointing shall be cement : sand (1 : 3) or otherwise agreed with water sufficient only to provide a workable consistency which can be rammed into the joint. Mortar shall be used within 1 hour of mixing. Cement shall comply with British Standards as detailed in BS 8500-2 Table 1 as appropriate; sand shall comply with BS EN 12620 and be of a grading commensurate with the work.

2. Additives and proprietary mixes may be used with the Engineer's agreement.

217. Timber

217.1. General

1. All timber that is used in the Works shall be sourced and procured from a forestry plantation that is subject to the requirements of an internationally recognised Sustainable Forest Management (SFM) Initiative.

2. All timbers used in tunnel construction or underground shall be deemed to be part of the Temporary Works, and shall be in accordance with the requirements of BS 5268 Part 2:2002 *Structural use of timber*.

3. Details of the proposed use of timber in Temporary Works shall be issued to the Engineer for agreement.

4. All timber that is left in situ in the Works shall be treated. The timber shall be impregnated with preservative fluid in accordance with BS 5268 Part 7:2002, to protect the material from decay and the level of treatment shall depend on the species specified and used in the Temporary Works.

5. All timber shall be inspected for damage or other strength-reducing factors that may have occurred after the stress grading operation has taken place. Any timber showing such damage shall be indelibly marked, as rejected. Reuse of timber shall be permitted but it shall be inspected for damage or excessive deterioration before reuse and if found unsuitable rejected.

6. When it is necessary to cut a piece of treated timber for use in the Temporary Works, the cut face(s) shall be treated preferably by immersion in the preservative used in the impregnation process. Alternatively the preservative may be applied liberally by brush.

7. All timber to be used underground shall be treated with a fire-resistant coating agreed with the Engineer, and in accordance with BS 5268, Part 7:2002 *Structural use of timber*.

200. Standards

200.1. All materials supplied to the Works shall conform to all of the following:

(*a*) This Specification.
(*b*) The appropriate British or European Standard.
(*c*) Where an industry certification scheme is available, material supplied shall be supplied in accordance with that scheme.
(*d*) Materials shall be supplied from a quality assured source, operating a Quality Assurance system in compliance with the relevant part of BS EN ISO 9001.

200.2. Where required in the Particular Specification or were stated on the Drawings, samples should be supplied and the subsequent material shall conform to the samples.

200.3. Materials used on site shall be used in accordance with the manufacturer's recommendations and instructions.

200.4. All materials should be handled and stored in a way to maintain their integrity and to avoid damage and degradation.

200.5. Details of the level of inspection and testing to be adopted in respect of supplied materials shall be agreed with the Engineer prior to commencement of work. Individual submissions are then restricted to those required by the Quality System.

201. Concrete

201.1. General

1. All concrete shall be produced in accordance with BS EN 206 and BS 8500 unless where otherwise provided for in the Contract.

2. Where concrete is to be placed in aggressive ground, appropriate ground investigation shall be undertaken to identify the nature of the chemical composition of groundwater and ground. The concrete, cast in situ or precast, shall comply with BRE Special Digest 1.

201.2. Constituent materials – cement

1. Cement and cementitious materials shall comply with the relevant British Standards, as detailed in BS 8500-2 Table 1.

2. The Contractor shall submit cement and cementitious material manufacturers' certificates in accordance with the relevant British Standard. Details of all cements and cementitious materials shall be supplied including any alternative sources that might be used. The Contractor shall show that the quantity and quality required can be attained and maintained throughout the construction period.

3. CEM I will comply with BS EN 197.

4. Where Sulphate resistance is required, the selected cement will be appropriate to the required Design Chemical (DC) class.

5. Where specified or appropriate to use, blast furnace cements, Portland slag cements and blended ground granulated blast furnace slag (ggbs) cements will comply with the blending proportions specified in BS 8500-2.

6. Where specified or appropriate to use, Portland fly ash cements and blended fly ash cements will comply with the blending proportions specified in BS 8500-2.

7. Where specified or appropriate to use, Portland limestone cements and blended limestone cements will comply with the blending proportions specified in BS 8500-2.

8. Cementitious materials shall have a reactive alkali content not exceeding a value of 0.6% by mass and/or the total mass of reactive alkali in the mix shall be calculated and controlled to satisfy the requirements of BS 8500-2 and the British Research Establishment (BRE) Digest 330. Certification will be supplied by the producer to demonstrate compliance with BRE Digest 330.

9. Cementitious materials shall be delivered in bulk or in sealed and marked bags, and shall be protected from the weather by enclosed transfer systems or other approved coverings.

Cements which have exceeded the manufacturer's designated shelf life will not be used, and appropriate measures shall be taken for its safe disposal or return to the manufacturer.

201.3. Constituent materials – aggregates

1. Aggregates shall conform to BS 8500-2. The Contractor shall obtain the agreement of the Engineer for the proposed aggregate sources, and shall demonstrate compliance with laboratory tests that shall be made at regular intervals to confirm the suitability of aggregate.

(*a*) normal and heavyweight aggregates shall conform to BS EN 12620
(*b*) lightweight aggregates shall conform to BS EN 13055-1
(*c*) coarse recycled concrete aggregate (RCA) shall conform to BS 8500-2.

2. Aggregate shall be free from earth, clay, loam and soft, clayey, shaley or decomposed stone, organic matter and other impurities and shall be hard and dense.

3. Aggregates shall not contain any other matter likely to affect the long-term durability of the concrete. Reference is to be made to the BRE Digest 330 for guidance in reducing the risk of deleterious alkali–silica reaction to the absolute minimum.

4. Tests shall be carried out in accordance with British Standards, as appropriate, and the results shall comply with the limits given therein, or as otherwise specified. Testing will be carried out to BS EN 932, BS EN 933, BS EN 1097 and BS EN 1744 as appropriate.

5. Crushed sand may be added to natural sand in approved proportions in order to achieve the required grading. When tested, the resultant material will comply with BS EN 12620.

6. Sand for mortars and grouts shall comply with BS EN 13139.

7. Coarse aggregate shall be as defined in BS EN 12620.

8. Coarse aggregate shall be tested for drying shrinkage characteristics in accordance with BS EN 1367-4. The drying shrinkage shall not exceed 0.075%.

9. The acid-soluble sulphate (SO_3) level shall not exceed the values specified in BS EN 12620.

10. The maximum permitted level of equivalent acid-soluble chloride ions (Cl^-) for any single constituent or combination of the constituents of the concrete in the hardened mix shall not exceed the limits given in BS EN 206-1.

11. The total estimated sulphate content (SO_3) shall comply with the limits given in BS EN 206-1.

12. Hardness and abrasion characteristics of the aggregate will comply with BS EN 12620.

13. Water absorption shall not exceed the permitted value in BS EN 12620.

14. Where specific thermal characteristics of the mix are required, the aggregate will be appropriately selected and tested in accordance with BS EN 1367.

15. Each size of aggregate shall be stored separately in drained concrete-based bins or on stages to prevent intermixing and the inclusion of foreign materials.

201.4. Constituent materials – water

1. Water to be used for mixing and curing concrete and mortar shall be fresh and free from sediment and dissolved or suspended matter which may be harmful and shall comply with the requirements of BS EN 206.

2. Recycled water may be used provided controls are in place to demonstrate compliance with BS EN 206.

201.5. Constituent materials – admixtures

1. Water-reducing admixtures in liquid form shall comply with BS EN 206 and BS EN 934.

2. Unless specified in the Contract, the use of set-retarding and water-reducing admixtures shall be subject to the agreement of the Engineer.

3. Admixtures not covered by BS EN standards will not be used.

201.6. Constituent materials – fibres

1. Fibres are generally accepted for use in concrete conforming to BS EN 206-1 and BS 8500 if the fibre conforms to BS EN 14889, a European Technical Approval or British Board of Agrément (BBA) certification.

2. Fibre-reinforced concrete will be trialled and tested to ensure it meets the designers' requirements before inclusion in the works. Historical data of the same fibre and dosage will be accepted in place of trials provided the data are deemed appropriate.

201.7. Constituent materials – additions

1. General suitability as a Type II addition is established for the following:

   (*a*) fly ash conforming to BS EN 450-1
   (*b*) silica fume conforming to BS EN 13263-1
   (*c*) ggbs conforming to BS EN 15167-1
   (*d*) metakaolin with an appropriate Agrément certificate.

2. General suitability as a Type I addition is established for the following:

   (*a*) filler aggregate conforming to BS EN 12620 or BS EN 13055-1
   (*b*) pigments conforming to BS EN 12878.

   General suitability of limestone fines conforming to BS 7979 is established for use in combinations conforming to BS 8500-2 Annex A.

201.8. Concrete mixes

1. The grade and properties of the concrete used in each part of the work shall be as stated on the Drawings or in the Particular Specification and shall be in accordance with BS 8500.

2. The selection design and quality control of mixes shall be carried out by the Contractor or on his behalf by the manufacturer.

3. If the finish of the concrete is required to be of a controlled or superior standard then trial panels will be manufactured 35 days in advance of the Works starting and the finish achieved will be approved by the Engineer before commencing work. The panel will be retained during the course of the Works to use as a comparative measure for the Works.

4. If existing data on materials and properties of trial concrete mixes are not available, preliminary laboratory tests shall be carried out to establish the mixes to satisfy the Specification with the available materials.

5. Laboratory trial mixes shall be tested to determine compliance with BS 8500 for all the required properties of the mix.

6. Unless otherwise agreed with the Engineer, field trial mixes shall be prepared under full-scale site conditions at least 35 days before the commencement of concreting and tested in accordance with BS EN 12350 and BS EN 12390.

7. The field trial mixes shall be tested to determine compliance under statistical evaluation where required by BS EN 206. An acceptable value for the limits of the required properties shall be established during the trials which shall thereafter be used to monitor the Quality Control of the mixes and set the standard of compliance.

201.9. Ready-mixed concrete

1. Use of ready-mixed concrete and its source shall be subject to the prior agreement of the Engineer, and the Contractor shall use only third-party accredited Quality Assured Companies.

2. Water shall not be added to concrete in a truck mixer drum other than at the batching plant, unless approved by the Engineer in a controlled manner under the supervision of the producer's representative and recorded on the delivery note. The mix shall be continuously agitated during transportation.

3. The transportation and placing times of ready-mixed concrete shall be reviewed in relation to all the circumstances including travel distance and risk of traffic delays *en route*. Unless special measures are taken, the concrete will be placed in the works within 2 hours after addition of the water to the cement. The time between consecutive loads finishing placing and starting placing shall not exceed 30 minutes.

4. The Contractor shall provide certificates to demonstrate compliance of each component of the mix with the relevant clauses of the specification. The delivery note for each batch shall state the designation of the concrete mix, the type of cement and minimum cement content, the maximum aggregate size, the

workability class of the mix, the chemical exposure class of the concrete, the admixtures used, the time at which the concrete was mixed and the weight of the constituents of each mix along with any other specified requirements.

5. Concrete temperature at the time of delivery, when measured in accordance with BS 8500, shall not exceed any value specified by the Engineer in the contract, or 35°C.

201.10. Concrete batching

1. Production control of concrete will satisfy the requirements of BS EN 206 and BS 8500-2.

2. All constituents will be weighed or metered in accordance with the limits prescribed in BS EN 206.

3. Admixtures shall only be introduced using purpose-made equipment accurately calibrated. Where such equipment is unavailable, and where agreed with the Engineer, alternative dosing methods to the manufacturer's recommendations may be adopted.

4. Water shall not be added to concrete after it has left the mixer unless controlled, recorded and agreed with the Engineer.

5. Materials shall not be heated unless agreed with the Engineer.

6. Where fibre reinforcement is added to the concrete mix, this shall only be introduced using purpose-made equipment.

201.11. Quality control

1. The Contractor shall plan all concrete Quality Management procedures in accordance with Section 200.5.

2. The conformity control of strength parameters required, will be demonstrated in accordance with BS EN 206-1. Specimens tested to demonstrate compliance will be cubes, cylinders or prisms appropriate to the testing standards and BS EN 206-1.

3. Test samples shall be made, cured, stored, transported and tested to BS EN 12350 and BS EN 12390. Spot samples will not be used to evaluate strength parameters.

4. Concrete cube test results will be acceptable if statistical analysis of the results meets the requirements of BS EN 206-1.

5. Concrete shall be tested for durability properties by means of absorption and capillary suction (sorptivity) tests where appropriate. An appropriate test method will be agreed by all parties before testing is undertaken.

6. Compaction factor, slump, Vebe, flow table or other workability tests shall be carried out as required during concreting of permanent works to control workability at the batching plant and at the site of the pour. The degree of workability shall be as specified or as determined during the trial mixes; permitted tolerances shall be in accordance with BS EN 206. Samples tested will be either spot samples or composite samples taken in accordance with BS EN 12350-1 and the appropriate tolerances for compliance will be applied in each case.

202. Reinforcement

202.1. Bar reinforcement

1. Reinforcement for use in reinforced concrete shall comply where appropriate with BS 4449, 4482, 4483 and BS EN 10080.

2. Reinforcement shall be obtained from a Certificated Authority for Reinforcing Steels (CARES) Quality Assurance approved supplier and the Contractor shall provide copies of the manufacturer's certificates of test results relating to the steel reinforcement to be supplied.

3. Reinforcement shall be stored in an approved manner above ground under cover and racked as necessary for protection from aggressive elements.

4. Steel reinforcement shall be cut and bent in accordance with BS 8666.

5. Tying wire shall be 1.6 mm diameter soft annealed mild steel, and when fixed shall not project into the concrete cover.

6. Where the Contract so requires, the Contractor shall produce bending schedules, prepared in accordance with BS 8666.

202.2. Welded wire fabric

1. Welded wire fabric shall comprise hard-drawn wire in accordance with BS 4482 and BS 4483. It shall be firmly fixed in place using an agreed method. Overlap between adjacent sheets of welded wire fabric shall be a minimum of 2 squares.

202.3. Fibre reinforcement

1. Fibre reinforcement shall be obtained from a supplier meeting the requirements of BS EN ISO 9001 or similar.

2. Steel fibres can be deformed steel fibre in accordance with BS EN 14889-1 either from mild steel or cold-drawn steel. Fibres in accordance with ASTM A820 may be used with the approval of the Engineer.

3. Structural, macro-synthetic fibres shall be in accordance with BS EN 14889-2. Only Class II fibres shall be used where fibres are incorporated for structural purposes.

4. Alternative fibres may be utilised following successful completion of proving trials which meet the Designer's performance requirements.

5. Fibres shall be stored, handled and dosed in accordance with the manufacturer's recommendations. Generally this will require them to be stored in dry, sealed containers until ready for use and shall be free from corrosion, oil, grease, chlorides, and deleterious materials which may reduce the efficiency of mixing or spraying processes, or which may reduce bond between the fibres and the sprayed concrete.

6. Fibres shall have an aspect ratio in the range 30–150 for lengths of 12.7–63.5 mm. Tolerances shall be in accordance with BS EN 14889.

7. The minimum tensile strength for steel fibres is 800 MPa and for macro-synthetic fibres 500 MPa.

203. Precast concrete linings

203.1. General

1. Precast concrete segments for linings shall be supplied by the Contractor from an agreed manufacturer, or manufactured in a purpose-built factory, for erection in the Works in accordance with the Contract requirements.

2. Segments of the lining shall be designed to withstand handling, storing and erection stresses as well as permanent loads. The Contractor shall provide to the Engineer copies of calculations and drawings to demonstrate adequacy of the designs.

3. Lining segments may be cast in existing moulds and be a manufacturer's standard design or be a particular design to suit the requirements of the project and tunnelling plant.

4. Concrete shall be in accordance with Section 201, of minimum strength class C40/50.

5. Reinforcement shall be in accordance with Section 202. Cages may be formed by welding or tying.

203.2. Manufacture of segments

1. Manufacturing facilities for segmental lining systems will be required to show:

   (*a*) A certified Quality Assurance and control programme to BS EN ISO 9001 approved by the Engineer
   (*b*) compliance with British Standards regarding materials, mixing and placing, curing and storing of concrete constituents, concrete segments and fixings.

2. The manufacturer's premises and methods shall be open to inspection by the Engineer for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance is provided to the Engineer on each visit.

203.3. Moulds

1. Moulds shall be robustly constructed, tightly jointed and properly maintained such that the dimensions of the segments are always within the specified tolerances.

2. Where new moulds are being manufactured for the particular project, the fabrication drawings shall be submitted to the Engineer for agreement.

3. Details of the moulds to be used for casting concrete segments shall be supplied to the Engineer for his agreement before prototype segments are cast. Trial segments may be made for the Engineer's inspection. Samples shall be marked indelibly and set aside for reference purposes.

203.4. Tolerances for the manufacture of bolted segments

203.4.1. Segments

Dimensions of individual precast concrete special segments shall be within the following tolerances:

(*a*) circumferential length	±1 mm
(*b*) thickness	+3 mm, −1.5 mm
(*c*) width	±1 mm
(*d*) square	diagonal dimension ±1 mm from theoretical dimension
(*e*) bolt holes: size	+1 mm, −0.2 mm
(*f*) bolt holes and dowel position	1 mm
(*g*) sealing gasket groove: depth	+0.5 mm, −0.0 mm
(*h*) sealing gasket groove: width	±0.5 mm
(*i*) sealing gasket groove: position	±1.5 mm from specified position
(*j*) longitudinal joints	
in a plane generally along the axis of the tunnel (longitudinal)	0.3 mm from theoretical plane with rate of deviation not exceeding 0.6 mm/m
in a radial plane	0.1 mm from theoretical plane with rate of deviation not exceeding 0.6 mm/m
(*k*) circumferential faces	0.5 mm from theoretical plane with rate of deviation not exceeding 1 mm/m
(*l*) smoothness of other faces	
back face	smooth float ±1.5 mm
front face	formed face ±1 mm
(*m*) mismatch of sealing groove at corners	<0.5 mm

203.4.2. Rings

At least two test rings shall be erected on a flat and level base, in a form and sequence representative of the construction arrangement to be agreed with the Engineer. All designed longitudinal packings are to be removed from both rings. The following dimensions shall be checked:

(*a*) internal diameter (adjusted for packer removal where necessary)	±0.2% ID or 6 mm maximum
(*b*) lip between adjacent segments on internal diameter	<3 mm
(*c*) gap between longitudinal segment joints (packings removed and bolts tightened)	1 mm feeler gauge not passing

203.5. Tolerances for the manufacture of expanded segments

203.5.1. Segments

Dimensions of individual precast concrete segments shall be within the following tolerances:

(*a*)	circumferential length	±1.0 mm
(*b*)	segment thickness (on backs)	±1.5 mm
(*c*)	width	±1.5 mm
(*d*)	regularity of surfaces:	

straight edge applied in any position parallel to axis of ring on extrados, intrados and cross-joint faces, and normal to axis on longitudinal joint and cross-joint

joints:	0.25 mm feeler gauge not passing
extrados; intrados:	1.25 mm feeler gauge not passing

203.5.2. Rings

At least two test rings shall be erected on a flat and level base, in a form and sequence representative of the construction arrangement to be agreed with the Engineer. All designed longitudinal packings are to be removed from both rings. The following dimensions shall be checked:

(*a*)	internal diameter with key in its design location	0.2% ID or 6 mm maximum
(*b*)	lip between adjacent segments on internal diameter	1.5 mm
(*c*)	gap between longitudinal segment joints	0.5 mm feeler gauge not passing

203.6. Opening sets

Special rings and opening sets shall be built as a complete set to the tolerances specified in clause 203.6 unless agreed otherwise with the Engineer. The first ring of a special set shall also be built on the test ring.

203.7. Marking of segments

As a minimum all segments except solid key shall have marked with indented upper case lettering the following information on the inner face:

(*a*) internal diameter of lining
(*b*) type of segment referenced to the detailed drawings
(*c*) a unique mould identification any special information to indicate the position or orientation of the segment in the ring
(*d*) the weight of segment in kilograms
(*e*) date of casting.

203.8. Joint packing

Where shown on the drawings a minimum 2 mm thick strip of stress distribution packing is to be incorporated in each longitudinal joint covering at least 80% of the joint surface area. The packing shall be in accordance with Section 214.

203.9. Gasket grooves

Where shown on the Drawings, gasket grooves shall be provided around all joint faces of each segment and key in accordance with the dimensions recommended by the gasket manufacturer.

203.10. Concrete cover

1. Concrete cover shall be as stated on the Drawings or in the Particular Specification.

2. Precast segmental lining systems shall be designed in accordance with BS 8500-1 for cover and concrete mix requirements.

203.11. Grout holes

Where specified, grout holes shall be provided in every segment excluding the key, and shall be a nominal 50 mm diameter or greater. They shall be either plain or threaded, and provided with a non-return valve.

203.12. Curing

Segments shall be cured in accordance with the provisions of ENV 13670-1.

203.13. Handling stacking and transport

1. The method of lifting and handling, the type of equipment and method of transport shall not damage the segments. Segments are to be stacked in a manner approved by the Engineer.

2. Segments shall not be transported to site or incorporated into the works until they have achieved the 28-day compressive characteristic strength, and in the case of fibre-reinforced segments their flexural or tensile strengths.

3. If the grout hole is to be used for segment handling, the contractor shall ensure that this has been catered for in the design.

203.14. Segments reinforced with steel fibres

1. Steel fibre reinforcement shall comply with Section 202.3.

2. Steel-fibre-reinforced concrete shall generally be designed to Technical Report No. 63 *Guidance for the design of steel-fibre-reinforced concrete* (The Concrete Society).

3. Fibre type and dosage shall be selected such that the performance requirements specified on the Drawings or in the Particular Specification are achieved. This shall be demonstrated by laboratory trials undertaken and agreed with the Engineer prior to commencement of segment casting.

4. Fibre type and dosage shall be selected for ease of use in the batching, mixing and concrete placement processes proposed as demonstrated by site trials.

5. Fibres may be collated with a fast-acting water-soluble glue, or may be uncollated individual fibres.

6. Fibres which tend to form fibre balls during batching shall not be used.

7. Steel fibres shall be added during the production process in a manner which does not interrupt or disrupt the normal mixing cycle.

8. Automatic fibre dosing equipment shall be capable of monitoring and recording steel fibre usage during the production process.

9. Production testing shall continue throughout segment casting to demonstrate that the specified performance is being achieved.

10. Steel-fibre-reinforced concrete flexural performance shall be determined and monitored in accordance with ASTM C 1609/C 1609M or JSCE-SF4 as agreed with the Engineer.

11. Steel-fibre-reinforced concrete tensile performance shall be determined and monitored in accordance with ASTM C496 or BS EN 12350 as agreed with the Engineer.

12. Fibres shall be added and mixed in a manner to produce a homogeneous distribution within the concrete matrix, and compacted and finished to ensure that fibres do not protrude from non-formed surfaces. Testing of concrete shall demonstrate that the fibres are being uniformly distributed throughout the concrete mix.

204. Spheroidal graphite cast iron (SGI) linings

204.1. General

1. SGI linings shall be supplied by an approved manufacturer who will be required to show:

(*a*) a Quality Assurance and control programme approved by the Engineer
(*b*) a record of successful use of his linings
(*c*) a compliance with British Standards regarding materials, manufacture, testing and storing of materials, segments and fixings as described in BS EN 1563:1997 *Founding spheroidal graphite cast iron*.

2. The manufacturer's premises and methods shall be available for inspection by the Engineer prior to giving approval for use and at reasonable times during production for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance and testing facilities are provided to the Engineer on each visit.

3. The Contractor shall ensure that the segments are capable of sustaining, without damage, forces occasioned by handling, erection and other operations.

4. Castings shall be manufactured in accordance with the Drawings and Specification. The Contractor shall produce prototype or pre-production segments to enable tests to be carried out on at least two rings of each diameter. Where the Contractor submits evidence, acceptable to the Engineer, of manufacture by his proposed source, of rings of similar size and specification, he may at his sole risk carry out the required pre-production tests on rings from initial production.

5. The materials used for castings shall have material designation EN-GJS-600-3 complying with the requirements of BS EN 1563:1997. The minimum 0.2% proof stress shall be confirmed by testing and all test results shall be supported by the appropriate documentation.

6. Castings shall be sound, clean and free from defects which in the opinion of the Engineer may affect their serviceability. They shall be properly fettled and free from sand, flashes etc. before receiving any protective coating.

7. The designer shall specify an appropriate coating that meets all the safety requirements in terms of fire resistance, occupational health, environmental and smoke emissions as well as achieving the specified design life.

8. Segment lifting points shall be incorporated into the segment ribs for handling purposes.

9. Where the Contractor is responsible for the SGI segment design this shall be stated in the Contract and the design requirements shall be defined in the Particular Specification.

204.2. Testing

1. Tests required to ensure compliance with this Specification shall be carried out by the Contractor at times and in places stated in a programme of testing agreed with the Engineer. The Contractor shall provide certificates confirming the test results.

2. The Contractor shall afford access and facilities to the Engineer at all reasonable times to all places engaged in the manufacture of segments to allow inspection of the production at any stage, to witness the required tests and to reject any segment that does not comply with this Specification.

3. The Contractor shall replace or rectify any segments delivered to site which are defective or do not comply with the Specification.

4. The supplier shall carry out such additional tensile testing as may be required for proper correlation of hardness, strength and microstructure.

204.3. Production testing

204.3.1. The Contractor shall carry out the following tests on pre-production castings to determine the acceptance criteria:

1. Spectrographic examination of each pour to determine the percentage composition of materials.

2. Ultrasonic testing of all critical points on 5% of castings selected by the Engineer. The Contractor shall obtain the Engineer's agreement for the methods of testing to be employed. The degree of allowable defects shall then be agreed with the Engineer subject to the ultrasonic test results and the results of any testing described in the paragraphs below.

3. If there is any doubt as to the significance of any defects indicated by the ultrasonic tests, the Contractor shall carry out further examination by either X-ray or sectioning techniques.

4. Microstructure examinations of materials from at least 5% of castings selected by the Engineer.

5. Hardness tests on at least 5% of castings, including those subjected to microstructure examination.

6. Additional tensile tests as may be required to establish the proper correlation of strength, hardness and microstructure.

7. Where sonic or ultrasonic testing is to be used during production, preliminary tests shall be carried out as necessary to establish the mean characteristics of the material and to determine allowable deviations.

204.3.2. The following tests shall be carried out during production:

1. Spectrographic examination of each pour to determine the percentage composition of materials.

2. Ultrasonic testing at points selected by the Engineer on 5% of all production castings. In the event of significant defects occurring, the Engineer may order ultrasonic testing to be carried out on a greater number of castings, and in the case of doubt as to the significance of such defects the Engineer may order or may allow X-ray examination to be carried out.

3. Hardness tests on 5% of all production castings. The Engineer may, if in his opinion the methods of manufacture or Quality Control employed by the Supplier warrant it, order hardness tests to be carried out on a greater number of castings.

4. Castings not satisfying the stated quality standards shall be rejected, unless a programme of repairs is agreed to by the Engineer. Making good surface defects shall only be permitted where such defects are minor and then only with the Engineer's agreement. Welded repairs shall not normally be permitted.

5. The number of tensile tests shall be in accordance with BS EN 1563:1997. Sufficient samples shall be produced for testing including the extra number required in the event of a test failure.

6. If any individually tested ladle does not have a test sample made and a tensile test carried out then at least one casting from that ladle shall have sonic/ultrasonic and hardness tests and be subject to microstructure analysis.

7. All tests shall be subject to the Engineer's agreement and may be witnessed by the Engineer or his Representative, unless specifically agreed otherwise.

204.4. Marking segments

1. Marks indicated on the Drawings shall be distinct and shall be cast on the inner surface of the skin of each segment or key as follows:

(*a*) internal diameter of lining
(*b*) type of segment
'O' ordinary
'T' top, the 'T' shall be at the key end of the segment
'X' special or taper
(*c*) employer's mark as instructed
(*d*) mark of manufacturer
(*e*) date of casting and mark identifying the casting with the appropriate test sample
(*f*) weight of segment in kilograms.

2. The lettering on the skin of segments shall not be less than 50 mm high and shall project not less than 2 mm above the surface. On solid keys the lettering shall not be less than 20 mm high and may be incised.

204.5. Machining and drilling

1. Machining shall be carried out to a 250 mm centreline average (CLA) with a grade N10 finish as defined in Table 2 of BS 1134 Part 1. Machining shall be carried out before application of the protective coating system.

2. All castings shall have the radial flanges machined to correct form and dimensions as defined by the Drawings and the Specification. Where shown on the Drawings, the circumferential flanges shall also be machined in accordance with this Specification. All gasket grooves shall be machined.

3. The machined faces of segments shall normally be plane and the radial flanges shall be square to the circumferential flanges within the specified tolerances.

4. Machined surfaces shall be protected immediately after machining by the specified coating.

5. Where countersinks are required they shall be machined concentric with the bolt holes.

204.6. Dimensions and tolerances

1. The accuracy of drilling bolt holes and matching flanges shall allow all similar segments to be interchangeable not only within individual rings but also with similar segments in other rings. Prior to the commencement of bulk manufacture, as a check on the casting, machining, spacing of bolt holes and interchangeability the Contractor shall carry out the following trials for each size of ring and taper.

   (*a*) Assemble and bolt together on a flat level base approved by the Engineer, segments to form three rings.
   (*b*) The rings shall be built one above the other with the radial joints staggered by approximately half a segment.
   (*c*) The segments shall be bolted together with bolts 3 mm smaller in diameter than the bolt holes.

2. The lowest ring shall be maintained as a master ring for the duration of the Contract. The segments for the other two rings shall be selected at random.

3. From time to time segments selected by the Engineer shall be built to form rings on the master rings, to ensure that tolerances and interchangeability of segments are being maintained.

4. Every taper ring shall be built on the appropriate master ring unless agreed otherwise.

5. Substantial steel templates, made in accordance with the Drawings of a design agreed with the Engineer, shall be provided, fitted with plugs 3 mm smaller in diameter than the bolt holes shown on the Drawings and of a length sufficient to pass entirely through the bolt holes.

6. Until such times as the Engineer has agreed that the setting up of the segments for machining and drilling will produce consistently accurate segments, all segments shall be built, using a template.

7. When the Engineer has agreed these setting up arrangements, sample segments shall be built, using a template at such intervals as the Engineer may indicate, to ensure that the segments conform with the Drawings and this Specification. The pins of the templates shall pass freely through the bolt holes when the inner edge of the template corresponds with the inner edge of the flange and the ends of the template, both in length and angle, correspond with the ends or sides of the segment – subject to the specified casting or machining tolerances.

   Master templates shall be provided for checking the working templates. The working templates shall normally be checked with the master templates after every 2000 uses or every 3 months.

   The Engineer may require the templates to be checked at any time.

8. Dimensions of SGI segments shall be within the following tolerances:

Table 1. SGI segment dimensions – tolerances

Parameter	Tolerance	
Dimensions over a machined face	+1.0 mm	−0.0 mm
The thickness of any elemental part of the segment shall not deviate from the designed dimension	+3.0 mm	−0.0 mm
Internal diameter of a completed ring (as a percentage of the design diameter)	+0.15%	−0.0%
Bolt holes		
Drilled diameter	+0.5 mm	−0.0 mm
Drill centres	±1.0 mm	
Pitch circle diameter (PCD – as a percentage of the design diameter)	+0.15%	−0.0%
Bolt hole for services (M10 @25 mm deep)		
Drilled diameter	+0.5 mm	−0.0 mm
Drill centres	±1.0 mm	
Caulking groove		
Half width dimension	±0.5 mm	
Depth	±0.5 mm	
Sealing groove		
Depth	±0.5 mm	
Width	±0.5 mm	
Grout plug holes		
Thread	$1\frac{1}{4}$ inch BSP	
Segment lifting point holes		
Diameter	±3.0	
Deviation from pitch circle diameter (PCD – as a percentage of the design diameter)	+0.15%	−0.0%

Dimensions of completed rings shall be within the following tolerances:

internal diameter up to 6.0 m: 40 mm maximum
internal diameter over 6.0 m: 60 mm maximum

Master ring segments shall fulfil the above tolerances.

204.7. Segment weights

1. The weight of segments shall be computed from the Drawings based on one cubic metre of metal having a weight of 7.17 tonnes.

2. Segments weighing less than the weight, computed in accordance with this clause, shall be rejected.

3. The Contractor shall make available to the Engineer copies of all delivery notes for the linings showing the weighbridge weights of each type of casting.

204.8. Grout holes

1. Grout holes shall be either cored or drilled, perpendicular to the internal face of the casting.

2. Unless otherwise specified, grout holes shall be threaded throughout their length in the segments and for a minimum depth of 25 mm in the inner face of solid key with 32 mm (1.25 inch, BSP) parallel pipe thread. When grout plugs complying with the Specification are engaged by hand, the large end of the threaded part shall protrude from the holes by between two and four threads. An internal boss shall be provided as detailed, to give the minimum thread length detailed on the Drawings. The Contractor supplying the SGI segments shall also supply the screw grout plugs.

3. As soon as the grout hole is tapped it shall be greased and the plug shall be screwed in from the concave side sufficiently tightly to prevent it becoming loosened or lost in transit.

204.9. Grout plugs

1. Grout plugs shall conform to BS 143 and BS 1256. They shall be made from malleable iron complying with BS EN 1562:1997 grade B 30-06 and shall have 32 mm (1.25 inch BSP) taper heads to BS 21.

2. The thread of the plugs shall be coated with grease after manufacture.

3. The segments shall be delivered to site complete with all grout plugs fitted in position.

204.10. Casting details

1. Washer pads, where required, shall be formed with faces perpendicular to the bolt holes.

2. All fillets shall be to the radius shown on the Drawings. Sharp corners resulting from the repair of damaged fillets in the moulds, shall not be accepted.

3. Grommet recesses may be cored or machined.

4. Bolt holes may be cored or drilled. Cored, circumferential bolt holes only shall be elongated by 5 mm.

204.11. Corrosion protection

1. Castings shall be fettled by shot blasting equivalent to Swedish Standard SSA 2.5. The castings shall then be machined to the specified tolerances and cleaned to the original SSA 2.5 immediately prior to application of the protective coating. Machined surfaces shall be protected with a coating meeting the requirements of the Particular Specification and approved by the Engineer.

2. Grit blasting of machined faces shall be subject to the agreement of the Engineer.

3. Prior to applying the protective coating, the segments shall be pre-cleaned with water-based cleaner, thoroughly rinsed to remove all residue and allowed to dry fully.

4. The protective coating shall be applied strictly in accordance with the manufacturer's written instructions. The finished thickness of the coating shall be within the limits specified. Should this coating be removed or deteriorate during the period of storage within the control or responsibility of the Contractor or his supplier, it shall be replaced or repaired as agreed with the Engineer.

204.12. Damaged segments

Segments which are damaged or defective shall be indelibly marked and shall be removed from site. No damaged or defective segments shall be delivered to the Works.

204.13. Ring removal

Where SGI segmental rings are intended to be removed under the Contract, they shall be designed and supplied with means for safe removal.

205. Structural steelwork and steel linings

205.1. General

1. Structural steelwork shall be in accordance with the *National Structural Steelwork Specification for Building Construction 5th Edition* (NSSSBC) published by the BCSA and the specific requirements set out in this Specification and on the Drawings.

2. Reference to the Steelwork Contractor in the NSSSBA shall be read as a reference to the Contractor.

205.2. Fatigue and dynamic loading

1. This Specification is applicable to structural steelwork subject to static loads only. Particular requirements in respect of dynamic loads or fatigue resistance shall be specified on the Design Drawings or in the Particular Specification.

205.3. Connection design

1. For the purpose of connection design the following details shall be as stated on the Drawings or in the Particular Specification:

   (*a*) The design standards to be used for connection design.
   (*b*) Unfactored and factored values of the forces and their combinations at each connection.
   (*c*) Movements to be accommodated by each connection.
   (*d*) Details of the design submissions to be provided by the Contractor for acceptance.

2. Types of connection detail shall be as shown on the Drawings.

3. 'Industry standard' connection details (as noted in the NSSSBC) are not applicable.

205.4. Materials

1. The steel material to be used including material grade, Standard number and impact quality shall be as stated on the Drawings or in the Particular Specification.

2. Steel materials shall be tested for through-thickness properties to the specified quality class in accordance with BS EN 10164:2004 where shown on the Drawings or stated in the Particular Specification.

3. Internal defects shall not exceed the limits set out in the Particular Specification.

4. The grades of bolt assemblies and their protective coatings shall be as stated on the Drawings or in the Particular Specification.

5. Individual components shall be traceable to their inspection and certification documents.

205.5. Fabrication

1. Fabrication details shall be as shown on the Drawings.

2. Thermal cutting shall not be used in areas identified on the Drawings or where stated in the Particular Specification.

3. Flame cut edges and ends shall be treated in accordance with Clause 4.3.3 of BS 5400 Part 6:1999.

4. Welding consumables shall be such that the mechanical properties of the deposited weld metal are not less than the specified minimum values in the product standard for the parent metal being welded.

5. Where noted on the Drawings or in the Particular Specification, special welding procedures shall be submitted for acceptance prior to fabrication work commencing.

6. Particular requirements for non-destructive testing of welds, in addition to those required by the NSSSBC, shall be as shown on the Drawings or as stated in the Particular Specification.

7. Full-size punching of holes shall not be used in areas identified on the Drawings or where stated in the Particular Specification.

8. Surfaces shall be machined as stated on the Drawings.

9. Arrises shall be smoothed by grinding or filing as necessary to allow the required thickness of protective coating to edges.

10. Flatness for full contact bearing shall be as stated in Clause 7.2.3 of BS 5950 Part 2:2001.

205.6. Protective treatment

1. Grades of preparation for protective treatment shall be as stated on the Drawings or in the Particular Specification.

2. Galvanised coatings shall be applied in accordance with BS EN ISO 1461.

3. The thickness and composition of any metal coating shall be as stated on the Drawings or in the Particular Specification.

4. Post-galvanising inspection shall be as stated on the Drawings or in the Particular Specification.

5. Paint treatments shall be as stated on the Drawings or in the Particular Specification. Stripe coats shall be applied to all edges. Materials used for paint treatment of structural steelwork shall be non-flammable, shall prevent the spread of flame and shall not give off harmful gases in a fire.

205.7. Steelwork erection

1. Hard stamping or other permanent identification marks shall not be used in areas identified on the Drawings as being unmarked.

2. The Contractor shall provide details of holes and attachments necessary for safety, lifting or erection to the Engineer for acceptance. Where required by the Engineer such attachments shall be removed on completion of steelwork erection.

3. Lubrication of threads for tightening of preloaded assemblies shall be in accordance with the bolt supplier's recommendations.

4. Steelwork members shall be marked, showing the weight in kilograms.

205.8. Bolt assemblies

1. The grades of bolt assemblies and their protective coatings shall be as stated on the Drawings or in the Particular Specification.

2. Where preloaded assemblies are required, the applicable Standard and type of system shall be as stated on the Drawings or in the Particular Specification.

3. The minimum number of clear threads protruding beyond the end of the nut, and remaining between the bearing surface of the nut and unthreaded part of the shank shall be as stated in BS 5950 Part 2:2001.

4. Washers shall be used unless specified or shown on the Drawings.

205.9. Fabricated steel segments

1. The procedures to be adopted for the fabrication of steel segments shall be agreed with the Engineer. Fabrication methods shall make due allowance for weld shrinkage, control of distortion, accuracy, ease of welding and avoidance of stress concentration. Preheating and stress relieving will be allowed but the Engineer may require procedural trials for the more complex joints. Templates and jigs shall be made of steel.

2. Fabrication drawings for fabricated steel segments shall be provided to the Engineer for agreement.

3. Marking, testing, machining and drilling, dimensions, tolerances and trial rings grout holes and grout plugs, and caulking shall follow the same general provisions as for SGI segments (refer to Section 204 of this Specification).

205.10. Cold-formed pressed steel segments

1. Steel segments made by a cold-forming process (liner plates) shall be obtained from an approved manufacturer who can demonstrate:

   (*a*) a satisfactory Quality Assurance and control programme
   (*b*) a record of successful production of such linings.

2. Steel used in the production of liner plates shall conform to ASTM A569, with a minimum yield strength of 190 MPa.

3. Design calculations for liner plates shall be provided by the Contractor and shall prove the suitability of the chosen section in respect of:

   (*a*) deflection
   (*b*) buckling
   (*c*) stiffness
   (*d*) joint strength.

4. Any damaged or distorted segments shall be discarded.

206. Jacking pipes

206.1. General

1. Concrete jacking pipes shall comply with the provisions of BS EN 1916 and BS 5911-1.

2. Vitrified clay jacking pipes shall comply with the provision of BS EN 295-7 and BS EN 12889:2000.

3. Manufacturers of jacking pipes will be required to show a third-party certified Quality Assurance and control programme to ISO 9000.

4. When requested a certificate shall be provided to the Engineer to confirm that the jacking pipes comply in all respects with the relevant standards.

5. The packing material shall be resilient and shall distribute pipe stresses arising from jacking loads. The packing material dimensions and installation shall be agreed with the Engineer prior to commencement of jacking operations.

6. The manufacturer shall provide, on request, a statement of the allowable distributed and deflected jacking loads. Details of the characteristics used in the assessment of the allowable jacking loads shall be included in the statement.

7. Provision shall be made for the injection of lubricating fluid or grout through pre-formed holes in the pipe walls. Lubrication holes shall be fitted with non-return valves.

8. All pipes shall be handled, unloaded and stacked in such a manner as to prevent damage to the pipes, in accordance with the manufacturer's recommendations.

9. Jointing shall be carried out in accordance with the manufacturer's instructions.

10. The manufacturer's premises and methods shall be open to inspection by the Engineer for the purpose of checking the quality of manufacture. The Contractor shall ensure that all necessary assistance is provided to the Engineer on each visit.

207. Support arches and lattice girders

207.1. General

1. Steel arches or lattice girders shall be installed to maintain the designed shape of the opening and if necessary provide an immediate support at the working face over the length of the last excavation completed. If necessary the installation of steel arches or lattice girders shall also prevent ground loss and shall improve load distribution.

2. For the design of support arches and lattice girders the following shall be taken into account:

   (*a*) axial stress and bending moment in the steel arch ribs induced by the ground loads
   (*b*) lateral stability and bracing of steel arches or lattice girders
   (*c*) method of installing the steel arches or lattice girders
   (*d*) method of blocking and spacing of blocking points
   (*e*) bearing capacity of the ground at the toe of the arch ribs
   (*f*) the stand-up time of the unsupported part of the excavation
   (*g*) the groundwater regime and permeability of the ground.

207.2. Arches/ribs

1. Arches, base plates, ties and connections shall be formed from steel conforming to BS 7668. Arches shall be rolled to suit the dimensional requirements of the Contract. Welding shall conform with BS EN 1011-1. Holes for ties, struts and any bolted connections shall be drilled. No burning will be allowed whether for temporary Works items or permanent elements.

2. Threaded tie rods and struts shall be of adequate length to suit arch centres and allow 25 mm projection each end beyond the nut.

3. Bolts for bolted connections shall be black bolts to BS 4190.

4. Where arches are to be provided as part of the Contractor's obligation for support the Contractor shall provide dimensional details of the arches, calculations regarding imposed loads and design and such other information that the Engineer may reasonably request.

5. Galvanised arches, where required, shall be treated in accordance with BS EN ISO 1461. All components, including the rods, fish plates, nuts and bolts shall be galvanised.

207.3. Lattice girders

1. Lattice girders shall consist of three primary bars, connected by stiffening elements to the manufacturer's design or as shown on the Drawings. They shall be designed so as to:

   (*a*) facilitate sprayed concrete penetration into and behind the girder, thereby minimising the creation of projection shadows and/or voids

(*b*) provide good-quality bonding between the steel and sprayed concrete, to form a composite structure acting as a continuous reinforced concrete lining
(*c*) make allowance for the specified tolerances including convergence.

2. Stiffening elements. A minimum 5% of the total moment of inertia shall be provided by the stiffening elements. This percentage is calculated as an average along the repeatable lengths of the lattice girder. To ensure stability against buckling, the maximum spacing between the stiffening elements shall be less than three times the cross-sectional height of the girder.

3. Dimensions and tolerances. The lattice girders shall be fabricated to meet minimum clearances and tolerances shown under consideration of accuracy of placement during construction, manufacturing tolerances, and of lining deflection following installation. Prior to installation, each girder shall be inspected as specified below and all measurements taken shall be recorded along with any comments. Any changes in the inspection frequency must be authorised by the Designer's SCL Engineer following a review of previous inspection results.

4. Each girder inspection shall check the following criteria:

(*a*) That the girder is fully identified with the girder type and the unique traceability reference.
(*b*) That the girder chord length ($\pm$25 mm) and height ($\pm$15 mm) is in accordance with the appropriate drawing detail subject to the specified tolerances.
(*c*) That the girder links and sinusoidals are in the correct positions and are adequately welded.
(*d*) That the reinforcement and plate types and sizes are as specified on the Drawings.

5. When inspecting weld quality, the following criteria shall be used:

(*a*) The reinforcement shall be free from undercut in excess of 1 mm.
(*b*) The weld metal deposition shall be even and blend smoothly with the bars.
(*c*) The weld metal shall be free from cracks and porosity.

6. The chord length shall be checked by measuring the distance from the outer edge of the connection plate to the corresponding point on the connection plate at the other end of the girder. The measurement shall be taken to the nearest millimetre.

7. The chord height shall be checked by placing a tight cord across the centreline of the girder between the outer edges of the end plates then measuring the height from the chord to the inside edge of the lower main bar. The measurement shall be taken to the nearest millmetre. Where the girder consists of a double radius the chord lines shall be taken along the outer edge of the connection plates to the point at which the radius changes.

8. Lattice girders shall also comply with the following tolerances:

(*a*) The erected lattice girders shall not deviate from the design shape and position by more than −0, +50 mm.
(*b*) Lattice girders shall be fabricated to include an allowance for 10 mm of convergence.

9. Fabrication. Each of the primary bars of the lattice girder segment shall be composed of only one piece of high-yield steel to BS 4449:2005 (minimum grade 500). Secondary bars are either plain round profile or deformed high yield to BS 4449:2005 (minimum grade 500). In addition all steel is to conform with Specification Series 1800 Structural Steelwork.

10. The connection elements at the end of the girder segments shall be constructed of flat or angle steel to BS EN 10025:2004, grade S275JR. Connections between lattice girder segments shall be bolted as shown on the Drawings; welded connections between segments shall not be permitted. Nuts and bolts supplied are to be grade 8.8 or higher.

11. All welding shall be carried out in accordance with BS EN 1011-1:2009, with welding personnel and fabrication facility UK Certification Authority for Reinforcing Steels (CARES) approved.

208. Spiles, dowels and rockbolts

208.1. Spiles

1. Spiles shall be either:

(*a*) steel bars or tubes with wall thicknesses not less than that specified and constructed from steel to BS 4449, or
(*b*) glass-reinforced plastic (GRP) bars or tubes with wall thicknesses not less than that specified.

2. The spile diameter shall not be less than that specified.

3. Pre-drilled and self-drilled spiles shall be grouted. If grout is to be used for spile installation it shall be commensurate with the ground conditions and angle of spile inclination.

4. If grout is used, Specification and methods should comply with those given in Section 208.2.

208.2. Rock dowels

1. Rock dowels shall be either:

(*a*) untensioned steel bars threaded at one end and provided with a face plate, shim plates and a conical seated washer and nut
(*b*) split or deformed steel tubes, or
(*c*) glass-fibre-reinforced resin rods.

2. Steel bars shall be grade 460, deformed type 2 bars complying with BS 4449. Threaded parts of bars, nuts and seatings shall comply with the requirements of BS 4190. Face plates shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralised slot to suit dimensions of the rock dowels.

3. Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

4. Cement for grouting in rock dowels shall conform to the requirements of British Standards as detailed in BS 8500-2 Table 1 as appropriate to the circumstances. Cement grout shall have a water/cement ratio commensurate with the product, either thixotropic grouts or pumpable grouts and shall achieve the characteristic strength as described in Section 304. Admixtures containing chlorides shall not be used. Other admixtures including plasticisers and expanding agents to BS EN 480 shall be used only with the Engineer's agreement.

5. Full details of resin-based grouts shall be agreed with the Engineer. Resin grouts shall be tested in accordance with BS 6319.

208.3. Rockbolts

1. Rockbolts are typically passive (non-tensioned) installations. In specialist circumstances they may be active (stressed, with

a debonded free length), to provide immediate support and prevent further unravelling. The bolt may be one of the following:

(*a*) solid steel bar (deformed) to BS 4449, or threaded bar of steel grades 500/600 N/mm^2 or 670/800 N/mm^2
(*b*) hollow steel bar of the self-drilling type, grade 500/600 N/mm^2
(*c*) slit steel tube with a tapered distal end, or folded steel tube which is expanded upon installation using high-pressure water injection
(*d*) glass-fibre-reinforced resin rods, solid or hollow.

Only item (*a*) can be debonded effectively for active support applications.

Alternative materials shall be subject to agreement with the Engineer.

2. Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

3. Rockbolts shall have face plates which shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralised slot to suit the dimensions of the rockbolts.

4. Cement for grout for rockbolts where required shall conform to the requirements of British Standards as detailed in BS 8500-2 Table 1 as appropriate to the circumstances. Cement grout shall have a water/cement ratio commensurate with the product, either thixotropic grouts or pumpable grouts and shall achieve the characteristic strength as described in Section 304. Admixtures containing chlorides shall not be used. Other admixtures including plasticisers and expanding agents to BS EN 480 shall be used only with the Engineer's agreement.

5. Full details of resin-based grouts where required shall be submitted to the Engineer for his approval. Resin grouts shall be tested in accordance with BS 6319.

208.4. Rock anchors

1. Rock anchors are specialised installations and are generally only required in localised areas of high load, where restraint is required, such as for stabilisation of a rock wedge.

2. Rock anchors feature a fixed length (bonded in a stable zone) and a free length (fully debonded). They are often heavily loaded and typically feature lengths of 10–30 m.

3. The anchor tendon may be:

(*a*) steel bar of grades 950/1050 N/mm^2 (prestressing steel), 670/800 N/mm^2 (high-strength rebar grade steel) or 500/600 N/mm^2 (rebar grade steel)
(*b*) steel strand of grades 1770/1500 N/mm^2, 1820/1545 N/mm^2 or 1860/1600 N/mm^2.

4. Corrosion protection for rock anchors shall be considered in the context of design life and aggressivity of the environment.

In general terms a design life of up to 5 years is classified as temporary. For temporary anchors an assessment of durability shall be made in line with procedures in BS EN 1537 and provided assessed corrosion does not lead to failure, no corrosion protection is necessary.

5. If design life exceeds 5 years or the aggressivity of the ground is deemed to present a high risk of failure, suitable corrosion protection (as outlined below) shall be provided.

6. Corrosion protection measures shall ensure the provision of a physical barrier between all areas of the stressed anchor tendon, including the head termination, and the ground/environment. The integrity of the protection barrier must be comprehensive, even after installation. Particular attention shall be paid to the section of the tendon at the underside of the bearing plate that is subjected to the highest risk of corrosion.

7. Corrosion protection options include:

(*a*) Double corrosion protection in accordance with BS 8081 – suitable for permanent works.
(*b*) Single corrosion protection – suitable for temporary works, where additional protection to overcome local aggressivity is required. Single corrosion protection will only provide a limited degree of protection and its use should be carefully assessed by the Engineer.
(*c*) Epoxy coating. This coating when comprehensive is highly effective; however, the coating is highly susceptible to damage and the anchors must be handled with extreme care.

8. Galvanising and sacrificial corrosion allowance only offer limited life spans in respect of corrosion protection. Furthermore, borehole grout, while beneficial where cover to the tendon is present, cannot be relied upon as a comprehensive corrosion protection mechanism as its integrity and degree of encapsulation cannot be assured.

9. Ground anchors shall be assessed and tested as prototypes and after installation according to a programme agreed with the Engineer following procedures and recommendations given in BS EN 1537.

209. Sprayed concrete constituent materials

1. The sprayed concrete shall comply with the BS EN 14487-1 *Sprayed concrete*, except as noted otherwise below.

2. The requirements listed below generally refer to high-quality temporary or permanent sprayed concrete.

3. This specification is primarily for the use of wet-mix sprayed concrete but in certain circumstances dry-mix sprayed concrete may be suitable.

209.1. Cement

1. Portland cement shall conform to the requirements of BS EN 197-1 or National Standards and must be suitable for sprayed concrete application.

2. As a minimum, Portland cement shall be CEM I, strength class 42.5; class N and R are both appropriate.

3. The Portland cement fineness shall not be less than 350 m^2/kg and C3A content not less than 5%.

4. The minimum Portland cement content shall be 360 kg/m^3.

5. The minimum total binder content shall be 400 kg/m^3.

Table 2. Maximum level of additions (by weight of binder)

Cementitious material	Maximum addition
Silica fume (solids)	15% of Portland cement
Pulverised Fuel Ash	30% of Portland cement
GGBS	30% of Portland cement

209.2. Pulverised fuel ash (PFA) and ground granulated blastfurnace slag (GGBS)

1. Pulverised fuel ash and ground granulated blast furnace slag shall conform to BS EN 450-1 and BS EN 15167 respectively and may also be included in the mix provided (see Table 2).

209.3. Silica fume

1. Silica fume shall be in the form of water slurry and shall comply with BS EN 13263-1.

2. Silica fume (microsilica) shall comply with the following requirements:

   (*a*) The content of SiO_2 by weight of dry mass shall be not less than 85%.
   (*b*) The silica fume shall not contain more than 0.4% elemental silica (by weight of dry mass) or any deleterious materials such as quartz, rust, and/or cellulose fibres.
   (*c*) The specific surface area shall not be less than 15 000 m^2/kg.
   (*d*) The carbon content shall not exceed 2% and the total alkali content as Na_2O equivalent shall not exceed 2%.

(*e*) SO_3 content (by weight of dry mass) shall be less than 2%.
(*f*) pH shall be 5.5 ± 1.0.
(*g*) The viscosity shall be 20 seconds with a 4 mm viscosity cup in accordance with British Board of Agrément Certificate 85/1568 and the relative density shall be between 1.3 and 1.4.
(*h*) The activity index shall at least 100% after 28 days.

3. Testing to establish compliance with item (2) above shall be carried out on a monthly basis.

4. Storage and handling: silica fume shall be regularly agitated by circulation pumps prior to use.

5. The compatibility of silica fume and liquid admixtures shall be established by carrying out appropriate accelerated testing procedures agreed with the Engineer.

6. The optimum content of silica fume shall be determined during site trials.

209.4. Aggregates

1. Aggregates for sprayed concrete shall comply with BS EN 12620 and the Section 201 of this Specification.

2. The maximum nominal particle size shall be 10 mm unless otherwise agreed with the Engineer and the grading shall lie within the envelope given in Table 3 and Figure 1 unless otherwise approved or specified elsewhere.

Table 3. Recommended aggregate gradation zone

Sieve	Min %	Max %
0.125	4	12
0.25	11	26
0.5	22	50
1.0	37	72
2.0	55	90
4.0	73	100
8.0	90	100
16.0	100	100

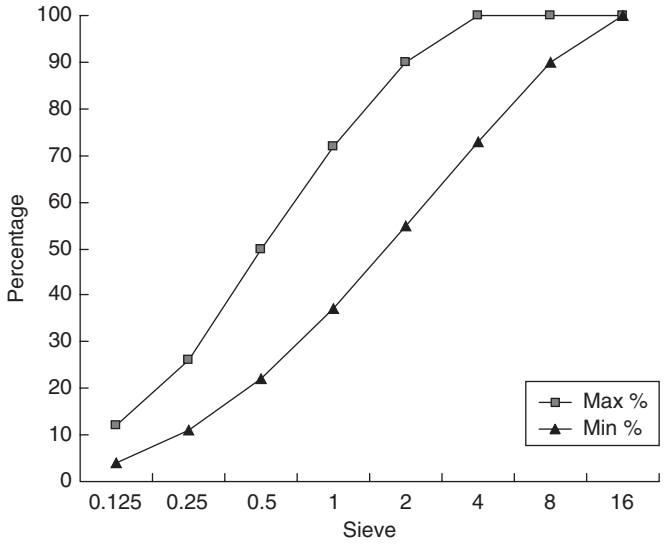

Figure 1. Recommended aggregate gradation zone

3. The aggregate shall be checked for chemical reactions, such as alkali–aggregate reaction, with latent hydraulic binders and admixtures, especially accelerators.

4. The grading and moisture content of the individual fractions of the aggregate shall be checked and recorded daily.

209.5. Water

1. Water shall comply with the main specification Section 201.4.

2. The water/cement ratio range for permanent sprayed concrete shall be not more than 0.50.

209.6. Admixtures

1. Admixtures may be used in sprayed concrete, subject to agreement with the Engineer.

2. Admixtures shall be free of chlorides such that the percentage of chlorides shall not exceed 0.1% by weight.

3. The required characteristic values and consistency of delivery to the site shall be agreed in writing with the manufacturer of each admixture before commencement of concrete spraying. Storage conditions and usage of admixtures shall comply with the manufacturer's recommendations.

4. Written confirmation of the stability of admixtures with the mix water shall be provided prior to commencement of site trials.

5. The content of SO_3 shall not exceed 4.8% by weight of total binder content.

6. Only liquid alkali-free accelerators (pH 3.0–8.0 and having alkali content less than 1% by weight Na_2O equivalent) shall be used unless pre-bagged dry mix is used where powdered accelerator has already been mixed in. Only the minimum quantity of accelerator necessary shall be permitted in normal concrete spraying operations. The quantity shall be determined by site trials, subject to maximum dosage of 8% by weight of cementitious materials. Higher dosages of accelerator can be considered subject to establishing the effect of the dosage rate on the medium and long-term strength development on the in situ concrete. At no stage in the strength development should the strength of the accelerated mix drop below 0.7 times the strength of the unaccelerated concrete mix.

7. Testing of accelerators and the base mix with respect to acceleration of setting, early strength and decrease of strength at a later age (28 days), shall take place in due time before commencement of concrete spraying.

8. Setting time of the Portland cement and accelerator shall be determined in accordance with BS EN 196-1 and 196-3. The results should be:

   (*a*) initial set <3 min
   (*b*) final set <10 min.

9. Laboratory testing of the selected type(s) of accelerator shall be carried out at dosages as recommended by the manufacturer, to

establish the variability of the above properties with dosage. Accelerators showing excessive variability with dosage will not be permitted.

10. Accelerators shall be selected so that, at the dosage chosen for use in the Works, the characteristic compressive strength of any sprayed concrete at an age of 28 days can be achieved. Compliance with this clause shall be demonstrated by site trials.

11. Accelerators delivered to site shall be tested at least once every two months for their reaction with the Portland cement used, with particular reference to the setting behaviour and strength decrease after 28 days. The stability of accelerators during storage shall be visually inspected at similar intervals. Storage times and working temperature ranges shall be in accordance with the manufacturer's recommendations. The manufacturer's safety instructions shall be observed.

12. Plasticisers and retarders complying with BS EN 934-2 may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects and optimum dosages of plasticisers and retarders shall be determined by site trials.

13. The influence of the plasticisers and retarders within the concrete mix shall be checked regularly for setting time, water reduction, and development of strength. These values shall be compared with the results from the pre-commencement trials.

14. Compatibility of plasticisers and retarders with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials.

15. Hydration control admixtures may be used to control the hydration of the mix as appropriate to expedite construction of the Works. The effects and optimum dosages of hydration control admixtures shall be determined by site trials.

16. Compatibility of hydration control admixtures with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials. Hydration control admixtures shall be used in accordance with the manufacturer's instructions.

209.7. Consistency

1. Flow shall be determined in accordance with BS EN 12350-5. The flow range should be set to ensure that the pump filling efficiency is greater than 80% at all times. The flow range for a mix should be set during the trial mix development. Generally flow values of 50 cm and 68 cm will give acceptable performance.

2. The temperature of the plastic concrete should be between 5°C and 35°C at all times during batching delivery and application.

209.8. Strength and quality

1. The compressive strength of the sprayed concrete in the short and long term shall be specified by the designer. Where early-age support is crucial to support unstable ground or minimise

ground movements, higher early-age strength will need to be specified.

2. The compressive strength of sprayed concrete at the age of 28 days shall be in accordance with BS EN 206-1, with minimum concrete strength class C32/40.

3. The early-strength development shall conform to Table 4, unless otherwise specified by the Designer.

Table 4. Sprayed concrete early strength development

Age	Test method	In situ strength: MPa
1 hour		0.5
3 hours	Penetration gun	1.0
9 hours	HILTI Tester,	2.0
12 hours	BS EN 14488-2	2.5
24 hours		5.0
28 days	BS EN 12504-1	27.2*

* For a C32/40 mix, with the reduction factor of 0.85 for cores from in situ concrete as per BS EN 13791 Table 1

4. The concrete should not show any decrease in strength with time.

5. For permanent sprayed concrete, durability is strongly influenced by concrete permeability. Accordingly the coefficient of water permeability should be less than $1 \times 10–11$ m/s at 28 days according to the test method described in Concrete Society Technical Note 31 *Permeability of site concrete*, or the penetration depth should be less then 50 mm at 28 days according to BS EN 12390-8.

209.9. Fibres

1. The structural performance of fibre-reinforced sprayed concrete shall be clearly established by the Designer. The Designer shall also specify an appropriate testing regime to determine the minimum fibre content and to establish compliance with the prescribed criteria. As a minimum, equivalent flexural strength values shall be specified.

2. Fibre reinforcement shall comply with Section 202.3.

210. Sheet waterproof membranes

210.1. Sheet waterproofing membrane systems

1. Sheet waterproofing membrane systems for tunnels should comprise a geotextile fleece fixed to the primary lining substrate, with a sheet waterproofing membrane fastened to this; see Section 312 for details of installation.

210.2. Materials – geotextile fleece

1. The purpose of the geotextile fleece is to protect the sheet membrane against mechanical puncture.

2. The geotextile, when used with a sheet waterproof membrane, provides a drainage path for any water seepage around the tunnel structure.

3. The geotextile fleece will also create a sliding surface to minimise tension and stress forming in the membrane and allow dissipation of the stresses, such as those generated via early-age thermal behaviour and settlement, generated in a secondary lining.

4. The geotextile fleece shall be a non-woven fleece and conform to the performance requirements shown in Table 5.

5. The geotextile is to provide adequate protection from chemical aggression caused in the curing processes of concrete.

Table 5. Performance requirements for geotextile fleece

Property	Test method	Requirement
Weight	DIN 53352	Not less than 700 g/m^2

6. Water transmissivity of the geotextile fleece should be designed to suit expected volume of water ingress.

210.3. Materials – fixing elements for sheet waterproofing membrane

1. The geotextile is fixed onto the substrate with non-projecting disks. The disks are secured through the geotextile and into the substrate with shot-fired nails.

2. The disks should be made of a compound that allows the sheet waterproofing membrane to be fully welded to the surface.

3. In order to prevent stresses being transferred from the secondary lining to the sheet waterproofing membrane, the resistance to failure in shear of the nails and disks must be less than the shear resistance of the sheet membrane itself.

210.4. Materials – sheet waterproof membrane

1. The sheet waterproof membrane shall consist of a continuous impermeable heat-welded sheet of one of the following materials:

   (*a*) soft polyvinyl chloride (PVC) unreinforced
   (*b*) flexible polyolefin (FPO/TPO) unreinforced

(*c*) high-density polyethylene (HDPE) in accordance with DIN 16776 Parts l and 2
(*d*) ethylene copolymerical bitumen (ECB).

2. The membrane as supplied shall be of such dimensions and shape as will result in the minimum of on-site seam welds.

3. Unless otherwise stated in the contract, the membrane shall conform to performance requirements and have properties shown in Table 6.

Table 6. Performance requirements of sheet waterproof membranes

Property	Test method	Requirement
Thickness	BS EN 1849-2	2.0 mm ±10%
Tensile strength	BS EN ISO 527-3	16 MPa
Elongation at break	BS EN ISO 527-3	Not less than 300% (−10%/+20%)
Resistance under water pressure	BS EN 1928 method B	5 bars at 1 hour
Root resistance	DD CEN/TS 14416	No penetration
Tear resistance	BS EN 12310-2	80 N/mm
Tensile strength of welded seam	BS EN 12317-2	Cracks occur next to the seam
Water absorption	BS EN ISO 62	<4.0%
Fire Rating	BS EN ISO 11925-2	Self-extinguishing
Smoke class	BS EN ISO 11925	E

4. Further guidance on test methods and requirements for mechanical properties and durability can be found in BS EN 13492:2004 (E) *Geosynthetic barriers – Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures*.

5. Where reinforced concrete is to be placed against the sheet waterproofing membrane a signalling layer, to give a visual indication of any mechanical damage, shall be provided on the exposed surface of the waterproofing membrane. The signalling layer shall be such that it does not adversely affect the seam welds.

210.5. Additional Items – sheet waterproofing systems

1. Where the waterproofing system is to be divided into sectors, the waterstops should be formed of material that can be welded to the sheet waterproofing membrane.

2. Additional drainage capacity can be provided by studded drainage membrane made from thermoplastic material attached prior to installation of the geotextile fleece.

3. Double-sleeved reinjectable hoses with offset openings and/or slots to dispense compressed injection material can be used to seal joints and fill the cavity formed during the casting of the secondary lining. The hose should be made of a material compatible to attachment to the sheet waterproofing membrane. The openings in the interior hose are to be offset from the openings in the outer hose to prevent the entry of any injection material.

211. Sprayed-applied waterproofing membrane

211.1. General

1. Spray-applied waterproofing systems include waterproofing linings formed in situ and cured in place.

2. Selected spray membrane systems must permit the safe construction of the secondary lining (cast-in-situ or sprayed) without reduction in waterproofing properties.

211.2. Materials

1. The materials will be prepared in accordance with the manufacturer's instructions. No site batching variations from these instructions will be permitted without written agreement from all parties including Designer and Manufacturer.

2. The product shall conform to the performance requirements shown in Table 7.

Table 7. Material performance criteria

Property	Requirements
Bond to substrate	Failure shown to be in substrate or bond >0.5 MPa
Permeability	Zero penetration of water through membrane
Crack bridging	Capable of bridging a 2 mm gap without diminishment of resistance to water permeation

3. Storage conditions of the product shall comply with the manufacturer's recommendations.

4. The manufacturer shall demonstrate the durability of the product for the design life of the project.

211.3. Materials – health and safety during application

1. Where the application of a particular product presents fire and Control of Substances Hazardous to Health Regulations (COSHH)-related hazards, notably in respect to the confined space environment, then measures shall be put in place to control these hazards. Appropriate measures could include:

   (*a*) adequate ventilation
   (*b*) fire detection
   (*c*) fire suppression
   (*d*) specialised personal protective equipment
   (*e*) exclusion zones
   (*f*) specific trained operatives
   (*g*) remote application
   (*h*) eye wash and first aid facilities.

2. For a particular product, where some or all of the identified hazards are adequately covered by a manufacturer's recommended application method, then when this product is used it shall be applied strictly in accordance with those recommendations.

211.4. Selection of spray-applied membrane systems – from track record or appropriate trials

1. The capability of the equipment, workmanship, materials and application methods under field conditions should be demonstrated by either:

   (*a*) previous relevant performance in similar conditions for projects with equivalent acceptance criteria
   (*b*) appropriate trials.

2. The criteria for the acceptance of the applied waterproof membrane's performance shall be in accordance with the project-specific requirements for degree of watertightness (please refer to Section 508 – or BS 8102 *Code of practice for protection of structures against water from the ground*).

3. The testing programme shall be started sufficiently early prior to installing the membrane to allow verification that the required watertightness can be achieved and allow repetition of the trials should the initial results prove unsatisfactory. All trials and acceptance tests shall be completed satisfactorily by the time installation commences.

4. Evidence must be available to demonstrate safe application of the proposed secondary lining within the chosen spray-applied waterproofing system. For a sprayed concrete secondary lining this evidence shall demonstrate that a sprayed lining can be applied to a fully cured spray membrane test section in the main tunnel crown with no observed instability of the freshly applied sprayed concrete, such as sagging or sprayed concrete fallout.

211.5. Quality assurance and requirements during trials

1. Trials, as required by the engineer to validate previous data, shall be carried out within the tunnel to assess the performance of the spray-applied waterproofing system in all conditions to be encountered during the permanent works, including where appropriate:

   (*a*) a dry area
   (*b*) a damp area
   (*c*) an area with active groundwater ingress.

2. The waterproofing system can include integrated water management measures as appropriate, including:

   (*a*) locally applied grout/injection systems
   (*b*) faster curing mix solutions
   (*c*) active drainage such as strips or pipes.

3. The test area shall be sufficiently large to adequately represent the permanent situation.

4. During trials the membrane and waterproofing shall be applied using the same equipment and methods, and by the same approved personnel, as those intended for the permanent Works.

5. Substrate surface roughness – the trials shall be carried out on the full range of surface roughness to be encountered during application of the permanent Works. This trial shall confirm

the requirement or otherwise for smoothing layers additional to those required as part of the standard waterproofing system.

6. A visual inspection of the spray-applied waterproof membrane shall be carried out. Areas in which the substrate is still visible, the spray-applied membrane is not sufficiently opaque (for opaque coloured membranes) or where the spray-applied waterproofing membrane is damaged, shall be marked up and an additional layer of spray-applied waterproof membrane applied with a minimum lap of 200 mm around the area.

7. Where the trials are carried out in the tunnel the spray-applied waterproofing membrane shall be repaired as for a defect, as detailed in clause 6.

8. Manufacturers shall detail post-application non-destructive testing to identify the integrity (in accordance with the specified dryness criteria) of the lining. These tests shall be carried out at a frequency and spacing as identified by the manufacturer. Where the integrity of the lining is shown to be insufficient, repairs shall be carried out in accordance with clause 6.

9. In order to provide an additional reference during full-scale application, the quantity of spray-applied waterproofing membrane applied to achieve the required thickness per metre squared (over the given substrate condition) shall be assessed and recorded.

Table 8. Trial criteria for spray-applied waterproof membranes

Property	Test method	Requirements
Bond to substrate	BS EN ISO 4624:2003 – Pull off test for adhesion, for resin-based materials (using a 50 mm dolly) or BS EN 1542:1999 – Pull off test, for all other materials	Failure of the substrate or bond >0.5 MPa at 28 days (as evidence of long-term water path obstruction)
Permeability	BS EN 12390-8:2000 (but sealed and tested for 28 days with spray-applied waterproof membrane located <25 mm from tested face of the specimen, within the primary and secondary layers) or Taywood Testing/similar appropriate where the lining is put to a 10 bar test for 28 days	Zero penetration of water through membrane
Crack bridging static test	BS EN 1062-7:2004 Part 7	Capable of bridging a 2 mm gap without diminishment of resistance to water permeation

10. Cores (concrete–membrane–concrete sandwich) and patches shall be taken from test panels or the testing area as required by the specification, in order to demonstrate the properties of the combined system specified in Table 8.

211.6. Quality Assurance construction testing

1. Coverage/continuity. A visual inspection of the spray-applied waterproof membrane shall be carried out. In addition manufacturers shall detail post-application non-destructive testing to identify the integrity of the lining. These tests shall be carried out as specified in Table 9 below. Areas in which the substrate is still visible, or where the spray-applied waterproof membrane's integrity is impaired, shall be marked up and an additional layer of spray-applied waterproof membrane applied with a minimum lap of 200 mm around the area.

2. Thickness. Product allowing, thickness measurements shall be carried out, as specified in Table 9, using a simple depth gauge. The equipment used shall be approved by the Engineer, with the thickness and location of the test recorded as appropriate. Adequate applied thickness may be additionally cross-referenced to the quantities per metre squared identified during trials.

3. The location of the thickness and coverage tests shall be determined to give even distribution around the entire lining (i.e. samples from the crown, axis and invert).

Table 9. Construction testing for spray-applied waterproof membranes

Parameter	Test method	Frequency	Pass/fail criteria
Coverage/ continuity	Visual	A visual inspection to be carried out continuously while the membrane is applied	100% coverage Where appropriate: lining should be 100% opaque
Thickness	Wet film thickness – depth gauge	As required in the Particular Specification but minimum 10 tests per 100 m^2	As per manufacturer's recommendations in given conditions, verified by site trials
	Application quantity measurement	Per batch	kg/m^2 to match minimum applied quantity determined during field trials
	Patch test	As required in the Particular Specification but minimum 1 test per 200 m^2	As per manufacturer's recommendations in given conditions, verified by site trials

212. Gaskets

212.1. Compression gaskets – general

1. Gaskets for precast concrete segmental lining shall be supplied by a specialist supplier certified to ISO 9001 or equivalent quality standard.

2. The gasket cross-section shall be dimensioned as detailed for the mating surfaces of the segmental tunnel linings. Gasket manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness. Prototype gaskets shall be fit-tested to assess stretch characteristics.

3. The material from which gaskets are to be manufactured shall withstand any aggressive response from the ground or groundwater and, where the tunnel is to carry effluents or liquids, the medium contained in the tunnel. In particular the gasket material shall withstand chemical attack and biological degradation such that the gasket functions properly for the design life of the facility.

212.2. Compression gaskets – testing

1. Gaskets shall be tested in accordance with the agreed quality procedure.

2. The test rig for assessing watertightness shall simulate a range of conditions of displacement and joint gap, including the worst combination to be encountered in the completed structure, and the type of joints to be constructed in the tunnel. In each test the water pressure shall be increased in increments of 0.5 bar and held at each value for 5 minutes. The final test pressure shall be as stated on the Drawings, or the maximum of:

   (*a*) at least 1 bar in excess of the maximum hydrostatic pressure to which the structure may be subjected
   (*b*) two times the maximum hydrostatic pressure to which the structure may be subjected.

3. This pressure shall be maintained for 72 hours during which no leakage shall occur at the gasketed faces. Tests shall be carried out at normal ambient temperature.

4. The gasket shall function under all combinations of packing and displacement encountered in the completed structure including permissible tolerances.

5. Based on accelerated aging tests, the projected residual compressive stress in the gasket material at the end of the design life shall not be less than 65% of the short-term compressive force for the fresh material. Where the residual compressive stress is less than this value, the test pressures in the watertightness test shall be reassessed.

6. The manufacturer shall provide details of the maximum load to fully compress the gasket in the groove.

212.3. Hydrophilic gaskets

1. Hydrophilic sealing material shall perform to the same effect as elastomeric gaskets. The composition and properties of the proposed material shall be agreed with the Engineer and sealing strips and joints shall be subjected to the same testing regime as set out for elastomeric gaskets.

2. Hydrophilic gasket material shall take into account the chemical composition of the groundwater.

3. Hydrophilic gaskets shall be of an extruded hydrophilic rubber of an appropriate profile and size to fit preformed grooves in concrete segments. The gasket shall be treated with a coating to delay the onset of swelling during erection of segments.

4. Hydrophilic gaskets shall be protected from contact with water, including rainwater, prior to erection.

212.4. Elastomeric gaskets

1. Elastomeric gaskets shall comply with the requirements of BS EN 681-2 and have an IRHD (international rubber hardness degrees) between 60 and 75. The material shall consist of a compound able to withstand the long-term stresses and strains, groundwater and internal chemical conditions without detriment to the specified performance.

2. The gasket cross-section shall be dimensioned to suit the groove as detailed for the mating faces of the segmental tunnel linings. Manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness unless specified otherwise on the Drawings.

3. The extruded section shall be joined to form a rectangular gasket that is a stretch fit into the grooves of the concrete segments. The corner joint shall be shot moulded and the comer pieces shall be of a different section from the extruded lengths in order that the watertightness characteristics described in this specification may be achieved and to avoid excessive load on the comers of the concrete segments.

4. Gaskets shall be fixed into the groove cast in the segmental tunnel linings prior to erection. The adhesive shall be as recommended by the manufacturer of the gasket.

5. Gasket faces shall be lubricated prior to erection with a product recommended by the gasket manufacturer and agreed with the Engineer.

212.5. Composite gaskets

1. Composite elastomeric and hydrophilic gaskets shall be tested to the same requirements as elastomeric gaskets. A time allowance for the expansion of the hydrophilic portion of the gasket shall be allowed for in the test where appropriate.

2. The gasket cross-section shall be dimensioned to suit the groove as detailed for the mating surfaces of the segmental tunnel linings. Manufacturing tolerances shall be ± 0.5 mm width and $+0.5/-0.0$ mm for thickness unless specified otherwise on the drawings.

3. Gaskets shall be manufactured from extruded solid sections with appropriate spaces within the section to enable the gasket to be fully compressible within the groove formed in the concrete segments. The gasket shall still be capable of further compression when its top surface is level with the top of the groove.

4. The extruded section shall be joined to form a rectangular gasket that is a stretch fit into the grooves of the concrete segments. The corner joint shall be shot moulded and the comer pieces shall be of a different section from the extruded lengths in order that the watertightness characteristics described in this specification may be achieved and to avoid excessive load on the comers of the concrete segments.

5. Gaskets shall be fixed into the groove cast in the segmental tunnel linings prior to erection. The adhesive shall be as recommended by the manufacturer of the gasket.

6. Gasket faces shall be lubricated prior to erection with a product recommended by the gasket manufacturer and agreed with the Engineer.

212.6. Gaskets for pipejack joints

1. Gaskets for pipejack joints shall provide a seal against the ingress of groundwater during jacking and in the permanent condition. Gasket material shall comply with the requirements of BS EN 681-2, including resistance to chemical attack and microbiological degradation.

2. The gasket shall be lubricated with a product recommended by the manufacturer and agreed with the Engineer.

213. Cement grout for cavity grouting

213.1. General

1. General-purpose cement grout shall be mixed in accordance with the proportions given in Table 10. The water content shall be kept to the minimum required to ensure a smooth, fluid mix.

Table 10. Mix proportions for cement grout

	Proportion by mass		
Class	**Cement**	**Sand**	**PFA**
G1	1	–	–
G2	1	3	–
G3	1	10	–
G4	1	–	10
G5	1	–	4
G6	1	–	0.5

2. Pulverised fuel ash (PFA) shall not be used as a constituent of grouts which contain sulphate-resisting cement.

3. Grout shall be used within 1 hour of mixing.

213.2. Special grouts

1. Where necessary due to the nature of the ground conditions or where adverse water conditions are anticipated then the requirements for the use of special grouts shall be stated in the Contract.

2. Special grouts supplied by proprietary manufacturers may be used subject to agreement with the Engineer.

3. Details of accelerating and retarding agents for proposed inclusion within the grout mix shall be submitted to the Engineer for agreement. Any such proposal shall be submitted in conjunction with a statement which outlines the Contractor's interpretation of ground behaviour during tunnel construction.

4. Primary grout for machine-driven tunnels shall be special grout injected through the tail skin of the machine as it advances.

5. The Contractor shall propose details of the primary grout, including the required setting times and strength gain to support the weight of the tunnel boring machine (TBM) and the backup and prevent ring distortion. 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 100 mm cubes shall be 1.5 N/mm^2 in 24 hours. The proposals shall be submitted to the Engineer for agreement prior to commencement of the Works.

6. Preconstruction grout trials shall be undertaken to demonstrate that the required setting times and strength gains will be

achieved. Details of the trials and results shall be submitted to the Engineer.

7. Records of batching and batcher calibration shall be maintained to demonstrate that grout batching is in accordance with the design mix. Alternatively, grout strength tests may be used.

213.3. Mixing

1. Grouts containing polymer additives shall only be mixed in a colloidal-type mixer.

2. Special grouts from proprietary manufacturers shall be mixed and used in accordance with the manufacturers' instructions.

213.4. Storage and delivery

1. Bagged grouts shall be stored under cover in dry surroundings and on a suitable platform, clear of the ground.

2. Bulk deliveries of grout constituents shall be stored in appropriate silos with suitable dust control and batch weighing equipment.

214. Packings

214.1. Packings for segmental linings

1. All forms of packing shall be of a shape commensurate with the lining, provided with bolt holes where required and of a width which does not prevent the proper operation of any gasket or seal included in the joint.

2. Timber packings shall be knot-free softwood, or plywood, sawn to shape with bolt holes where applicable. They shall be treated to retard rot and fire, and shall be available in all necessary thicknesses.

3. Stress distribution packing for longitudinal joints in concrete-rings shall be cut from an approved bituminous felt fibre based sheet to the thickness defined on the drawings to the shape required with bolt holes where applicable. Alternative materials to bituminous felt shall be agreed with the Engineer.

4. Steel packings shall be machined and provided in thicknesses of not less than 2 mm. They shall be protected from corrosion in the manner specified for mild steel segments.

5. Packings shall only be used where detailed on the drawings or agreed with the Engineer.

214.2. Packings for opening frames

1. Packings and folding wedges for opening frames shall be as detailed on the Drawings and shall be made of mild steel.

2. To prevent buckling, all packings and folding wedges shall be located at circumferential joints of the tunnel lining segments and at stiffeners in opening frames.

214.3. Packings for jacking pipes

1. Packings for jacking pipes are included in Section 206.

215. Grommets and bolts

215.1. Grommets

1. Grommets for precast concrete linings shall be polyethylene.
2. Grommets for cast iron or steel linings shall be of low-density polyethylene.

215.2. Bolts

1. Bolts shall generally be black bolts to BS 4190.
2. Sherardised bolts, where required, shall be treated to BS 4921 Class 2.
3. Galvanised bolts shall be hot-dip spun to BS EN ISO 1461.
4. Stainless steel bolts, where required, shall be to BS EN ISO 3506-2.

216. Pointing and caulking material

216.1. Caulking

1. Lead for caulking shall comply with BS EN 12588:1999.

2. Lead shall be supplied in rod or strip of widths appropriate to the segment joints, or as lead wool.

3. Cementitious caulking compound cord shall be asbestos free.

216.2. Pointing

1. Mortar for pointing shall be cement : sand (1 : 3) or otherwise agreed with water sufficient only to provide a workable consistency which can be rammed into the joint. Mortar shall be used within 1 hour of mixing. Cement shall comply with British Standards as detailed in BS 8500-2 Table 1 as appropriate; sand shall comply with BS EN 12620 and be of a grading commensurate with the work.

2. Additives and proprietary mixes may be used with the Engineer's agreement.

217. Timber

217.1. General

1. All timber that is used in the Works shall be sourced and procured from a forestry plantation that is subject to the requirements of an internationally recognised Sustainable Forest Management (SFM) Initiative.

2. All timbers used in tunnel construction or underground shall be deemed to be part of the Temporary Works, and shall be in accordance with the requirements of BS 5268 Part 2:2002 *Structural use of timber*.

3. Details of the proposed use of timber in Temporary Works shall be issued to the Engineer for agreement.

4. All timber that is left in situ in the Works shall be treated. The timber shall be impregnated with preservative fluid in accordance with BS 5268 Part 7:2002, to protect the material from decay and the level of treatment shall depend on the species specified and used in the Temporary Works.

5. All timber shall be inspected for damage or other strength-reducing factors that may have occurred after the stress grading operation has taken place. Any timber showing such damage shall be indelibly marked, as rejected. Reuse of timber shall be permitted but it shall be inspected for damage or excessive deterioration before reuse and if found unsuitable rejected.

6. When it is necessary to cut a piece of treated timber for use in the Temporary Works, the cut face(s) shall be treated preferably by immersion in the preservative used in the impregnation process. Alternatively the preservative may be applied liberally by brush.

7. All timber to be used underground shall be treated with a fire-resistant coating agreed with the Engineer, and in accordance with BS 5268, Part 7:2002 *Structural use of timber*.

3. Methods

301. Excavation for tunnels

301.1. General

1. The Contractor shall be responsible for the safety and security of excavations at all times during the execution of the Contract.

2. Mechanised techniques for excavation shall be used wherever practicable to eliminate or reduce health and safety risks.

3. Use of hand-held tools shall comply with the guidance given in *The Management of Hand–Arm Vibration in Tunnelling Guide to Good Practice*, by the British Tunnelling Society.

4. The Contractor shall provide details of his proposed methods for excavation support and spoil removal to the Engineer for agreement. No excavation shall take place until the Engineer's agreement has been obtained. Such agreement shall not relieve the Contractor of any of his obligations under the Contract.

5. Excavation shall be carried out in a uniform and controlled manner and over-cutting shall be kept to a minimum consistent with the need to maintain the necessary clearance for construction of the Works.

6. The invert of the tunnel shall be protected against damage and deterioration which may be caused by construction traffic. Any other surfaces which deteriorate or are damaged shall be made good to a standard agreed with the Engineer.

7. Excavation shall be carried out in sections limited to such lengths, depths and widths as may be safely executed having regard to all the circumstances and as appropriate to the ground conditions and the equipment and method of construction being used.

8. In water-bearing strata the Contractor shall use such methods and take such steps as are necessary to control flows and maintain the stability of the excavation.

9. Where necessary to ensure the safety and security of the Works, excavation shall be continuous by day and night.

10. Weekends, general holidays and enforced stoppages will require the Works to be made safe and inspected by the Contractor at intervals agreed with the Engineer.

11. Any voids formed during the excavation process by machine overcut slips, falls of material, overbreak and temporary works shall be filled completely with grout, concrete, sprayed concrete or other approved durable material.

12. Where the Contract specifies limits to surface settlement and/or protection in respect of existing services or structures, the

Contractor shall provide calculations demonstrating that the method of excavation will result in compliance with those requirements. Details of the monitoring arrangements which are proposed for the recording of movements and the verification of the degree of any settlement or damage to services or structures shall be in accordance with Section 329.

13. Where agreed or required by the Engineer, temporary support shall be left in the Works. Generally, untreated timber shall not be left permanently in the Works.

14. The volume of excavated material shall be measured and recorded as the Works proceed. The Contractor shall present to the Engineer at regular intervals specified in the Contract a reconciliation of volumetric advance of tunnel against volume of materials excavated and volume of grout placed.

15. All excavation shall be carried out to a profile as close as possible to the specified excavation line.

16. The Contractor shall be constantly aware of the possibility of slips and ground movement which may be caused by his method or order of excavation. He shall maintain on-site material, and equipment, for use in ensuring the stability of the face.

17. The proximity of other tunnels and excavations shall be taken into account when determining the method of excavation.

18. Where stated on the Drawings or in the Particular Specification, the Contractor shall undertake tunnel excavation, support and grouting to control ground loss to below the specified values.

301.2. Rock

1. Where excavation requires the use of blasting, the provisions of Section 308 shall also apply.

2. On exposure of a fresh rock face, the rock strata in the face walls and roof shall be mapped geologically in accordance with the requirements of the Contract. The Contractor shall provide access for mapping.

3. Any unsound areas of rock shall be reported to the Engineer immediately together with a record of the Contractor's action. The face shall not be advanced until the area is properly secured.

4. Where an in situ lining is specified, at no point will rock be allowed to intrude within the specified limit as shown on the Drawings.

5. Any face of exposed ground, where excavation is to be discontinued for whatever reason, shall be supported by timber, rockbolts, sprayed concrete or other means agreed with the Engineer.

301.3. Soft ground

1. In ground which is not self-supporting, measures shall be taken to ensure that no undue loss of or softening of the ground

occurs at the face, and that there is no run of material from behind supports or lining.

2. In any exposed ground, temporary emergency support shall be available at the face at all times.

3. Ground and groundwater conditions in any exposed face shall be logged.

302. Drilling

302.1. General

1. Drill rigs shall meet the requirements of BS EN 791.

2. Use of hand-held drilling rigs shall comply with the guidance given in *The Management of Hand–Arm Vibration in Tunnelling Guide to Good Practice*, by the British Tunnelling Society.

3. Drilling shall be carried out to provide holes of the diameters, lengths and inclinations required within the deviation limits given on the Specification and Drawings.

4. The Contractor shall keep a written record of all holes drilled, material recovered and water-flows or seepage and provide the Engineer with a copy if required.

302.2. Blast hole drilling

Holes intended to be charged with explosives for blasting shall be drilled in strict accordance with the agreed pattern, in spacing, direction and depth.

302.3. Probe hole drilling

Probe hole drilling shall be in accordance with Section 310.

303. Temporary Works and ground support

303.1. General

1. Materials used for Temporary Works shall comply with the requirements of BS 5975:2008 *Code of Practice for Temporary Works* and the materials specifications defined elsewhere in this Specification.

2. All Temporary Works shall be designed and erected in accordance with the requirements of BS 5975:2008.

3. Where the use of timber is proposed for ground support or for any Temporary Works, the design shall be undertaken in accordance with the provisions of the Particular Specification, and either BS 5268 Part 2:2002 *Structural Use of Timber* or Eurocode 5.

4. Calculations and drawings shall be submitted to the Engineer for his agreement, as part of a comprehensive method statement, covering the Temporary Works.

5. Temporary Works shall be managed and supervised by appropriately experienced and competent personnel.

6. Details of the competency of personnel engaged in the design and erection of all Temporary Works shall be submitted to the Engineer for his agreement.

7. Full facilities shall be provided for the Engineer to inspect work in progress.

304. Spiling, dowelling and rockbolting

304.1. Spiling

1. Where spiling is employed to provide support for advancing the excavation, spiles shall be driven into the ground or placed in pre-drilled and grouted holes as specified on the contract drawings or by the Engineer.

2. The embedded length shall be not less than that specified by the Designer (typically 1 m beyond the proposed advance of the excavation).

3. The accuracy of installation shall be better than $\pm 5^{\circ}$ away from the alignment specified.

4. The number, location, overlap and angle of spiles shall be commensurate with the ground conditions and methodology specified on the contract drawings or by the Engineer.

5. Details of spiling shall be agreed with the Engineer in accordance with Clause 4 of Section 301.1.

6. Spiles shall be installed such that a tensile bond is formed between the spile, the ground ahead of the proposed excavation, and the sprayed concrete lining. Typically this may involve grouting the spile into the hole for pre-drilled and self-drilling spiles or hammering the spile in.

7. Care shall be taken during installation of spiles to ensure minimum disturbance of the ground due to the installation process.

8. Probing shall be carried out in conjunction with spiling in order that fully embedded spiles are installed prior to the required location.

304.2. Rock dowelling

1. Rock dowels shall be inserted into pre-drilled holes in the ground and grouted up. The number, location, lengths and angles of inclination shall be commensurate with ground conditions. The diameter of holes shall be designed to allow for installation of dowels and grout to ensure effective transfer of shear stress from rock to the dowel.

2. Holes for the installation of dowels shall be drilled straight and with an accuracy of $\pm 10^{\circ}$. On completion of each hole, and prior to the installation of each dowel, holes shall be cleaned to remove debris. Where water-flush is employed, the amount of water shall be kept to an absolute minimum.

3. A regular surface shall be provided to seat the face plate by trimming rock surfaces or forming pads of quick-setting mortar. Where mortar pads are required they shall be of adequate thickness and extend beyond the face plate by 25 mm all round at that thickness before being chamfered at

45°. Care shall be taken to ensure that the mortar does not interfere with the installed dowel.

4. Cementitious grouting material shall be injected starting from the furthest point of the drilled hole so that the dowel is completely encased in grout. Grout shall not be used after a period equivalent to its initial setting time. Where cement grout is used, a set of six cubes of cement grout shall be taken when each series of rock dowels is in progress. Sampling, preparation, curing and testing shall be in accordance with BS EN 196. Half the cubes shall be tested at 1 day and the remainder at 28 days. The average compressive strength determined from any group of cubes shall exceed the specified characteristic strength by:

   1 N/mm^2 for cement grout tested at 1 day
   3 N/mm^2 for cement grout tested at 28 days.

5. Resin grouting capsules shall be installed as directed by the manufacturer.

6. The proposed pattern for dowels and full details of the dowels and installation thereof shall be agreed with the Engineer. Where required, dowels shall be installed in the pattern and locations and manner shown on the Drawings.

304.3. Rockbolting

1. Where rockbolts are employed, full details of the bolts and installation shall be agreed with the Engineer. The pattern and type of rockbolt and the length and diameter of bolts shall be commensurate with the rock characteristics. Where required, rockbolts shall be installed in the pattern and locations and manner shown on the Drawings.

2. Where required by the Contract, the Contractor shall carefully inspect the excavation as it progresses, and if conditions arise that require a change in the excavation and/or support systems, then revised proposals shall be agreed with the Engineer.

3. Rockbolts shall be provided with an even and secure bearing for their face plates. Holes shall be drilled to produce straight holes of the required length, and with an accuracy of ±10°, and cleaned out by flushing with compressed air or with clean water to remove debris prior to fixing the rockbolt. The amount of water-flushing shall be kept to an absolute minimum.

4. Grouting of the rockbolts shall take account of the following:

   (*a*) Inclined rockbolts:
   - Flowing grouts may be placed by an injection pipe at the mouth of the borehole against packing material to seal the mouth and require a breather tube to prevent air-locks within the hole.
   - Thixotropic grouts are typically placed by tremie pipe to the distal end of the borehole, with the grout flowing back down the annulus of the borehole.

(*b*) Declined rockbolts: a single tremie pipe to the base of the borehole for solid bars or a self-drilling hollow bar installed using simultaneous drill and grout.
(*c*) Horizontal rockbolts. Bolts should be $\pm 10^{\circ}$ to ensure that grout can be trapped in the borehole either by gravity or through the use of packers on inclined bores.

5. Rockbolts shall be fixed as soon as possible after excavation. A selection of rockbolts shall be tested. Where excavation is progressed by blasting, any rockbolts within 3 m of the face shall be retested. Any rockbolt which fails a test shall be adjusted to restore its nominated load or replaced as necessary.

6. The Contractor shall carry out in situ tests as agreed with the Engineer. Testing is to be generally in accordance with the procedures given in ISRM Document 2, Part 1 *Suggested methods of rockbolt testing*.

7. Unless otherwise provided for in the Contract, at least 5% of the first 100 bolts installed shall be subject to test. Thereafter 2.5% of subsequent bolts shall be tested. The remedial actions following any bolt test failures shall be agreed with the Engineer.

304.4. Load testing

1. Before commencing rockbolting or dowelling a test programme shall be undertaken to establish the capacity of the rockbolts/dowels to provide the support required.

2. Suitability load testing and acceptance load testing for rockbolts and dowels shall be undertaken in accordance with an agreed quality control programme as set out in the Drawings or the Particular Specification.

304.5. Records

1. For each dowel or rockbolt installed, the following information shall be recorded:

(*a*) reference number
(*b*) type of installation
(*c*) name of person taking record
(*d*) date of drilling
(*e*) length and orientation of drill hole
(*f*) consistency, colour, structure and type of rock or material
(*g*) rates of penetration and water flow if any
(*h*) date of dowel or bolt installation
(*i*) length of installation
(*j*) details of tests, where carried out.

305. Sprayed concrete

305.1. General

1. Sprayed concrete shall be applied by either the wet or dry process as appropriate to the circumstances. All aspects of the application of sprayed concrete shall be subject to the agreement of the Engineer. Particular emphasis shall be placed on the provision of adequate ventilation.

2. Where sprayed concrete is provided as temporary ground support until the permanent lining is in place, details shall be proposed for agreement with the Engineer 28 days in advance.

3. The Contractor shall develop a sprayed concrete mix and a plan for its production and application. Constituent materials shall comply with those listed in Section 209. Admixtures shall be compatible with each other and the mix. Details of the mix design and technical data demonstrating compliance with BS EN 206-1 and BS 8500 will be submitted to the Engineer for approval.

4. The sprayed concrete shall be developed in two stages:

   (*a*) the production of a suitable base concrete
   (*b*) the production of sprayed concrete from the base concrete.

5. The sprayed concrete mix design shall, unless otherwise stated, comply with the characteristic strengths specified by the Designer for early-age and long-term loading.

6. For conformity control of sprayed concrete, three inspection categories have been specified (see BS EN 14487-1 Clause 7). Generally SCL linings will fall into Inspection Category 2, unless the sprayed concrete is permanent, in which case it will be in Inspection Category 3 (see BS EN 14487-1 Annex A, Table A.3).

7. A representative of the Designer should be on site at all times to check that the materials and workmanship are consistent with the design intent, and to ensure that ground and groundwater conditions are in accordance with design assumptions. The Contractor shall establish a procedure to respond effectively to changes in ground and groundwater conditions from the design assumptions (see also Section 329 of this specification).

8. The Contractor shall establish and maintain the instrumentation and monitoring required by the design. The Contractor shall establish a procedure that will enable prompt and regular review and effective response to the results from the instrumentation and monitoring. The SCL designer shall be included in the monitoring review procedure (see also Section 329 of this Specification).

305.2. Proficiency

1. Nozzlemen shall hold relevant certificates of competence issued by the Contractor or written evidence of previous satisfactory work indicating compliance with EFNARC Nozzleman Certification Scheme, ACI 506R-03 (USA) or similar National Standards to the approval of the Engineer. Each crew shall demonstrate acceptable proficiency in the application of sprayed concrete to trial areas before being employed on the Works to the agreement of the Engineer.

2. Subject to the Engineer's agreement, tests for proficiency may be combined with trial mix tests.

3. Tests for proficiency shall use the equipment selected for use in the Works where practicable.

305.3. Batching and mixing

1. Batching and mixing shall be carried out by equipment capable of properly mixing materials in sufficient quantity to maintain the continuous application of sprayed concrete and to the accuracy defined in BS EN 14487-2.

2. All measuring equipment shall be maintained in a clean serviceable condition and shall be zeroed daily and calibrated regularly.

3. The addition of fibres shall be at a stage in the mixing suitable for the sprayed concreting equipment. Fibres shall be added and mixed in a manner to avoid clumping and bending of fibres. Any fibre clumps in the mix shall be diverted and removed by means of a screen placed over the sprayed concrete hopper. Fibres shall be uniformly distributed throughout the mortar matrix without isolated concentrations.

305.4. Application

1. Details of all equipment to be used shall be made available to the Engineer prior to commencement of site trials. The sprayed concrete nozzle and ancillary equipment shall be of an adequate capacity for the volumes to be applied.

2. The equipment selected and approved by the Engineer will be capable of maintaining the ratio of concrete and accelerator as selected from the trials and approved by the Engineer. The actual ratio of accelerator to concrete selected shall be identified at the nozzle, and take into account the filling efficiency of the equipment and the efficiency of the accelerator dosage equipment to overcome the air and concrete pressure at the nozzle while spraying at typical outputs and air flows.

3. A complete stand-by sprayed concrete system of plant and ancillary equipment in full working order shall be available for the duration of the tunnel excavation.

4. The sprayed concrete system shall supply air, water and other constituents uncontaminated by material deleterious to sprayed concrete. In particular, care shall be taken to exclude oil from the air supply.

5. Equipment shall be thoroughly cleaned at least once per shift. The spray nozzle shall be checked for wear and where necessary replaced.

6. Transport pipes consisting of hoses and pipes shall be designed to convey the concrete efficiently and without leakage or blockage. The transport pipes shall have uniform diameter appropriate to the mix characteristics determined by site trials and be free of any dents or kinks between the sprayed concrete machine and the nozzle.

7. Working area for sprayed concreting shall be well illuminated and ventilated. Dust pollution shall be minimised by choice of appropriate equipment and by means of additional ventilation, water sprays, and by maintaining equipment in good order. Protective clothing and dust masks shall be provided for and used by all persons present during spraying.

8. The equipment shall allow for air and water in any combination to be available for preparation of surfaces and/or cleaning of finished work.

9. Dosing of admixtures by hand shall not be permitted.

10. A boom mounting or similar device shall be provided for the spray nozzle unless it can be demonstrated to the Engineer that the use of such equipment is impractical.

11. The Contractor shall enable the Engineer access to the sprayed concrete Works at all times, and shall allow the Engineer access to inspect the excavated ground surface prior to spraying if requested.

12. The method of spraying should ensure a high-quality product (see BS EN 14487-2 Clauses 5.1.1, 5.1.2, 5.2.2 and 9.1). In particular, the spray nozzle shall be kept as perpendicular as possible to the surface and care shall be taken to achieve a regular properly compacted coating of the correct thickness.

13. The sprayed concrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause, the nozzleman shall direct it away from the work until it again becomes constant.

14. The thickness and position of the sprayed concrete shall be defined by screed boards, lattice arches, guide wires, depth pins, lasers or other means.

15. For vertical and near-vertical surfaces application shall commence at the bottom and the leading edge of the work shall be maintained at a slope. Downward spraying shall be avoided where possible. The nozzle may be inclined sufficiently to ensure reinforcement is properly embedded.

16. Prior to continuation of spraying from a joint or leading-edge position or in any other circumstances where sprayed concrete has hardened beyond its initial set, loose material shall be removed by jetting with a compressed air lance. Any laitance which has been allowed to take final set shall be removed and cleaned by jetting with air and water.

17. All rebound material shall be removed from the working area and shall not be used in the Works.

18. All joints in the sprayed concrete lining shall be as specified in the Design.

19. The surface to receive sprayed concrete shall be damp but shall not exhibit free water.

20. 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.

21. Sprayed concrete shall be left in its natural finish without further working except as required to trim excess thickness where the sprayed concrete shall be allowed to stiffen sufficiently before being trimmed with an approved cutting screed.

22. 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.

23. The base mix concrete may be used up to 2 hours after the addition of water to the cement provided that the sprayed concrete can be applied satisfactorily. Any unused material after this time shall be discarded. This period may be extended by the use of hydration control admixtures, subject to the approval of the Engineer.

24. The Contractor shall verify the thickness of any sprayed concrete layer by drilling 25 mm diameter percussion probe holes at any location requested by the Engineer. The Contractor shall provide facilities to the Engineer to allow inspection of the probe holes (see BS EN 14487-2 Clause 10.2). All holes should be backfilled with non-shrink mortar unless otherwise specified.

305.5. Curing

1. Sprayed concrete shall be cured in accordance with BS EN 14487-2 Clause 9.3 unless otherwise approved by the Engineer.

2. Proprietary curing compounds or methods may be used only with the agreement of the Engineer. Membrane curing shall not be used where a further layer of sprayed concrete is to be applied.

305.6. Defects and repairs

1. Before a subsequent layer of sprayed concrete is placed the preceding layer shall be checked for defects.

2. Areas of work shall be properly compacted and bonded and free from honeycombing, laminations, dry or sandy patches, voids, sagged or slumped material, rebound, excessive cracking and overspray.

3. Where defects occur, the Contractor shall agree with the Designer and the Engineer proposals for the removal of the defective material and replacement by material without defect. Where a defect is required to be rectified, the area to be replaced shall in any event be not less than 300 mm × 300 mm.

305.7. Reinforcement

1. Reinforcement shall be securely fixed conforming as closely as practicable to the excavated profile but not less than 10 mm from the underlying surface (see BS EN 14487-2 Clause 6).

2. Where two layers of reinforcement are to be incorporated in the work, the rear layer shall be sprayed prior to fixing the front layer.

3. Lattice girders shall comply with Section 207.3 and Section 306.1 of this specification.

305.8. Tests for trial mixes

1. The Contractor shall propose to and agree with the Engineer trial mixes for the works at least 56 days before their commencement. Tunnelling shall not be permitted to start until the preconstruction tests have been approved by the Engineer.

305.9. Test panels and acceptance tests

1. The performance requirements shall be set by the Designer.

2. The site trials shall employ the equipment which will be used in the Works and the constituent materials shall be fully representative of those to be used in the Works.

3. For each type of sprayed concrete to be used a trial mix shall be designed by the Contractor and prepared with the constituent materials in the proportion proposed. Target workability values shall be determined for the wet mix process. Sampling and testing procedures shall be in accordance with BS EN 12350. A clean, dry mixer shall be used and the first batch discarded.

4. The equipment proposed for the application of concrete in the Works shall be used for the trial. The trial will establish whether the selected equipment is capable of efficiently mixing concrete, accelerator and air at the nozzle, and be capable of positioning the nozzle at a suitable distance and orientation to the surface geometry of the structure to which the concrete is to be applied.

5. During the trials the Contractor will establish the volume of air required to give adequate compaction of the material using the nozzle and conveyance lines selected for the Works. If the delivery equipment or nozzles are to be changed during the course of the works the volume of air required will need to be verified again. The equipment will be maintained adequately, to ensure that the required volume of air can be maintained while spraying. Air pressure can only be used as a control if the air delivery system is not altered from the original verification trial. No additional taps or restrictions will be permitted to be added into the system without repeating the verification trials.

6. If a particular quality of finish is required other than as sprayed, the trials will evaluate the methods and tools to be

used to achieve the required finish and the Engineer will approve the method and quality of finish achieved.

7. From the trial mix an experienced nozzleman shall prepare sufficient test panels as per BS EN 14488-1 Clauses 4.3 and 5.4. The sprayed concrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging.

8. The panels shall not be moved for 18 hours after spraying and shall be stored without disturbance at a temperature of 15–25°C and covered by polythene sheet until the time of coring.

9. Cores for strength tests shall be obtained from the panels at 1 day in accordance with BS EN 14487-1. The cores will be visually inspected and the dimensions and comments regarding the quality of the cores will be recorded as required in BS EN 12504-1. The cores will be free from lamination. The cores for strength tests shall be stored in water.

10. No sets of cores to be tested at any given age shall come from the same panel. Sets of cores to be tested at different ages (i.e. 1 day and 28 days) may come from the same panel. For each test at least one spare specimen shall be provided. The testing requirements shall be: compressive strength in spray direction after 1 day and 28 days on a set of five cores each as per BS EN 14487-1. The correction for in situ compressive strengths is defined in BS EN 13791.

11. The Contractor shall carry out other tests and trials during the period of the site trials as specified in BS EN 14487-1 Clause 7.3, to confirm that the proposed mixes and methods meet the minimum performance requirements, unless otherwise agreed with the Engineer.

12. If required by the Engineer, the trial shall include the construction of the proposed joints including layer joints and advance joints. Samples taken from across the joints will then be taken and the results reported.

13. The site trials shall be repeated if the source or quality of any of the materials, mix proportions or placing equipment is to be changed during the course of the Works.

14. Should any mix fail to produce satisfactory sprayed concrete, the Contractor shall repeat the construction of test panels and test either the same mix, plant, and labour or make such adjustments as he considers necessary.

305.10. Production tests

1. Tests shall be carried out on a routine basis 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).

2. Where the nominal required sprayed concrete thickness is less than 100 mm, the cores for the compressive strength testing shall be taken from areas where the actual thickness is greater

than 100 mm. Alternatively additional sprayed concrete thickness shall be applied in selected areas agreed by the Engineer for subsequent coring of test specimens.

3. Compressive strength tests shall be carried out on prepared test cores in accordance with BS EN 14487-1 and BS EN 14488-2. The time of coring shall be as close as possible to 24 hours after placing. Cores required for 28-day strength tests shall be obtained at the same time as those for 1-day tests and stored in the laboratory in accordance with BS EN 12504-1 and BS EN 12390-2.

4. The frequency of coring shall be in accordance with BS EN 14487-1. The minimum sampling frequencies are valid for production volumes or areas as indicated in Table 11. For volumes or areas smaller than those in Table 11, at least one test sample shall be taken.

Table 11. Control of sprayed concrete properties (see BS EN 14487-1)

Method No.	Type of test	Inspection/test according to	Minimum sampling frequency		
			Strengthening of ground		
			Category 1	Category 2	Category 3
Control of fresh concrete					
1	Water/cement ratio of fresh concrete when using wet mix method	By calculation or by test method			Daily
2	Accelerator	From record of quantity added			Daily
3	Fibre content in the fresh concrete	According to BS EN 14488-7	Min 1	1/200 m^3 or 1/1000 m^2	1/100 m^3 or 1/500 m^2
Control of hardened concrete					
4	Strength test of young sprayed concrete	BS EN 14488-2	1/5000 m^2 or 1/2 months	1/2500 m^2 or 1/month	1/250 m^2 or 2/months
5	Compressive strength	BS EN 12504-1	1/1000 m^3 or 1/5000 m^2	1/500 m^3 or 1/2500 m^2	1/250 m^3 or 1/1250 m^2
6	Density of hardened concrete	BS EN 12390-7	When testing compressive strength		
7	Resistance to water penetration	BS EN 12390-8	1	1/6 months	1/month
8	Freeze–thaw resistance	As no European Standard on this issue is available at the publication of this document, National Standards apply	1	1/6 months	1/month
9	Bond strength	BS EN 14488-4		1/2500 m^2	1/1250 m^2
Control of fibre-reinforced sprayed concrete					
10	Fibre content of hardened concrete (this test is alternative to method No. 3 when it is not practical to determine the fibre content from the fresh sprayed concrete)	BS EN 14488-7	When testing residual strength or energy absorption capacity		
11	Residual strength or energy absorption capacity	BS EN 14488-3 or BS EN 14488-5	1/2000 m^3 or 1/10 000 m^2	1/400 m^3 or 1/2000 m^2	1/100 m^3 or 1/500 m^2
12	Ultimate flexural strength	BS EN 14488-3	When testing residual strength		

5. The strength of sprayed concrete measured by cores taken from the Works shall be acceptable if the compressive strength results comply with the requirements stated in Section 209.8 of this Specification.

6. Mechanical rebound hammers shall not be used to obtain indirect compressive strength of sprayed concrete.

7. If the results of any production test do not comply with the evaluation criteria, the results and tests procedures shall first be checked and confirmed. The Engineer may require that additional tests be carried out by the Contractor to determine the extent of the non-compliance and/or new mix proportions or methods determined to avoid further failures.

8. Where sprayed concrete does not comply with the required strength, the Contractor shall execute remedial work which may involve additional sprayed concrete or replacement in sections where it is safe to do so. The Contractor shall take into account any limits placed on the tunnel profile dimensions resulting from the Specification. The Contractor shall submit to the Engineer for agreement, a method statement, specification and calculations for remedial work.

9. The Engineer shall, in the event of repeated failure in Quality Control, require the Contractor to adjust the mix to achieve the required strength.

10. The Contractor shall keep a record in a form to be agreed with the Engineer of all tests on sprayed concrete, which shall be kept on site identifying the tests with the section of work to which they relate.

11. Site-specific calibration is required for the strength tests of young sprayed concrete in BS EN 14488-2.

12. For permanent linings, test panels sprayed in the tunnel can be used instead of taking samples from the lining.

13. All core holes in the lining should be backfilled with non-shrink mortar of an equivalent strength unless otherwise specified.

306. Ground support with arches

306.1. Steel arches/ ribs and lattice girders

1. The Contractor shall provide method statements for the erection of arches to the Engineer for agreement. Arch materials shall conform to Section 207.

2. Steel arch ribs and full circle ribs shall be firmly fixed in their final positions against the excavation. Arch bases shall be provided with integral base plates of size to suit the bearing capacity of the ground and shall bear on rock or concrete of adequate strength. Arches and ribs shall be sufficiently clear of the excavation and the final internal profile of the structure to accommodate any required concrete cover.

3. The number of joints in the arch shall be varied to suit the Contractor's method of working subject to the Engineer's agreement. Steel tie bars and struts between arches shall be installed where shown on the Drawings.

4. A minimum 50 mm thick sprayed concrete layer must be in place before the installation of the lattice girders. Under no circumstance shall lattice girders be installed under unsupported ground.

5. Lattice girder segments shall be secured by use of temporary wood blocking, steel wedges, concrete spacers, mortar sacks and/or other appropriate means to maintain position during application of sprayed concrete. The means of support shall be subject to the approval of the Engineer. All wood blocking shall be removed during the next phase of excavation and any void infilled with sprayed concrete to ensure continuity of the primary lining.

6. Lattice girder segments shall have butt plates and the method of installation shall ensure tight connection of all elements.

7. Immediately prior to concreting, casting or spraying, the arches, ties and struts shall be rendered clean and free from deleterious matter.

8. Lattice girders shall be firmly fixed in their final position against the excavation prior to application of sprayed concrete. Lattice girders shall be sufficiently clear of the excavation and final internal profile of the structure to accommodate the required sprayed concrete cover.

307. Forepoling

307.1. General

1. Forepoling boards can be steel (trench sheets or similar) or timber shaped to suit and adequate for the purpose. They shall be driven from the supporting frame in a slightly upwardly inclined direction at the crown of the heading and should penetrate at least half a set beyond the next excavation cycle.

2. On completion of the excavation cycle the next supporting frame is to be installed and all necessary heading supports fitted and wedged tight including wedges between the head tree and boards prior to continuing excavation.

3. The next set of poling boards are then installed immediately below the previous set and above the head tree by removing the wedges one by one, and then the boards are driven as before. In the event that full penetration is not achieved, the boards can be fully driven to their required location during the excavation cycle.

4. Upon completion of each advance or at the end of each shift all head and side timbers should be fully grouted up.

5. Great care shall be taken to prevent the disturbance of face boards and supports in general during the forepoling cycle.

308. Explosives

308.1. General

1. The Contractor shall use explosives only in circumstances where it is safe to do so having due regard to the safety of persons, third-party property and the safety of the Works. Explosives shall not be used without the agreement of the Engineer.

2. The Contractor shall obtain all necessary licences and consents and shall provide secure storage facilities for all explosives and equipment in accordance with BS 5607:1998 *Code of practice for the safe use of explosives in the construction industry* and the requirements of the local police force and the Engineer.

3. Explosives shall be handled and used only by the Contractor's duly authorised personnel. The names and qualifications of such personnel shall be submitted to the Engineer in writing in advance of any possible use of explosives.

4. Blasting operations shall be carried out only under the direction of an experienced operator. The Contractor shall appoint one competent person to be responsible for the security of explosives.

5. At an early stage, in advance of the proposed use of explosives, the Contractor shall notify the Engineer, third parties, statutory authorities and services which have an interest in or are likely to be affected by blasting operations, of the general nature of the operation. The Contractor shall subsequently give a minimum of 14 days notice to the Engineer and others described above of the proposed use of explosives. With this notification the Contractor shall submit to the Engineer a detailed method statement on all aspects of the proposed use of explosives, including the treatment of misfires.

6. Blasting shall be carried out carefully so as to avoid loosening or shattering rock beyond the required line of excavation, and loose or shattered rock (where it does not contribute to stability of the excavation) shall be removed by scaling down or other means before personnel will be permitted to restart operations after blasting.

7. Notices of blasting operations shall be posted on site. Before each firing, the Contractor shall give audible warning, clear the area, and shall take positive measures to prevent personnel from entering the danger area.

8. The Contractor shall monitor the results of blasting closely and, where it is proper to do so, shall propose changes to his blasting operation for the agreement of the Engineer.

9. Under no circumstances shall any holes be charged until completion of all drilling operations at the face.

10. After each blasting operation the tunnel drive shall be sufficiently ventilated to remove any nitrous gases and the atmospheric conditions shall be constantly checked prior to personnel accessing the excavated face.

11. No person shall be allowed to approach the face and no face operation shall commence until the Contractor's authorised person in charge of the operation has given permission.

12. As soon as practicable after blasting and without undue delay the Contractor shall erect such support as may be necessary to safeguard the excavation and personnel.

13. The shot-firer must keep a record of the number of shots fired, their time of firing, type and weights of explosives used and the type and number of detonators used, together with a record of the post-blast situation for each and every location.

14. A copy of the record shall be available to the Engineer at the end of every shift on which shots are fired.

15. The Contractor shall comply with the following documents in respect of the use of explosives:

(*a*) Explosives Act 1875
(*b*) Amendment to Explosives Act 1875, dated July 1923
(*c*) The Manufacture and Storage of Explosives Regulations 2005
(*d*) BS 5607:1998 *Code of practice for the safe use of explosives in the construction industry*
(*e*) Control of Explosives Regulations 1991
(*f*) Carriage of Explosives by Road. Road Traffic (Carriage of Explosives) Regulations 1996
(*g*) PD CLC/TR 50426:2004 *Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation. Guide*
(*h*) Quarries (Explosives) Regulations 1988, as far as it is relevant to tunnel works.

308.2. Blasting vibrations

1. For structures in the proximity of blasting, the peak particle velocity shall be measured at the locations immediately adjacent to the structure nearest to the face being blasted or any other location where it is necessary to limit vibration.

2. Vibration monitoring proposals shall be submitted to the Engineer for his agreement.

3. The measurement of peak particle velocity shall be obtained from instruments capable of measuring along three orthogonal axes, one of which shall be aligned parallel to the centre line of the excavation and another shall be vertical. The Contractor is to provide supports for the measuring instrument if so required by the manufacturer's instructions.

4. The measurements of the particle velocities shall be the responsibility of the Contractor. Copies of the readings in an agreed form shall be supplied to the Engineer.

5. Equipment for measurement of vibration shall be in accordance with BS 7385 Part 2:1993.

6. Prior to the commencement of blasting in any location, the Contractor shall demonstrate by the use of test firings, or by other means, that neither the peak particle velocities given in BS 7385 Part 2 nor those stated in the Particular Specification will be exceeded.

309. Groundwater

309.1. General

1. Unless specifically authorised or approved by the Engineer under the Contract, lowering of the natural groundwater table shall not be permitted.

2. Any proposals to lower the water table shall take account of the risks of causing settlement. Removal of groundwater shall not cause damage to the Works, nor to third-party property and shall not cause nuisance either by the removal of ground or by settlement.

3. Any impact on other groundwater abstractions shall be assessed, mitigated and monitored in line with the agreement with the holder of the abstraction licence and the Environment Agency.

4. The Contractor's working methods and systems shall be designed to control groundwater to permit the construction of shafts, tunnels, breakouts and connections. Methods shall be in accordance with best practice as outlined in CIRIA Report C515 *Groundwater control – design and practice*. The Contractor shall submit proposals to the Engineer for controlling and monitoring any dewatering system, including monitoring changes in groundwater level/pressures and settlement monitoring, prior to commencing installation and running of any dewatering system. The dewatering system shall include a system for identifying ingress of soil material during the dewatering operation.

5. In planning temporary pumping systems, the Contractor shall take due consideration of water quality, pressure, quantity and variations in water levels.

6. The Contractor shall obtain the necessary consents from the appropriate authorities to abstract, recharge and dispose of groundwater. See Section 507.4.

7. In areas of contaminated land, abandoned mine workings and other possible water-filled voids, the Contractor shall take account of the potential hazards of inundation of the Works.

8. Any temporary works for the control of water shall be removed and the ground reinstated when they are no longer required.

9. Groundwater lowering as a method of ground stabilisation is further considered in Section 404.

310. Probing ahead

310.1. General

1. Where required, the Contractor shall be responsible for probing ahead of the tunnel face in order to prove or investigate the ground.

2. The selection of plant for probing shall be agreed with the Engineer and shall take into account the probable nature of the ground ahead and its water-bearing capacity.

3. Probing shall be carried out such that at all times the distance of probed ground ahead of the face is sufficient to allow modification of the method of working ahead of any change in ground conditions. The number of probes, their positions in the face and angles with respect to the tunnel drive shall be governed by the actual ground conditions encountered and the machinery in use subject to minimum requirements specified on the contract drawings.

4. The maximum probed distance ahead of the face shall be governed by the ground conditions and the degree of uncertainty with distance, subject to minimum requirements specified on the contract drawings.

5. Should the information obtained from probing indicate that forward ground conditions will require a modification of the method of working, the Contractor shall prepare proposals for the Engineer's agreement.

6. The diameter of probe holes shall be not less than 38 mm.

7. The flush used shall be suitable for the type of ground conditions anticipated and the machinery in use.

8. A trial shall be carried out in advance of tunnelling activities in order to identify the optimum drill bit, drill diameter, flush and percussion rate. These parameters shall be kept constant during drilling to allow direct comparison between probe holes.

9. An accurate and systematic record of probe hole positions (positions in the face and angles with respect to tunnel drives), drill penetration rate, drill parameters (percussion, torque, thrust), flush (colour, percentage return), drilling sounds (loud, quiet, intermittent), water strikes and interpretation of the nature of the ground ahead shall be noted at the time the holes are bored and a copy provided to the Engineer.

10. Full facilities shall be provided for the Engineer to inspect probing work in progress.

311. Break-outs from shafts and tunnels

311.1. General

1. For the junctions of tunnels and shafts the Contractor shall submit, for the Engineer's agreement, Temporary Works details and method statement describing the details of the work, with drawings and calculations. They shall take account of relevant information provided by the Engineer and Designer.

2. Tunnel and shaft linings shall not be broken out until all necessary Temporary Works, including ground treatment, where appropriate, have been completed to ensure the structural and geotechnical stability of the Works.

3. In segmentally lined tunnels and shafts, segments shall not be removed or lining broken open until the temporary supports and/or ground treatment processes have been properly installed. Adequate wedges and packings shall be installed to limit deformation of the lining buring breaking out.

4. Where dowels are used between segments to transfer loads around the opening, the details shall be provided to the Engineer for agreement. The details shall prevent damage to any gaskets or shall include detailed proposals of how the watertightness is to be maintained.

5. Temporary supports shall not be removed until so agreed by the Engineer and the work for which they are required has been completed and the structure is capable of carrying the imposed loads. Once junction work is commenced it shall be completed as expeditiously as practicable.

6. The break-out shall be of sufficient dimensions to accommodate the permanent structure to be built. Adequate working space shall be provided to enable the Works to be undertaken safely.

7. The break-up for a tunnel shall enable the construction of a stable initial length of an adequate tunnel lining, built within the specified construction tolerances.

312. Installation of sheeted waterproof membranes

312.1. Surface preparation

1. Prior to application of the geotextile fleece layer the primary lining shall be surveyed to confirm that it does not encroach into the designed extrados of the secondary lining. Any proposals to rectify areas of the primary lining shall be agreed with the Engineer.

2. The surface shall be prepared in accordance with the manufacturer's instructions. Except where indicated on the Drawings, all fixtures shall be removed from the primary lining prior to application of the geotextile fleece layer. All core holes shall be backfilled with mortar to be flush with the surface of the primary lining.

3. For sheet waterproof membranes, the profile of the substrate (tunnel surface) shall not have any irregularities that exceed a ratio of length to depth of 5:1 and its minimum radius shall be 200 mm. The substrate surface shall be free from protrusions or sharp edges which may lead to membrane puncture. Crushed aggregates of a grain size greater than 10 mm shall not be used.

4. Groundwater penetrating through the primary tunnel lining shall be collected and drained by appropriate measures. This drainage shall be maintained throughout the membrane placing process, and shall be so arranged that excess water pressure behind the membrane cannot develop.

312.2. Geotextile fleece layer

A layer of protective geotextile shall be attached to the substrate by suitable non-projecting fastenings installed directly through the geotextile fleece. When fixing the geotextile fleece overhead, sufficient fixings shall be installed to ensure the fleece is in close contact with the substrate and is self-supporting. The sheets shall overlap by at least 200 mm.

312.3. Waterproof membrane

1. The material for the waterproof membrane shall be in accordance with Section 210.

2. The applicator shall undergo thorough on-site training and be approved by the manufacturer or supplier of the welding equipment.

3. When placing the sheet waterproof membrane, no other Works shall be carried out in the vicinity which may cause personnel or equipment to come into contact with the sheet waterproof membrane before it has been protected. If it is likely that excessive dust may be generated in the vicinity of the Works (vehicle movements etc.) then dust suppression measures shall be put in place.

4. Waterproof membranes shall not be stored in direct sunlight prior to use. Waterproof membranes shall be protected from damage at all times.

5. The amount of membrane stored in the tunnel shall not exceed one day's production to minimise the fire load stored underground.

6. The sheet waterproof membrane shall be fixed to the tunnel structure by means of fastening devices which preserve the integrity of the sheet waterproof membrane. Sufficient fixings shall be installed to ensure the fleece is in close contact with the substrate and is self-supporting.

7. All sheet waterproof membrane overlaps shall be welded in accordance with the membrane manufacturer's instructions.

8. Where waterproof membrane has been installed in the tunnel invert, it shall be protected from any damage as soon as possible after testing.

312.4. Construction joints: geotextile fleece

1. Joints shall be in accordance with the manufacturer's instructions.

2. Joints shall have a minimum overlap as specified in 312.2.

312.5. Construction joints: sheet waterproof membrane

1. Radial joints between sheets of sheet waterproof membrane shall be welded using flat-faced fillet welds. Two lines of weld shall be used on each joint forming a double seam of at least 15 mm wide, with the minimum sheet waterproof membrane overlap 80 mm for manual welding and 100 mm for automatic welding.

2. If protrusions through the membrane are required, they shall be fitted with collars to maintain the watertightness of the system.

3. Star or cross joints shall be avoided.

4. The length of material roll shall be procured to enable a complete extrados to be installed as a continuous length. Longitudinal joints shall be avoided.

312.6. Quality Assurance and control – field trials

1. Field trials shall be made to demonstrate the capability of the equipment, workmanship, materials and application methods under field conditions.

2. The testing programme shall be started sufficiently early prior to installing the membrane to ensure that the required watertightness can be achieved and allow repetition of the trials should the initial results prove unsatisfactory. All trials and acceptance tests shall be completed satisfactorily by the time installation commences.

3. Prior to construction, trials shall be carried out in order to establish the speed and temperature of joint welding required to achieve welds which are acceptable to the Engineer. If hand-welded joints are proposed at junctions, then this type of weld shall be pre-tested and agreed with the Engineer.

312.7. Quality Assurance and control – construction testing

1. A visual inspection of the sheet waterproof membrane shall be carried out as specified in Table 12. Areas where the sheet waterproof membrane is damaged shall be marked up, repairs

carried out and tested in accordance with the manufacturer's instructions.

2. All welded joints shall be tested in accordance with Table 12. Any joints that fail the test and require repair shall be marked with a permanent marker, at the time of the test.

3. Repairs and hand-welded joints shall be tested by hand-held vacuum chamber in accordance with Table 12.

Table 12. Construction testing for sheet waterproof membrane

Parameter	Test method	Frequency	Pass/fail criteria
Coverage	Visual	A visual inspection to be carried out continuously while the membrane is applied	100% coverage
Double welded seam joints	DIN 16726	Every joint	Pressure drop not to be greater than 20% when a 2 bar pressure is applied for 10 minutes
Hand welding and repairs	ASTM D5641-94 (2006)	Every hand-weld and repair	Pressure drop not to be greater than 20% when a 0.3 bar pressure is applied for 10 minutes

4. A visual inspection of the fleece shall be carried out. Areas in which the substrate is still visible, or where the fleece is damaged, shall be marked up and an additional layer of fleece applied with a minimum lap of 200 mm around the area.

312.8. Defective membrane

1. Where tears, rips or defective joints in the geotextile fleece are noted these shall be repaired with a minimum overlap of 200 mm.

2. Where tears, rips or defective joints in the sheet waterproof membrane are noted these shall be repaired in accordance with manufacturer's recommendations. These shall be tested by hand-held vacuum chamber in accordance with Table 12.

3. Any sheet waterproof membrane not meeting specified requirements shall be removed and replaced including any associated water management measures or smoothing layer. The cause of the problem shall be rectified before placing any further sheet waterproof membrane.

312.9. Secondary lining concrete works

The placing of secondary lining concrete sequence and processes shall be such that they do not displace or damage the geotextile fleece or sheet waterproofing membrane.

313. Installation of sprayed-applied waterproof membrane

313.1. Substrate preparation

1. Prior to application of the waterproof membrane the primary lining shall be surveyed to confirm that it does not encroach into the designed extrados of the secondary lining. Any proposals to rectify areas of the primary lining shall be agreed with the Engineer.

2. The surface shall be prepared such as to give a suitable finish in accordance with the manufacturer's instructions.

3. Field trials shall be used to determine the most effective method of achieving the required finish.

4. Before application of the spray-applied waterproof membrane, the sprayed concrete surface shall be thoroughly cleaned using compressed air and water (without oil contamination). All surface contamination, such as dust, oil, loose particles, etc., shall be removed.

5. If a non- resin-based spray-applied waterproof membrane is used, the surface shall be damp before application of the spray-applied waterproof membrane as per the manufacturer's instructions.

6. The substrate surface texture shall be adequately smooth to permit an even continuous spray membrane application with a minimum thickness of 3 mm. Where the surface texture roughness is too excessive to 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 5 to 10 mm thick and shall use sand (with a grading of 0 to 4 mm) as the aggregate. The regulating layer shall not encroach into the designed extrados of the secondary lining.

7. Groundwater ingress shall be pre-sealed by resin injection, fast-setting impermeable mortar, or managed by drainage systems so that there is no running water on the surface during membrane application. This drainage shall be maintained throughout the membrane installation works and shall be arranged such that excess water pressure cannot develop behind the membrane.

8. For each area of groundwater ingress, countermeasures shall be submitted to the Engineer for approval.

9. Where a drainage system is used the Contractor must demonstrate the sprayed waterproofing system remains effective where it is applied to or overlaps the drainage system.

313.2. Application

1. During membrane application, the environmental conditions local to the spraying shall be in accordance with the membrane

manufacturer's instructions. Ventilation should be not less than 0.5 m/s to provide optimal application and curing conditions.

2. When spraying the spray-applied waterproof membrane, no other works shall be carried out in the vicinity which may cause personnel to come into contact with the spray-applied waterproof membrane before it has sufficiently cured.

313.3. Equipment

1. The spray-applied membrane may be applied robotically. Robotic application shall be as approved by the membrane manufacturer.

2. Application of the spray-applied waterproof membrane shall be in accordance with the recommendations of the manufacturer.

313.4. Construction joints

1. Where the spray-applied waterproof membrane is sprayed in alternate bays, or there is an interruption in spraying of more than 6 hours, there shall be a minimum overlap of 200 mm with the existing spray-applied waterproof membrane and the surface shall be cleaned prior to application.

2. Cleaning requirements for construction joints shall be confirmed following site trials, validated by bond strength testing.

313.5. Defective membrane

1. 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 membrane. Where an area is deemed defective the section shall be removed, cleaned and resprayed with a minimum overlap of 200 mm from the boundaries of the defect.

2. Any spray-applied waterproof membrane not meeting specified requirements shall be removed and replaced including any associated water ingress control measures or smoothing layer. The cause of the problem shall be rectified before placing any further spray-applied waterproof membrane.

313.6. Secondary lining construction

1. Prior to secondary lining construction, the membrane shall be inspected for defects, pinholes and 100% coverage.

2. Where a spray-applied waterproof membrane has been installed then the secondary lining concrete shall not be applied until the spray-applied waterproof membrane has cured sufficiently to achieve a minimum Shore A hardness of 50.

3. As soon as practicably possible after the membrane has been installed it shall be protected by the construction of the secondary lining.

314. Tunnel boring machines (TBMs) and shields

314.1. General

1. Unless otherwise stated in the Contract, the Contractor shall be fully responsible for the selection, design and supply of tunnelling machines, shields and ancillary equipment.

2. The Contractor shall take into consideration all geological and other relevant information made available to him. The Contractor shall satisfy himself as to the suitability of the machines or shields which he will provide.

3. The tunnelling machine selected shall provide adequate settlement control when operating in the anticipated strata and shall be suitable to meet settlement limits where defined in the Particular Specification.

4. The primary standards to be complied with are BS EN 12336 and BS EN 815.

314.2. Machine characteristics

1. All tunnelling machines shall be designed with adequate safety margins for the anticipated duty and manufactured to comply with all relevant safety standards. The design and layout of the TBM control and other workstations shall be carefully considered to provide good ergonomics, visibility and a safe working environment.

2. Adequate provision shall be made for maintenance, including handling heavy components. Individual replacement of major components such as electric motors, hydraulic pumps and motors, propulsion and face rams shall be possible.

3. The machine design shall consider the safe replacement of excavation tools during the tunnel drive.

4. The external diameter of the TBM or shield shall be designed to produce minimum overbreak and the least necessary clearance for the proper construction of the Works. Design shall take into account the horizontal and vertical alignment to be negotiated. Provision shall be made to limit and correct roll of the machine.

5. Where probing ahead may be required, there shall be a provision for making horizontal and raking exploratory holes. Where machines have pressure bulkheads the probing and grouting points shall have the facility to install glands and valves to withstand the pressures envisaged.

6. All machines and shields except those used exclusively for pipejacking shall be self-propelled. Where propulsion is by means of hydraulic rams thrusting off previously constructed segmental lining, ram shoes and facings shall be designed to distribute the thrust without causing damage to the constructed lining. Ram shoe pads shall be adequately secured. Propulsion rams

shall be capable of operating individually or collectively in any combination. They shall permit the insertion of a key closing segment, if used, in any location.

7. Where open shields are to be equipped with face rams for the support of excavation they shall be capable of operating individually or collectively in any combination. Face rams shall be designed to accommodate the loads necessary to make the face secure. The operation of face rams shall be interlinked with that of the propulsion rams.

8. Arrangements for extraction, transport and disposal of spoil shall be appropriate for the material to be handled.

9. Where sledges drawn by the TBM or shield are used, they shall be designed such that they do not damage the permanent or temporary lining.

10. Segment erection systems shall be capable of picking up and placing segments safely and accurately. Lifting and gripping systems shall be designed to handle the loads with an adequate factor of safety and without damaging segment sealing systems. If required, erection systems shall be capable of compressing joint gaskets.

11. The erector shall be in clear view of the operator. A safety device shall be fitted to avoid accidental release of segments during handling and placing.

12. All operating functions of TBM or shield, including rate of advancement, shall be accessible to the TBM or shield driver.

314.3. Guidance

1. An adequate guidance system shall be installed on tunnelling machines with a display to show the position and attitude of the machine relative to the design alignment. The display shall be visible to the machine driver at all times.

2. A secondary means such as a plumb-bob or other apparatus shall be used to check inclination, and to indicate roll. Shields shall be furnished with a means of controlling orientation.

3. Detailed guidance information shall be checked against the tunnel alignment control at regular intervals as agreed with the Engineer.

314.4. Fire protection

1. Fire protection and fire-fighting arrangements as required by the relevant standards shall be incorporated on all shields and tunnelling machines. The equipment shall include, but not be limited to:

(*a*) fire extinguishers
(*b*) sprinkler systems
(*c*) a high-density foam drencher system.

A warning signal both audible and visual shall be provided.

2. Tunnel boring machines, other than remote control machines, shall also be equipped with the following:

(*a*) significant electrical items protected by direct injection of extinguishant into enclosures from a fixed system
(*b*) a fixed extinguisher system discharging foam or powder over hydraulic pumps, motors and storage tanks
(*c*) water spray curtain at the outbye end
(*d*) additional fire protection as appropriate to size and layout of the tunnelling machines.

314.5. Contractor's submission

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.

314.6. Inspection and testing

1. The Contractor shall be responsible for the quality of materials used or present within the TBM or shield and must ensure that all materials used or present are adequate for the task they are to perform.

2. The Engineer shall be permitted at any stage during manufacture to inspect, examine and test on the manufacturer's premises the materials, workmanship and performance of all plant and components to be supplied under the Contract. Such inspections, examination or testing shall not release the Contractor from any obligation as specified under the Contract.

3. When tests are to be made at the premises of the manufacturer or elsewhere, except where otherwise specified, the Contractor shall provide such assistance, labour, materials, electricity, fuel, stores, apparatus and instruments as may be requisite and as may be demanded to carry out such tests efficiently.

4. New and reconditioned machines shall be assembled at the manufacturer's works on completion of fabrication or modification and tested to demonstrate that all components operate correctly. Test running will also be required at site following assembly, prior to commencement of tunnel driving.

314.7. Personnel and training

1. The Contractor shall ensure that all key personnel who are responsible for driving, maintenance and controlling the machine have received the necessary training in the duties that they are required to perform. Preferably the training shall be done within a system of national vocational qualifications. Such training shall include emergency procedures.

2. The Contractor shall provide and maintain a complete list of the names of persons, and their duties, responsible for the operation of the machine, who have completed the appropriate training to an accepted standard.

315. Slurry and earth pressure balance machines

315.1. General

1. A slurry machine is a tunnel boring machine with a bulkhead located behind the face to form a pressure chamber. Bentonite slurry or other medium is introduced into the chamber under appropriate pressure to equalise ground pressure and to be mixed with material excavated by rotary cutter wheel. The resultant slurry is removed by pumping.

2. An earth pressure balance machine (EPBM) is a tunnel boring machine with a pressure bulkhead located behind the face to form a pressure chamber. The excavated material is retained in the pressure chamber under pressure and is extracted by means of a screw mechanism in an operation integrated with excavation. Liquids and additives may be admitted to the chamber to mix with excavated material.

3. Slurry and earth pressure balance machines shall generally comply with Section 314.

315.2. Machine characteristics

1. The machine shall be fitted with a pressure bulkhead capable of withstanding the total pressure envisaged plus an adequate working and safety margin. Where machine size permits, this bulkhead shall include provision for a means of access to the pressure chamber.

2. The pressure control system shall maintain the required pressure on the face at all periods when the machine is advancing, and when standing. Control shall be such that the pressure can be adjusted to suit changing face conditions and maintain stability at all times.

3. Pressure sensors capable of working in air, liquid, spoil/liquid and spoil media shall be mounted on the pressure bulkhead or slurry pipework with pressure gauges in the control cabin reading the pressure in the chamber.

4. All tools on the cutter head including the copy and gauge cutters shall be of robust and durable construction in order to minimise the need for replacement during the drive. Excavation tools shall be replaceable from the chamber. A system to indicate wear of the tools shall be provided.

5. If the machine requires the application of low-pressure compressed air to gain access to the pressure chamber, air locks and bulkheads shall comply with the provisions of BS EN 12110. Work in compressed air shall comply with Section 401.

6. Propulsion rams and shoes shall be designed to take account of the additional forces required to propel the shield forward with the face pressurised. The load from any one ram or combination of rams shall be limited to avoid damage to the lining.

7. The tailskin shall be of a length to ensure that the tail seals are fully engaged on the last ring built after shoving, or on a pipejacking lead pipe.

8. Tail seals shall be designed to withstand the maximum pressure at the tunnel invert, plus additional operational pressures from propulsion and grouting, with an adequate safety margin. They shall prevent ingress of water, slurry, grout and other materials into the tunnel. Tail seals are to be replaceable and accessible for maintenance during operations. The type of seal is to be fully compatible with the tunnel lining used.

9. An emergency tail seal shall be available in the event of a significant breach of the main seals.

315.3. Grouting

Grouting shall be by injection through the tailskin unless otherwise agreed with the Engineer. The grouting system shall include measurement of grout injection pressures and volumes.

315.4. Spoil removal

1. The excavation and disposal arrangements shall be capable of dealing with the full range of materials expected. Generally the disposal system shall accommodate material produced by the cutting equipment. A trap may be provided for the retention of pieces of material which would otherwise cause damage to or stop up the disposal system.

2. Slurry machines shall be provided with means of accurately controlling and adjusting the density and viscosity of the medium supplied to the pressure chamber and introducing additives where required. Pipework, pumps and separation plant shall be designed to accommodate the maximum rate of advance at which the machine will be progressed. The separation plant shall be such that an assessment of the nature and volume of excavated material can be made.

3. Earth pressure balance machines shall be provided with a screw conveyor of sufficient length that the face pressure can be dissipated along its length. Injection points shall be incorporated into the screw conveyor for the introduction of additives.

315.5. Instrumentation

1. The monitoring and control instrumentation shall be grouped in suitable panels allowing good visibility and communications within the working area.

2. Instruments and controls shall include, but not be limited to the following:

   (*a*) face pressure gauges
   (*b*) machine position, inclination and roll
   (*c*) cutterhead rotation speed, direction, torque and thrust
   (*d*) cutterhead door aperture status (where fitted)
   (*e*) ram thrust pressures, stroke and speed singly and in combination
   (*f*) slurry flows and pressure (slurry machines)
   (*g*) screw rotation speeds and pressure drop (EPBMs)
   (*h*) electrical power

(*i*) means of measuring and recording the volume of material excavated per ring of advance
(*j*) TBM advance rates
(*k*) ram extension
(*l*) if required by the Contract, provisions shall be made for data logging of all the above functions
(*m*) grout quantity
(*n*) volume of soil conditioning constituent materials including air, water, foaming agents and polymers.

316. Open-faced tunnel boring machines

316.1. General

1. An open-faced tunnel boring machine is defined as one in which there is no pressure chamber.

2. Open-faced machines shall be constructed to allow compliance with Sections 301.1 to 301.3 inclusive and Sections 314.1 to 314.7.

3. Where lateral gripper pads are fitted they shall provide adequate reaction for the forward motion of the machine without imposing excessive loads on tunnel lining, tunnel supports or the surrounding ground.

4. Where required by the ground conditions, the machine shall be equipped with a water spray system, dust shield and dust scrubber system.

5. The cutterhead shall be designed to allow access to the face for the purpose of inspection, testing, sampling and repair. Access dimensions shall be in accordance with the requirements of BS EN 12336.

316.2. Unshielded tunnelling machines

1. The machine design shall permit the installation of ground support adjacent to the tunnel face as required by the ground conditions.

2. The design of gripper pads and trailing gear of unshielded machines shall allow installation of full profile steel arch ribs within 3 m of the tunnel face.

3. The machine design shall allow the mounting of rock drills capable of drilling radial holes within 3 m of the tunnel face at any point on the tunnel circumference, including sidewalls and invert.

4. The design shall also allow for drilling, spiling, probing or ground treatment holes around the top 120° of the tunnel perimeter at angles of not more than 20° to the tunnel axis and extending at least 10 m ahead of the tunnel face.

5. Provision shall be made in the machine design for installing temporary or primary lining, including sprayed concrete and mesh, behind the TBM gripper assembly.

316.3. Shielded tunnelling machines

1. All shielded tunnelling machines shall comply with BS EN 12336.

317. Hand shields and mechanised open shields

317.1. General

1. Hand shields are tunnel shields with or without working platforms where excavation uses hand tools. Mechanised open shields are similar but with an excavating mechanism mounted within the shield or action separately within the shield.

2. Use of hand-held excavation tools shall comply with the guidance given in *The Management of Hand–Arm Vibration in Tunnelling Guide to Good Practice*, by the British Tunnelling Society.

3. Hand and mechanised open shields shall comply generally with Section 314.

317.2. Boom cutting machines

1. Boom cutting machines (roadheaders) mounted in shields shall comply in all respects with BS EN 12111:2002 and BS EN 12336:2005 + A1:2008.

2. Boom cutting machines shall have adequate total power and cutterhead power and be equipped with appropriate types and numbers of picks, cutters, discs and/or teeth, to excavate the rock efficiently. Self-propelled roadheaders shall comply with BS EN 12111:2002. Excavation shall be in accordance with Section 301.

3. The cutter head boom shall be capable of operating both transversely and vertically and in conjunction with the mobility of the machine shall be able to excavate the face to a neat profile with minimum overbreak to suit the permanent work. Cutters shall be easily replaceable. When mounted in shields, automatic profiling equipment is recommended.

4. The machine shall be provided with dust suppression and/or extraction equipment including water spray arrangements.

5. Where roadheaders are not provided with an integral spoil loading system the Contractor shall provide a mechanised spoil removal system to suit the speed and operation of excavation. Personnel shall not enter the cutting area.

317.3. Backhoe machines

1. Shields equipped with backhoe excavating equipment shall comply with appropriate clauses of BS EN 12336:2005 + A1:2008.

2. Where backhoes are not provided with an integral, separate, spoil loading system, the method of operation shall be such that personnel access to the cutting and loading area is not required.

3. All excavating devices shall be fitted with fail to safe load holding valves to prevent sudden movement, should any hydraulic hose failure occur.

4. All movements of the excavating device shall require dual button control to prevent any inadvertent movements.

318. Tunnelling machines and shield operation

318.1. General

1. The Contractor shall take full responsibility for the performance of the tunnelling machines and shields engaged on the Works. He shall employ personnel who are trained in, and have experience of, the type of machine or shield used.

2. The Contractor shall plan his excavation processes, especially at the commencement and completion of drives, in such a way as to prevent ground movement which might adversely affect the permanent work and existing structures. The Contractor shall present a detailed method statement to the Engineer for his agreement. This statement shall include but not be limited to:

(*a*) the proposed method of transportation and erection of tunnelling machines or shields
(*b*) the proposed method of commencing the tunnel drives until all the ancillary equipment is installed, including any ground treatment or dewatering required; temporary thrust arrangements shall be detailed
(*c*) the method of determining ground conditions ahead of the face and the assessment of the risk of altered ground conditions
(*d*) the proposed method for controlling volume loss from tunnelling
(*e*) the proposed method for reconciling the volume of material excavated with the volumetric rate of advance of the tunnel
(*f*) the proposed method of junctioning including dismantling the machines or shields
(*g*) the method of ensuring that any voids created during the excavation process are adequately grouted as soon as practicable after excavation.

3. Before tunnelling commences, the Contractor shall ensure that all machine systems are operational including all temporary and permanent ground support systems.

318.2. Excavation

1. Excavation shall comply with Section 301.

2. Machines and shields shall be moved forward and excavation made for one unit of the tunnel excavation and lining at a time and only after completion of the previously erected support. The method used shall ensure correct alignment at all times without imposing excessive loads on the tunnel supports, lining or on the surrounding ground. Careful control of the working face shall be maintained to prevent overbreak and loss of ground.

3. Where linings are constructed behind a shield without a tail skin, excavation shall not commence until a complete ring of

lining is available at the erector. Ring erection shall commence immediately after advancement of the shield is complete.

4. When tunnelling under or near existing structures or utility infrastructure, a specific method statement shall be submitted to the Engineer for agreement.

319. Pipe jacking

319.1. General

1. Pipe jacking is defined as the installation of a tunnel lining by jacking pipes behind a shield, tunnelling machine or auger boring machine. The technique can also be used to install rectangular or other sections.

2. Excavation shall be carried out from within a machine or shield equipped with jacks capable of maintaining and adjusting the alignment and shall comply with Section 301.

3. Where applicable, machines and shields shall comply with BS EN 12336, and appropriate parts of Sections 314 to 317 of this Specification (excepting 314.2.5 and 314.2.10). Operations shall comply with Section 318 as appropriate.

4. The contractor shall be responsible for the equipment and systems to provide the forces necessary for the installation of the full pipe string and for the design, provision and introduction of intermediate jacking stations.

5. Appropriate provision shall be made for supporting an exposed excavation face where necessary.

6. The Contractor shall submit method statements for all operations for the agreement of the Engineer before commencement of work. The methods used shall be in accordance with the *Guide to best practice for the installation of pipe jacks and microtunnels* published by the Pipe Jacking Association.

319.2. Thrust and reception pits

1. Thrust and reception pits and shafts shall be designed and constructed to allow the safe operation of plant, equipment and handling of materials and to withstand all loadings imposed by ground pressure, superimposed loads from surface structures and the maximum anticipated thrust forces. Where Permanent Works accommodate the thrust arrangements, these shall be designed to ensure that the Permanent Work is not damaged.

2. In all cases the Contractor shall submit his proposals including calculations to the Engineer for his agreement as required.

319.3. Operation

1. All key personnel shall be experienced in the pipe jacking process and hold relevant skills accreditation.

2. Before any particular pipe jack length commences, sufficient pipes and, if required, intermediate jacking station assemblies shall be available to ensure continuous operation.

3. The agreement of the Engineer shall be sought for inclusion in the Permanent Works of repaired pipes.

4. The jacking force applied by the thrust pit jacks, or an intermediate jacking station shall not exceed the allowable distributed or deflected design load for any pipe being jacked.

5. Thrust loads shall be transferred to pipes through a thrust ring which shall be sufficiently rigid to ensure even distribution of the load.

6. Changes to line and level shall be gradual. The manufacturer's stated permitted draw or angular deflection on any individual joint shall not be exceeded.

7. Intermediate jacking stations shall be inserted to a predetermined plan. Operation shall commence when loading reaches a predetermined level, which shall be less than the allowable distributed and deflected jacking loads as determined by the manufacturer.

8. To avoid excessive loading it may be necessary to undertake continuous jacking until completion of the drive. Where this is necessary the Contractor shall put in place appropriate measures to minimise noise and disturbance.

9. Where necessary means shall be provided to ensure that the pipeline remains stationary when face balance pressure is maintained and when any jacking rams are retracted.

10. Where required under the Contract, or agreed with the Engineer as part of the operational method statement, a lubricating and ground support fluid shall be injected into the annulus between the exterior of the pipe and the ground. This fluid shall be maintained under pressure until completion of the drive. The lubrication injection points shall consist of a minimum of three holes equally spaced around the circumference of the pipe.

11. Where necessary, the lubricant may contain an approved additive to limit water loss.

12. Where the quantities of lubricant injected significantly exceeds the theoretical volumes, this shall be reported to the Engineer.

13. Where required under the Contract, grouting of the pipe annulus shall be carried out on completion.

319.4. Packing and sealing

Joint packing material shall be included at each pipe joint and at any jacking station in accordance with the pipe manufacturer's recommendations.

319.5. Monitoring and instrumentation

1. The Contractor shall maintain site records of jacking loads, line and level measurements, the distance moved and the relationship between them. Copies of all records shall be available to the Engineer at intervals to be agreed.

2. The jacking force instrumentation shall be calibrated for each drive by the Contractor. The calibration certificate shall be made available to the Engineer.

3. Survey control and guidance shall generally comply with Section 319.3. Line and level monitoring shall be carried out in conjunction with the pipe deviation angle. Further monitoring shall comply with Section 329.

319.6. Tolerances

1. Pipe jacking shall be carried out in accordance with the alignment tolerances given in Section 328.

2. Notwithstanding the specified alignment tolerances, the rate of change of direction in any plane, or combination of planes, shall be agreed with the Engineer, taking into account the pipe length, diameter, over-cut, jacking loads, and the manufacturer's recommendations.

319.7. Microtunnelling

1. The term *microtunnelling* is generally applied to small-diameter tunnels and pipelines installed by pipe jacking methods behind a remotely controlled tunnel boring machine.

2. The microtunnelling machine shall be selected with regard to the ground conditions, length of drive and other relevant factors.

3. Microtunnelling shall comply generally with the provisions of Section 319.

4. Microtunnelling machines shall comply generally with the provisions of Sections 314, 315 and 316 as appropriate.

320. Jacked box tunnelling

320.1. General

1. Jacked box tunnelling is a technique for installing rectangular reinforced concrete box tunnels at shallow depth beneath existing traffic arteries such as railways and highways. The technique avoids the cost and inconvenience of traffic disruption associated with cut-and-cover tunnelling.

2. The principal components of a jacked box tunnel are the reinforced concrete box which may comprise one or more segments, an open-face cellular tunnelling shield fixed to the front end of the leading segment, hydraulic jacks in jacking stations between segments and at the rear end of the trailing segment, anti-drag systems, lubrication and grouting systems, and a combined casting and jacking base constructed within a jacking pit.

3. The tunnelling system is designed to install the box tunnel beneath the traffic artery safely, within alignment tolerances and with ground movements controlled so as to keep movements of the overlying infrastructure within acceptable limits. The tunnel is advanced through the ground in typically 150 mm increments each alternating with equal increments of face excavation. In formulating the design, account is taken of site-specific factors including ground conditions, topography, working space, access and maintenance of the traffic artery.

4. Guidance can be obtained on the use of an integrated jacked box tunnelling system with anti-drag systems in the paper by Allenby and Ropkins (2007).

320.2. Design principles

1. Jacked box tunnelling relies on ground which is capable of standing in an open face, supported if necessary by the internal walls and shelves of a cellular tunnelling shield. Unless totally free-standing the ground must be capable of being penetrated by the shield's perimeter cutting edges, internal walls and shelves without being destabilised. It may be necessary to modify the ground in advance of tunnelling by dewatering, grouting or freezing.

2. The tunnel shall be long enough to avoid construction activities interfering with the traffic artery. A longer tunnel may be appropriate to avoid the need for expensive jacking pit headwall works.

3. Intermediate jacking stations shall be used when there is insufficient jacking thrust available at the rear jacking station to advance a monolithic tunnel. Jacking thrust shall be transferred through the jacking base into a stable mass of adjacent ground.

4. Anti-drag systems shall normally be used at both the top and bottom of the tunnel. The former is essential to prevent

drag-induced movement of the overlying ground, while the latter provides an economical means of maintaining the box segments on an accurate vertical alignment when they move off the jacking base. Both anti-drag systems, in combination with appropriate lubrication, reduce drag forces and jacking loads.

5. Control of box horizontal alignment shall be achieved by means of side guides constructed on the jacking base and if necessary by the application of eccentric jacking thrust. It is important to ensure the tunnel face is uniformly excavated so as to minimise eccentric shield embedment loads and the risk of misalignment.

320.3. Site investigation

1. A comprehensive site investigation shall be carried out in the area of the proposed tunnel and its associated Temporary Works. This will identify the nature of the ground and the presence of groundwater. Both short-term and long-term strength parameters for the ground shall be determined. The ability of the ground to stand in an unsupported face and the effect of groundwater on face stability shall be investigated using open trial pits.

320.4. Tunnelling shield

1. The tunnelling shield shall be designed to support the overlying ground and infrastructure and to provide safe working conditions for miners and machine operators.

2. In soft ground the tunnelling shield shall be provided with internal walls and shelves, the front of which penetrate the ground and support the face.

3. In hard free-standing ground the shield perimeter shall be provided with a reinforced cutting edge to assist in accurate trimming and minimise over-break.

320.5. Jacking system

1. Sufficient jacking capacity shall be provided to overcome the jacking load with a suitable factor of safety. Additional jacking capacity shall be provided where eccentric thrust is required for steerage purposes.

2. The box segments and all components of the jacking system shall be designed to withstand the maximum anticipated jacking thrust with a suitable factor of safety.

320.6. Anti-drag systems

1. Anti-drag systems shall be designed to effectively separate the moving box segments from the adjacent ground by interposing a stationary separation layer.

2. They shall be designed to carry the drag loads imparted to them with a suitable factor of safety. They shall normally be anchored at the jacking pit where the load is taken either into the jacking base or into a stable mass of adjacent ground.

3. The top anti-drag system shall be designed to restrict movement of the overlying ground in the direction of tunnelling so that movements of overlying infrastructure are maintained within acceptable limits.

4. The bottom anti-drag system shall be designed to prevent disturbance of the underlying ground and to maintain ground-bearing pressures within allowable limits.

320.7. Prediction of ground movements

1. A prediction of ground movements arising from the tunnelling operation shall be made. An empirical method of prediction based on observations of ground movements on previous similar jacked box tunnel projects is acceptable.

2. Settlement predictions shall take into account the ground conditions, box cross-section dimensions and casting tolerances, depth of cover, shield over-cut and travel distance.

3. Predictions of ground movements in the direction of tunnelling shall take account of the drag forces developed between the top anti-drag system and the box segments, the elastic stiffness of the top anti-drag system and any external restraints to movement of the prism of ground overlying the box.

320.8. Design

1. Conceptual design of the tunnelling system shall be carried out by the Designer who shall be competent and highly experienced in jacked box tunnelling.

2. Detailed design of tunnelling system components shall be carried out by competent, experienced engineers.

3. All design shall be independently checked.

320.9. Construction

1. The Contractor shall submit his proposals for the construction Works, including Drawings, Specifications, method statements and calculations, to the Engineer prior to commencement of construction. In the case of patented or proprietary systems, the Designer, for reasons of confidentiality, may not wish to submit calculations in which case he shall satisfy the Engineer as to his capability by reference to experience gained on projects of a similar nature and magnitude.

2. When constructing the casting/jacking base, the top surface and all jacking equipment bearing surfaces shall be formed to tight tolerances. This is necessary to avoid local crushing when the box segments move along the jacking base and to provide an accurate launching surface for the box segments. When constructing the shield, box segments and intermediate jacking stations the outer surfaces and jacking equipment bearing surfaces shall be formed to specified tolerances. This minimises shield over-cut and ground settlements and ensures the safe transfer of jacking thrust. Fabricated steel components will be required in the shield, anti-drag system anchorages and jacking system. In view of the high loads carried by the components and the need for dimensional accuracy they shall be fabricated with care to the required tolerances.

320.10. Tunnelling operations

1. The Contractor shall submit detailed method statements for all tunnelling operations for the agreement of the Engineer prior to commencement of tunnelling works.

2. Tunnelling operations shall normally be carried out on a continuous basis in order to maintain a stable face and maximise productivity.

3. All key personnel shall be competent and experienced in jacked box tunnelling. Members of the workforce shall hold a relevant Trade Qualification or a National Vocational Qualification or a Plant Operators Certificate.

4. Adequate on-site training shall be given to key personnel and the workforce.

5. Adequate spares and spare machines shall be held on site. In some instances limited access into the box may necessitate storing spare excavating equipment inside the box.

6. The jacking force applied at any jacking station shall not exceed the designed allowable force to ensure that no part of the box tunnel, shield, jacking equipment and jacking base are over-stressed. Jacking force instrumentation shall be calibrated by the Contractor and the calibration certificate made available to the Engineer.

7. Box alignment shall be monitored prior to each increment of advance and the correct combination of jacks selected at each jacking station to either maintain or correct the alignment as appropriate. It should be noted that the dimensional magnitude of large jacked box tunnels does not permit a rapid steerage response to misalignment.

8. Real-time monitoring of ground surface and infrastructure movements in the vicinity of the tunnelling works shall be carried out before, during and after tunnelling. The depth of shield embedment and the amount of jacking thrust shall be adjusted in response to observed movements. Where appropriate the surface infrastructure shall be periodically realigned or resurfaced to maintain it within specified positional tolerances.

9. The Contractor shall maintain records of ground movements, face conditions, jacking loads and box alignment against distance moved. Copies of all records shall be made available to the Engineer at intervals to be agreed.

10. Once tunnelling is complete the box extrados–ground interface shall be systematically grouted. Residual voids at intermediate jacking stations shall then be infilled with reinforced concrete to achieve a monolithic final structure.

321. Construction of segmental tunnel lining

321.1. General

1. The type of tunnel lining and/or ground support system to be used shall be as specified on the Drawings and in the Particular Specification.

2. The Contractor shall agree with the Engineer all details for the method of construction of linings and support systems including transport, handling and erection.

321.2. Segmental lining: general

1. Before erection of each ring of segmental lining, any loose material or other obstructions shall be removed from the ring building area.

2. All faces of all tunnel lining segments shall be thoroughly cleared of foreign matter and debris prior to placing of the segment.

3. Where the lining is to be grouted, the shape of the ring shall be maintained until the ring is stabilised.

4. Erection of segmental linings shall be by purpose-made mechanical system or be manual, aided by mechanical means, in such a way as not to damage the lining. Manual erection will only be permitted by specific agreement with the Engineer after submission of assessments under the Manual Handling Operations Regulations 1992 (as amended). The erection of linings shall follow the agreed method at all times.

321.3. Erection of bolted lining

1. The erection of each ring will normally commence with the invert segments and proceed by building and bolting subsequent segments on alternative sides where possible up to the key or top segment at the predetermined position. Segment positions shall be maintained during erection and after completion of the ring build. Lubrication of the gasket shall be undertaken to reduce friction effects and the likelihood of damage to the gasket.

2. The radial joint bolts shall be tightened at the time each segment is positioned to maintain joint faces in contact and to maintain compression of the gaskets where used.

3. The first segment placed shall be maintained in its correct position and the circumferential joint bolts of all remaining segments shall be located and loosely secured to allow correct formation of the ring shape.

4. After completion of the build and before excavation for the subsequent stroke, all circumferential joint bolts shall be tightened. Further retightening of the bolts shall be performed after completion of the subsequent stroke and prior to erection of the next ring.

5. The roll of the lining shall be maintained in accordance with the limitations of bolt hole clearances to ensure full circumferential bolting of the lining to be achieved or as otherwise specified on the Drawings.

6. Where proprietary forms of segment fixings and fastenings are used, methods of erection shall follow the segment manufacturer's recommendations.

321.4. Tapered segmental lining

1. Where tapered rings are used they shall be erected in such orientation as may be necessary to produce the specified alignments and grades of the tunnel.

2. The orientation of the taper shall be decided after each excavation cycle prior to erection of the next ring.

321.5. Grouting of bolted lining

1. The annulus between the segmental lining and the ground shall be grouted immediately after leaving the shield tail skin, or as otherwise agreed with the Engineer. Where grouting through the tail skin is being adopted, this shall be concurrent with the TBM advance.

2. Grouting of segmental linings shall be in accordance with Section 323.

321.6. Erection of expanded lining

1. Where unbolted lining is erected using an expanding process, the Contractor shall ensure that the lining extrados is in proper contact with the surrounding ground prior to application of the expanding force and that the excavated profile will permit the expansion process.

2. A range of key segment widths shall be maintained by the Contractor.

3. The excavated profile shall be lubricated to reduce skin friction during the expansion process.

4. A joint lubricating compound shall be applied to all wedge faces of each segment to be expanded.

5. Where the length of the key segment is less than the width of other segments comprising the ring, the pockets formed shall be cleaned of all debris to the excavated profile and filled with the concrete grade specified on the Drawings.

321.7. Packing

1. Where specified, packings of form and type set out in Section 214 shall be inserted between the circumferential faces of segmental lining, to assist in distributing machine or shield thrust ram forces.

2. Packing shall be used for the correction of line and level and for segmental plane error corrections and also for ring plane alignment correction. Packing shall not in general exceed 6 mm thickness, or half the sealing capacity of the gasket, whichever is the lesser.

3. Packings greater than 6 mm required for designed alignment control shall be subject to the agreement of the Engineer.

4. Packings shall not be used in radial joints, unless shown on the Drawings.

5. Packing at any one point in the circumferential joint shall be feathered out to zero in steps of not more than 3 mm.

321.8. Defective work

1. Any segments which are damaged or defective prior to erection shall be indelibly marked, and removed from site.

2. Any part of the tunnel lining which does not comply with the required tolerances or quality immediately after erection shall be rectified. Advancement of the face shall be suspended until the Contractor's proposals for rectification have received the Engineer's agreement.

3. The Contractor shall submit proposals for the repair of any rings built into the Works for the agreement of the Engineer.

322. Segment gaskets

322.1. General

1. Gaskets shall be in accordance with Section 212.

2. Gaskets shall be fitted into the grooves provided in the edges of the segment to be sealed in the manner recommended by the gasket manufacturer. The gasket dimensions shall be compatible with the groove profile, subject to the specified tolerances.

3. Gaskets shall be fitted to segments before being taken into the tunnel and shall be protected from damage during transport.

4. Care shall be taken to avoid displacing the gaskets during segment handling. No deleterious material shall be permitted in the groove or on the gasket.

5. Compression and hydrophilic rubber gaskets shall be bonded in position in the groove provided in the edges of the segment in accordance with the manufacturer's instructions.

6. Hydrophilic and composite (compression/hydrophilic) gaskets shall be protected from the effects of rain or accidental wetting. Segments with hydrophilic or composite gaskets shall not be erected in standing water.

7. Gaskets to be cast into the concrete segment shall be securely held in place in the mould during casting, and shall not be damaged during the demoulding process or cause damage to the segment.

323. Grouting

323.1. Cavity grouting of segmental lining

1. The term *cavity grouting* shall mean the grouting required to fill the cavities or voids between the excavated profile and the permanent linings of underground works including that due to ground relaxation and any void between permanent and temporary linings. Grout for cavity grouting shall be as described in Section 213.

2. Primary grouting is the initial cavity grouting which is applied immediately after a unit of lining has been built.

3. Where primary grouting does not completely fill all cavities, secondary grouting shall be carried out.

4. The Contractor shall provide a grouting method statement for the Engineer's agreement. The proposals shall include details and location of the mixing plant and grout pump, mix design and constituents, pumping rates and pressures, injection points, methods of monitoring, recording and controlling the sequence, preventing grout leakage and reconciling the volume of grout placed with the theoretical volume required.

323.2. Primary grouting

1. Primary grouting shall be undertaken at a pressure sufficient to place the grout properly but not greater than 1 bar above the prevailing hydrostatic pressure at the location of grouting unless the lining and equipment have been designed for higher pressures, and agreed with the Engineer.

2. Primary grouting shall be timed so as to minimise ground movement.

3. For linings erected behind a closed-face TBM, primary grout shall be injected via the shield tail skin unless otherwise agreed with the Engineer. In other cases primary grout shall be injected through grout holes provided in the linings.

4. In segmental linings grouted through grout holes, primary grouting shall proceed in sequence from invert to soffit in such manner that all air and excess water are expelled from the cavity progressively ahead of grouting. Valves shall be connected into the grout holes in order to allow the grout to set under pressure when the grout hose is disconnected. After the grout has set, permanent plugs shall be installed.

5. Any sealing material or device installed at the leading edge of the ring to prevent grout loss shall be removed upon completion of primary grouting.

6. For segmental linings grouted through the tail shield, the Contractor shall propose a grouting sequence for approval by the Engineer.

7. The Contractor shall ensure that grouting pressures do not result in ground heave or overstress or distortion of lining or distortion or damage to gaskets or damage to other structures.

8. Grouting equipment shall be fitted with a pressure gauge and automatic pressure release valves capable of being preset to a specific pressure. Grout pressure is to be measured at the nozzle with a suitable gauge.

9. Primary grouting to segmentally lined shafts constructed by underpinning shall be carried out after the erection of each ring.

10. Grouting shall be carried out at pressures to completely fill the cavity with grout.

11. Where shafts are constructed by sinking as caissons, grouting shall be undertaken on completion of the primary lining and shall be carried out in such a manner that any lubrication fluid is displaced by grout without distortion of the lining.

12. Where the primary void filling is by pea gravel injection, subsequent grouting shall be carried out in stages to the agreement of the Engineer.

13. Grouting of pipe jack tunnels shall be in accordance with Section 319.3.13.

323.3. Secondary grouting

1. Secondary grouting shall be undertaken in selected rings by means of removing grout plugs from the tunnel lining and drilling a hole to the back of the existing grout.

2. Secondary grouting is the regrouting of lining and shall be completed as soon as practicable but within 14 days of the primary grouting or when the face has advanced 50 m from the location of primary grouting whichever first occurs. Secondary grouting shall be at a pressure consistent with filling all voids but shall not exceed the design pressures stated in the Particular Specification.

3. Upon completion of grouting, threaded grout plugs shall be fully tightened into the lining.

323.4. Cavity grouting of in situ lining

1. The Contractor shall grout all cavities, voids and spaces remaining unfilled outside the in situ concrete lining. Grouting of a section of lining will not be allowed until that section has achieved its design strength.

2. Procedures for cavity grouting of in situ lining to tunnels and shafts constructed with a waterproof membrane shall be subject to agreement with the Engineer.

3. Grout for cavity grouting shall be as described in Section 213, except where otherwise agreed by the Engineer, who may direct that large voids be filled with other materials. The grout consistency shall be sufficiently fluid, but not more so, to ensure that the grout flows freely under low ($< 100\,kN/m^2$)

pressure into all parts of the space to be filled via grout pipes or grout holes provided for the purpose.

4. The injection points shall be provided and used for cavity grouting at an average of at least one per 2.5 linear metres of tunnel and more frequently in any areas of excessive over-break. Vent pipes shall be provided extending to the highest points of cavities. The injection points for cavity grouting in arched roofs shall be located within 500 mm of the crown unless otherwise agreed by the Engineer.

5. The Contractor's proposals for the installation of grout pipes shall be submitted to the Engineer for agreement. Grout pipes and grout holes for cavity grouting shall be at least 40 mm internal diameter.

6. Grouting shall be carried out by equipment similar to that used for segmental tunnel grouting. Grouting pressures shall be such as will not damage the Works or any other property.

7. Grout pipes shall not remain within 25 mm of a finished concrete internal surface, and when no longer required all injection holes in concrete linings shall be filled with dry pack mortar to within 25 mm of the finished concrete surface and finally made good.

324. Pointing and caulking

324.1. Pointing

Segment joints to be pointed shall be cleaned of all grout, dust and deleterious matter so as to leave the recess to be pointed clean and undamaged. In the case of circumferential joints containing packings, cleaning and pointing shall extend at least to the packing or a minimum of 20 mm. The pointing material shall be pressed into the joints so that they are completely filled and then given a steel trowel finish flush with the inside periphery of the ring.

324.2. Caulking

1. Segment joints to be caulked shall be cleaned of all grout, dust and deleterious matter so as to leave the recess to be caulked clean and undamaged. Caulking tools with widths as close as practicable to the widths of the recesses shall be used. Caulking materials shall be forced into the joints so that the full depth is filled. No visible leaks shall remain on completion.

2. Lead caulking shall be used with spheroid graphite cast iron (SGI) segments.

324.3. Lead caulking

1. Lead rod used for caulking shall be as close as practicable in width to the width of the recess to be caulked. The lead shall be driven into the recess to fill it completely, forming a continuous solid mass up to the inner surface of the lining.

2. Where both circumferential and radial flanges are machined, the caulking in the radial joints shall be bonded with that of the circumferential joints.

3. Where circumferential joints are unmachined, packing which has been inserted in joints shall be cut out completely and the joint rendered clean prior to caulking. Caulking shall be built up to a depth of 25 mm in the recesses of the unmachined joints. At corners of segments the caulking in the circumferential joints shall be carefully bonded into the caulking of the radial joints by means of block joints built up in the circumferential caulking recess.

4. Lead wool used for caulking shall be compacted by the caulking tools to form a solid mass for the full depth of the joint.

324.4. Cementitious cord caulking

Caulking using cementitious cord shall be used with concrete segments and shall be carefully bonded at joint intersections.

325. In situ concrete linings other than sprayed concrete

325.1. General

1. All surfaces to be in contact with the in situ concrete lining shall be thoroughly cleaned and scaled of all loose or defective material.

2. The surfaces of waterproofing membranes shall be thoroughly cleaned to remove any loose and foreign materials. They shall be cleaned by washing with a stream of air and water, but care shall be taken not to displace the membrane or its fixing and seals.

3. Concrete shall not be placed in still or running water and shall not be subjected to the action of running water until after the concrete has set. Where water flows from surfaces against which the concrete is placed, it shall be excluded from the space to be filled with concrete.

4. All formwork shall be true to form, securely made and supported, and joints shall be sealed to prevent the loss of cement from the mix. Where required, grout pipes shall be incorporated for pressure relief and subsequent grouting.

5. Concreting shall not commence until the formwork has been inspected and agreed with the Engineer.

6. Concrete shall be placed continuously in each length of formwork.

7. Care shall be taken in the case of exposed concrete faces of the tunnel and shaft linings that no irregularity occurs between successive sections.

8. The build-up of water pressure behind uncured linings shall be prevented.

9. The sequence of work within the tunnels or shafts shall be so arranged that no damage occurs to permanent linings. The proposed sequences and methods of operations shall be agreed with the Engineer.

10. Before any concrete is placed for tunnel linings the Contractor shall demonstrate to the Engineer that his concrete mix, equipment and working methods are capable of producing fully compacted concrete to the required surface finish. If required by the Particular Specification this shall take the form of a trial length.

325.2. Temperature monitoring of the concrete

1. The concrete temperature at the time of placing shall not exceed 35°C nor be less than 5°C.

2. Where included in the Contract and where directed by the Engineer, the Contractor shall install an array of thermocouples. The

Contractor shall monitor the thermocouples to show that the temperature gradient from the core to the face shall at no time exceed 20°C. Results shall be made available to the Engineer.

325.3. Transport of concrete

1. Mixed concrete shall be conveyed to its position in the tunnel by pumping, agitator cars or as otherwise agreed with the Engineer. Alternative methods will be required to prove their success in conveying concrete rapidly, without segregation and the loss of materials.

2. Concrete conveying equipment shall be checked by means of site trials prior to general use for its ability to deliver uniform concrete. Slump tests shall be made on samples of concrete taken from the first and last one-tenth of a batch of mixed concrete. If these slumps differ by more than 25 mm the equipment shall not be approved for use until the condition causing the inconsistency is corrected. Concrete conveying equipment used shall be examined daily for accumulations of hardened concrete or mortar, or for wear of the blades. Where necessary, the uniformity test may be repeated.

325.4. Concrete placing equipment

1. Concrete shall be placed by pumping equipment of suitable types, subject to the agreement of the Engineer.

2. Where pumping equipment is used it shall have adequate placing capacity and be capable of delivering the concrete in a continuous uninterrupted flow. The equipment shall incorporate gauges for measuring the pressure in the delivery line and a pressure regulating system. Pumping equipment, storage hoppers, and delivery pipelines shall be lubricated at the start of each concreting operation with a batch of cement-sand mortar and shall be thoroughly cleaned at the end of the operation.

3. Concrete placing using pneumatic equipment shall be subject to the agreement of the Engineer.

325.5. Placing concrete

1. Concrete shall be placed while still sufficiently plastic for adequate compaction and shall be carefully worked around all reinforcement and embedded fixtures and corners of the formwork.

2. Concrete shall be placed as close as possible to its final position, in continuous near level layers not exceeding 500 mm. Each layer shall be compacted before succeeding layers are placed.

3. Placing equipment shall be operated by experienced operators only. In general, the concrete placing shall continue uninterrupted until the structure is filled over the entire length of the formwork. In the event of equipment breakdown or if for any other unavoidable reason placing is interrupted, the Contractor shall thoroughly compact the concrete to a reasonable level or flat slope while the concrete is plastic. The concrete at the surface of such cold joints shall be cleaned with a high-pressure air water jet before the concrete achieves a primary set, to provide an irregular clean surface free from laitance. Prior to restarting concreting, the surface shall be wetted. The work shall be so carried out that a sound dense homogeneous structural element is produced.

4. Concrete shall not be subjected to disturbance between 4 hours and 24 hours after placing.

5. The Contractor shall keep on the site a complete record of the work showing the time, date and location of concrete placed in each part of the Works. This record shall be available for inspection by the Engineer.

325.6. Compaction

1. Concrete shall be compacted to produce a dense uniform mass. Except where otherwise agreed with the Engineer, vibration shall be applied continuously and evenly along the work during the placing of concrete in a manner which does not promote segregation of the components and until the expulsion of air has ceased.

2. Unless otherwise agreed, concrete shall be compacted by high-frequency mechanical vibrators. Immersion-type vibrators or heavy-duty formwork vibrators shall be used.

3. Immersion vibrators shall, wherever practicable, be operated in a near vertical position, and the vibrating head shall penetrate and revibrate concrete in the upper portion of the underlying layer. They shall be withdrawn slowly to avoid the formation of voids and shall be carefully positioned to avoid contact of the vibrating head with the formwork.

4. Vibrators shall not be allowed to contact reinforcement or inserts, nor shall they be used as a means of moving concrete along the formwork. The Contractor shall provide standby vibrators during concreting.

5. Particular care shall be taken with the compaction of concrete surrounding water bars to avoid honeycombing and to prevent the displacement of the water bar. Care shall also be taken to avoid displacement of prefixed pipes, blockouts, thermocouples and the like.

6. Where placing concrete for tunnel linings, formwork vibrators shall be used for compacting concrete in the tunnel arch above the highest openings in the formwork. They shall be operated at intervals of not more than 1.2 m behind the advancing slope of the concrete in the shoulders and crown of the arch. The location and operation of the vibrators shall be carefully coordinated with the withdrawal of the discharge line so as to avoid settlement and flow of the concrete from the filled crown.

325.7. Curing and protection

1. Immediately after compaction and thereafter for the curing period the concrete shall be protected against harmful effects of weather, rain, rapid temperature changes, frost and from drying out.

2. All concrete should be allowed to cure by methods which will ensure the production of concrete of the specified quality.

3. Curing materials and methods shall be compatible with any subsequent waterproofing.

4. Periods for curing shall be as recommended in Section 6 of ENV 13670-1. The Contractor shall agree his proposals with the Engineer.

5. Concrete shall not normally be placed when the temperature at the location of the Work is below, or likely to fall below, 5°C before the section of work can be completed except in emergencies.

325.8. Construction joints

1. Construction joints shall be positioned only where agreed with the Engineer.

2. Formed construction joints shall be formed using purpose-made stop ends. Expanded metal stop ends shall not be used.

3. Unformed construction joints shall be formed using a grout check or similar so that the exposed edge is a crisp true line.

4. Kickers shall be constructed integrally with the structure below.

5. The joint surface shall be either: brushed using water to remove laitance and expose the aggregate without disturbing it, treated with retarder and then water-jetted to remove laitance and expose the aggregate without disturbing it; or lightly roughened by light chipping or needle-gunning of set concrete. Hacking of set concrete shall not be permitted.

6. Construction joints shall be clean and damp, with no standing water, immediately before wet concrete is placed against them.

325.9. Defective work

1. Concrete which is honeycombed, damaged by faulty curing, or fails to attain the specified or characteristic strength, and concrete work which in any way fails to comply with the Specification, will be considered to be defective.

2. Defective work shall be removed and replaced. The methods used for such removal and subsequent reconstruction shall be agreed with the Engineer.

325.10. Formwork

1. Before construction commences, the Contractor shall obtain the Engineer's agreement to the general method and system proposed and shall submit detailed drawings of the formwork to the Engineer for agreement where required by the Particular Specification.

2. All formwork shall be so dimensioned, constructed and securely braced as to prevent displacement.

3. All joints in the formwork and between the formwork and previous work shall be sufficiently tight to prevent loss of liquid from the concrete.

4. Formers for all chases, grooves, recesses, etc. shall be securely fixed as part of the formwork. No part of the concrete shall be cut away for any such item, or for any other reason, without the Engineer's agreement.

5. The face of the formwork shall be clean and applied with non-staining release agent. The agent shall not touch reinforcement, or items to be embedded, and shall not be allowed to collect in the bottom of the formwork, or flow onto previously placed concrete.

6. Before any concrete is placed, the Contractor shall examine and clean out the formwork, and ensure that the specified reinforcement cover is attained.

7. Formwork shall be eased, struck or removed in such a manner that the structure is not distorted, damaged or overloaded.

8. Except where otherwise agreed, formwork shall not be eased or struck until:

   (*a*) the concrete has attained sufficient strength to support itself in the position cast without deformation
   or
   (*b*) a minimum period in line with Section 6 of ENV 13670-1.

9. Where cyclical casting, e.g. in situ concrete tunnel lining, striking times may be agreed with the Engineer following criteria determined from trial lengths.

325.11. Concrete finishes

Formed surfaces

1. Formed concrete finishes shall be as specified on the Drawings with reference to Table 13 below.

Table 13. Formed concrete finishes

F1	No specific requirement
F2	The irregularities in the finish shall be no greater than those obtained from the use of wrought thickness square-edged boards arranged in a uniform pattern. Fins shall be removed and imperfections shall be made good
F3	The resulting finish shall be smooth and of uniform texture and appearance. The formwork lining shall leave no stain on the concrete and shall be so joined and fixed to its backing that it imparts no blemishes. It shall be of the same type and obtained from only one source throughout any one structure. The Contractor shall make good any imperfections in the finish. Internal ties and embedded metal parts shall not be used

2. All formwork joints for F2 and F3 finish shall form a regular pattern.

Unformed surfaces

3. Unformed concrete finishes shall be as specified on the Drawings with reference to Table 14 below.

4. When required in the Particular Specification and before commencing concreting the Contractor shall prepare a trial panel to demonstrate that the required surface finish can be achieved by the equipment and methods proposed. The panel shall be filled with the proposed concrete compacted by the method to be used in the work. When agreed with the Engineer the trial

Table 14. Unformed concrete finishes

U1: Screeded finish	The concrete shall be levelled and screeded. No further work shall be applied to the surface unless it is a first stage for a wood float or steel trowel finish
U2: Wood float	A pre-screeded finish shall be floated with light finish pressure using a wooden float to eliminate surface irregularities
U3: Steel trowel finish	A steel trowelled finish shall be first wood-floated and then trowelled under firm pressure with a steel float to produce a dense, smooth, uniform surface. The final surface shall be free from trowel marks

panel shall be retained and will form the benchmark against which all Works concrete shall be prepared.

5. When stated in the Particular Specification, each constituent material shall be obtained from a single consistent source. The aggregates shall be free of any impurities that may cause staining. The mix proportions and the grading shall be maintained constant. The same type of material and release agent shall be used in formwork throughout similar exposed areas.

6. Release agents shall be selected to leave no stains on the concrete surface and shall be applied evenly.

7. Where the concrete surface is to receive waterproofing it shall be in accordance with the waterproofing system manufacturer's recommendations.

8. Permanently exposed concrete surfaces shall be protected from rust marks and stains of all kinds.

9. After removal of the formwork, no treatment, other than that approved for curing, shall be applied to the concrete until its surfaces have been inspected by the Engineer.

10. Where any surface fails to comply with the Specification in respect of finish, dimensional tolerance, or in any other way, the Contractor shall rectify the work as agreed with the Engineer.

11. The Contractor shall be responsible for preventing any damage to the finished concrete surfaces, and shall adopt any necessary protective measures to prevent subsequent staining from any cause.

325.12. Fixing bar and mesh reinforcement

1. The Contractor may adjust the position of lap joints to fit in with available stock lengths, or construction joints, subject to the Engineer's agreement to the altered positions. The Contractor shall amend the bending schedules, as necessary, to allow for such alterations.

2. The bending of reinforcement bars shall be in accordance with BS 8666 unless otherwise shown on the Drawings and bending schedules. Bars shall be bent cold.

3. Reinforcement shall be free of all mill scale and thoroughly cleaned to remove all loose rust, oil, grease, or other harmful matter immediately prior to being placed in position in the Works, and maintained thus until finally encased in concrete.

4. All reinforcement shall be accurately placed, securely fixed, and adequately maintained in the positions shown on the Drawings. The reinforcement shall be fixed so that the cover specified on the Drawings or in the Particular Specification is achieved, subject to the tolerances specified therein.

5. Reinforcement shall not be rebent on site unless agreed with the Engineer.

6. Spacers and chairs shall comply with BS 7973-1 and be 'Heavy' category as per Table 1 of that standard. Spacer blocks shall be of comparable strength, durability and appearance to the surrounding concrete and shall be factory produced. Site-produced concrete or mortar cover blocks shall not be used.

7. Spacers and chairs shall ensure that the reinforcement is correctly positioned, be as small as possible consistent with their purpose, and designed so that they will not overturn or be displaced when the concrete is placed. Wire cast in the block for the purpose of tying it to the reinforcement shall be as specified in Clause 10 below.

8. Spacers and chairs shall be fixed in accordance with BS 7973-2.

9. Projecting ends of ties or clips shall not encroach into the concrete cover.

10. Tying wires shall be 1.6 mm soft annealed iron wire unless the Particular Specification or Drawings require the use of stainless steel tying wire. Where stainless steel tying wire is required it shall be 1.2 mm diameter stainless steel wire throughout the structure.

11. Concreting shall not commence until the reinforcement has been inspected in accordance with the Inspection and Test Plan.

325.13. Inspection of completed structure

1. The Contractor shall carry out a cover meter survey over all reinforced concrete surfaces within 24 hours of removal of formwork. The cover survey shall be undertaken on a 500 mm grid over the whole structure. Access for the Engineer to verify cover meter surveys shall be provided.

326. Shafts

326.1. General

1. Excavation shall comply with Section 301 and the relevant clauses of BS 6164.

2. Prior to excavation, the shaft area shall be thoroughly checked for existing pipes, cables or structures and the appropriate measures taken in agreement with the Engineer.

326.2. Safety

1. Shafts shall be provided with guard rails and toe boards or rings at least 1.2 m above the surrounding ground level.

2. At all times shafts shall be provided with safe primary and secondary means of access and egress.

3. Should heavy plant and heavy loads have to be located in close proximity to any shaft, the Contractor shall take into account the effects of these loads as well as any ground loads when designing the shaft.

4. The Contractor shall guard against distortion of shaft lining during construction and the possibility of shaft settlement or uplift at an intermediate stage of construction.

326.3. Temporary shafts

1. Full details of temporary shafts required by the Contractor's working methods shall be submitted to the Engineer for his agreement. Such shafts shall be adequately sized for all operations required for the execution of the Works.

2. Backfill for temporary working shafts shall comprise material agreed by the Engineer.

3. Where the Contractor wishes to recover temporary shaft linings the structure shall be removed in safe stages as backfilling proceeds, taking care to maintain the safety and structural integrity of the remaining lining. No part of Temporary Works shall be left in the ground within 2 m of the designed final surface level.

326.4. Construction

1. Shaft sinking shall be carried out by a method suitable for all the particular circumstances of the site including ground parameters, groundwater, depth and final purpose.

2. Where work is done by underpinning, only that ground which may be safely excavated for the installation of one ring or one unit of support shall be carried out. Until that depth is properly secured by permanent or temporary shaft lining, no further excavation shall take place. In the case of pre-formed rings, securing shall include grouting.

3. Where work is done by a caisson operation, a cutting edge shall be fitted to the leading ring. The Contractor's details for bolting

caisson rings shall avoid working at height where practicable. The cutting edge shall be maintained at an even level all round during shaft sinking. Jacking arrangements or kentledge shall be adequate for the work. The Contractor's arrangements shall ensure the stability of any kentledge. A lubrication space shall be maintained completely filled with the lubricating material around the full shaft periphery during sinking. On completion of sinking the lubricating material shall be displaced with grout.

4. Concrete walls installed by slurry trench or secant piling techniques shall comply with best practice. The Contractor's proposals shall be submitted to the Engineer for his agreement.

5. Where low-pressure compressed air is used to assist shaft construction, air decks and locks shall be designed by the Contractor to give adequate margins of safety against the air pressures to be used in the shaft. Work shall comply with Section 401. The Contractor's proposals shall be submitted to the Engineer for his agreement.

6. Excavation in rock shall generally be carried out by methods outlined in Sections 301 and 308. Where explosives are used, full-width shaft covers and blasting mats shall be installed during blasting.

7. Segmental shafts shall be constructed in accordance with the relevant clauses of Section 321.

8. Packings in segmental shafts shall be in accordance with Section 214. Caulking and pointing, where specified, shall be in accordance with Sections 216 and 324 of the Specification. Where segment gaskets are required they shall be in accordance with Sections 212 and 322 of the Specification.

9. Full details of Temporary Works required by the Contractor's method of working for the construction of tunnel or pipejack eyes in the shaft lining, shall be submitted to the Engineer for his agreement.

10. Shaft bases shall be concreted as shown on the Drawings. In the case of Temporary Works shafts the Contractor shall submit his proposals for the shaft base structure taking account of ground and groundwater forces and sealing the shaft against water entry. Water pressure shall not be allowed to build up under shaft bases until the shaft has sufficient resistance to prevent flotation. The construction sequence shown on the Drawings shall be followed unless agreed with the Engineer.

11. In the event that dewatering, grouting for ground treatment or freezing is employed, the work shall comply with Section 400 of this Specification.

327. Timber headings

327.1. General

1. Timber headings are defined as small tunnels and excavation shall comply with Section 301.

2. Timber headings are classified as Temporary Works and shall comply with Section 303.

3. Timber headings shall be designed and erected in accordance with the requirements of BS 5975:2008 *Code of Practice for Temporary Works Procedures* and the relevant British Standards or Eurocodes for structural design.

4. Calculations and drawings shall be submitted to the Engineer for his agreement, as part of a fully detailed method statement, describing and illustrating the alignment, depth, dimensions of the timber components, stages of the excavation and erection of the timber heading.

5. Whilst headings which are to contain pipes shall be of the minimum size reasonable to allow the pipes to be properly laid, surrounded with concrete or other specified material and then packed, the minimum heading size shall not be less than the minimum size required to undertake the work safely.

6. Where so required, support shall be withdrawn with the Engineer's agreement as the work of packing or backfilling the heading proceeds. Backfill shall be concrete.

7. Where grouting is required, grout pipes shall be left in the top of the heading projecting behind each head tree and the whole grouted solid. Grouting shall be carried out at the end of each shift or after three settings have been packed, whichever is the shorter interval.

328. Tolerances for tunnels, shafts and underground works

328.1. All tunnels and shafts

1. Tunnels and shafts shall be constructed to the centre lines required by the Contract, and subsequently agreed on site with the Engineer.

2. Unless otherwise stated on the Drawings, overall tolerances allowed in respect of the departure of any point on the internal profile of the structure from its established centre line shall be as given in Table 15, measured on completion of the lining construction and grouting. The tolerance includes all building errors.

Table 15. Overall tolerances

		Tunnel diameter	
		<5 m	>5 m
1. Expanded segmental linings:	Line and Level	±25 mm	±40 mm
2. Grouted segmental lining:	Line and Level	±35 mm	±50 mm
3. Cast-in-situ concrete lining:	Line and Level	±35 mm	±50 mm
4. Cast-in-situ hydraulic invert:	Line Level	±35 mm ±10 mm	±50 mm ±10 mm
5. Sprayed concrete lining:	Line and Level	±30 mm	±75 mm
6. Pipe jacking:	Line Level	±50 mm ±35 mm	–

Where there are hydraulic requirements, no backfalls forming localised ponding shall be allowed.

3. Shafts shall be sunk to a maximum divergence of 1:300 from the design centre line at any depth.

328.2. Segmental lined tunnels and shafts

1. The maximum lipping between the edges of adjacent segments shall be 5 mm.

2. The plane of each segmental ring shall not depart at any point from the plane surface normal to the longitudinal axis by more than 10 mm.

3. The maximum and minimum measured diameters in any one ring shall be within 1% of the theoretical design diameter of the ring measured on completion of ring build and grouting, or such other tolerance stated in the Particular Specification. This tolerance includes all building errors.

328.3. Sprayed concrete lined tunnels and shafts

1. The maximum lipping between the edges of adjacent sprayed panels shall be 10 mm.

2. The plane of each sprayed ring shall not depart at any point from the plane surface normal to the longitudinal axis by more than 20 mm.

3. The maximum and minimum measured diameters in any one sprayed ring shall be within 1% of the theoretical design diameter of the ring, or such other tolerance stated in the Particular Specification. This tolerance includes all building errors.

329. Monitoring recording and the control process of underground works

329.1. General

1. The Contractor shall submit to the Engineer for agreement a detailed method statement for instrumentation and monitoring, including instrumentation layout, trigger, design and allowable values and the procedures for evaluating the monitored data.

2. The Contractor shall appoint within his site team an experienced Monitoring Engineer who shall lead the Contractor's monitoring team. The Monitoring Engineer shall present the results of the previous day's monitoring in the daily monitoring meeting with the Engineer where they shall be presented to the Engineer by the Monitoring Engineer (see Section 329.3).

3. The frequency of such review meeting may be increased if requested by the Engineer.

4. The Contractor's Site Manager shall attend monitoring review meetings if requested by the Engineer.

5. The accuracy and precision of the measurement required will depend on the purpose of the monitoring.

6. Assessments shall be carried out to establish the zone of influence due to tunnelling works and to determine the likely damage that will occur to existing above-ground and subsurface infrastructure.

7. The outcome of the assessments shall determine the type and amount of monitoring that will be required.

8. Early preconstruction instrumentation requirements shall be determined so that baseline measurements can be taken, for an appropriate period, to establish the stability of the monitoring system and any possible effects of any underlying environmental trends that could be attributed to the Works.

329.2. Ground movement monitoring

1. Unless otherwise provided for in the contract, the Contractor shall monitor the effects of tunnel construction at the surface, including all ground movements and the effects on all structures, including the Works. Where specifically requested, the subsurface effects, including movements of the water table, shall also be monitored.

2. Unless otherwise provided for in the contract, monitoring equipment and instruments shall be provided by the Contractor to enable the response of structures to be determined. Equipment and instruments shall be installed to the manufacturer's instructions and shall be calibrated and tested as appropriate. Monitoring pins and devices shall be securely fixed in position. Due regard shall be given to the construction of the structure to be monitored and the layout of its primary support.

3. Monitoring shall be referenced to stable survey stations located outside the zone of influence of the Works and not subject to ground movement. Such benchmarks and coordinated stations shall be established and agreed with the Engineer before any ground is excavated and before any ground treatment or dewatering takes place. They shall be checked at intervals during the duration of the Works.

4. The Contractor shall observe, record and analyse the readings to establish trends in movement and reconcile movements measured with those predicted. He shall provide a copy of all recorded results to the Engineer. He shall make available results to the Engineer in accordance with an agreed programme; however, movement greater than predicted shall be reported to the engineer immediately.

5. Prior to construction Works commencing, a defect survey shall be carried out of all structures within the zone of influence and a schedule of defects shall be prepared. This schedule shall be agreed by the Contractor and the owner of the structure, or his representative, prior to the start of construction. Existing pipelines, tunnels and services shall be regarded as structures.

6. During the execution of the Works, defects which have been scheduled shall be inspected and monitored as necessary. Defects which arise during the course of the Works shall be recorded. The Contractor shall keep records of such inspections and a copy shall be available to the Engineer.

7. Monitoring of settlement, scheduled defects and defects arising during the course of the works shall continue at agreed intervals for a period of at least 6 months after completion.

329.3. Monitoring of tunnel excavation

1. The Contractor shall survey, monitor and record tunnel and shaft construction as it proceeds, to form a record of the work. Monitoring shall generally be per unit of advance and include line, level, cross-sectional accuracy, shift advance, total advance.

2. Where shields and machines are employed the Contractor shall monitor per unit advance, the attitude of the shield or machine. Information to be recorded includes rate of advance, line, level, square, plumb, roll. Where applicable, face pressure, slurry density, slurry viscosity, slurry level, slurry flow, cutter speed, rotation direction, torque screw conveyor speed, air pressure, and to the degree of accuracy applicable, volume of material excavated.

3. When pipe jacking, the Contractor shall also monitor and record the jacking forces and quantity, type, consumption and pressure of injected lubricants.

4. Where grouting is carried out, the type, volume and pressure of grout shall be recorded.

5. All information recorded by the Contractor shall be provided to the Engineer on a daily basis unless another interval has been agreed.

6. Where the Contractor considers that any corrective action he may take will exceed the tolerances in the Contract, he shall so inform the Engineer and obtain his agreement.

7. The strata exposed in the tunnel face shall be mapped and recorded where possible, and the nature of the excavated material shall be noted in all cases.

8. All significant groundwater ingress shall be recorded and monitored.

9. All atmospheric testing shall be recorded and monitoring for all gases carried out in accordance with BS 6164.

10. The Contractor shall keep copies of all recent face records at the workface for the information of supervisory personnel.

329.4. Tunnel and shaft linings

1. When constructing segmental lining, the Contractor shall undertake survey checks pertinent to the accurate erection and position of segments during each ring build. The relative attitudes of the lining and the tunnelling machine/shield shall be recorded.

329.5. Daily review meeting (DRM)

1. The monitoring instrumentation shall be read on a regular basis – as per Drawings and monitoring plan – and the results made available for a daily review meeting (DRM) attended by the senior members of the Contractor's and the Engineer's staff. Input into the meeting shall also include current geotechnical investigations, face logs, tunnel boring machine (TBM) reports and any recent non-conformance reports relating to the tunnel construction.

2. This DRM shall be held daily during the excavation of the tunnels unless otherwise agreed by the Contractor and the Engineer.

3. At the meeting the Contractor shall present the current results of monitoring of the tunnels, together with trends in these results and comparison with the deformations predicted by the calculations.

4. The outcome of the meeting shall be a report, the Required Excavation and Support Sheet (RESS), agreed by the Contractor and the Engineer, which states that tunnelling may continue as proposed, or gives the requirements for modifications to the tunnelling (e.g. shorter advances, smaller headings, higher face pressure and annulus grouting around the TBM).

5. If no agreed report is available by a specified time each day then the tunnel shall be made safe and tunnelling be stopped.

6. All records from these meetings including face logging and monitoring results shall be kept and be available for inspection until the termination of the contract.

329.6. Key performance indicators

1. A key performance indicator (KPI) system shall be developed for monitoring movements so that actions can be taken in a

timely manner, thereby ensuring that damage to existing buildings and subsurface infrastructure is within calculated predictions.

2. The KPIs to be used to guide construction shall relate to specific monitoring activities:

(*a*) in-tunnel convergence monitoring (SCL)
(*b*) spoil reconciliation (TBM)
(*c*) ground movement monitoring
(*d*) monitoring of adjacent and overlying structures.

3. The KPI values specified in the design documentation shall be used to indicate whether or not there is cause for concern during tunnel construction. To ensure that the response is appropriate for any specific concern, certain procedures shall be implemented when a KPI is exceeded. These are summarised below.

(*a*) A full review of the lining performance shall be conducted for the relevant tunnel section and checked against the KPI values. This includes checks on the ground/soil conditions, the quality of construction and the monitoring results provided by the Contractor.
(*b*) A comprehensive review of the trends for monitoring data specific to the area of concern shall be carried out by the Contractor and the Engineer.
(*c*) The Contractor shall assess the extent to which the deformations comply with the SCL serviceability and extreme limit conditions.
(*d*) Together with the Engineer, the Contractor shall decide whether changes in the SCL excavation sequences or TBM face pressure are required. This is an interactive process that will determine whether it is safe to proceed with construction or, if there is reasonable cause for concern, the extent to which it is necessary to implement additional measures or emergency procedures. These measures will be included in a new RESS.
(*e*) The Contractor and Engineer shall implement the Action Plan, the emergency response to implement contingency measures. If there is reasonable cause for concern, it is emphasised that the response must be rapid.
(*f*) The performance of the tunnel is kept under continuous review until the monitoring data indicate that KPI trends show a stable condition.

4. At least three trigger values shall be established: a green, amber and red limit. The green limit marks the boundary of normal behaviour. The amber marks the boundary of serviceability while the red trigger should be set below the ultimate capacity of the lining. The Contractor's Action Plan should include pre-planned contingency measures that can be taken if a trigger value is exceeded.

5. If a trigger value is reached, first the site team should check that the reading is correct and consistent with the readings from other instruments. If the trigger has really been breached,

then contingency measures will be instigated, in accordance with a predefined Action Plan and as directed in the DRM. The contingency measures are designed to correct any anomalous behaviour.

329.7. RESS – Required Excavation and Support Sheet

1. Based on the design and the evaluation of the results of monitoring, a RESS will be issued as the outcome of the Daily Review Meeting (DRM) (see Section 329.5). In the absence of any approved changes, the RESS will reflect exactly what is shown on the relevant design drawings.

2. The RESS shall be prepared and endorsed by the Contractor's Site Manager responsible for the tunnelling works, the designer and the Engineer on site. Unless all the three signatures are obtained, the proposals indicated on the RESS shall not be implemented.

3. The RESS shall address, but not necessary be limited to, the following matters:

   (*a*) the tunnel section (chainages) to which the RESS is applicable
   (*b*) the support to be installed
   (*c*) the excavation sequence
   (*d*) the method of working related to ground support including staging of application of sprayed-concrete layers and lapping of reinforcement
   (*e*) monitoring to be installed in the tunnel section in question
   (*f*) measures to be taken during stoppage of works
   (*g*) other instructions relevant to the tunnel section in question
   (*h*) reference to relevant Design Drawings
   (*i*) face pressure
   (*j*) soil conditioning
   (*k*) annulus grouting (around TBM).

4. A copy of the RESS will be given to the foreman in charge of the work in the tunnel and shall be kept at the working face.

5. A RESS is required for every metre of the length of the tunnels.

6. If for any reason the approved design method of working is changed, then this will be reviewed prior to the DRM and, subject to acceptance by the Engineer, a new RESS will be issued.

329.8. Contingency measures and emergency procedures

1. The Contractor shall determine contingency measures to deal with potential hazards that may affect the Works. The Contractor shall submit for approval to the Engineer an Action Plan which shall detail the actions, procedures and contingency measures to be followed in the event that the monitoring system shows unacceptable levels of deformation/movement if potential hazards occur.

2. Hazards to be addressed include:

   (*a*) changing ground conditions
   (*b*) excessive movement of the linings
   (*c*) excessive ground movement

(*d*) excessive settlement of the existing structures
(*e*) unplanned stoppages
(*f*) mechanical excavation plant failure
(*g*) insufficient labour resources
(*h*) failure of services to underground works (air, light, power, etc.)
(*i*) incidents within underground works
(*j*) delay in supply of sprayed concrete (SCL)
(*k*) delay in supply of segments (TBM).

3. In underground construction works, changes tend to be progressive with evidence of structure or ground behaviour becoming apparent before failure occurs. For this situation a system of hierarchical trigger levels will be appropriate. This allows proportionate response to adverse indications from monitoring.

4. Trigger levels will be based on the results of assessments of at-risk infrastructure. If the assessment indicates that the at-risk infrastructure is unlikely to be able to tolerate the change due to the Works, then triggers will be set based on the levels of change that will be tolerable.

5. There may be some situations where change is less progressive and monitoring may simply be required to give a yes/no response. In these cases reporting is simple and systems of triggers are not appropriate.

330. Survey and setting out

330.1. Datum for the Works

1. The level datum for the Works shall normally be the agreed national datum or as stated in the Contract.

2. The plan survey shall be conducted to a Works grid established over the area of the Works. Unless otherwise given in the Contract, the orientation of the Works grid shall relate to the national survey grid.

330.2. Survey bench marks

1. The Contractor shall install all level and survey stations required. Such stations shall be of robust construction, protected against damage and the influence of any movement which may arise from the execution of the Works.

2. The Contractor shall check the condition and resurvey survey stations at intervals during the progress of the Works.

3. The Contractor shall provide the Engineer with the location and description of all survey stations, the results of surveys and all calculations. Where required, he shall give adequate opportunity for the Engineer to check such stations prior to their utilisation.

4. The degree of accuracy employed in the survey and setting out shall be such as will allow the alignment, levels and dimensions specified for the Works to be achieved.

5. The Contractor shall ensure that all surveying equipment used for the Works is properly maintained and that the performance of the equipment complies with the manufacturer's specification for accuracy.

4. Ground stabilisation processes

401. Compressed air working

401.1. General

All work shall be carried out in compliance with *The Work in Compressed Air Regulations 1996*, SI No. 1656, and the accompanying *Guidance* published by the Health and Safety Executive. The appropriate provisions of BS 6164 shall also be applied. Bulkheads and locks shall be designed in accordance with BS EN 12110.

401.2. Submission of information

1. The Contractor shall submit for the Engineer's agreement a method statement naming the person in charge of the work in compressed air, his deputies if any and the Contract Medical Advisor along with a description of the type, capacity and arrangement of plant and medical facilities he proposes to install including low-pressure compressed air plant, standby plant, power sources, air cleaning, air cooling plant, communications systems, bulkhead and locking arrangements.

2. The Contractor shall also submit to the Engineer for his review as required by the Contract, full details of the design of the airlocks and working chamber. Where an airlock is steel pressure vessel, copies of the most recent hydraulic test of the vessel will suffice.

401.3. Initial pressurisation

Once the equipment has been installed, the Contractor shall, in normal circumstances, ensure that an independent check on design and installation to verify safety of the installation is carried out and obtain the agreement of the Engineer prior to pressurising any shaft or tunnel. Procedures for functional pressure testing of the workings shall be agreed with the Engineer. If the Contractor has to apply compressed air for safety reasons in an emergency, then the Engineer shall be informed without delay.

401.4. Minimisation of leakage

All necessary precautions are to be taken in order to minimise the escape of air through the ground.

401.5. Changes in working conditions

Any change in working pressure or sudden or unexpected change in working conditions shall be immediately reported to the Engineer and shall be logged as an incident and reported accordingly.

401.6. Submission of daily records

Records of working pressure, air quality, delivery volume and temperature shall be submitted daily to the Engineer. Systems to monitor these parameters in real time shall relay critical data to the site manager's offices and be equipped with devices which alarm when preset levels are exceeded.

401.7. Exposure records

Exposure records for all personnel working in compressed air shall be available to the Engineer on request. On completion of the compressed air works, a full set of exposure records shall be submitted to the Engineer for safe keeping.

A full set of exposure records shall be offered to the Health and Safety Executive for research purposes.

401.8. Decompression of working chamber

The decompression of the working chamber shall be carried out in stages to minimise ground movements and to allow pore water pressure to re-establish itself in the ground surrounding the tunnel. The air pressure in the tunnel shall be reduced at a rate not greater than 0.2 bar per 8 hours. Once the air pressure has reached 0.5 bar the Contractor may decompress to atmospheric pressure at his discretion.

401.9. Settlement

A set of levels shall be agreed with the Engineer on relevant settlement points prior to commencement of decompression. Settlement readings shall be retaken at 24-hour intervals to ascertain if movement is occurring due to decompression. Settlement readings shall continue daily for a further period of 7 days following full decompression of the workings during which time the compressed air equipment must be maintained in the event that recompression is required.

401.10. Emergency procedures

A notice setting out details of emergency procedures shall be provided at the airlock.

401.11. Storage of materials

When bagged cement is used, no more than one day's supply shall be stored in the working chamber. Empty bags shall be removed at the end of each shift. Essential timber for emergency ground support shall be stored in the working chamber but hydraulic oil, spare conveyor belting or other flammable materials shall not be stored in the compressed air tunnel or shaft.

401.12. Burning and welding

Hot work shall only be carried out under a 'Permit to work' procedure. Cylinders of oxygen and fuel gas to be used in burning or welding shall be of the smallest practicable size and only equipment approved by the Engineer shall be allowed underground. All cylinders shall be transported in a robust cage and shall be fitted with non-return valves and flashback arrestors at the cylinder end. The cage shall contain a fire extinguisher and a cylinder valve key. The cylinders shall be removed from the workings immediately after use. Persons carrying out burning or welding in compressed air shall be provided with fire-resistant 'Nomex' overalls or equivalent. A fire watchman with a hose connected to a suitable water supply shall oversee the operations and remain on duty for 30 minutes thereafter. Spare cylinders shall not be stored underground.

402. Grouting for ground stabilisation and groundwater control

402.1. General

1. Grouting for ground stabilisation shall mean injecting grout for the safe progress of the Works, the elimination or mitigation of settlement and the reduction of groundwater inflows into the Works. Cementitious grout with suitable additives will be used, followed where necessary with chemical grouts as the nature of the ground to be treated and the purpose of the grouting dictates.

2. Grouting shall be carried out only by contractors employing staff and operatives skilled in the work and notified in advance to the Engineer. They shall produce evidence of satisfactory performance on projects where the purpose of the work and extent was comparable.

3. The Contractor shall carry out such trials, additional tests and ground investigation as he deems necessary to formulate his proposals.

4. The Contractor shall take precautions to minimise hydrofracture stress levels within the ground imposed by grouting which might cause damage to structures and/or heave. Where significant stress changes are likely to be imposed, the Contractor shall employ systems to monitor and protect sensitive structures.

5. The Contractor shall take precautions to avoid injected grout entering sewers, drains, granular drainage blankets or other underground structures.

6. The performance of any grouting system shall be monitored by the Contractor in accordance with the Contract, and interpretation of the results agreed with the Engineer.

402.2. Contractor's proposals

1. The Contractor shall agree with the Engineer details of the proposed grouting scheme including:

(*a*) where grouting design is the responsibility of the Contractor, information and case records to support the grouting proposed in respect of its ability to penetrate the strata and its ground enhancement effect
(*b*) where grouting design is the responsibility of the Contractor, specific criteria to measure the adequacy, sufficiency or completeness of the ground treatment
(*c*) details of the treatment zone and grout injection patterns with respect to the Works and adjacent structures
(*d*) details of plant proposed
(*e*) method statement and programme including arrangements for storage of materials, mixing grout, Quality Control of grout, recording grouting pressures and grout take and tests to prove the efficacy of the grout in the ground,

health aspects associated with the materials and grout proposed at all stages of the process and during excavation of treated ground, and means of protecting persons from any adverse effects

(*f*) an assessment of the environmental impact of the materials and methods proposed

(*g*) an occupational health risk assessment, including methods of risk reduction on all aspects of the grouting operation.

2. Where the grouting contractor is responsible for the design of the grouting, he shall automatically record grouting pressures and flows and produce ongoing assessments of the grout performance in relation to the objectives of the design.

402.3. Drilling

1. Any drilling to be undertaken for the grouting works shall be carried out in such manner as to minimise ground disturbance and soil loss. Where drilling or treatment techniques employing air or foam/air are proposed, the issues of escape of air into the ground and disturbance of previously grouted ground shall be agreed with the Engineer.

2. Drill tubes left in the ground after final use shall be flushed out and filled with an approved cementitious grout. Each tube shall be cut off at least 1 m below ground level and the area restored.

402.4. Plant

Plant shall be brought to site and maintained in good working order. Batching and mixing plant shall be provided with gauges and equipment which will control accurately the proportions of materials within the required limits and ensure proper mixing and injection of the grout. Gauges shall be checked at the start of each shift. Spares for plant and spare gauges shall be held at site. Current calibration certificates shall be available on site for all electronic measurement equipment.

402.5. Disposal of waste

1. The Contractor shall dispose of leakage and wash-out water from injection points and risers in a safe way and shall not allow them to contaminate the site or watercourses or property elsewhere. The Contractor shall take preventative measures to avoid leakage and shall take measures to stop up leakages should they occur. He shall submit his proposals to the Engineer for his consent.

2. The Contractor shall adopt proper safety precautions to avoid health hazards to all persons, dependent on the nature of the grouts in use.

402.6. Records

The Contractor shall keep full and detailed records as are appropriate to the type of treatment being carried out, including direction and full depth of injection pipe, quantities of materials used, time, location and volume of grout injected, volume of grout to waste by leakage and other reasons, pressure of injection (measured as close to the injection point as possible), both for initial injections and re-injections. Copies of such records shall be given on a daily basis to the Engineer. Continuous automated monitoring of grout pressures and flows shall be made and presented electronically along with summary records. Records of tests carried out on the treated ground shall also be given to the Engineer.

403. Ground freezing

403.1. General

Freezing for stabilisation and enhancement of the engineering properties of ground shall be carried out only by specialist contractors or subcontractors employing design staff and operatives skilled in the work. They shall produce evidence of satisfactory performance on projects of comparable type, extent and where the purpose of freezing is also comparable. The requirements of BS 6164 in respect of ground freezing shall be complied with.

403.2. Process

1. Ground freezing is a process for temporarily supporting the ground during excavation to facilitate the installation of permanent Works. It may be used only to prevent water ingress in the case of competent (self-standing when excavated) rock or for strength enhancement, in addition to the prevention of water ingress, in the case of soils.

2. The process comprises two parts:

(*a*) Design, installation, operation and performance of the ground freezing system, i.e. freeze tube layout, drilling of freeze tube holes, alignment surveying of the freeze tube holes, insertion and grouting up of the freeze tubes, coolant mains installation, freeze plant specification and monitoring and control of the process, all of which are specialist freeze contractor's items.

(*b*) Prediction of the frozen ground behaviour, i.e. evaluation of the rock or soil unfrozen and frozen thermal and geotechnical properties, thermal performance evaluation, heave and thaw settlement estimates and determination of the frozen ground structural behaviour during excavation including strength and deformation calculations, all of which are specialist designer items.

403.3. Methods

1. Freezing shall be carried out by the more appropriate of:

(*a*) a closed recirculating coolant system, typically a compressed primary refrigerant removing heat on evaporation from a secondary non-toxic, non-flammable refrigerant through a heat exchanger

(*b*) vaporising a non-toxic, non-flammable cryogenic liquid in an open circuit system and exhausting gas to atmosphere.

2. The freezing process shall solidify groundwater in and around the Works and provide adequate ground conditions, without additional measures, for the safe and proper construction of the permanent work and minimisation of settlement.

403.4. Precautions

1. The Contractor shall take all proper precautions for the safety of persons and property on site and elsewhere appropriate to the methods of work and materials used. In particular he

shall be aware of the possibility of the release of gases and liquids detrimental to health.

2. Vessels and pipes at extreme low temperatures shall be so protected that there is no possibility of accidental contact.

3. The Contractor shall carry out a risk assessment, including identifying methods of risk reduction, on all aspects of the ground freezing proposals including the risk to persons in the tunnel and the risk to persons off-site from exhaust gas emissions.

4. The Contractor shall take all proper precautions to ensure the safety and security of stored cryogenic liquid.

403.5. Method statement

1. Where designed by the Contractor, he shall be responsible for the calculation of the total volume of ground to be frozen, the volume to be frozen at any one time, the intensity of freezing and the numbers and location of freeze and monitoring pipes. Calculations, method statement and programme shall be agreed with the Engineer.

2. The method statement shall include a description of:

   (*a*) plant and materials to be used
   (*b*) drilling and installation of refrigeration pipes
   (*c*) installation of surface piping system and refrigeration plant
   (*d*) installation of instrumentation to monitor the freezing process
   (*e*) maintenance of the frozen ground during underground construction of the permanent work
   (*f*) removal of the system and demobilisation.

403.6. Freeze pipes

Freeze and monitoring pipe installation shall be carried out by rotary drilling techniques using a low-viscosity, non-toxic water-based drilling mud to suit the strata and conditions present in the volume of ground to be treated. The pipes shall be installed to the accuracy of position and alignment necessary to freeze and monitor properly the desired volume of ground. Freeze and monitoring pipes shall be subjected to a pressure test equal to 1.5 times the expected operating pressure to ensure that refrigerant does not leak into the ground.

403.7. Plant

1. Plant shall be of adequate capacity to ensure that the volume of ground to be treated will be frozen and maintained in the required state throughout the construction of the Works. Adequate provision shall be made for regular maintenance and spares and additional equipment shall be held for use in the event of equipment or power failure.

2. Plant and pipework shall be fitted with appropriate valves, controls and instruments to ensure safe and proper operation of the system. Valve operating handles shall be insulated.

403.8. Monitoring and records

1. The Contractor shall be responsible for monitoring the process during installation and maintenance of the work. Monitoring shall include:

(*a*) the flow of refrigerant within the system so that losses due to leaks will be detected and remedial measures taken
(*b*) the pressure of refrigerant in the system
(*c*) the temperatures of refrigerants and ground
(*d*) vertical and horizontal movements at the surface of the ground and, where required, at buildings, utilities and other structures.

The method and frequency of monitoring movement shall be agreed with the Engineer.

2. The Contractor shall monitor continuously flow and pressure of the refrigerant and temperature of refrigerant and ground.

3. The results of all observations shall be made available to the Engineer.

4. Excavation in frozen ground shall not commence until the Contractor is satisfied that the freezing operation is complete and maintenance of the freeze is established and the Contractor has received the Engineer's consent. The Contractor shall ensure that his working practices do not interfere with the integrity of the frozen ground. He shall observe and record the strata as excavation proceeds and where any ground is shown to be not properly frozen to enable safe excavation he shall immediately secure the face, stop work and propose suitable remedial works.

5. Maintenance of freeze shall be terminated only after the permanent structure is complete and with the Engineer's agreement. Upon cessation of freezing the system and ground shall be allowed to warm up naturally. Monitoring of ground temperatures and surface horizontal and vertical movement shall be continued for a period prescribed by the Engineer.

6. When no longer required, freeze and monitoring pipes shall be flushed out and filled with an approved cementitious grout. Each pipe shall be cut off 1 m below ground level and the area restored.

404. Dewatering

404.1. General

1. Where dewatering operations are used they shall be kept to the minimum necessary for the execution of the Works. All work shall be carried out in accordance with CIRIA Report C515 *Groundwater control – design and practice*.

2. Dewatering will not be permitted unless the Contractor can show by approved calculations and in situ tests that the effect of such dewatering will not adversely affect the Works, will not cause settlements exceeding the limits set down in the Contract and will not cause damage to existing properties and structures.

3. Prior to commencement of dewatering, the Contractor shall notify the Environment Agency (Scottish Environment Protection Agency or other regulatory body) and obtain any necessary consents or permits.

4. Construction work shall not commence until the dewatering operation has been proven to be effective at the agreed monitoring locations.

404.2. Contractor's proposals

Details of any proposed ground dewatering system shall be agreed with the Engineer before such systems are installed on site.

Proposed details shall include:

(*a*) a dimensioned plan or plans with appropriate cross-sections showing the size, location, depth of each well, predicted drawdown profile and arrangements for disposal of discharged water
(*b*) depth of filter zone (and any grout seals) at each well
(*c*) method of drilling or jetting wells, boring diameter and any drilling muds or additives
(*d*) type of screen and casing
(*e*) type, size and capacity of pumps
(*f*) method statement, programme, risk assessment and safety plan
(*g*) predicted pumping rates
(*h*) calculations for the predicted drawdown profile and discharge
(*i*) assessment of settlement and damage risk including mitigation measures to protect sensitive structures/soils, e.g. localised recharge, where applicable
(*j*) arrangements for the measurement and control of water abstraction and the detection of fines or other material which may be drawn into the system
(*k*) proposed treatment of wells when they are no longer required
(*l*) any additional ground investigation necessary to provide data for the above
(*m*) arrangements for duty and standby power supplies

(*n*) arrangements for monitoring the drawdown of the dewatering, including location of monitoring wells and the frequency of monitoring.

404.3. Drilling and jetting

1. Any drilling or jetting to install dewatering or observation wells shall be carried out in such a manner as to minimise ground disturbance and soil loss. Drilling muds such as bentonite shall not be permitted, only environmentally acceptable biodegradable drilling fluids and additives shall be used where prior approval is obtained from the Engineer.

2. Drilling records of the encountered ground shall be maintained and issued to the Engineer.

404.4. Plant

1. Plant shall be delivered to site and maintained in good working order. Plant and pipework shall be fitted with appropriate valves, controls and gauges.

2. Each dewatering well shall be capable of individual adjustment and being shut down and isolated from the rest of the system.

3. Appropriate standby equipment and spares shall be maintained on site at all times.

404.5. Operations

The Contractor shall take measures to minimise any planned or unplanned interruptions in pumping. Call-out procedures shall be in place to ensure appropriate personnel are available on a continuous 24-hour basis during the period of dewatering.

404.6. Monitoring and records

1. If existing structures may be affected by dewatering-induced settlements, a building condition survey shall be carried out prior to commencement of dewatering. The Contractor shall monitor ground levels, property and structures for settlement and damage during the period of dewatering and for a period thereafter as specified in the Contract.

2. The Contractor shall determine the extent of the drawdown profile by means of regular monitoring of observation wells installed at appropriate locations:

(*a*) monitoring ground levels, property and structures
(*b*) reading from observation wells
(*c*) pumping rates and discharge from each well.

3. The extent of the zone of monitoring should be determined based on the predicted drawdown profile.

4. The Contractor shall keep full and detailed records of all monitoring carried out. Copies of such records shall be available to the Engineer.

405. Compensation grouting

405.1. General Compensation grouting consists of the introduction into the ground of grout layers to compensate for normal tunnelling settlement and to control ground and existing structure movements.

405.2. Execution Grouting shall in general be in accordance with Sections 402.1 to 402.6.

405.3. Monitoring Monitoring of compensation grouting shall be in accordance with Section 329.

405.4. Assessment Continual reappraisal of the effects on the ground and structures of compensation grouting shall be carried out by the Contractor and agreed with the Engineer. Amendments shall be made to the grouting procedures to maintain the designed control.

5. Working environment

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501. Temporary electrical installations

501.1. General

1. The Contractor shall be responsible for obtaining an adequate electrical supply for all his Site operations.

2. Installations shall comply with BS EN 60204 *Safety of machinery. Electrical equipment of machines* and BS 7671 *Requirements for electrical installations. IEE Wiring Regulations*, supplemented but not superseded by the relevant clauses of BS 6164.

3. If so required by the Engineer, the Contractor shall make available a copy of all certificates prepared upon completion of electrical installations and prepared for all required periodic checks.

4. The Contractor shall appoint a competent person to be solely responsible for ensuring the safety of all temporary electrical equipment on site.

5. The Contractor is to comply at all times with the Electricity at Work Regulations.

502. Ventilation during construction

502.1. General

1. Pits, shaft tunnels and headings shall at all times be kept ventilated to maintain an atmosphere fit for respiration and free from oxygen deficiency, potentially explosive or noxious gases and dust, whether present naturally or otherwise. Ventilation shall also be used to maintain a safe working temperature.

2. The Contractor shall take proper precautions to ensure that the Works are kept in a safe and workable condition throughout. In all tunnelling operations the Contractor shall comply with the relevant recommendations of BS 6164 *Code of practice for safety in tunnelling in the construction industry* and HSE Guidance Note EH 40 *Occupational exposure limits*.

3. The Works shall be undertaken in a way that ensures compliance with The Best Practice Guide for *Occupational Exposure to Nitrogen Monoxide in a Tunnel Environment* by the British Tunnelling Society.

4. Where more than one pollutant is present any adverse interaction between them shall be identified and mitigated.

5. In underground workings and in confined spaces the air breathed by persons shall contain not less than 19% of oxygen by volume.

6. Smoking is forbidden in tunnels, headings, pits or shafts and all confined spaces.

7. In rock excavation all drill holes shall be wet drilled.

502.2. Ventilation systems

1. The Contractor shall agree ventilation proposals with the Engineer. Agreement shall not relieve the Contractor of his obligations under the Contract.

2. Proposals shall include but not be limited to the types of fan employed, siting arrangements where appropriate, the power supply and the fan performance data, together with duct characteristics.

3. In forcing systems, fans shall normally be placed on the surface.

4. If booster fans are to be employed by in-line staging, they shall be of an approved flameproof (FLP) construction and a monitoring system shall be installed so that the status and condition of such fans can be monitored at all times.

5. The inlet to any surface forcing fan shall have unobstructed access to fresh air. It shall not be in the vicinity of a storage site for oil, chemical or diesel drums. The fan shall also be

sited so that it cannot draw in internal combustion engine fumes or gas from charging batteries.

6. Provision shall be made for the fan to be run continuously whether persons are within the underground works or not.

7. Where a fan has been stopped and restarted, the condition of the air shall be tested before personnel enter the tunnel. If only forcing surface-mounted fans are employed, the ventilation system should be restarted and run continuously ensuring that any plugs of oxygen-deficient, flammable or noxious mixtures of gas are flushed out. Care should be taken that workmen do not encounter any plugs of these gases on re-entry to the tunnel. The Contractor should take into account that air residence time in long drivages can be several hours and that layered gases of different densities are difficult to disperse, especially where the gradient of the tunnel changes.

8. The outlet of the duct shall be kept as close to the face as is practicable, designed to avoid turbulence and creation of dust and not more than 10 m away.

9. Where dust is being produced by the tunnelling system, exhaust ventilation shall be used to extract such dust from the working area.

10. Tunnelling shall not continue more than 10 m from the shaft or pit unless positive ventilation has been established.

502.3. Monitoring

1. Atmospheric monitoring equipment shall be positioned at each working face, inbye of each airlock, and also within 20 m of the tunnel entrance when the tunnel has advanced 250 m or more. Monitors shall also be provided every 500 m along the tunnel. Monitoring equipment shall be capable of continuously monitoring the levels of potentially explosive gases, toxic gases and radioactive gases as appropriate and the oxygen content. The equipment shall give both visual and audible warning of the presence of potentially explosive, radioactive or toxic gases and where the oxygen content falls below safe working levels. An immediate and effective means of communicating warnings to the surface shall be installed. The atmospheric monitoring system shall be a fixed system supplemented by portable monitoring equipment as necessary, except in small tunnels where the use of portable equipment only shall be permitted at the discretion of the Engineer.

2. Each working shaft and the full length of all tunnels shall be monitored continuously in accordance with Clause 1 of Section 502.3 for the presence of explosive or noxious gases or lack of oxygen. Records shall be kept of monitoring results. Should the workings be found to contain explosive or noxious gases above the level set out in BS 6164 or HSE guidance document EH40, or oxygen content below the level set out in BS 6164, all work shall stop and the Works shall be evacuated until a safe atmosphere is established.

502.4. Start-up ventilation

1. If the ventilation system is for any reason not in operation for a period greater than 2 hours, a start-up procedure shall be

invoked. This requires that the shaft and tunnel shall not be re-entered until one complete air change in the tunnel has taken place and the tunnel atmosphere shown, by monitoring, to be safe.

2. Persons re-entering after shutdown must carry instruments to detect for the presence of dangerous gases and the sufficiency of oxygen, and these must be used continuously during re-entry.

502.5. Checking and inspection

1. During each shift, the following checks shall be made:

(*a*) The fan or fans shall be checked for heat, unusual noise and vibration. The results shall be reported and remedial action taken if required.
(*b*) The ventilation ducting shall be checked for damage and the joints checked for integrity. The results shall be reported and remedial action taken if required.
(*c*) The atmospheric monitoring system shall be checked at both local and remote stations and the results recorded.

2. The air flow quantities shall be checked at both the face and 20 m from the shaft bottom on a weekly basis. These figures shall be recorded and compared with the calculated flows. Any shortfall shall be made good.

3. The ventilation records shall be maintained and be made available for inspection by the Engineer.

502.6. Ventilation failure

1. In the event of ventilation equipment failure all personnel shall be withdrawn from the underground workings.

2. In the event of ventilation equipment failure, where a tunnel boring machine is in use, it shall automatically be stopped and isolated until the ventilation is restored.

502.7. Ventilation after breakthrough

1. After tunnel breakthrough, ventilation facilities designed to ensure safe atmospheric conditions throughout the tunnel system shall be installed.

503. Lighting

503.1. General

1. Floodlighting on the site surface shall be adequate for the safe operation of the site. It shall be shrouded where necessary to ensure the light is directed to areas within the site, and to avoid nuisance.

2. Lighting in the tunnel shall extend the full length and not be less than that required for safe working and access.

3. An alternative source of power and emergency lighting system shall be provided to allow emergency securing operations and evacuation safely in the event of a primary power failure. An adequate number of hand lamps shall be located at key points underground.

504. Noise and vibration

504.1. General

1. The Contractor shall minimise occupational exposure to noise and vibration, the amount of noise emitted to the environment and the environmental vibration levels generated by his work activity. Reference is to be made to the requirements of the Control of Pollution Act 1974, with particular reference to Part III sections 60 and 61, Part III of the Environmental Protection Act 1990, the Control of Noise at Work Regulations 2005, the Control of Vibration at Work Regulations 2005 in all respects, notwithstanding any liabilities, obligations or restrictions given elsewhere.

2. The Contractor shall follow the recommendations set out in BS 5228 Parts 1 and 2 on control of noise and vibration arising from the Works. Vibration limits shall conform to BS 7385 Part 2 and BS 6472.

3. The Contractor shall select and utilise methods of working and items of plant and control in his Works so as to minimise noise and vibration levels, including occupational noise and vibration exposure of the workforce, and not to exceed maximum permitted noise and vibration levels specified in the Contract. In particular, the Contractor shall take into account the legislation referring to the exposure levels from hand-held pneumatic tools and comply with the BTS publication *The Management of Hand–Arm Vibration in Tunnelling Guide to Good Practice*. Where noise and vibration limits are the subject of notices under section 60 or 61 of the Control of Pollution Act 1974 the Contractor shall comply with the requirements of the Specification in addition to those requirements imposed by the sections 60 and 61 Notices.

4. The adherence to any vibration levels specified in the Contract does not relieve the Contractor of his obligations with respect to structural or other property damage, or his obligations under the Control of Pollution Act 1974.

504.2. Temporary fencings and barriers

1. Where required the Contractor shall erect and maintain throughout the construction period temporary fencing of appropriate height taking account of the need for this fencing to act as a noise barrier around all working areas. The fencing shall be dismantled and re-erected as the progress of the Works requires.

2. The line of the fencing shall be uniform and the exterior face of the fencing shall be treated with a durable finish. Where required, in order to prevent reflection of noise, the Contractor shall line the inside of fencing with sound-absorbent material with accepted acoustic absorption properties. The material shall be fire and water resistant.

3. Local fencing barriers or shelters shall be erected as necessary to shield particular activities, such as those involving the use

of pneumatic or hydraulic techniques, and all stationary plant. The guidance and advice detailed in BS 5228-1 shall be applied.

504.3. Plant and equipment

1. The Contractor shall select and use plant, equipment and working practices which minimise occupational exposure to noise and vibration and minimise emissions of noise and vibration to the environment.

2. All plant shall be properly maintained and relevant service records completed. All plant shall be provided with effective silencers and vibration-dampening devices, and shall be operated according to the manufacturer's recommendations in such a manner as to avoid causing any excessive noise emission or vibration. The noise emitted by an item of plant shall not exceed the relevant values quoted in the most stringent of the relevant EU Directive/UK Statutory Instrument and the relevant values quoted in BS 5228-1. All plant operating on the site in intermittent use shall be shut down in the intervening periods between use.

504.4. Transport restrictions

On specific contracts it may be necessary to restrict traffic movements at peak times, and to avoid undue disturbance to residents. Truck movements may also be precluded for a period at sites which are located near to schools.

Any specific requirements are given in Section 120 General provisions.

504.5. Noise and vibration monitoring

1. Where monitoring is required the Contractor shall provide, calibrate, operate according to the manufacturer's recommendations appropriate equipment for monitoring construction noise and vibration throughout the construction period.

2. Noise analysers shall be capable of measuring unattended the equivalent continuous noise level, L_{Aeq}, to the Type 1 standard set out in BS EN 61672-1:2003.

3. Vibration measuring systems shall be in accordance with BS 7385.

4. The Contractor shall arrange for adequate standby equipment.

504.6. Noise and vibration levels

1. The Contractor shall measure the noise and vibration levels generated by the construction work during working hours throughout the period of construction.

2. The Contractor shall notify the Engineer immediately whenever the specified noise or vibration limit has been exceeded, and agree measures to avoid repetition.

3. Any items of plant causing excessive noise or vibration levels shall be removed from the site and substituted by alternative compliant equipment.

4. The Engineer may instruct the Contractor to devise and use an alternative process if a construction method is causing unnecessary disturbance.

505. Access and egress

505.1. General

The Contractor shall make all arrangements and assume full responsibility for transportation to the Site of all construction plant, materials and supplies needed for the proper execution of the Works.

505.2. Designated access routes

Where designated access routes are indicated in the Contract, the Contractor shall use no other without the agreement of the Engineer.

505.3. Maintenance of routes

1. All public and private highways and roads which are being used by the Contractor's, Subcontractors' or Suppliers' vehicles for the construction of the Works shall be kept clean and free of dirt and mud arising from the Works. The Contractor, unless otherwise provided for in the Contract, shall provide, maintain and use as necessary suitable equipment including mechanical road sweepers, throughout the course of the Works where and as agreed with the highway authority.

2. The Contractor shall provide, maintain and use mechanical wheel washers and high-pressure hosing facilities at work sites and at such additional locations as required under the Contract.

3. The Contractor shall be responsible for all maintenance in all respects of all site roads.

4. Any area of public highway which is closed because of the Works shall not be reopened until appropriate safety and traffic management measures have been completed and until the Engineer confirms that it is in a suitable condition for use by the public.

5. The Contractor shall protect the public from the Works by secure fencing and gates and shall control access through the gates as required under the Contract.

505.4. Access for others

1. The Contractor shall at all times meet the full requirements for access for Fire, Ambulance and other emergency services and maintain liaison with them in that respect.

2. The Contractor shall at all times maintain access for the authorised representatives of utility providers and allow emergency operations to be carried out on any utility or service facilities within the Site.

3. The Contractor shall not use public or private rights of way for depositing or storing plant or materials. The Contractor shall maintain those parts of the public or private rights of way not temporarily occupied by the Works in a clean, passable and safe condition at all times.

4. The Contractor shall execute the Works in such a manner that safe pedestrian access, including disabled person access, to all properties is maintained at all times.

5. Unless otherwise provided in the Contract, methods of construction and programming of the Works shall be such that vehicular access to properties affected by the Works is not restricted.

505.5. Traffic safety and management

1. When carrying out work on trafficked highways the Contractor shall comply with the New Roads and Streetworks Act 1991 and HSE's guidance booklet *Safe use of vehicles on construction sites: A guide for clients, designers, contractors, managers and workers involved with construction transport* so far as it affects personnel who are required to undertake work on highways.

2. Where work is carried out on or adjacent to a trafficked highway the Contractor shall ensure that personnel shall, at all times, wear high-visibility fluorescent garments in accordance with Chapter 8 of the *Traffic Signs Manual*. Garments should comply with BS EN 471.

3. All proposals, details, execution, maintenance, removal and necessary reinstatement associated with traffic safety and management and temporary decking and other temporary structures on, or subways beneath, the highway shall be subject to the approval of the appropriate authorities. The Contractor shall supply all information required, for consultation with the appropriate authorities including the local authority, police and other authorities with jurisdiction or interest.

4. The Contractor shall agree a traffic management plan with the Engineer based on consultation and agreement with highway authorities. This shall show the scheme of traffic safety and management measures including the provision of safety zones and traffic signing. The plan shall include the requirements of emergency services for access into and through the site.

5. Fenced storage areas, gantries, loading bays, skips and other temporary structures on the public highway shall be provided and maintained to the conditions of a licence issued by the local authority.

6. All traffic safety and management measures necessitated by the Works shall be fully operational before the Contractor commences any work which affects the public highway.

7. The Contractor shall devise and put into effect traffic management procedures, including appropriate speed limits, within the site including on haul roads and temporary access roads, which are to an equivalent standard to those for a public highway unless directed otherwise by the Engineer.

505.6. Signing and signalling

1. The Contractor shall provide suitable entry and exit signs, at the points of access to and from the site, for vehicles and plant engaged on the Works. As far as possible, vehicles and plant shall enter and exit the site in a forwards direction.

2. Unless otherwise specified, the Contractor shall make all necessary arrangements including notices to relevant authorities for the provision, erection, maintenance, repositioning, covering and uncovering and final removal of all traffic signs as the progress of the Works requires.

3. The Contractor shall devise and put into operation traffic management arrangements to separate pedestrian and vehicular traffic. Pedestrian access shall be clearly signed and provided with barriers of adequate strength.

4. The Contractor shall be responsible for the design, provision and maintenance of all temporary traffic signals and associated equipment unless otherwise given in the Contract.

505.7. Temporary lighting

Where required during the execution of the Works, the Contractor shall provide and maintain temporary lighting for the highways. Temporary lighting shall provide the same level of illumination as that of the existing street lighting it replaces. Temporary lighting shall be provided and approved prior to the removal of any existing street lighting.

505.8. Survey and reinstatement

1. Prior to commencing the Works the Contractor shall carry out a condition survey of all roads and footways adjacent to the Site. The survey record shall be available to the Contractor.

2. Unless stated otherwise, the Contractor shall reinstate all roads and footways affected by the Works to the extent, lines and levels that existed prior to the commencement of the Works and to standards that are at least equivalent to those that existed prior to the commencement of the Works or the Street Works Act 1993.

3. Unless stated otherwise the Contractor shall reinstate all surface water drainage systems (including but not restricted to gullies, channels, catchpits, piperuns, manholes and covers and the like) affected by the Works. The standard of reinstatement shall be at least equivalent to that existing prior to the Contract commencing.

505.9. Access within Works

1. The Contractor shall provide safe access in and about the Site and underground workings, and shall comply with the recommendations of BS 6164.

2. All shafts shall have a ladder access in addition to any mechanical means.

3. The Contractor shall provide a safe designated pedestrian access in the tunnel and throughout the site area at all times. This shall have a firm, level, slip-resistant and continuous surface and shall be suitable for use in emergencies when lighting may be unavailable.

4. The Contractor shall segregate pedestrian and vehicular access routes.

5. The Contractor shall maintain a clear means of egress from each tunnel face at all times. Such means of egress through or

past tunnelling machines, trains and similar obstructions shall meet the minimum dimensions in BS EN 12336.

6. The Contractor shall establish, maintain and operate a system whereby the presence of personnel underground is recorded, together with their location where appropriate.

506. Atmospheric testing

506.1. General

1. The parties to the Contract shall produce a schedule of gases and pollutants to be tested for, including both the frequency and the methods of testing. The recommendations of BS 6164 Section 4 shall be followed but this shall not restrict the range of testing to be carried out in any particular location.

2. No underground workings may be entered, except for rescue with appropriate respiratory protective equipment, where the oxygen content is below 19% by volume of the air present, or where explosive or noxious gases are present at concentrations in excess of safe limits.

506.2. Temperature

The Contractor shall avoid, if practicable, employing labour in areas where the wet bulb temperature is greater than 27°C. The recommendations of BS 6164 Clause 15.3 shall be applied. Where this requirement cannot be met, the Contractor shall devise and agree with the Engineer safe systems of work which take account of the exposure to heat or cold of the workforce.

507. Disposal of spoil and water

507.1. Spoil waste programme

The Contractor shall prepare a Site Waste Management Plan (SWMP), which sets out in detail how spoil and all waste is to be categorised, disposed of and monitored, the programme for disposal and how legislation is to be complied with. This plan will address all waste matters at the site and have specific documented mechanisms for adopting a 'reduce, reuse, recycle' approach to waste minimisation for dealing with all wastes. The SWMP will be reviewed by the Engineer and accepted or approved as required by the Contract.

507.2. Disposal of solid waste spoil

The Contractor shall remove all excavated material, spoil, surplus materials and rubbish from whatever source on site and shall, except where otherwise specified in the Contract, make his own arrangements for their disposal and provide all the necessary facilities to achieve this. The Contractor shall also comply with any legal or local authority requirements applying to the handling and disposal of any contaminated spoil.

507.3. Monitoring spoil removal

1. The Contractor shall set up a system to control and monitor the transport of spoil from Site to the tip site, in accordance with the current legislation. The system shall be agreed with the Engineer and will provide evidence that each load has been deposited at a licensed tip site.

2. The Contractor shall retain auditable records of waste removed from site. Waste Transfer Notices should be collated and submitted to the Engineer. Transfer and Consignment notes shall be kept in the site file.

3. The Contractor shall comply with all statutes and statutory instruments relating to spoil disposal.

507.4. Liquid waste disposal

1. The Contractor shall comply with the provisions of the Water Act 2003 where water is being pumped from the Works.

2. Before discharging any surplus water, the Contractor shall obtain the prior approval of the owner of the sewer or watercourse and of the Environment Agency.

3. The Contractor shall ensure that the condition of any discharged water complies with permitted limits. The parameters to be monitored include pH values, temperature and suspended solids.

508. Leakage and infiltration

508.1. General

1. Tunnels, shafts and underground works may be classified according to criteria of water leakage according to Table 16 in Section 508.2 below.

2. For tunnels, shafts and underground works for which the Specification does not require a specific measure of leakage or test, the Works shall be substantially watertight with no identifiable flow of water penetrating the lining (i.e. Class 3). Leakage which in the opinion of the Engineer is concentrated or significant or affects the use of the Works shall be sealed by the Contractor using approved methods and materials.

508.2. Leakage criteria and classes of tunnel

The tunnel leakage criteria are specified according to the class of tunnel as given in Table 16.

Table 16. Tunnel class

Class	Dampness characteristics	Typical tunnel use	Definition	Allowable daily leakage: l/m^2 *
1.	Absolutely dry	Storage rooms and working areas	No damp areas visible on the tunnel lining	0.01
2.	Substantially dry	Road tunnels with a risk of frost	Occasional damp patches, which do not discolour blotting paper, detectable on the tunnel lining	0.05
3.	Capillary dampness	Road tunnels and rail tunnels	Occasional damp patches on the tunnel lining, but no drops of water	0.1
4.	Small amounts of dripping water	Utility tunnels	Occasional drops of water	0.2
5.	Dripping water	Drainage and sewer tunnels	Occasional drops of water	0.5

* Daily leakage is defined in litres per square metre of tunnel lining

508.3. Leakage tests

Where tunnels, shafts and underground works are required to perform to a specific measure of leakage or infiltration the work shall be acceptable only when successfully tested in accordance with the measures stated in the Contract. In the event that the test is unsuccessful the Contractor shall ascertain the areas where leakage or infiltration occur and seal them using approved methods and materials and retest.

508.4. Watertightness of tunnels and shafts

Unless specifically provided otherwise in the Contract, infiltration into completed tunnels and shafts shall not exceed the values specified in Section 508.2 for the class of tunnel specified.

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