

BS 6164:2011



BSI Standards Publication

Code of practice for health and safety in tunnelling in the construction industry

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Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 July 2011. It was prepared by Subcommittee B/513/2/2, *Drilling, piling and tunnelling*, under the authority of Technical Committee B/513, *Construction equipment and plant, and site safety*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 6164:2001, which is withdrawn.

Information about this document

This British Standard takes into account the advances in technology and equipment that are available to the tunnelling industry. It also takes account of new techniques and the effect of changes in legislation and guidance relating to health and safety and environmental matters. These changes include The Construction (Design and Management) Regulations 2007 [1] and the guidance to The Work in Compressed Air Regulations 1996 [2]. The document is written for all involved in tunnelling projects and addresses the safety of both those engaged in the tunnelling process and those who could be affected by it.

The text follows the pattern established by the previous edition of BS 6164. Clauses contain recommendations for and guidance on health and safety practices in shaft sinking and tunnelling. However, the text has been significantly updated to reflect current and developing best practices.

The International System of Units (SI) is followed in this British Standard, with the exception of the unit used for pressure, which is the bar.

NOTE 1 bar = 10^5 N/m² = 10^5 Pa.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and competent people, for whose use it has been produced.

This is a full revision of the standard, which reflects also the current changes in European Standards relating to tunnelling machinery.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This British Standard makes recommendations for and gives guidance on health and safety practices in shaft sinking and tunnel construction.

The standard includes health and safety recommendations that are also relevant to cut-and-cover tunnelling, immersed tube tunnels and other forms of underground construction as well as to the maintenance, renovation and repair of shafts and tunnels. The recommendations are not intended to apply to the construction of shafts or tunnels for the purpose of mineral extraction.

NOTE 1 The design, manufacture and use of plant and machinery are referred to only where safety considerations are affected. Various European Standards relating to the design of tunnel boring machines (TBMs) are currently under revision.

NOTE 2 Current legislation relating to occupational health and safety can be found at www.hse.gov.uk.

2 Normative references

Standards publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 476-4, *Fire tests on building materials and structures – Part 4: Non-combustibility test for materials*

BS 476-20, *Fire tests on building materials and structures – Part 20: Method for determination of the fire resistance of elements of construction (general principles)*

BS 476-21, *Fire tests on building materials and structures – Part 21: Methods for determination of the fire resistance of loadbearing elements of construction*

BS 476-22, *Fire tests on building materials and structures – Part 22: Methods for determination of the fire resistance of non-loadbearing elements of construction*

BS 638-4, *Arc welding power sources equipment and accessories – Part 4: Specification for welding cables*

BS 638-5, *Arc welding power sources equipment and accessories – Part 5: Specification for accessories*

BS 638-7, *Arc welding power sources equipment and accessories – Part 7: Specification for safety requirements for installation and use*

BS 1129, *Specification for portable timber ladders, steps, trestles and lightweight stagings*

BS 4363, *Specification for distribution assemblies for reduced low voltage electricity supplies for construction and building sites*

BS 4592-1, *Industrial type flooring and stair treads – Part 1: Metal open bar gratings – Specification*

BS 4592-2, *Industrial type flooring and stair treads – Part 2: Expanded metal gratings – Specification*

BS 4592-3, *Industrial type flooring and stair treads – Part 3: Cold formed metal planks – Specification*

BS 4592-5, *Industrial type flooring and stair treads – Part 5: Solid plates in metal and glass reinforced plastics (GRP) – Specification*

- BS 4727-1:1983, *Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms – Part 1: Terms common to power, telecommunications and electronics – Group 01: Fundamental terminology*
- BS 5045 (all parts), *Transportable gas containers*
- BS 5306-1, *Code of practice for fire extinguishing installations and equipment on premises – Part 1: Hose reels and foam inlets*
- BS 5306-3, *Fire extinguishing installations and equipment on premises – Part 3: Commissioning and maintenance of portable fire extinguishers – Code of practice*
- BS 5306-8, *Fire extinguishing installations and equipment on premises – Part 8: Selection and installation of portable fire extinguishers – Code of practice*
- BS 5395-3, *Stairs, ladders and walkways – Part 3: Code of practice for the design of industrial type stairs, permanent ladders and walkways*
- BS 5607, *Code of practice for the safe use of explosives in the construction industry*
- BS 5911-1, *Concrete pipes and ancillary concrete products – Part 1: Specification for unreinforced and reinforced concrete pipes (including jacking pipes) and fittings with flexible joints (complementary to BS EN 1916:2002)*
- BS 5930, *Code of practice for site investigations*
- BS 5975, *Code of practice for temporary works procedures and the permissible stress design of falsework*
- BS 6100-3:2007, *Building and civil engineering – Vocabulary – Part 3: Civil engineering – General*
- BS 6387:1994, *Specification for performance requirements for cables required to maintain circuit integrity under fire conditions*
- BS 6657, *Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation – Guide*
- BS 6724, *Electric cables – Thermosetting insulated, armoured cables for voltages of 600/1 000 V and 1 900/3 300 V, having low emission of smoke and corrosive gases when affected by fire*
- BS 7121-1, *Code of practice for safe use of cranes – Part 1: General*
- BS 7121-5, *Code of practice for safe use of cranes – Part 5: Tower cranes*
- BS 7375, *Distribution of electricity on construction and demolition sites – Code of practice*
- BS 7430, *Code of practice for earthing*
- BS 7671, *Requirements for electrical installations – IEE wiring regulations*
- BS 7835, *Electric cables – Armoured cables with thermosetting insulation for rated voltages from 3.8/6.6 kV to 19/33 kV having low emission of smoke and corrosive gases when affected by fire – Requirements and test methods*
- BS 7863, *Recommendations for colour coding to indicate the extinguishing media contained in portable fire extinguishers*
- BS 8467, *Protective clothing – Personal protective ensembles for use against chemical, biological, radiological and nuclear (CBRN) agents – Categorization, performance requirements and test methods*
- BS EN 3-10, *Portable fire extinguishers – Part 10: Provisions for evaluating the conformity of a portable fire extinguisher to EN 3-7*
- BS EN 166, *Personal eye-protection – Specifications*

- BS EN 206-1, *Concrete – Part 1: Specification, performance, production and conformity*
- BS EN 388, *Protective gloves against mechanical risks*
- BS EN 397, *Specification for industrial safety helmets*
- BS EN 474 (all parts), *Earth-moving machinery*
- BS EN 529, *Respiratory protective devices – Recommendations for selection, use, care and maintenance – Guidance document*
- BS EN 730-1, *Gas welding equipment – Safety devices – Part 1: Incorporating a flame (flashback) arrestor*
- BS EN 730-2, *Gas welding equipment – Safety devices – Part 2: Not incorporating a flame (flashback) arrestor*
- BS EN 791, *Drill rigs – Safety*
- BS EN 815, *Safety of unshielded tunnel boring machines and rodless shaft boring machines for rock*
- BS EN 1679-1, *Reciprocating internal combustion engines – Safety – Part 1: Compression ignition engines*
- BS EN 1800, *Transportable gas cylinders – Acetylene cylinders – Basic requirements, definitions and type testing*
- BS EN 1889-1, *Machines for underground mines – Mobile machines working underground – Safety – Part 1: Rubber tyred vehicles*
- BS EN 1889-2, *Machines for underground mines – Mobile machines working underground – Safety – Part 2: Rail locomotives*
- BS EN 1916 (all parts), *Limits and fits for engineering*
- BS EN 1992 (all parts), *Eurocode 2 – Design of concrete structures*
- BS EN 12110, *Tunnelling machines – Air locks – Safety requirements*
- BS EN 12111, *Tunnelling machines – Road headers, continuous miners and impact rippers – Safety requirements*
- BS EN 12336, *Tunnelling machines – Shield machines, thrust boring machines, auger boring machines, lining erection equipment – Safety requirements*
- BS EN 12862, *Transportable gas cylinders – Specification for the design and construction of refillable transportable welded aluminium alloy gas cylinders*
- BS EN 16191 ¹⁾, *Tunnelling machinery – Safety requirements*
- BS EN 50104, *Electrical apparatus for the detection and measurement of oxygen – Performance requirements and test methods*
- BS EN 60034-5, *Rotating electrical machines – Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification*
- BS EN 60076-1, *Power transformers – Part 1: General*
- BS EN 60079-1, *Explosive atmospheres – Part 1: Equipment protection by flameproof enclosures “d”*
- BS EN 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*
- BS EN 60079-10-2, *Explosive atmospheres – Part 10-2: Classification of areas – Combustible dust atmospheres*

¹⁾ In preparation.

BS EN 60079-14:2008, *Explosive atmospheres – Part 14: Electrical installations design, selection and erection*

BS EN 60079-29-1, *Explosive atmospheres – Part 29-1: Gas detectors – Performance requirements of detectors for flammable gases*

BS EN 60309-1, *Plugs, socket-outlets and couplers for industrial purposes – Part 1: General requirements*

BS EN 60332-3 (all parts), *Tests on electric and optical fibre cables under fire conditions*

BS EN 60529:1992, *Degrees of protection provided by enclosures (IP code)*

BS EN 60836, *Specifications for unused silicone insulating liquids for electrotechnical purposes*

BS EN 61008, *Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules*

BS EN 61099, *Specification for unused synthetic organic esters for electrical purposes*

BS EN 61241 (all parts), *Electrical apparatus for use in the presence of combustible dust*

BS EN ISO 2503, *Gas welding equipment – Pressure regulators and pressure regulators with flow-metering devices for gas cylinders used in welding, cutting and allied processes up to 300 bar (30 MPa)*

BS EN ISO 3821, *Gas welding equipment – Rubber hoses for welding, cutting and allied processes (ISO 3821:2008)*

BS EN ISO 5172, *Gas welding equipment – Blowpipes for gas welding, heating and cutting – Specifications and tests*

BS EN ISO 7731, *Ergonomics – Danger signals for public and work areas – Auditory danger signals (ISO 7731:2003)*

BS EN ISO 12922, *Lubricants, industrial oils and related products (class L) – Family H (hydraulic systems) – Specifications for categories HFAE, HFAS, HFB, HFC, HFDR and HFDU*

BS EN ISO 20344, *Personal protective equipment – Test methods for footwear*

BS EN ISO 20345, *Personal protective equipment – Safety footwear*

BS IEC 1008-2-2, *Implementation of IEC 1008-2-2:1990 – Specification for residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's) – Part 2-2: Applicability of the general rules to RCCB's functionally dependent on line voltage*

CP 3010, *Code of practice for safe use of cranes (mobile cranes, tower cranes and derrick cranes)*

Other publications

[N1]BTS. Occupational exposure to nitrogen monoxide in a tunnel environment – Best practice guide. London: BTS, 2008.

[N2]BRITISH DRILLING ASSOCIATION. *Codes of safe drilling practice*. Daventry: British Drilling Association, 2002.

[N3]BRITISH DRILLING ASSOCIATION. Guidance notes for the protection of persons from rotating parts and ejected or falling material involved in the drilling process. Daventry: British Drilling Association, 2000.

[N4] FEDERATION OF PILING SPECIALISTS/HSE. Notes for the guidance on PUWER (Regulations 11 and 12) in relation to guarding and cleaning of augers on piling operations. Beckenham: Federation of Piling Specialists, 2010.

[N5] SITE INVESTIGATION STEERING GROUP. Site investigation in construction – Guidelines for the safe investigation by drilling of landfills and contaminated land. London: Thomas Telford, 1993.

[N6] CIRIA. Tunnels – Inspection, assessment and maintenance [RP712]. London: CIRIA, 2004.

3 Terms and definitions

For the purposes of this British Standard, the definitions given in BS 6100-3:2007 apply, together with those for electrotechnical and related terms given in BS 4727-1:Group 01:1983.

4 The control of risk

4.1 From hazard identification to safe systems of work

4.1.1 General

The achievement of good health and safety performance on site, and the avoidance of any “adverse events”, such as accidents, cases of ill health, incidents and losses, arises from the effective identification of hazards and control of risks. Identifying hazards and risks, and determining the level of risk and how it is to be controlled, should not be a one-off exercise undertaken by the contractor. It should be a continuous process that starts at the planning and design stages and continues through the construction stage of the project into its maintenance.

Risks arise from hazards. Hazards (such as unstable ground, water, noise, dust, moving machinery and electricity) have the potential for harm to persons, the tunnel and the surrounding environment. The risk associated with any one hazard is an expression of whether that hazard is likely to occur, the frequency at which it could occur, and the consequences if it did occur. Some hazards (such as working at height) are encountered in everyday working, and precautions against the risk of falling are well understood and easily implemented. Low frequency but high consequence tunnelling events can occur (such as substantial ground collapses, or underground fires). Their consequences for the work force and others (e.g. third parties) can be very severe and they should be considered as part of the overall hazard and risk management system.

A structured approach should include the following stages.

- a) The possible hazards that could be encountered during construction and maintenance should be carefully identified in order to control risk. Generic approaches to the evaluation of risk often result in an incomplete picture. Hazard identification should be undertaken on a project-specific basis.
- b) Hazards should be eliminated at the design stage where possible.
- c) An evaluation of the risks arising from the residual hazards which cannot be eliminated should be undertaken.

NOTE 1 Certain hazards in tunnelling can give rise to several risks. For example, ground contaminants such as benzene, toluene and xylene pose the risk of fire or explosion and are themselves carcinogenic.

- d) An assessment of the risks should be carried out in order to prioritize the necessary risk-control measures. Risks that are identified as trivial should be

discarded from further consideration. Care should be taken to identify and investigate risks which, although very unlikely to occur, could have serious consequences.

- e) Risk control strategies should be first addressed at the design stage. Further risk-control measures should be taken for those residual risks that remain to be addressed during the construction stage. For example, risk-control measures might be needed to control risks arising from noise, dust, atmospheric pollutants, handling and use of dangerous chemicals, moving plant and transport. The detail of these risk-control measures should be devised by those in control of the construction works, but information on hazards and risks known by the client, the planners and the designers should be passed on to those devising risk-control measures at the beginning of the construction stage.

NOTE 2 The ultimate aim of this process is to devise project-specific safe systems of work.

NOTE 3 For further information see the BTS/ABI "Joint Code of Practice for Risk Management of Tunnel Works in the UK" [3].

4.1.2 Devising safe systems of work

Arriving at a safe system of work is a process that involves work and decisions by the client, the designers, the specifiers of the work, and the contractors, and should not be confined to the construction stage alone. Quantified risk assessment may be used where there is appropriate relevant data. The general principle is that the control measures should be proportionate to the risk. If the risk is substantial and the possible consequences are high, then more time, effort and resources should be expended in carefully identifying and controlling this risk.

A team approach that harnesses the knowledge and experience of all concerned has many benefits. Input from experienced designers and contractor and machinery suppliers during the design and planning stages can be beneficial. Input from the public emergency services and infrastructure owners affected by the proposed works should also be sought during these early stages.

Prior to commencement of the site work, the principal contractor should have prepared a construction-stage health and safety plan, taking into account the information received from other members of the project team. This plan should be regularly reviewed and revised as appropriate, in the light of experience as construction work proceeds.

4.2 Planning for contingencies and emergencies (see Clause 14)

Care should be taken to draw up specific plans for dealing with both contingencies and emergencies that might be foreseen on the project.

Contingencies are events which are planned for but which might or might not occur. An example is the degree of variability of the ground or water conditions. Plans should be made in advance to address such factors.

NOTE 1 It might be appropriate to have extra pumping capacity underground or, on a compressed-air tunnelling contract, and it might be appropriate to have extra compressor plant or extra ground-support equipment readily available on site.

Emergencies are events the occurrence of which cannot be predicted but cannot be ruled out. The first consideration should be to identify the types of possible emergencies in the context of the project. Those attempting to draw up a list of possible emergencies should have as wide a knowledge of the industry as possible and should be prepared to undertake research to supplement knowledge derived from their own experience.

NOTE 2 Emergencies that are unlikely but not impossible could include:

- a) a fire underground for example, involving a TBM;
- b) the sudden collapse of an open face of excavation in soft ground, possibly also involving a flow or slide of loose material;
- c) the sudden flooding of a tunnel due to unexpected pressure or quantity of water;
- d) an underground explosion, perhaps due to the undetected presence of methane;
- e) gross atmospheric pollution, which might be associated with oxygen deficiency;
- f) the failure of the tunnel lining, which might cut off persons from their normal means of egress;
- g) a complete power failure underground, which would result in substantial egress and rescue problems; and
- h) some form of emergency external to the underground works, but which would require immediate evacuation or rescue of persons underground.

Emergencies arising from the tunnelling activities can adversely effect persons and infrastructure not directly involved in the works and this should be recognized in emergency planning.

The nature of possible emergencies should be discussed with the public emergency services. Planning for emergencies should endeavour to harness the skills and experience of those who have had experience in dealing with such situations. A single emergency plan is unlikely to adequately address the range of emergencies which could occur.

NOTE 3 Recommendations for managing emergencies involving flooding and inundation are given in Clause 10, and for managing fire emergencies, in Clause 14.

4.3 Types of accidents

COMMENTARY ON 4.3

The types of accident that can occur in tunnelling are similar to those in the construction industry in general. These types of accident are described in Table 1, together with examples and references to the corresponding clauses that give guidance on preventive measures.

4.4 Occupational health

4.4.1 Health surveillance

NOTE 1 In general in the construction industry, lost time from occupational ill-health is significantly greater than from accidents.

As part of the overall control of risk, care should be taken to manage occupational health during construction on site.

Tunnel workers are a peripatetic group, often living away from home and with limited access to community health services; pre-employment health screening should be carried out on prospective employees relevant to their job function.

NOTE 2 For example, exposure of underground workers to dust could exacerbate chest complaints.

NOTE 3 Occupational health hazards relevant to tunnelling are described in Table 2. For some, statutory pre-exposure health surveillance is required

If elimination of the hazard is not possible, measures should be taken to minimize exposure by, for example, mechanization, ventilation, substitution of less hazardous alternatives, reduction of shift length or rotation of work patterns. In some cases, control measures can introduce other risks, which should be controlled.

Table 1 Accidents – Indicative examples of cause and prevention (not in order of priority)

Accident category	Examples	Precautions and/or principal references	Other refs
Falling from a height	Falling down shaft	Fixed barriers	20.6 and 20.7
Falling on the level	Falling within cutterhead	Harness and fixed anchor points on TBMs	
	Tripping or slipping	Unobstructed and well maintained walkways, good housekeeping, good lighting	Clause 17, Clause 22
Materials falling from a height	Tools and small items dropped or kicked off platforms or from shaft	Toe boards; proper stacking and storage; hand tools provided with restraint straps	20.6
	Slung loads dropped	Correct slinging and loading; loading area kept clear. See BS 7121-1 to BS 7121-5, CP 3010 and BS EN 13157	20.6, 21.2
Materials falling from stacks or vehicles	Shotcrete falling	Restrict access for personnel	
	Collapse of stacks, e.g. timber, segments, cement bags	Properly designed foundation for stacks; systematic building of and maintenance of stacks	8.3.2, 20.6
	Loads falling from vehicle	Loads properly stacked and secured; level road or track well maintained	20.6
Injury from fall of ground	Collapse of open face	See Clause 7 and Clause 8	
	Rock fall	Barring down loose rock; immediate support	7.8
Flooding or inrush of water	Broken sewer or water main, groundwater inrush, etc.	See Clause 10	
Lifting machinery	Cranes and hoists	See Clause 21	
	Hoisting and placing of segments at face	Mechanize process where possible. Properly designed and tested roller bolts and winch tables	8.3.2, 8.3.3
	Forklifts – loads suspended from forks	Load restraint, driver training	
	Fall from erector	Conformity to BS EN 12336	
Other machinery	Excavating machines	Exclusion of persons from operating zone; safe procedures defined and enforced; see Clause 7 and 23.2 and 23.3	
	Grouting operations	Equipment properly maintained; operation by trained persons; see 8.3.5	
	Conveyors	See 23.5	
Vehicles	Locomotives and rolling stock	See 23.1	
	Rubber-tyred vehicles	See 23.2	
Electrical installation	Electrocution	See Clause 25	13.3
Fire and explosion	Burns, concussion	See Clause 12, Clause 13 and Clause 14	11.5, 25.3.7
Atmospheric pollution	Atmospheric contaminants	See Clause 12, Clause 15 and Clause 16	11.3
Handling hazardous materials	Soil conditioners	Avoidance of spillage and contact. Adherence to manufacturer's data sheets. Suitable PPE	
Accidents associated with TBMs		See BS EN 12336	

4.4.2 Control of residual occupational health risks

NOTE Attention is drawn to Regulation 6 of The Management of Health and Safety at Work Regulations 1999 [4], which requires a programme of health surveillance. Information is given in HSE publication HSG61 [5].

Site managers, supervisory staff and designers should be able to recognize occupational health hazards associated with tunnel construction work activities. Supervisory staff should have an awareness of the symptoms of occupational ill-health.

Early reporting of symptoms should be encouraged to enable prompt reference to the employer's occupational health advisor. Where appropriate, underground workers should be given regular medical examinations by an occupational health specialist.

4.4.3 Provision of information

Information on exposure levels and associated risk control measures should be made available to employees, both directly and through trade union-appointed safety representatives where these exist.

4.4.4 Record keeping

COMMENTARY ON 4.4.4

There are requirements for the keeping of records of assessments and exposures in both general health and safety legislation and in hazard-specific legislation such as The Control of Noise at Work Regulations 2005 [6] and The Control of Vibration at Work Regulations 2005 [7].

Where no statutory requirement for record keeping exists, records should be retained for 20 years.

4.4.5 Washing facilities and potable water

Care should be taken to maintain good personal hygiene, particularly where work involves contact with contaminated ground and with irritant or caustic substances. This should also be done where toilet facilities are limited.

Underground workers should have ready access to supplies of cold potable water.

4.4.6 Mitigation measures

4.4.6.1 Noise

All reasonably practicable steps should be taken to reduce noise exposure, including substitution by less noisy equipment or by placing machinery in noise enclosures.

NOTE See The Control of Noise at Work Regulations 2005 [6].

4.4.6.2 Manual handling

Risks involved in manual handling should be reduced by the mechanization of the excavation and lining erection processes, the breaking-down of loads into smaller components, the provision of lifting points, and job rotation.

NOTE See The Manual Handling Operations Regulations 1992 [8].

4.4.6.3 Work-related upper limb disorders

Mechanization and job rotation should be employed to reduce the risk of work-related upper limb disorders.

NOTE See The Manual Handling Operations Regulations 1992 [8].

4.4.6.4 Hand–arm vibration syndrome

Mechanization and job rotation should be employed to reduce the risk of hand–arm vibration syndrome (HAVS). In addition, there should be a programme of clinical examinations by an occupational health specialist under the supervision of a medical practitioner experienced in HAVS.

NOTE See The Control of Vibration at Work Regulations 2005 [7].

Table 2 Principal occupational health hazards (1 of 2)

Hazard	Occurrence	Possible symptoms and/or consequences	Text reference
Physical			
1 Noise	Prolonged exposure to high noise levels. Pneumatic tools such as clay spades or rock drills. Machinery.	Long-term irreversible hearing loss.	4.4.2, 4.4.3, 4.4.4, 19.1, 19.2
2 Manual handling (lifting, carrying, pushing/pulling)	Hand excavation techniques. Erection of lining by hand. Use of heavy, awkward, slippery, sharp tools.	Pain including low back pain and restricted body movements that can lead to permanent disability. Prolapsed disc. Muscle/tendon damage.	4.4.3, 8.3, Clause 21
	Repetitive, frequent or prolonged operations requiring force, gripping, squeezing of hands, rotation of wrists. Awkward posture.	Work-related upper limb disorders. Pain, numbness and restricted body movement which can lead to permanent disability.	4.4.3, 19.3
3 Vibration	Prolonged exposure to high vibration hand-held tools. Concrete/rock breakers. Clay spades. Percussive drills.	Hand–arm vibration syndrome. Tingling or pins and needles in the fingers, and numbness. Whiteness at the fingertips when exposed to the cold. Finger paleness followed by a rapid red hand flush, plus finger throbbing. More frequent attacks causing hand pain and reduced dexterity. Eventually blue–black appearance of the fingers.	4.4.3, 4.4.4, 19.3
4 Heat	Hand excavation in conditions of high temperatures, high humidity, or low rate of air movement. Exacerbated by working in compressed air.	Heat stress and strain. Exhaustion. Increased heart rate and body temperature and sweating and salt imbalance. Fainting.	4.4.5, note to Clause 11, 15.3, 15.6

Table 2 Principal occupational health hazards (2 of 2)

5 Hyperbaric atmosphere	Work in compressed air.	Decompression illness. Signs and symptoms can include: <i>Acute:</i> Limb joint pains, skin rashes, itching, mottling, numbness, tingling, weakness, paralysis, visual disturbance, unconsciousness, convulsions. <i>Chronic:</i> Bone necrosis.	Clause 11
Chemical			
1 Cementitious materials, additives, epoxy resins	Prolonged direct skin contamination of hands, forearms, legs from concreting, grouting, slurries, rock bolting. Application of sprayed concrete.	Redness, itching, scaling, blistering, cracking and bleeding of exposed skin causing irritant or allergic dermatitis.	4.4.5, 7.13.2, 7.16, Table 4, 8.3.5
2 Respirable crystalline silica	Machine cutting of rock. Application of sprayed concrete, drilling, breaking, crushing, conveying, cutting, loading of rock.	Increasing breathlessness, heart failure, acute silicosis, accelerated silicosis, lung fibrosis.	4.4.2, 4.4.3, 4.4.4, Clause 16
3 Other respirable dusts	Machine cutting of rock. Application of sprayed concrete, drilling and blasting.	Irritation of respiratory tract. Accumulation of dust in the lungs.	7.8, Clause 16
4 Solvents	Skin contact, contamination of tunnel atmosphere. Contaminated land.	Principally skin irritation including dermatitis. Nausea and giddiness.	4.4.3, 15.4.3.11
5 Hydrocarbons	Particulates from diesel engine exhaust emissions.	Irritation of eyes and respiratory tract. Might be a link with cancer (cause unclear).	15.4.3, 24.4.1
Biological			
Contaminated water or soil	Infection through poor hygiene practices, skin cuts and abrasions or rubbing eyes when working in contaminated land or water sewage.	Weil's Disease (leptospirosis) – a bacterial infection carried in contaminated water and soil. Early symptoms include sudden high temperature, loss of kidney function, influenza-like illness, joint and muscle pains. Conjunctivitis and jaundice can occur.	4.4.3, 4.4.5, Clause 26

4.4.6.5 Heat stress and exhaustion

Mechanization, ventilation and job rotation should be employed to reduce the risk of heat stress and exhaustion. Adequate supplies of cold potable water should be made available.

4.4.6.6 Skin problems

Skin problems can be reduced in a number of ways, including the use of remotely operated equipment, and the use of personal protective equipment (PPE) such as gloves and overalls. When contact has occurred, contaminated skin should be washed immediately with hot water and cuts covered with waterproof dressings. Barrier creams should be used before work, and moisturizer creams to replenish skin oils. Contaminated PPE should be disposed of or, if appropriate, cleaned before reuse.

4.4.6.7 Dust (including respirable crystalline silica)

Exposure to dust (including respirable crystalline silica) should be reduced by local exhaust ventilation and the use of water sprays. Wet-mix shotcrete should be used to reduce the amount of dust generated in sprayed concrete lining applications.

5 Investigation and information gathering

5.1 General

The safety of tunnelling works is critically dependent on adequate pre-construction investigation of the ground and site, and proper interpretation of the information obtained. All reasonably accessible information relevant to the construction of a tunnel, and to any maintenance, renovation or repair of it, should be obtained and studied before the work starts. Project-specific studies (see 5.3) should be carried out before tunnel construction can proceed, and should continue during the construction stage.

There should be the fullest practicable disclosure of all relevant information, and gaps in the information, to those responsible for design, for planning, and for construction. Ground information should be relevant to, and as complete as practicable for, the needs of the design processes. It is therefore desirable that the designer, taking advice from others as appropriate, should establish the requirements for, and have technical control of, data acquisition for the site and ground investigation programme. This could include on-site design involvement during the site investigation contracts.

The recommendations set out in 5.2 and 5.3 should be treated as a basic checklist, and in no sense as a comprehensive specification.

NOTE BS 5930 deals with site investigations in considerable detail.

Particular reference should be made to the tunnelling addendum in the "Specification for Ground Investigation" [9]. Changes in nomenclature, particularly in regard to strength categorization, and design philosophy resulting from the adoption of Eurocodes should be taken into account.

5.2 Preliminary studies

5.2.1 Topography

Ordnance Survey maps and plans normally provide sufficient detail for the preliminary studies and for the basic siting of the works; however, up-to-date information not yet embodied in published editions of the maps and historical maps should be obtained from the Ordnance Survey.

NOTE 1 Local authority records, often available through local library and archive services, can be useful sources of information on the history of land use.

NOTE 2 Old editions of maps, such as the “County” series pre-1939 at scales 1:10 560 and 1:2 500, can be important documentary sources, as they record workings and structures and watercourses now perhaps abandoned and concealed. Aerial photographs are held by the Ministry of Defence, Ordnance Survey, air survey companies and internet mapping sites. Comparison of recent and earlier aerial photographs can give important information on the masking of earlier features.

NOTE 3 Proprietary websites giving topographical information can be a useful initial source of information.

In tidal waters and coastal areas, Admiralty charts show the topography and nature of the seabed. The date of the information displayed on the charts is important, and local port or harbour authorities should be contacted for the most recent information on local harbours and their environs.

5.2.2 Geology and hydrogeology

NOTE The published maps, both solid and drift editions, together with the relevant sheet memoirs, supplemented by much information accessible in the published and unpublished records and from information lodged with the British Geological Survey and of the Geological Society, provide the essential background information to tunnel siting and construction. Other useful material includes soil maps, a grid-references list of available borehole logs, memoirs of the Soil Survey of Great Britain, contaminated-land maps and land utilization maps. Geomorphological studies can also be of benefit, particularly in the vicinity of tunnel portals to be formed in natural slopes.

The information from these sources might not necessarily be consistent, and checks should be made on its accuracy, applicability and relevance.

5.2.3 Hydrology

NOTE Records of surface water levels and flooding can usually be obtained from the Environment Agency in tidal waters. Admiralty charts and other Admiralty publications provide essential information that can be supplemented by the records of local harbour authorities. Tidal predictions embodied in Admiralty tide tables are of great importance for work at or near sea level.

Discharge rates for rivers should be ascertained. All appropriate records and predictions should be fully examined for their relevance to particular locations. Advice from those with local knowledge can be invaluable.

5.2.4 Existing structures, services, old workings and unexploded ordnance

Knowledge of all structures, buildings and earthworks within any possible zone of influence of the tunnel construction should be sought and studied. Plans of buildings and other structures, including previous developments on the site, should be examined both from the point of view of ground support required within and adjacent to the tunnel and of danger and damage to existing structures from settlement or vibration. Such plans are likely to be in the possession of the owners or deposited with the local authority.

NOTE 1 Industrial works, waste tips, waste disposal sites and landfill sites, whether operational, closed or abandoned, can pose a range of hazards to tunnelling works, particularly if hazardous substances have infiltrated the strata to be tunnelled.

A search should be made for records of any wells, culverts, boreholes, borrow pits, and any old mine workings in the area. These records can also provide information on water table levels. Records of previous tunnel construction can also provide valuable information. Publications of learned societies and libraries can also contain evidence of previous land use. In mining areas, the fullest information on existing and abandoned coal and other mines should be consulted, but it should be noted that this might be incomplete in respect of mine work undertaken before 1909. Coal-mining records are retained by the Coal Authority. Enquiries should be made as to whether there are any records of the occurrence of methane or other gases. Local knowledge of pits, adits, drifts and other working is sometimes available.

Forms of structural support to existing buildings and structures, such as piles or temporary or permanent ground anchors, should be fully investigated, as they can pose hazards to the tunnelling operations and are themselves liable to be detrimentally affected by tunnelling works. Tunnelling works should not take place within the zone of influence of ground anchors without their impact on the anchors being assessed.

The fullest practicable information on underground services and structures should be obtained from cable and communications companies, from electricity, gas, water and drainage companies, and from any other organizations owning underground services such as oil pipelines, and structures, such as transport operators. Where appropriate, the actual location of these services should be verified. Drawings should not be relied upon, as they might be incomplete or insufficiently accurate. It should be noted that trunk mains and services might be the responsibility of national rather than local utility providers.

NOTE 2 Guidance on assessing the risk from unexploded ordnance is published by CIRIA [10].

Where possible, a comprehensive walkover survey of the proposed tunnel alignment should be undertaken.

5.2.5 Weather

The influence of local weather conditions on tunnel construction should be taken into account, e.g. patterns of rainfall and barometric pressure changes and the likelihood of electrical storms. Daily rainfall data from the Meteorological Office should be obtained for comparison with periods of observation in groundwater conditions.

5.3 Project-specific studies

5.3.1 General

All site investigations should be carried out in accordance with BS 5930 and the tunnelling addendum in the "Specification for Ground Investigation" [9].

5.3.2 Boreholes

Boreholes (vertical, horizontal or inclined) should be sited to provide information specific to the tunnel to be constructed, renovated or repaired. Geological and hydrogeological information obtained from maps and other records should be used to supplement data from boreholes. The boreholes should be located close to the line of the proposed tunnel, but not so close as to intersect it, unless for some specific reason.

NOTE 1 A borehole too close to, or intersecting, a tunnel or shaft can constitute a serious hazard if water is present, and particularly when compressed-air tunnelling methods are employed. The siting of a borehole where a shaft is to be sunk makes correlation possible between the borehole data and the actual ground encountered.

If a borehole intersects an aquifer it should be sealed at the appropriate location. All boreholes should be properly filled and capped using concrete plugs.

NOTE 2 The number of boreholes undertaken depends on a number of factors, including the length of the tunnel and the character and variability of the ground.

The original pattern of boreholes normally should be supplemented by additional boreholes to check on areas of doubt and concern and resolve special problems appearing at the construction stage. Continuity of strata between boreholes should not be assumed.

All boreholes should be taken to a depth of at least 2 diameters below the intended tunnel invert, and these boreholes should be adequately sampled and recorded to enable geological structures and hazards adjacent to the proposed tunnel excavation to be determined. At least one deep borehole specifically for correlation of the stratigraphy of the site geology should be sunk.

Drilling operations and sampling should be supervised in order to maximize the usefulness and quality of the information recovered. Records of locations, strata found, water strikes, contamination, testing and abandonment of all boreholes should be made. Copies of borehole records should be offered to the British Geological Survey. Samples of rock, subsoil and groundwater should be properly identified, labelled, and photographed where necessary, sealed and stored for further examination if required.

Consideration should be given to the use of the most appropriate methods for obtaining undisturbed samples of soil by, for example, rotary coring and thin wall sampling tubes, in order to provide the best information on soil structure, stress/strain behaviour and anisotropy.

5.3.3 Information logging

COMMENTARY ON 5.3.3

The following techniques for information logging are available.

- a) *stratigraphic logging, by an experienced geologist; and*
- b) *borehole logging, using appropriate techniques for the ground conditions by an experienced geologist.*

The experience of the logging geologist should be in accordance with the recommendations in the Site Investigation Steering Group publications at www.ags.org.uk/business/bestsi.cfm.

NOTE Valuable additional information can be obtained from local exposures of strata or from large diameter auger boring in which the strata can be examined in situ, or from test pits or shafts.

Specific safety precautions should be taken to prevent danger from loose ground, water, gases and other hazards when boreholes and pits are being inspected. The visual inspection of boreholes, where required, should be undertaken by remote means such as cameras.

An appropriate laboratory testing programme should be followed to aid the determination of methods of excavation, ground support and spoil disposal.

5.3.4 Geophysical investigation

Geophysical methods applicable to tunnel conditions include seismic, electrical ground resistivity, ground radar and micro-gravity surveys. These methods should not be used on their own, but as an adjunct to borehole and other information.

NOTE 1 These methods can trace well-defined boundaries between underground strata and provide a more comprehensive picture and identify anomalies, which can then be examined further by, for example, additional boreholes.

NOTE 2 In urban areas the use of geophysical methods might not be appropriate because of the interference from existing services and structures. Radar and micro-gravity have been used successfully to identify swallow holes and similar features.

NOTE 3 For a subaqueous tunnel, a marine seismic survey can assist in charting the seabed or riverbed, determining bedrock surface and discovering buried channels. The survey can help to decide locations for site investigation boreholes.

NOTE 4 Reference ought to be made to the CIRIA Report C562 [11].

5.3.5 Surface survey

An accurate site survey should be made for the purposes of setting-out and tunnel construction. This survey should define accurately the relationship of the tunnel to all boreholes, existing structures and other features that could be affected.

NOTE 1 An aerial or satellite survey can provide valuable additional information, particularly for a major tunnelling project.

Reference points, related to Ordnance Survey or GPS reference points, for the coordinate grid system of the survey should be established and preserved, as should benchmarks for levelling. The stability of all reference points should be checked and referenced.

Existing surface features, such as manholes and valve covers, should be identified and recorded, as these help to locate existing sewers and other buried services.

NOTE 2 Datums for tide levels can vary in accordance with local practice.

5.3.6 Subsurface survey

In addition to the surface topography, any underground structures should be accurately related to the proposed tunnel alignment. The accuracy of the available survey information should be taken into account.

The structures that should be surveyed include:

- existing basements and foundations;
- existing headings, tunnels and underground workings;
- main sewers;
- underground services of any kind.

The heads of any ground or rock anchors that can be located, should be accurately surveyed. Owners' plans of basements, foundations, anchors and piles should, if possible, be verified.

If any existing structure or service intersects, or is very close to the proposed tunnel, any special hazards that could result should be carefully examined and appropriate precautions should be taken.

5.3.7 Structural survey

All buildings and structures that could be affected by the tunnel construction should be surveyed to determine their condition prior to, during, and after the proposed tunnelling operations.

5.3.8 Groundwater tests

Where the response of the groundwater regime to pumping or other methods of creating a differential hydraulic head could be important to the stability of the proposed tunnel or shaft, consideration should be given to carrying out pumping tests in boreholes sunk specifically for the purpose.

NOTE 1 Where water levels in the area are variable or could be affected by tunnelling operations, observation wells to observe and record any variations of levels are desirable. They might be needed prior to, and during, tunnelling work.

Water levels in boreholes should be recorded, and any perched water tables or artesian supplies should be identified.

NOTE 2 In water-bearing ground, permeability tests in boreholes can contribute valuable information.

Where tidal variations are critical, as in the case of compressed-air working, tide gauges should be provided.

Where necessary, other water tests should be made for salinity, acidity or pollution and/or the presence of chemicals or dissolved gases of natural or artificial origin.

The effects of changes in ground water level resulting from abstraction or recovery, extending over the lifetime of the tunnel, should be considered.

5.3.9 Gas

Ground conditions should be established to ascertain the risk arising from gas such as methane, radon or other gaseous pollutants being present or likely to be released from the ground or groundwater and tests undertaken accordingly. Tests should be carried out to ascertain the nature of the gases present (see Table 7) and their respective concentrations.

NOTE 1 Gas can migrate into the works both during construction and future operation.

The effects of changes in atmospheric pressure on gas release should be recognized. In particular it should be noted that the reduction in atmospheric pressure can lead to significantly increased gas release.

NOTE 2 This applies in particular to tunnelling work in or adjacent to:

- a) coal measures;*
- b) landfill sites;*
- c) glauconitic sands;*
- d) permeable strata where air has been introduced by previous compressed-air workings; and*
- e) areas where the lowering of the water table has caused deoxygenation.*

Gas can be dissolved in water and enter a tunnel with any water ingress. Groundwater can travel considerable distances into tunnelling works.

5.3.10 Blasting trials

Where a tunnel is to be driven through rock using explosives, and in proximity to any vibration-sensitive structure or building, blasting trials should be carried out to determine the vibration parameters of the rock mass.

5.4 Ground investigation during construction

5.4.1 General

COMMENTARY ON 5.4.1

It might be necessary to continue ground investigation during the construction stage.

The water pressures in hard rock or the porewater pressure in soft ground should be checked. It should be noted that this is particularly important where sprayed concrete lining is employed.

5.4.2 Probing ahead

COMMENTARY ON 5.4.2

According to the method of construction, probing ahead of the tunnel face can provide valuable additional information and can improve the overall quality of the data concerning the ground ahead of the tunnel construction. The extent to which probing is actually employed depends on the likely hazards.

In extremely bad ground conditions, probing in all directions might be necessary, combined with ground treatment. In extensive investigations of this kind, care should be taken, when drilling, to avoid penetrating any suspected aquifers above or below the tunnel construction (see 9.1.3 and 9.2).

5.4.3 Pilot tunnel

COMMENTARY ON 5.4.3

For large open-face tunnels, a pilot tunnel (usually located within the cross-section of the intended tunnel) might be the appropriate method for ascertaining the nature and behaviour of the ground in advance of the main tunnel construction. This indicates the need for possible special construction, ground treatment or ground support.

6 Detailed planning for health and safety

COMMENTARY ON CLAUSE 6

The Construction (Design and Management) Regulations 2007 [1] require all parties to work together to reduce health and safety hazards and risks.

6.1 Integral nature of design and construction

It should be noted that the interdependence of design and construction and their appropriateness to the ground and environmental conditions is more safety-critical in the execution of underground work than in other construction work. There should be authoritative engineering continuity through the stages of planning, investigation, design and construction. If there is a change in the engineering direction of the works, the essential continuity should be maintained and fragmentation of the total planning, design and construction process should be avoided. There should be input from the designer during the construction phase to ensure the design is constructed as envisaged.

6.2 Pre-construction-stage organization

Clients are ultimately responsible for good health and safety performance. They should appreciate that this is in everyone's interest, and involves competence, cooperation and coordination along with the provision of adequate resources.

6.3 Construction stage

6.3.1 Organization

The construction-phase health and safety plan is the fundamental document that sets out safe working practices throughout the construction of a tunnel and should be based on the information supplied by the client on the residual risks. It should be prepared by persons suitably experienced in the tunnelling operations likely to be involved, including the types of plant and equipment to be used.

Contractors should carry out an assessment of the risks posed to their employees and to non-employees. These risk assessments should be used to devise and implement safe systems of work.

The health and safety plan should define a clear chain of responsibility and channels of communication on engineering safety matters. This is particularly important in, for example, the choice of ground-support systems and decisions concerning safety at the tunnel face.

The principal contractor should plan manage and coordinate the activities of all other contractors.

NOTE Part IV of The Construction (Design and Management) Regulations 2007 [1] includes requirements for the provision, accessibility and maintenance of welfare facilities.

Welfare should be given particular consideration in long tunnels, deep shafts and in other remote locations.

Where tunnel size permits, welfare facilities should be located underground, including on tunnel boring machines (TBMs).

6.3.2 Statutory controls

NOTE 1 Statutory health and safety duties and responsibilities with respect to "construction work" are set out in The Health and Safety at Work etc. Act 1974 [12], and the "relevant statutory provisions", which are the various sets of regulations that might apply to individual work activities. Administration and enforcement is undertaken by the Health and Safety Executive (HSE).

Notification of the construction work should be given to the HSE, and details of the information required to be sent can be found in The Construction (Design and Management) Regulations 2007 [1] and (if applicable) The Work in Compressed Air Regulations 1996 [2]. The HSE should be consulted regarding the obtaining and completion of all relevant notices, registers, and official forms.

In the case of any construction work involving operational railways, HM Railways Inspectorate within the Office of Rail Regulation is the enforcement authority that should be consulted.

Certain accidents, cases of ill health and specific incidents should be reported to the HSE, and these are specified in The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 [13].

All accidents and incidents, whether or not they result in personal injury or losses, should be reported to employers by the individual involved or their immediate superior, and then in turn to the principal contractor.

Records should be kept, and these, together with the results of any associated investigation work and details of similar incidents from elsewhere, should be studied and analysed, and appropriate action taken.

NOTE 2 Inspection of a shaft or tunnel by a competent person is a statutory requirement of The Construction (Design and Management) Regulations 2007 [1]. The results of these inspections provide a valuable record of conditions at the time.

An appropriate schedule of inspection should be drawn up and implemented when the work, for whatever reason, is not continuous, e.g. at weekends and during holiday periods or during other interruptions in the tunnelling work.

NOTE 3 The use of remote monitoring systems, including remotely monitored instrumentation or closed-circuit television (CCTV), can eliminate or reduce the need for persons to enter the tunnel.

Where it is necessary to enter the tunnel, the recommendations given in 15.5 should be observed.

6.3.3 Supervision and inspection

All tunnelling operations should be subject to appropriate supervision. Understanding, making engineering judgements, and taking action in response to varying ground conditions should be done in order to maintain safe working conditions. The client should appoint appropriately qualified and experienced persons to monitor all site activities, and to assist in overall promotion of health and safety.

6.3.4 Temporary works

The design of the permanent works should take account of the constructability of the works and any associated temporary works. Even if the primary lining is considered temporary works, it should be subject to an independent design check.

NOTE Temporary works of a substantial character are invariably necessary in the construction of shafts and tunnels, and in their maintenance, renovation and repair. They can constitute an essential element of the permanent construction, as in the case of, for example, a pilot tunnel, a working shaft or the framing to form an opening. They can also be structurally independent incidental works, such as working gantries, access systems, thrust pits and walls.

Health and safety issues relating to these works should be taken into account early in the design stage. In tunnelling, the adequacy of temporary support is often critical to the loading on the permanent structure. Drawings, calculations, specifications and any contributions to the construction-stage health and safety plan should be prepared and followed. Where any failure of these temporary works would have a significant adverse effect on the health and safety of persons or on the surface or sub-surface environment, the temporary works should be the subject of an independent design check. Once checked and approved, changes should only be made after direct consultation with the appropriate designer.

The principal contractor should appoint a person to ensure safety in the design, checking, construction or installation and use of temporary works in accordance with BS 5975 and should encourage cooperation and coordination between contractors.

6.3.5 Records and reports

Proper and adequate records of the physical aspects of the work in tunnel construction and repair should be kept. This is not only for safety during construction, but for safety in any necessary future maintenance and repair work. They should also be kept to assist any future tunnelling or other work in the vicinity.

NOTE Such records will be part of the health and safety file, required under The Construction (Design and Management) Regulations 2007 [1], for the project.

The content of the health and safety file should be the subject of early discussion with the client. It should contain a longitudinal geological section record based on day-to-day records of the strata encountered, correlated with any borehole records or other records, and with any abnormal ground levels, tidal or river levels and rainfall, along with records of atmospheric conditions. In addition, settlements and movements of the tunnel lining and supports, and the ground above and adjacent to the tunnel, should be recorded.

6.3.6 Recruitment of project personnel

How health and safety issues are handled in the context of the recruitment of personnel for a tunnelling project should be addressed in employers' company health and safety policies.

Pre-employment health screening should be carried out on prospective employees relevant to their job function. All persons working on tunnel construction should have a high standard of physical fitness. All persons working underground should be at least 18 years old and all plant operators and banksmen should be at least 21 years old.

6.3.7 Competence and training

6.3.7.1 Competence

NOTE 1 The most vital contribution to health and safety in any tunnelling operation is through competent engineers, managers and workforce; the role of the first line supervisors is of particular importance.

Competence is gained through a combination of training and experience; all persons underground should be competent for the environment in which they are working and for the work tasks and activities they are required to carry out.

NOTE 2 Appendix 4 of The Construction (Design and Management) Regulations 2007 [1] describes requirements for competence.

Engineers, managers and supervisors should be competent both with respect to the work under construction, and in the techniques of management, communications and supervision.

Evidence of relevant competence, such as the achievement of recognized qualifications, should be sought which could include, for example, qualifications in project management or health and safety management, or other further educational qualifications.

National Vocational Qualifications (NVQs) in tunnelling-related subjects are an appropriate qualification and are available. Those in jobs for which tunnelling-related NVQs are available should either be in possession of an NVQ or be working towards one. Clients should encourage the use of NVQs as an indicator of competence.

The duty holder appointed under the Electricity at Work Regulations should be familiar with all aspects of underground installations (see 25.1). They should have access to professional electrical engineering advice and supervision.

Persons trained in the use of specialized tunnelling plant should also be experienced in general procedures for tunnelling and should be familiar with both health and safety instructions and operating instructions provided by plant manufacturers and suppliers.

NOTE 3 Specialized tunnelling plant includes items such as TBMs, segment erectors (including winches), concrete spraying equipment, grout pans, drilling and coring equipment and pipe jacking pressure systems.

6.3.7.2 Information and training

COMMENTARY ON 6.3.7.2

It is a legal requirement for all persons at work to be given appropriate information on and training in health and safety related to the risks they might encounter at work. Special training requirements apply in certain circumstances, for example first-aid, plant operation, and, for work in compressed air.

In addition to basic site inductions, specific induction training should always be given before any person starts work underground, whether as a new employee or as a person new to the project. Persons who are new to the industry are particularly vulnerable, and their induction training and the degree of supervision of their work should reflect this. Specific induction training should cover:

- information on possible hazards, risks and health effects;

- the devised safe methods of working to address the hazards and risks;
- site rules imposed by the principal contractor and prohibited activities;
- the provision, use and care of protective equipment;
- site communications and procedures;
- those with particular responsibilities for health and safety;
- actions in the event of any emergency, particularly raising the alarm, places of safety underground and egress from underground workplaces.

Toolbox talks are established as a valuable method of on-the-job-training at the workplace and for imparting and updating health and safety knowledge. Such talks should be held frequently. They should cover method statements for new or major work activity, reinforce knowledge about ongoing activities and draw attention to near misses or incidents which have occurred. They should be fairly brief and restricted to essentials, but allow for feedback and questions from those present. The talks should also take place whenever circumstances in the workplace change significantly or when new hazards are anticipated or become evident.

Visitors to underground projects should be given appropriate induction training. They should be accompanied by an experienced member of the project staff when on site.

6.3.8 Personal protective equipment

6.3.8.1 General

Good health and safety performance are achieved by the effective identification and control of hazards and risks, but risk elimination can only go so far, and residual risks should be controlled. Reliance on personal protective equipment should be regarded as a last resort. However, in tunnel construction works, some personal protective equipment should be used. Compatibility between items and user acceptance should also be considered.

6.3.8.2 Head protection

All persons on site should normally wear protective headgear conforming to BS EN 397 at all times.

6.3.8.3 Foot protection

Boots, with steel sole plates, toe protection and providing ankle support, conforming to BS EN ISO 20344 and BS EN ISO 20345 should be worn at all times.

6.3.8.4 Hand protection

Gloves conforming to BS EN 388 should be worn where a person is at risk from cuts, abrasions, burns or contact with corrosive or irritant substances. Elbow-length gloves should be worn when grouting or handling corrosive or irritant substances. Barrier creams should be made available and used by site personnel.

6.3.8.5 Eye protection

Light eye protection conforming to BS EN 166 should be considered as a minimum level of protection.

Safety goggles, face shields and fixed shields should always be worn by site personnel engaged on sandblasting, shotblasting, pressurized air and water cleaning, spraying concrete, grinding or chipping, metal cutting, burning and welding, grout mixing and placing. They should also be worn where there is a foreseeable risk of injury while breaking, cutting or drilling concrete or stone or similar material, and by persons handling or injecting hazardous liquids under pressure.

6.3.8.6 Whole-body protection

Everyone underground should wear flame retardant clothing with integral high-visibility strips or panels.

NOTE See BS EN ISO 11612.

Additional protective clothing should be provided and used where appropriate to the risk, for example in excessively wet conditions, when burning or welding, when handling hazardous substances or working in contaminated ground.

6.3.8.7 Respiratory protection

Where there is a risk of respiratory damage from dusts, ventilation should be employed to extract or dilute any hazardous materials. The use of respiratory protective equipment, for example dust masks or airstream helmets, should be employed as a last resort.

For work in high levels of contamination, for example where chemical protection is required, expert advice should be obtained and followed.

6.3.8.8 Hearing protection

NOTE Guidance on the selection and care of hearing protection is free to download at www.hse.gov.uk/pubns/books/l108.htm, and can also be found in BS EN 458. See also Clause 19.

6.3.8.9 Self-rescuers

All persons underground should carry an oxygen self-rescuer.

NOTE See 14.10.

6.3.9 First aid provision and procedures

6.3.9.1 General

NOTE 1 Attention is drawn to The Health and Safety (First Aid) Regulations 1981 [14] and associated guidance document L74 [15]. These direct and guide employers in the provision of first aid for persons injured at work.

Persons trained in first aid and capable of responding rapidly to any incident should be available at all times on each shift and at all working locations.

NOTE 2 Considerable advance planning and coordination with public emergency services might be required if the tunnel is in a particularly inaccessible location.

All persons should be informed of the first aid arrangements.

All employers should train their on-site supervisory personnel in managing emergencies involving first aid. All personnel should be told that, in the event of serious injury, a casualty should be moved only by a trained first-aider, unless there is the immediate risk of further injury.

Good communications should be put in place between the working areas and the surface facilities. A clear plan of action should be formulated to speed up the transfer of any injured persons from working areas and to ensure that ambulances can reach shaft tops or other access points quickly. Lifting arrangements in shafts should take this into account. Clear instructions should be given to all persons on the procedures to be adopted for evacuating tunnels in an emergency and for ensuring that injured persons are not left behind or unaccounted for.

6.3.9.2 First aid facilities

First aid boxes should be provided. They should be made of suitable material (e.g. metal or plastic), and should be designed to protect the contents as far as possible from damp and dirt. They should be clearly identified: the recommended marking is a white cross on a green background. Boxes should be readily accessible to working areas and should be in the charge of designated first-aiders on each shift. Appropriate eye wash facilities should also be provided.

A list of first-aiders, and how they can be contacted, should be prominently displayed at key locations within the tunnel.

NOTE HSE publication L74 [15] gives guidance on equipping first aid boxes.

6.3.9.3 First aid rooms

A properly constructed and equipped first aid room should be provided to be used for treatment and rest. This should be located at a surface facility.

It should be in the charge of a person trained in first aid and should be available during all working hours.

6.3.9.4 First aid training

NOTE 1 Attention is drawn to The Health and Safety (First Aid) Regulations 1981 [14] which require persons with first aid responsibilities to have successfully undergone a course of training, and to be in possession of a current certificate issued by an organization approved by the HSE.

NOTE 2 Details of such organizations are available from offices of the HSE.

First-aiders should be specifically trained to deal with the range and location of incidents likely to occur in tunnelling operations including maintenance and fit-out.

6.3.9.5 Stretchers

Stretchers (complete with blankets) suitable for the confined space of a tunnel should be provided and maintained. They should be readily accessible for use in working areas in an emergency, and should be protected against dirt and damp. In particular, where access to a tunnel is by a shaft, stretchers should, where practicable, be stored at tunnel level. Appropriate means of safely transporting an injured person to the surface should be provided (see 21.6.4).

6.3.9.6 Ambulances

The local ambulance service should be notified of the location of the site and the nature of the work to be carried out. All employees should be made aware of the procedure for calling an ambulance.

NOTE On a geographically inaccessible site, it might be necessary to provide a vehicle immediately available on site which is suitable for transporting stretcher cases.

A notice giving the address of the hospital dealing with emergencies should be prominently displayed.

6.3.9.7 Transport underground

Where necessary, a rescue skip, train or dedicated vehicle should be provided to expedite the rescue of casualties from long tunnels.

7 Excavation and ground support

7.1 General

COMMENTARY ON 7.1

Increasingly in tunnelling practice internationally, the terms “mechanized tunnelling” and “conventional tunnelling” are used to describe the tunnel technique being used. “Mechanized tunnelling” refers to tunnels excavated by TBM in soft ground or hard rock, while “conventional tunnelling” refers to tunnels excavated incrementally in soft ground with or without the protection of an open-faced shield and, increasingly, supported by sprayed concrete lining. Timber and segmental linings were used as the lining material for conventional tunnelling and are still used today, e.g. small headings for service crossings under city streets. In hard rock, “conventional tunnelling” refers to tunnels normally constructed using self-propelled excavators and other equipment, e.g. roadheaders, or drill and blast techniques.

As the excavation and the support of the ground are often one operation, appropriate cross-references are made to Clause 8 and other relevant clauses.

7.2 Basic principles

The essence of safe excavation should be to ensure the stability of the ground and minimize surface settlement and ground movement at all times. This is achieved by either:

- providing continuous ground support as part of the excavation sequence (e.g. closed-face technique); or
- opening up only as much ground as is safely self-supporting (e.g. open-face technique) until temporary or permanent support can be provided.

The amount of ground opened up varies from a small excavation in soft clay or loose sand, which should receive immediate support, to the total excavated surface of a tunnel in sound hard rock, which can safely remain unlined for many weeks or indeed permanently. Following a full risk assessment, a safe system of work should be devised, implemented and maintained at all times.

NOTE 1 The time intervals between excavation, immediate support and final lining are critical to the whole construction procedure and its cost. As soon as a volume of ground is excavated, there is a redistribution of stresses in the remaining ground. This can initiate movement in the ground, which can cease quickly in sound rock, or can continue to develop slowly in firm and stiff clays or rapidly in soft to very soft clays, sand or gravel (see 7.3).

If the effects are to be localized, immediate support should be provided to prevent progressive deterioration and instability.

NOTE 2 The stand-up times of unsupported ground range from seconds to days or weeks. The nature of the necessary ground support varies from mere containment to support for full overburden.

Major factors that should be taken into account when determining the loads to be taken in the ground-support system include:

- a) the size and depth of the tunnel;
- b) the shape of the tunnel;
- c) the method and speed of excavation and lining;
- d) the stiffness and water tightness of the lining system;

- e) the groundwater regime;
- f) the structural geology;
- g) the proximity of other surface and underground structures;
- h) the construction of adjacent tunnels and other underground structures;
- i) vibration.

NOTE 3 Depending on the influence of these factors, and in particular groundwater, it can sometimes be safe to leave a small face almost indefinitely, whereas extensive and continuous support can be required for a larger face in similar material.

It should be noted that experience and sound judgement are essential in assessing how much ground can safely be opened up and for how long it can remain unsupported. In some types of mechanized tunnelling, it is not always possible to see the excavation face upon which a decision is to be made. In this case, alternative methods of assessing the face support required should be considered.

NOTE 4 These include, where practicable, inspection of the excavated material, forward probing (assuming suitable facility within the machine), ground radar and excavation volume assessment.

NOTE 5 Where sudden changes in ground condition are encountered, immediate temporary support and containment can be vital. In loose ground, where silt and sand start to run, mechanically closing down the face or alternatively stuffing quickly with bags of straw or similar material can be effective in minimizing ground loss and maintaining the stability of the face.

The means of containment should be readily available.

In conventional tunnelling, which involves incremental excavation and support, continuous observation of both the ground and the ground support should be carried out.

NOTE 6 Extensive guidance is provided in the HSE report "Safety of the New Austrian Tunnelling Method (NATM) Tunnels" [16] and the ICE design and practice guide "Sprayed Concrete Linings (NATM) for Tunnels in Soft Ground" [17].

While sprayed concrete linings practice has moved on since these documents were published (e.g. the use of fibre reinforcement in shotcrete in place of mesh), the principles in them remain sound and should be adhered to.

7.3 Ground movement control

COMMENTARY ON 7.3

For tunnels in urban areas, control of ground movement is very important. It can be the determining factor when deciding on the tunnelling technique to be adopted.

As the amount of ground movement around a tunnel is a function of the ground loss, stress relief and changes to hydrogeology, the excavation process should be managed to ensure ground movement is minimized. Monitoring of ground movement can give real-time results and, where control of ground movement is critical, should be used as part of the overall management of the construction process.

7.4 Ground characteristics

7.4.1 General

COMMENTARY ON 7.4.1

Soils and rocks are not homogeneous. The following sub-clauses (7.4.2, 7.4.3, 7.4.4, 7.4.5 and 7.4.6) offer guidance on the general characteristics of various soil types, but ground conditions can change continuously as the tunnel proceeds, and the material being excavated is unlikely to match any single category described in these subclauses.

It is a fundamental principle of tunnelling that the tunnel horizon should avoid any soil/rock interface; similarly for any interface between cohesive and non-cohesive soils.

7.4.2 Granular soil

7.4.2.1 General

It should be noted that a granular, non-cohesive soil has little or no stand-up ability and only lies at its angle of repose.

NOTE Failure in granular soils can occur as:

- a) *slow or fast ravelling, when material begins to dry out or to loosen due to overstress;*
- b) *running in dry granular materials lacking cohesion;*
- c) *when a granular material becomes fluid, flowing as a viscous mixture.*

7.4.2.2 Sand and gravel

COMMENTARY ON 7.4.2.2

In sand and gravel there is no plasticity and little yielding under stress, but a small fall of loose material can quickly destroy any arching action which is carrying the load and result in sudden progressive collapse.

Support should be provided immediately in order to prevent initiation of movement. If water is present, restraint is of even greater importance, and further precautions against the washing-out of fine material, resulting in loosening of the whole, should be considered.

NOTE A closed-face machine with a pressurized heavy slurry, such as bentonite, does not only support the sand and gravel but also negate the effects of the groundwater by equalizing the hydrostatic head.

Potentially unstable open faces should be carefully boxed up or closed down, and all voids grouted, whenever routine excavation progress is interrupted.

7.4.3 Cohesive soil

7.4.3.1 General

In soils having some degree of cohesion and plasticity, ranging from silts to clays, the possibility failure occurring from the following reasons should be considered.

- a) Ravelling, where the ground dries out or is overstressed, but fractures rather than flows.
- b) Squeezing, where a clay is overstressed and slowly extrudes without visible fractures.
- c) Flowing, by vibration or liquefaction in moist or saturated silts, and by vibration in clays.

- d) Swelling, of clay absorbing water, possibly from the atmosphere, and increasing in volume.

NOTE Some fluvial and marine clays are particularly sensitive. Soft, sensitive clays sometimes appear safe but are in fact subject to loss of strength and progressive collapse (sensitivity relates to the rate of loss of strength on disturbance).

If sensitivity is suspected at any stage, then vane tests should be carried out.

7.4.3.2 Clay

COMMENTARY ON 7.4.3.2

In soft clays, and in stiff clays where discontinuities (i.e. slickensides or “greasy backs”) are present, it might be necessary to provide, as soon as practicable, support that restrains movement. The plastic characteristics of clays can result in a gradual development of ground disturbance. Immediate support keeps disturbance to a minimum. Changes of moisture content in clays due to exposure of the surface and load changes can, over a long period, result in swelling or shrinkage, with a consequent increase in the load on the supports.

In hand excavations where timber supports are used, these should be tightly wedged into position with a system of timber or steel struts.

NOTE 1 In open-faced shields, hydraulic struts might be used. These allow the shield to move forward while keeping a controlled support on the face by maintaining hydraulic pressure. In soft plastic clays, a closed-face machine might be appropriate.

NOTE 2 In a tunnel in clay, or any yielding ground, additional temporary support may be needed to seal the clay surface if a normal cycle of operations is interrupted.

All voids should be boxed up and grouted, or the face should be sealed with sprayed concrete.

7.4.3.3 Silt

The cohesion of silt can suddenly be lost due to changes in water content and the face should be fully supported unless cohesion can be relied upon. When a tunnel in silt is below the water table, compressed air, freezing, dewatering, a closed-face TBM or other stabilization measures should be used.

7.4.3.4 Chalk

COMMENTARY ON 7.4.3.4

Chalk is a fine-grained limestone. Its nature varies widely, depending on its mineral content and the degree of weathering. It can be soft, and therefore unstable when excavated, or it can be hard, requiring significant break-out effort. Soft chalk can be putty-like.

Fracturing, block size, permeability and the frequency of bedding joints are also variable. Chalk can be relatively homogeneous, or discontinuous and blocky. It can be a significant aquifer, containing open and water-bearing fissures, or it can be dense and of low permeability.

Care should be taken as these conditions can be encountered in varying combinations, affecting the safety of the excavation, the working conditions within the tunnel and the viability of the chosen methods of excavation and support.

NOTE 1 The presence, or otherwise, of flints within the chalk mass is of particular importance.

NOTE 2 Excavation, particularly mechanized excavation, can be adversely affected by the presence of flints, which can result in rapid and excessive wear of cutters.

7.4.3.5 Rock

COMMENTARY ON 7.4.3.5

After excavation or blasting in rock, there is normally an arching action across the tunnel in the newly exposed roof, with some support from the undisturbed rock ahead of the face. The value of this support depends greatly on the direction and slope of the planes of weakness in the immediate vicinity and the method of excavation.

The dip and strike of the bedding planes, the spacing and pattern of joints, and the presence of faults and any consequent fracturing and crushing should be taken into consideration when assessing the stability of the excavation, and in the design of the supports. In particular, the designer should consider the thickness of rock cover beneath superficial deposits as it might be appropriate to increase the depth of the tunnel.

NOTE 1 The arching action is accompanied by redistribution of stresses. There can be movement of blocks of rock and ingress of water acting as a lubricant. Continued redistribution of the stresses can result in rock falls and repetition of the process at higher levels. This can lead to the formation of a void above the tunnel profile.

NOTE 2 Slabs of rock present in the crown can fail in bending.

Rock tunnels that break with a square crown should always be treated with caution. The risk of breaking into faults, fissures or cavities should be recognized and assessed.

NOTE 3 Faults can contain water or gas under high pressure. At faults, changes in the strata can be encountered and there might be zones of extensive fracture, often with slickensides and fissures filled with gouge or pug.

NOTE 4 In fault and shear zones, rock can be altered so much as to acquire the characteristics of soil. This alteration, when combined with the presence of groundwater and higher cover or in-situ stresses, results in some of the most difficult tunnelling conditions found. In such fault zones, full-face excavation might be possible if pre-drainage, pre-grouting and forepoling are employed.

Advance exploration (e.g. forward probing or drilling), followed by grouting or other special precautions should be considered, particularly in sub-aqueous tunnelling.

7.4.4 Made ground and contaminated ground

COMMENTARY ON 7.4.4

Made ground, often encountered in shaft sinking and shallow depth tunnels, might be unstable, non-homogeneous and require full support.

The investigation and information-gathering process (see Clause 5) should establish the nature of the ground and, in particular, the presence of hydrocarbons, solvents, bacteria, gases and contaminants.

In contaminated soils the use of a slurry TBM should be considered as it can mitigate problems of exposure to contaminants in the TBM.

7.5 Indicative methods of tunnelling

A risk assessment as outlined in 4.1.2 should be carried out to determine the methods of tunnel excavation technique and ground support to be considered.

NOTE The initial support might be the first stage in the ground-support system or, as in some uses of sprayed concrete, the only functional lining of the completed tunnel.

7.6 Methods of excavation and spoil removal

7.6.1 General

Tunnels are usually driven using mechanical excavation and lining techniques. However, it should be noted that hand excavation, because of its adaptability in confined spaces, is still an essential part of the overall tunnelling process and is used typically for short tunnel drives (see 7.6.3) in appropriate ground conditions, break-outs from shafts, short connections and back drives, cutter maintenance chambers and enlargements. Hand excavation should only be used when it is not possible to allow the safe use of mechanical excavation plant.

7.6.2 Mechanized tunnelling, including machines for pipe jacking and microtunnelling

The safety of the machinery should be considered an essential aspect of overall tunnelling safety.

Machinery used should conform to relevant tunnelling machinery standards: BS EN 815, BS EN 12110, BS EN 12111 and BS EN 12336.

All machinery should be operated strictly in accordance with the manufacturer's instructions.

NOTE 1 BS EN 12336 and BS EN 815 are currently being combined into a single standard.

NOTE 2 The terminology and machine classification system used in these standards sometimes varies from that commonly used in the UK.

7.6.3 Conventional tunnelling

COMMENTARY ON 7.6.3

A variety of mechanical excavation and loading equipment is used in conventional tunnelling. Conventional tunnelling in soil or rock sometimes needs separate equipment for excavating and loading away the spoil.

The system of work should ensure that persons are kept clear of moving plant and equipment, which is usually self-propelled. Therefore, the additional risks from moving plant should be assessed and controlled. Conveyors should be considered for the transport of spoil as they significantly reduce the number of vehicle movements.

NOTE 1 For guidance on the installation and use of conveyors, see 23.5.

Power is often routed to excavation and loading equipment by means of hoses or electric cables, which should be kept clear of moving plant, and should be prevented from being subjected to excessive tension. Safety chains should be fitted to hoses and cables at the point of entry to the machine, and retention devices should be provided at hose and cable connections.

NOTE 2 Attention is drawn to the recommendations for lighting given in Clause 17.

7.6.4 Hand excavation

Before considering hand excavation, reference should be made to the PJA/BTS/HSE document "Tunnelling and Pipejacking – Guidance for Designers" [18].

NOTE Hand excavation uses either conventional picks and shovels or air-powered picks, breakers and clay spades. The main hazards of this type of work include confined space, noise, hand-arm vibration, manual handling, working at height and heat.

Short shifts and/or frequent rotation of persons around different tasks should be considered, with a view to limit exposure to noise, vibration and manual handling risks. Adequate working space and, where necessary, proper working platforms should be provided (see 7.6.3).

As hand excavation should be limited to works where mechanical excavation is not reasonably practicable, it should be given at the design stage if mechanical excavation methods are viable.

7.7 Ground support for conventional tunnelling in soft ground

7.7.1 Construction risks

For larger tunnels in soft ground, major construction risks which should be considered include instability of the newly excavated ground, damage to new the lining and excessive ground movement. These can present a risk to personnel in the tunnel, buried utilities and subsurface or surface structures. Consideration should be given to the subdivision of the cross-section, e.g. by adopting a top-heading (crown), bench and invert construction sequence. The benefits of using a pilot tunnel to subdivide the face should also be considered (see 7.13).

In all cases the specified method and sequencing should be adhered to.

Where necessary, the stability of excavated surfaces should be enhanced by doming and by applying a coat of sprayed concrete.

NOTE The stability of the face can be further enhanced by the use of glass fibre dowels.

A comprehensive system to ensure that ground conditions, excavation and lining procedures, materials quality control and post-lining ground movements should be used to meet the designer's assumptions and requirements. Any deviations should trigger an immediate reassessment of procedures.

The extensive guidance, found in the HSE report "Safety of the New Austrian Tunnelling Method (NATM) Tunnels" [16] and the ICE "Sprayed Concrete Linings" [17] should be followed both by the designers and those constructing the tunnels.

The risk to persons in the tunnel from working under unsupported ground should also be minimized.

7.7.2 Initial support and profile control of SCL tunnels

As soon as possible after excavation, an initial coat of sprayed concrete should be applied to the excavated faces as a rapid means of temporary support, to stop deterioration of the ground surface, secure any loose material and minimize changes in the self-supporting characteristics of the ground. Remote means of controlling the excavation and sprayed concrete profile should be considered.

For initial support, fibre-reinforced sprayed concrete should preferably be applied by robotic sprayer. The installation of lattice girders and mesh in the crown of the tunnel should only be carried out after the application of an initial layer of sprayed concrete. Consideration should be given to the methods of profile control when using sidewall drift construction methods.

7.7.3 Water proofing

COMMENTARY ON 7.7.3

Often a waterproof membrane is required within the permanent lining. This can be either a sheet membrane or a spray-applied membrane.

Particular care should be taken to minimize the risk of fire from exposed sheet membrane and to minimize health risk from sprayed materials.

7.7.4 Sprayed concrete

7.7.4.1 General

COMMENTARY ON 7.7.4.1

The term “sprayed concrete” covers all pneumatically applied mixes of cement, water, additive and aggregate, including “shotcrete” and “gunite”, using wet or dry processes.

Additives including retarders, activators, accelerators, silica fume and other materials should be used to improve the properties of the concrete mix both during placing and in the medium and long term.

7.7.4.2 Precautions

Where reasonably practicable, sprayed concrete work should be carried out by wet-process spraying, using remotely operated spraying equipment, thus reducing the risk to the operator from exposure to dust and hazardous materials.

The minimization of dust emissions should be an integral part of the mix design process. Reference should also be made to Clause 16 for recommendations on the control of dust.

Where remote techniques cannot be used, operators should have full protective clothing and use respirators and eye protection. Any skin likely to be exposed to hazardous materials should be protected with a barrier cream. Full facilities for washing and clothes-changing should be provided. Other persons should work at a safe distance from the placing operations to reduce their exposure.

Flexible supply pipes for sprayed concrete should be wired or chained at joints to prevent them from flailing about if a joint bursts while they are in use.

NOTE The dry process can cause a build-up of electrostatic charge in the nozzle, resulting in an electrical discharge which could initiate an explosion in the presence of methane or other potentially explosive materials.

The dry process should not be used when tunnelling through coal measures.

7.7.4.3 Sprayed concrete lining (SCL)

When installing sprayed concrete linings, particular care should be taken to adhere to the specified methods (see also 7.2).

7.7.5 Contingency and emergency plans

Contingency and emergency plans should be in place so they can be implemented when necessary, along with sufficient supplies of the materials identified in the plan (see 4.2).

7.8 Tunnelling machines

7.8.1 Open-faced shields

7.8.1.1 General

COMMENTARY ON 7.8.1.1

An open-faced shield provides initial support and protection during excavation and lining erection or pipe installation. Its features include a cutting edge that can, in suitable ground, be used for trimming the periphery of the excavation, and a tail skin that provides protection within which the lining can be erected or a lead pipe fitted. In most conditions, it is useful to extend forward the cutting edge of the crown to form a hood.

Excavation should not take place beyond the area protected by the shield.

In some shattered rock conditions, or where there is a mixed face (e.g. of rock and soft ground), the rock should be excavated clear of the cutting edge. It might then be necessary to provide crown and shoulder support in the form of headboards or hydraulic poling plates that span between the shield cutting edge and the face timbering.

Before shoving the shield, excavation should be complete to the stage where excessive shield or pipe jack ram pressures are not required. Unless an expanded lining is to be used, ground movement should be minimized by grouting as soon as possible.

NOTE 1 In pipe jacking, the shield is designed to produce a small overbreak to the external diameter of the pipeline. Normally a lubricant such as bentonite is introduced into this overbreak to reduce friction and minimize ground movement.

All shields should have provision for face support, which might be needed continuously as tunnelling proceeds or kept for emergency use only. When face support is necessary, it should be normally held by hydraulic face jacks which maintain a given pressure on the face timbering and yield as the shield is jacked forward. When using segmental linings, the face support is likely to be infrequent. In this case, the support should be strutted back through the shield to the completed segmental lining, which allows the shield to be jacked forward without affecting the timbering.

NOTE 2 Other means of face support, such as breasting doors, sand trays or forepoling, might be adopted.

Cutter booms or backacters installed for excavation should be properly maintained. A set of sized and cut timbers should also be kept available for emergency use. When the shield is being jacked off segmental rings, the person designated as shield operator should check that nobody can become trapped between the rams and the lining.

On a large diameter shield, excavation should be carried out, and ground support provided, from properly constructed and guarded working platforms. Scaffolding is not sufficiently robust for this purpose, as the uprights are liable to be knocked away by falling debris. Where there is a hood on the shield, working platforms with a sliding facility should be provided in order to get the platforms close to the face.

NOTE 3 Working platforms can frequently be temporary, being installed only for the initial support and mucking part of the tunnelling cycle and then removed.

Responsibility for the design, safe installation and use of working platforms should be given to a designated person.

Where excavated material is normally removed from the face on a belt or chain conveyor running from the bottom of the shield, these machines should be fitted with appropriate guards and emergency stop facilities.

7.8.2 Tunnel boring machines (TBMs)

7.8.2.1 General

COMMENTARY ON 7.8.2.1

A TBM has a rotary wheel excavator capable of cutting the whole tunnel face at each revolution of the wheel. It can be shielded or unshielded. Excavated material is normally lifted onto a central conveyor by scoops attached to the cutting wheel. These machines are usually employed in ground where face support is not normally required, although some machines are fitted with hydraulically operated mechanical doors which can close down the face and provide support. Generally, TBMs are fitted within a shield, but see 7.6.4.4.

A safe system of work at the tunnel face, including provision for rescue, and for the inspection, maintenance and changing of cutters, should be put in place before work begins.

7.8.2.2 Slurry machines

COMMENTARY ON 7.8.2.2

Slurry machines are shielded TBMs with a fixed bulkhead separating the excavation chamber from the rest of the machine. Pressurized slurry pumped into the excavation chamber provides support to the excavated face and balances the groundwater pressure. Slurry and excavated material are pumped out and then piped to the surface for separation; the clean slurry is then pumped back to the face.

There should be appropriate means of clearing slurry and excavated material from the cutter-head chamber before man-entry.

NOTE On most machines, head access is through an airlock.

7.8.2.3 Earth-pressure balance machines (EPBs)

COMMENTARY ON 7.8.2.3

Earth-pressure balance machines are shielded TBMs with a closing bulkhead separating the excavation chamber from the rest of the machine. They have a balanced screw conveyor to remove excavated spoil, while maintaining a pressure in the remoulded soil within the excavation chamber sufficient to support the face throughout the excavation process. Some EPB machines are provided with an airlock for face access under pressure.

The plug of excavated material within the excavation chamber and/or the screw conveyor forms an impervious barrier to contain groundwater. Conditioning agents such as bentonite, polymers and foam can be injected at the cutter head to improve the efficiency of the machine and the effectiveness of groundwater and material control.

The hazardous nature, if any, of these chemicals should be assessed.

7.8.2.4 Hard-rock TBMs

COMMENTARY ON 7.8.2.4

Hard-rock TBMs are used for excavating rock of a range of strengths, abrasiveness, jointing and water. They can be fully or partially shielded.

The risk assessment should cover sudden changes in rock conditions and control measures should be devised. Provision should be made for probing ahead of the face to ascertain the presence of fissures, faults and other changes in the ground and ground water. Where cover is shallow or uncertain, probes should be made to a point above and ahead of the crown of the machine and should be plugged immediately.

Means of installing appropriate ground support should be immediately available close to the cutter head, e.g. rock bolting equipment.

NOTE Where required, a fully shielded hard-rock TBM can erect segmental linings. Some slurry machines can be used in certain hard rock conditions.

7.8.2.5 Segment-erection equipment

The segment and other lining erection equipment should conform to the requirements of BS EN 12336.

NOTE The area around the segment- and other lining-erection equipment is one of the most hazardous areas of a tunnelling machine where persons invariably have to work in restricted spaces, close to the structural elements being erected (see 8.3). The visibility of the operator can be restricted.

Site personnel on and immediately behind a machine should be given clear instruction and training on the safe system of work.

The tunnel lining should be erected using a purpose-designed full-circle erector where practicable. Where that is not practicable, the lining should be erected by other appropriate means, including:

- a roller path erector;
- a bird's-wing erector; or
- by hand, with mechanical assistance such as winches with snatch blocks and roller bolts.

Wire ropes, connection pins and other lifting devices used in lining erection should be inspected frequently as they are subject to heavy wear and damage. Figure-of-eight devices cause excessive rope damage and should not normally be used as rope terminations.

7.9 Conventional tunnelling in rock

7.9.1 Excavation techniques

7.9.1.1 Drill-and-blast

NOTE 1 Drill-and-blast methods are used for a variety of rock tunnels.

Blasting patterns should be designed to reduce the risk of damage to the excavated surface, which can loosen the rock. Where appropriate, consideration should be given to the use of smooth blasting or pre-splitting techniques. For preference, non-electric detonation systems should be used.

NOTE 2 Apart from the hazards associated with the storage, handling and use of explosives, which are comprehensively dealt with in BS 5607, the main hazards associated with drill-and-blast techniques include noise, vibration and dust from the use of drilling equipment, fumes from the explosives and falls of ground. The risk depends upon the characteristics of the rock and its structure, on the techniques adopted for drilling and blasting, and on the materials used.

The system of work should be reviewed and modified, if necessary, as experience in the prevailing ground conditions is gained.

Following blasting, and before re-entry, a check should be made to ensure that the tunnel atmosphere is fit for respiration (see also Clause 15).

The risk from rock falls is most acute in the period after the blast and before temporary support, if required, is completed. Following blasting or re-entry to the tunnel face, the walls, sides, face and support systems should be inspected before normal work commences. Where temporary support is required, this should be installed in a safe manner.

Scaling should be done by mechanical means where reasonably practicable. Scaling should be carried out systematically, working towards the face. Apart from checking the area of the ground that has just been fired, areas that have previously been scaled should be re-checked. Scaling should be carried out regularly and should be checked by a supervisor. The persons carrying out manual scaling should stand to one side of the area of rock being worked. Scaling bars of adequate length should be used and appropriate means of safe access provided.

If support is necessary, it should be provided as soon as practicable after scaling, so as to maintain the overall integrity of the rock mass and to prevent minor roof falls.

Air and hydraulic drills should be mounted on a frame or on an independent self-propelled machine base (drilling jumbo) wherever possible. Drill rigs should conform to BS EN 791.

NOTE 3 In larger faces, several drills can be mounted on the same machine base and operated independently.

The use of air drills and pusher legs should be minimized because of the health hazards associated with their use.

Flying rock can easily damage tunnel machinery or services. Vulnerable plant and equipment should be checked for damage before use.

It should be noted that noise and vibration arise from the use of rotary percussive tools, and exposure levels in tunnelling are normally high.

NOTE 4 See Clause 19 for further guidance on noise and vibration.

7.9.1.2 Roadheaders and other part face machines

NOTE Where rock strengths or joint patterns permit, roadheaders, or other part-face machines, can be used for excavation.

The precautions in 7.9.1.1 should be observed equally to the use of roadheaders etc.

7.9.2 Steel arches and packing

7.9.2.1 General

Where steel arch ribs, in conjunction with timber or steel poling, are used to provide immediate support, they should be fixed, wedged and packed up as soon as practicable after excavation. Arched support varies widely in size and geometry, and the type of arch and spacing should be designed for the actual ground conditions encountered.

The capability to install a number of predetermined support regimes for the expected range of rock mass classifications should be available on site. A supervisor who has the experience to assess changes in ground conditions, identify the appropriate support regime and the authority to implement it, should always be present on site.

Where necessary, scaling should be carried out before arches and frames are erected.

NOTE Recommendations related to scaling of rock surfaces are given in 7.8.

7.9.2.2 Two-part arches

An inverted U-shaped arch with one bolted joint at the crown is commonly used in tunnels up to 3.5 m high. The arch should be founded on rock capable of sustaining the transmitted load, or that footplates are provided. Support to resist non-vertical loads in the arches should also be provided. If horseshoe-shaped arches are used, the foot of the arch should be effectively restrained from movement.

Arches should be securely fixed to each other with ties and struts.

NOTE It might also be necessary to rock-bolt the arches or to fix steel dowel pins alongside the arch in order to stop movement during subsequent blasting.

The packing between arch and rock should be wedged tight, and the arches should be securely packed, particularly at springing level, to stop sideways movement at that point. All joints should be made in accordance with the design requirements. Arch rib supports adjacent to the face should be checked for movement after each round is fired. Arches used to support a top heading should be secured before lower excavation proceeds.

7.9.2.3 Large or multi-part arches and frames

All the recommendations listed in 7.9.2.2 for the correct setting of two-part arches apply, but in addition, the following recommendations should be followed.

- a) The erection procedure should be specified and should clearly provide for their safe handling and erection.
- b) The erection equipment (which can often be mounted on excavating or drilling machinery) should be properly designed for the particular situation.
- c) Access to the bolted joints and for packing should be from properly designed platforms, stagings or mechanical/hydraulic access equipment.

7.9.2.4 Steel lattice ribs

NOTE In tunnels with sprayed concrete support, supplementary support is often provided by steel lattice ribs embedded in the concrete around the complete tunnel circumference.

These ribs should be installed in sections corresponding to the excavation stages, with bolted joints at the bench surfaces.

7.9.2.5 Support between arches

Where necessary, support should be provided between arches to prevent falls of loose rock.

NOTE This support is normally in the form of mesh, timber, steel sheets or concrete panels spanning between the arches.

7.9.3 Rock bolting

COMMENTARY ON 7.9.3

Rock bolting, using either mechanically anchored or chemically anchored bolts, is a common method of providing temporary support or can be an element of the permanent support system. While rock bolts can be used merely to tie back loose slabs which would otherwise be liable to fall, their more fundamental use is in preventing separation across discontinuities such as joints, fissures and bedding planes so that the integrity of the exposed rock structure can be maintained.

The pattern and type of bolting, and the length and diameter of the bolts, should be determined after study of the particular circumstances, which can vary rapidly as tunnelling progresses.

NOTE 1 The safe installation and functioning of a rock bolting system depends on its suitability for the rock characteristics and the excavation and lining methods.

The anchorage should be of sufficient depth and should be designed to resist the full pull-out value of the bolt without slipping in the bore or crushing the rock locally. Load tests in situ should be carried out on representative bolts.

NOTE 2 Further guidance is available in BS 8081.

7.10 Compressed air

Compressed air (see Clause 11) should be applied to control ground water to improve the stability of the tunnel face, though additional face support might still be necessary.

NOTE Compressed air can reduce settlement caused by ground movement. Very significant reductions in the number of exposures can be achieved by the use of a closed-face TBM in preference to applying compressed air to the whole tunnel.

7.11 Geotechnical processes for ground improvement and water management

7.11.1 Freezing

7.11.1.1 General

COMMENTARY ON 7.11.1.1

Water-bearing ground can be strengthened and made impermeable if it can be frozen and kept frozen. Freezing can be a particularly effective technique in silts and in gravels with silty layers that are very difficult to treat by grouting. Freezing is often achieved by the circulation of a coolant at temperatures significantly below 0 °C in a system of coaxial pipes in boreholes in the ground. Freezing of groundwater takes place slowly compared to other forms of ground improvement and can be impossible if there is an underground flow of water which brings in heat at a rate faster than the freezing process can extract.

The development and maintenance of the freeze should be confirmed by thermocouples located in monitoring boreholes within the ground to be frozen. There is a residual risk that pockets of unfrozen ground remain, and contingency plans should be put in place to avoid this.

After installation, all boreholes should be surveyed throughout their length to confirm their exact position. Boreholes that are out of position should be redrilled.

It should be noted that ground heave can result from the expansion of water on freezing and from the build-up of ice layers. Care should be taken as this can be a hazard to overlying or buried structures and services.

NOTE 1 Water mains within the freezing zone might need to be insulated.

If a timber heading is driven through frozen ground, there is likely to be a build-up of ice on timber supports, therefore the utmost care should be taken in refilling the heading in order to prevent ice from being left to form a void and cause settlement.

NOTE 2 If the ice cannot be wholly thawed or removed, subsequent pressure grouting might be necessary through pipes left in and leading to the critical areas.

Where the ambient temperature is sufficiently low to lead to discomfort, personnel should be protected from the cold. Self-rescuers (see 14.10), appropriate for cold environments, should be provided.

7.11.1.2 Brine

Where the coolant is brine, tunnel excavation should not take place within 0.5 m of a live freeze pipe.

7.11.1.3 Liquid nitrogen

COMMENTARY ON 7.11.1.3

Freezing by liquid nitrogen is possible. Because nitrogen is so cold, it acts more quickly.

The risks from handling a cryogenic liquid and of leaks of liquid nitrogen evaporating in the tunnel should be assessed.

Liquid nitrogen should be stored on the surface. All surface pipework should be protected from impact damage. Where possible, the freeze pipes should be installed vertically in the ground to be frozen. Where the freeze pipes have to be aligned horizontally within the tunnel or shaft, the pipework in the tunnel or shaft should be tested for leak tightness before use. Liquid nitrogen should be supplied through boreholes from the surface, which are close to the point of distribution, into the freeze pipes, in preference to being piped through the tunnel.

Pipework should be sized to minimize the amount of liquid that could be discharged into the tunnel if a freeze pipe leaks or breaks. Appropriate flow control and flow-limiting devices should be installed.

Atmospheric monitoring equipment should be installed in the vicinity of the freeze, and of any freeze pipes in the tunnel, to detect leaks. Any cold gas that has leaked tends to collect in sumps, and the monitoring system should take account of this.

NOTE 1 Additional emergency ventilation might be necessary.

Exhaust nitrogen should be discharged through a chimney on the surface. The prevailing wind direction should be considered when siting the chimney. The chimney should be sited away from work areas and from site boundaries.

NOTE 2 Fans might be needed to dissipate the cold nitrogen from around the base of the chimney on calm days.

A risk assessment should be carried out before excavation is carried out in close proximity to a live freeze pipe.

Bulk storage of liquid nitrogen should be in a secure area protected from site traffic. Because of the large quantities of cryogenic liquid likely to be required, the risks both to the workforce and to the public from its transport to site and storage on site should be carefully assessed.

7.11.2 Ground injection

COMMENTARY ON 7.11.2

Cementitious or chemical ground treatment in advance of tunnelling can usefully enhance safety particularly in open-face excavation. It does this directly by improving the characteristics of the ground to be excavated and indirectly by sealing off water, or strengthening the overlying or surrounding ground.

The design of a suitable grouting system and pattern for particular circumstances is very specialized and expert advice should be sought.

It should be noted that if sand or gravel is expected in the tunnel face, particularly if it is water-bearing, its permeability can be greatly reduced by the injection of suitable grout mixtures, cohesive strength can be added, and if the tunnel is being driven under compressed air, the air requirements can be greatly reduced.

The choice of grout mixture and the spacing and pattern of injection holes should be determined largely by the grain size of each stratum (e.g. cement grout does not travel far or prove effective except in very coarse open gravel).

Progressively finer grouts of lower viscosity should be used in progressively finer soils. Most difficult of all are silts, which should normally be treated only by clauage.

NOTE 1 Clays cannot be treated by permeation grouting.

The permeability of the ground is rarely consistent and the possibility of meeting untreated pockets should never be ignored. Groundwater quality should be taken into account when designing the grout.

Where fissured rock is to be treated, it can be difficult to locate and treat all significant fissures, especially if some are filled with gouge or soft clay, therefore advanced ground treatment by grouting should be considered.

NOTE 2 This can be carried out from the surface, from a pilot tunnel or through the tunnel face during construction.

NOTE 3 When compressed air is being used in a tunnel it can result in the grout being blown aside during injection.

NOTE 4 Where excessive fine content in the ground prevents permeation grouting, or where by choice an alternative grouting method is required, jet grouting (the disaggregation of the ground using cement grouting) can be considered.

Control and mitigation measures should be taken to avoid excessive pressures that can cause ground movement and structural damage.

The toxic and environmental risks from chemical grouts should be assessed. In all cases, the chemical properties of the grout used should be taken into account and the risks arising from the handling of the materials during and after mixing, including risks from burst pipes and hoses, should be assessed.

Stringent precautions should be taken due to the toxicity of some grouts, including the provision of protective clothing and full washing facilities. Care should be taken, since grouting from within the confined space of the tunnel, particularly in a small pilot tunnel, can increase the risk of toxicity. Measures should also be taken to avoid pollution and damage at the surface from spillage and waste discharge.

Arrangements for collection and disposal of waste should be made in advance and should be approved by all relevant authorities. Similar arrangements should be made with authorities responsible for the prevention of pollution of underground water.

It should be noted that excavation in ground previously impregnated with cementitious or chemical grouts can release toxic gases or vapours.

7.11.3 Dewatering

COMMENTARY ON 7.11.3

For shallow tunnels in water-bearing sands and gravels, the ground can be stabilized by means of well-point dewatering. For deeper tunnels, greater drawdown of the water table can be achieved by using deep wells and submersible pumps.

The loss of fines from the ground should be prevented.

The main hazards which should be taken into account when installing and using these systems are settlement at the surface due to lowering of the water table, and failure of the dewatering system while the tunnel is being driven.

NOTE The latter causes the ground to revert to its former unstable condition and rapid and massive ground loss can follow.

The dewatering system should be set up with the best available equipment and plant, systems should be duplicated where possible, and surface pipework should be protected from accidental damage.

Settlement due to dewatering can affect third-party property and cause damage and injury, therefore consideration should be given to the following precautions.

- The use of a piezometer to monitor the groundwater level.
- The construction of recharge wells to maintain groundwater level adjacent to sensitive structures.
- The installation of cut-off walls to protect sensitive foundations.

7.11.4 Depressurization

It should be noted that there is a risk of instability in a conventional tunnel being driven in clay but close to an interface with granular material in which there is artesian pressure. The granular material should be depressurized.

NOTE Depressurization can be achieved by pumping from boreholes or by well pointing.

7.12 Small headings and small tunnels

7.12.1 General

For small headings and tunnels reference should be made to the PJA/BTS/HSE guidance for designers [18].

Because of the very confined space in small headings and tunnels, some hazards are intensified, and as such projects are often very limited in space, time and resources, systems designed for larger projects should not be applied. Those working under such conditions should become familiar with the hazards of this type of work, and a risk assessment should be carried out to establish appropriate methodology before work commences.

7.12.2 Hand-driven segmental lined tunnel without a shield

COMMENTARY ON 7.12.2

Occasionally tunnels or chambers are excavated and cast iron or precast concrete segments are built without the use of a shield. In general terms, the procedure for excavation of a full tunnel face in soft ground without use of a shield is to excavate from the top downwards, securing the top and face as soon as exposed. The face is taken out in steps or benches. In firmer ground it can be safe to take the face down vertically with little or no timbering.

Particular attention should be paid to any foreseeable health and safety risks whilst devising and implementing working procedures for excavating the tunnel and handling and erecting the segmental linings.

Before considering hand excavation, reference should be made to the PJA/BTS/HSE guidance for designers [18] and the guidance in that document should be followed.

7.12.3 Timber headings

Timber headings are generally temporary in character and should not be less than 1.2 m high by 1.0 m wide.

NOTE Timber headings are driven in order to explore the ground ahead of the main tunnel, or for operations such as pipe laying, or to provide access between two points. No permanent lining is required because the heading is either refilled or becomes part of the main tunnel. The risk of collapse or excessive settlement is greater with small timbered headings than with other forms of tunnel construction.

Only the highest standards of workmanship in initial timbering and subsequent back filling should be used.

The size of timber used should be appropriate for the type of ground and the size of the heading and be designed to support the surrounding ground. No timber less than 38 mm thick should be used for headboards. All timber should be checked for imperfections that could reduce strength. All materials required for the heading should be readily available as close as is practicable to the face.

Special care should be taken with laying track and maintaining clearances between the bogies and skips and the support timber.

7.12.4 Back filling

Small headings should be back filled with concrete and then be backgrouted.

7.12.5 Rescue and escape

In small headings and tunnels, persons cannot walk upright and can pass one another only with difficulty; as a result, it is normal practice for a single person to excavate the face, although a second should always be present.

As the public emergency services might not be prepared to enter small headings and tunnels, site-specific arrangements should exist for the rescue and escape of the face workers in the event of accident, injury, illness, collapse of the tunnel face, immobilization of a locomotive, derailment or fire.

7.12.6 Ventilation

COMMENTARY ON 7.12.6

Ventilation can be a particularly difficult problem as there is little or no natural circulation, and shallow tunnels through variable ground frequently pass through or near ground with organic content or with other contamination that could pollute the tunnel atmosphere.

A forced ventilation system should be used to limit the ingress of contaminants, and to supply fresh air to the face.

NOTE Low-volume, high-pressure ventilation systems with silencers at the point of discharge to control noise emissions can be appropriate owing to the lack of space.

7.13 Pilot tunnels

Pilot tunnels are built to provide detailed information on ground conditions, including groundwater regimes. They should also be used in advance of large conventional tunnels in soft ground where control of settlement is important (7.16). The lining of the pilot tunnel should be designed to facilitate its subsequent safe dismantling or excavation.

7.14 Pipe and box jacking

7.14.1 Pipe jacking

COMMENTARY ON 7.14.1

Pipe jacking is a system in which pipes or similar structures (see 8.3.4 and 8.3.5 for jacking boxes) are thrust through the ground and the material from the face is removed through the pipeline. The pipes are introduced at the jacking pit and cumulatively thrust forward by jacks.

NOTE 1 For information on pipe jacking, "An Introduction to Pipe Jacking and Microtunnelling Design" [19] and the "Guide to Best Practice for the Installation of Pipe Jacks and Microtunnels" [20] ought to be consulted.

The high jacking loads necessary to propel the pipe forward should be resisted by a properly designed and constructed abutment or thrust wall at the working pit. Hydraulic rams and any load-spreading rings, spacing blocks or packers should be carefully secured, with all loaded surfaces precisely aligned perpendicular to the thrust. As far as possible, persons should be protected from and withdrawn from the vicinity of highly stressed equipment during thrusting. Hydraulic pipes and, in particular, flexible hoses, should be properly protected from crushing and impact damage.

NOTE 2 The use of a lubricant injected through the pipes or structural walls on to the sliding surfaces helps to reduce jacking loads.

If lubricants are injected at high pressures, eye protection should be provided.

When jacking pipes through loose or water-bearing soils, a slurry machine or an earth-pressure balance machine should be used to contain the face safely. When jacking pipes into sensitive clays, the techniques adopted should take into account any displacement of the soil caused by entry of the pipes, and possible heave or settlement of the ground surface. Particular care should be taken when jacking pipes beneath railway tracks, rivers, canals, other water courses and sensitive structures.

All persons in the jacking pit should be provided with shelter or protection within the part-completed pipeline or elsewhere and instructed to seek shelter while pipes are lowered.

NOTE 2 Remotely controlled TBMs can be used to carry out the excavation without any persons entering the tunnel.

7.14.2 Box jacking

COMMENTARY ON 7.14.2

Box jacking is similar in basic principles to pipejacking. The major differences are the use large cross-section, thick-walled square or rectangular reinforced concrete box units rather than circular pipes, the often limited cover above the box and the relatively short length of the overall jacked structure. A typical box jack application would be the formation of an opening through a railway embankment for the passage of a new road. See the paper by Allenby and Ropkins on jacked box tunnelling [21].

Similar precautions to those for pipejacking should be taken when box jacking. As box jacks are often undertaken at shallow cover through existing infrastructure embankments, measures should be taken to control both vertical and horizontal ground movement around the advancing box so that movements of overlying or adjacent infrastructure are minimised and maintained within acceptable limits. Typically this should be achieved by the use of a compartmentalized shield at the face through which mechanical excavation can be undertaken.

Face stability should be maintained and ground loss should be controlled by using the shield tunnelling techniques described in 7.6.1. Where cover to the box is shallow, an anti-drag system should be used to minimize disturbance of the overlying ground and thus prevent possible disruption to any surface infrastructure. An anti-drag system, in combination with an appropriate lubricant such as bentonite, should normally be used both above and below the box to minimize ground movement induced by drag and to prevent possible disruption to surface infrastructure.

NOTE The anti-drag system reduces drag forces and jacking loads, while at the same time it assists in controlling the vertical alignment within acceptable tolerances.

Careful control of the jacking operation should be maintained to ensure the structure being jacked is not damaged by local overloading and that line and level are maintained.

In poor ground, the use of ground improvement techniques such as dewatering, grouting or ground freezing should be employed to facilitate tunnelling as in any open faced shield tunnelling operation.

When jacking through an embankment, it should be buttressed to prevent distress during the final stages of jacking, by constructing a temporary berm on the exit side of the embankment.

When the box has been jacked into its final position, the box/ground interface should be grouted to minimize settlement.

7.15 Soil conditioners and lubricants

COMMENTARY ON 7.15

Compounds such as bentonites, polymers and foams are increasingly being used to modify the ground in order to support the face in unstable ground conditions, to lower pipe jacking forces (see 7.14.1) and to improve spoil characteristics for transport from the face to the surface. These materials are collectively known as soil conditioners. Some of these materials are hazardous to health in their preparation and/or usage (see Table 3). Many of these materials present a hazard in their disposal.

The physical and the chemical properties of the soil/conditioner mixture should be analysed when determining the appropriate method of disposal, in order to minimize risks to the environment and to the public.

The risk assessment for the tunnelling process should take account of any health hazards resulting from the use of these compounds.

The manufacturers' safety data sheets, which give recommendations for handling and personal protective equipment, should be complied with.

Materials used as soil conditioners include those given in Table 3. This should not be regarded as a comprehensive list. New materials are continually being introduced and reference should be made to the manufacturer for information relating to their composition, associated hazards and safe use.

7.16 Settlement control – Mechanized tunnelling

In TBM-driven tunnels (see 7.6.4), the volume of spoil removed should be reconciled against the volumetric advance rate on a routine basis (23.5.2). The contractor should establish a system to monitor the full range of parameters which could give early warning that over-excavation is occurring. In addition a series of limits on these parameters should be established which, if exceeded, would cause tunnel excavation to cease until it was established that over-excavation was not occurring. Continuous monitoring of these parameters during excavation should be undertaken separately from TBM operation. The grout injection system should be included in this monitoring system.

NOTE 1 The application of compressed air or the maintenance of high face pressures can be beneficial in controlling ground movement at the face.

On open-faced shields (see 7.6.1 and 7.6.2) visual inspection of the overbreak should be undertaken.

NOTE 2 A face loss of around 0.5% can be achieved with careful control of but typically 1% face loss is allowed for in the design process.

NOTE 3 Reference ought to be made to the BTS report on closed-face working [22].

NOTE 4 See also the HSE report "The Risk to Third Parties from Bored Tunnelling in Soft Ground" [23].

Table 3 Soil conditioners

Material	Principal components	Typical use	Hazard
Bentonite	sodium, potassium, calcium montmorillonite	as a slurry in slurry shields and to modify the soil in EPB machines or as a ground support and lubricating medium round jacked pipes and in TBMs	respirable dust in dry state slippery when wet skin irritant
Polymers	artificial: polyacrylamides polyacrylates carboxymethyl cellulose Natural starch guar	additives to bentonite to modify viscosity, as lubricants	generally considered to be non-toxic, but safety data sheets should be consulted for specific hazards and relevant control measures slippery when wet
Foams and foaming agents	synthetic foams containing: synthetic detergents glycol ether foam fluorocarbon Protein foams containing: protein foaming agent glycol based foam booster	for modifying soils to improve handling characteristics	toxic, irritant safety data sheets should be consulted for hazards and control measures
Other materials	hexylene glycol	solvent used as foam	toxic irritant safety data sheets should be consulted
	ethylene glycol ether	solvent used as foam	toxic irritant safety data sheets should be consulted
	soda ash	increase pH for use in conditions	safety data sheets should be consulted for hazards and control measures
	lime	possible modifier to improve characteristics at disposal state	
	cement	dispersants, thinners in bentonite slurries	

7.17 Compensation grouting

NOTE Compensation grouting is where grout is injected into the strata overlying a tunnel to compensate for ground loss from tunnelling operations.

If use is made of compensation grouting and/or permeation grouting, the load effects of such grouting on the primary and secondary tunnel linings on the face stability and on adjacent structures and services should be considered during the design and construction of the tunnel.

Compensation grouting should not be undertaken within 3 m of the face or lining of the tunnel being built, unless specific provision has been made for such grouting. Allowance should also be made for normal deviation of the grout pipes from line and level when determining the extent of the exclusion zone.

Grouting should not create unwanted fracture planes in the ground.

7.18 Pipe arches and spiles

The use of pipe arches and spiles for settlement control or ground support should not lead to the formation of a plane of weakness in the ground above the tunnel.

8 Permanent support

8.1 General

COMMENTARY ON 8.1

The majority of tunnels require some form of permanent ground support. This can include temporary primary support followed by a permanent secondary lining, or a primary lining which itself permanently supports the ground. Some tunnels include a non-structural lining to improve the functional performance of the tunnel. Rock bolts, rock anchors and dowels might be incorporated as part of the permanent support system.

In designing the tunnel lining, matters taken into account should include the information available and the investigations, as described in Clause 5.

NOTE Alternative vertical and horizontal tunnel alignments might have to be considered and a number of methods of construction might be available.

The tunnel design should be based on a particular method that is deemed to be safe for the ground conditions; other methods may be used by the contractor, provided they are equally safe.

The support system specified should be designed for ground loadings and hydrostatic pressure and for external and internal special loading arising from such factors as adjacent foundations, piles, water pressures and traffic loads. It should be noted that temporary loading can arise from the transfer of shield jacking loads or the application of compressed air (see Clause 11).

Handling requirements should be considered as part of the design process, so that structural elements can be set in place without damage.

8.2 In-situ linings

8.2.1 Primary lining

Arch ribs with lagging, or other systems, may be employed as part of the permanent in-situ lining. If so, they should generally be built in, possibly with additional ribs or reinforcement, as appropriate. The building in of untreated softwood timber should be avoided (see 7.9).

NOTE In-situ primary linings generally take the form of sprayed concrete lining.

8.2.2 Secondary lining

In-situ secondary linings should either be placed behind formwork or sprayed on to the internal surface of the tunnel. Good practice in the production, placing and compaction of concrete should be adhered to as it increases its durability and reduces maintenance and the risks associated with such work.

Concrete should be specified, produced, transported and tested in accordance with BS 5328-1, BS 5328-2, BS 5328-3 and BS 5328-4.