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

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 162, an inside back cover and a back cover.

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This British Standard supersedes BS 6164:2001, which is withdrawn.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/m^2 = 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 a 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 within cutterhead	Harness and fixed anchor points on TBMs	
Falling on the level	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**
	Shotcrete falling	Restrict access for personnel	
Materials falling from stacks or vehicles	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: *Acute:* Limb joint pains, skin rashes, itching, mottling, numbness, tingling, weakness, paralysis, visual disturbance, unconsciousness, convulsions. *Chronic:* 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/businesss/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 claquage.

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: polyacylamides 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 cement	possible modifier to improve characteristics at disposal state	
	lignosulfonates complex phosphates	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 increase its durability and reduce 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.

Formwork should be usually constructed so that it can be moved along the tunnel and reused. Its strength and rigidity should be adequate for loads imposed both by the wet concrete and by handling procedures as inadequate formwork can lead to difficulties in constructing in-situ concrete linings and result in unplanned and inherently dangerous situations, and a poor quality of lining. Formwork erected by hand should be made as light and as easy to handle as possible.

NOTE The equipment employed for depositing concrete behind formwork can include a concrete pump.

The discharge nozzle should be properly secured and guarded, and any joints in the supply pipes should be secured to prevent the pipes from flailing about if a joint bursts during concreting.

With sprayed concrete, the hazardous area is more extensive, since no formwork is provided. To reduce exposure to hazardous materials, remote spraying techniques should be considered (see **7.10**).

8.3 Prefabricated linings

8.3.1 General

*COMMENTARY ON **8.3.1***

Prefabricated linings are most commonly used for circular tunnels and are sometimes used for oval or other cross-sections.

This type of lining can be considered under three general categories.

a) Bolted or other structurally rigid systems that are self-supporting and outside which grout or other material has to be injected to complete the support system.

b) Expanded systems that are forced against the ground by circumferential thrust thereby applying immediate support to the ground. This can be erected with or without bolts.

*c) Jacking pipes (see **8.3.4**).*

8.3.2 Segments

*COMMENTARY ON **8.3.2***

Segmental linings consist of a number of units (segments) which make up a "ring". These units are usually of cast iron or precast concrete, but steel or other materials can be used.

The segmental nature of units means that ordinary equipment should be adapted and special devices for their safe and efficient handling and erection should be provided. Segments should be provided with sufficient holes or attachments to allow for safe handling at all stages. Quick-release attachments, such as segment lifting "fingers", should be employed only where their design prevents the accidental displacement of the load.

NOTE 1 Pneumatic (vacuum) lifting could be considered as an alternative that saves the need to providing holes and concentrated loading points.

The lifting, transportation, handling, storage and erection of the units should be considered as part of the segment design process. Improvised and poorly maintained equipment should not be used for handling segments.

When considering ring length, the designer should be aware that the width available between the uprights of the gantry frames through which segments can pass, is limited by the need to provide access along the outside of the gantry complying with the requirements of BS EN 12336.

NOTE 2 Similar considerations regarding access apply to the length of segments when in the segment magazine area.

Segments should be stacked, preferably on level ground, so that they are stable, and not likely to be damaged and individual segments are prevented from toppling. Segment stacks on the surface should be arranged so as not to impose additional loading on tunnel excavations or overload the ground on which they rest. Stacks of segments should be designed, located and constructed to facilitate safe handling and to ensure that no excessive and unacceptable loads are imparted into individual segments within a stack which might deform or crack individual units.

8.3.3 Transportation and erection

A safe system of work should be employed for the transfer of segments from surface storage to the point of erection.

NOTE 1 Within the tunnel, segments are normally transported on a bogie.

A positive means of attachment or a specially shaped bogie should be provided so that loads cannot shift during transit. The segments should not be subjected to abnormal loads during transport or erection that could be detrimental to their design strength as part of the permanent lining.

Segment transfer and erection systems should be provided wherever practicable, but the handling arrangements at the face can involve some manual handling, at least in guiding the units into position. There are various types of segment erector, which are normally mounted on the shield (see **7.6.6**).

NOTE 2 In a small-diameter tunnel, where segments could need manual handling, pipe jacking might be considered.

In all cases, the procedure for the handling and erection of segments should be carefully planned and erection personnel should be properly trained to keep clear of danger points, and others should be kept away from the working area. Manual handling aids should be provided for all lifts over 25 kg.

The designated operator of an erector or erection winch should be situated where there is a clear view of the whole operation.

NOTE 3 The erector operator might be provided with alternative control points for the remote control of the erector. If a clear view is not obtainable, the use of CCTV might be necessary.

Shove ram thrust (nip) should not be relied upon as the sole means of supporting segments. All segments which could fall out should be positively supported using bolts or building bars.

Where manual assistance is necessary, erection gantries should be constructed to provide a safe place of work and means of access.

Lining erection is a hazardous operation. The requirements of BS EN 12336 should be applied.

8.3.4 Jacking pipes and boxes

8.3.4.1 Jacking pipes

Concrete jacking pipes should conform to BS 5911-120 as a minimum, but should be designed to meet more onerous requirements for superimposed loads where necessary. Standard pipes should be designed to enable the jacking forces to be transmitted along the pipeline without damaging the joints. The joints should be designed to produce the flexibility necessary for installing the pipeline and for accommodating any future ground movement. The joint should also provide a high degree of watertightness.

NOTE 1 Any minor leaks may be sealed by caulking or other approved methods. Pipes conforming to BS 5911-120 are produced in a range of lengths, diameters and joint profiles.

NOTE 2 Square and rectangular precast concrete units for jacking are normally purpose-made.

Design loads should include those arising from handling and placing the units. Lifting points should be provided.

8.3.4.2 Jacking boxes

Concrete jacking boxes should conform to BS EN 1992 as a minimum, but should be designed to meet more onerous requirements for superimposed loads where necessary. Boxes should be designed to enable the jacking forces to be transmitted along the line of the box and through interjack stations, if used, without causing distress or damaging the joints. If interjack stations are used, they should be designed and positioned to produce the flexibility necessary for installing the complete box and for accommodating any future ground movement.

NOTE Match casting is an effective means of ensuring compatibility between adjacent joint surfaces.

The joint should also provide a high degree of watertightness. Any minor leaks should be sealed by caulking or other similar methods.

Design loads should include those arising from handling and placing the units. Lifting points should be provided.

8.3.5 Grouting behind the lining

Bolted linings should be supported in order to ensure structural integrity. The lining and the ground should also be in full and uniform contact. In cases where the ground is liable to move quickly, and the avoidance of settlement is important, grout should be injected as soon as practicable under sufficient pressure to fill all voids.

NOTE 1 On some TBMs, grout can be injected through pipes set into the tailskin, thereby enabling instantaneous void filling as the machine advances.

The injection pressure should be decided by an experienced engineer after consideration of:

- the depth of overburden;
- the presence of underground structures or services.

NOTE 2 Leaks can occur when grout is freshly mixed and under pressure, especially at the point of injection.

The injection nozzle should be positively attached to the lining by a threaded connection or an expanding rubber sleeve.

NOTE 3 Under certain conditions, two-stage void filling can be effective, pea gravel being injected as the shield is shoved, in order to provide immediate support, and the voids in the gravel later being injected with cement or similar grout when convenient.

NOTE 4 Most grouting mixtures contain hazardous materials, which can affect the skin and eyes. Some grouting mixtures present a hazard to the environment.

Substitution of less hazardous materials should be considered from the outset.

Persons should be trained and provided with protective clothing to wear as well as eye and, when necessary, respiratory protection.

8.4 Construction of openings

Where an opening leading out of a tunnel is required, and this opening is greater than half the diameter of the main tunnel, the complete tunnel should preferably be constructed first and the opening formed subsequently (see **20.5**).

In mechanized tunnelling, the tunnel designer should facilitate the formation of openings by specifying opening sets or soft keys.

Temporary support, adequate to carry the whole of the estimated load (including the load in rings forming the jambs to the opening), should first be designed and fixed in place. Extensive experience of this type of work should be considered necessary, both for its design and for its execution. Complete and even contact should be made between the temporary members and the permanent work. All struts should be tightened securely with hardwood or steel wedges and packings.

8.5 Monitoring of loads and deformation

8.5.1 General

Throughout the construction stage of a tunnel or during maintenance, renovation or repair, and in situations where movement or settlement is particularly sensitive, frequent inspection of the finished lining should be carried out by an engineer familiar with the type of work. Completed linings should be checked for any settlement and change of shape. Cracks should be kept under observation, their details recorded and the cause of the cracking determined.

NOTE 1 Monitoring of ground movement around the tunnel, load build-up on the lining and changes in groundwater levels can help in the early identification of problems.

Leakage of water or fine soil should be recorded, and loose bolts and grout plugs and empty grout holes marked and noted.

NOTE 2 Settlement at the surface and near the foundations of adjacent structures or buildings can seriously affect their safety, and possibly the safety of the tunnel.

Where new tunnels or foundations are being constructed close to existing tunnels or other underground structures, the existing structures should be regularly inspected and monitored for any movement within the zone of influence.

NOTE 3 Some settlement above tunnel excavation is almost inevitable where the tunnel is in soft ground and at limited depth, but can usually be reduced by special methods and techniques. Differential settlement between different parts of the same structure or building can cause structural damage.

Routine checks of any structures affected should comprise photographs, inspection and recording of cracks and defects before, during and after tunnelling, with accurate surveying based on reference points outside any zone of movement.

NOTE 4 In special cases where structures are particularly sensitive to settlement, more elaborate monitoring might be necessary, using inclinometers and strain gauges within boreholes or piles to detect and measure ground movement surrounding the structure. Where compensation grouting is being used, it might be necessary to monitor the tunnel to ascertain whether the grouting has imposed additional load on it or movements to it.

8.5.2 Inclined shafts and escalator shafts

NOTE Due to the steep angle used on escalator drives, they are invariably classified as shafts rather than adits. Excavation, ground-support, and transport systems, however, all tend to follow tunnelling practice.

To minimize the dangers presented by the steep gradient, special attention should be given to preventing unintentional movement of plant and equipment on the sloping invert.

Where possible, excavation should be carried out from a horizontal platform.

The design of the face support system and access stages should be given particular care to check that the correct transfer of face loads takes place. Detailed method statements, and thorough personnel training, should be provided at the commencement of the shaft.

Shafts should be driven downhill wherever possible. If, at the beginning of the construction stage, the shaft has to be raised uphill, a pilot should ideally be driven before enlarging from above using the pilot for the transport system. Uphill drives should be planned in such a way as to minimize the risk from overhanging ground falling away. Transport systems on uphill drives should be limited to overhead (monorail) types, which can be rope, rack or friction operated. Very careful advancing techniques should be used, as the safety features need to pace with the moving face as the shaft is constructed.

Personnel access should be by stairs or walkways with gripper battens.

9 Management of groundwater

9.1 Control of groundwater

9.1.1 General

The presence of water should be analysed in the construction and maintenance of tunnels. In all routine provisions for handling water, the contingency of inundation should be taken into account. Stabilizing an inundation is a very specialized procedure and expert advice should be sought. (For further details of the hazards of inundation and the precautions that should be taken, see Clause **10**.)

NOTE 1 Groundwater inflow can lead to the wash-out of any fine-grained loose material, thereby altering the strength characteristics of the ground and so influencing the stability of the excavation. Where a significant volume of water is present (as in saturated ground, sub-aqueous tunnelling, or where artesian water is encountered), any flow can destabilize the tunnel through loss of shear strength, piping or the creation of voids within the ground. Ground loss can lead to significant surface and subsurface settlement, with consequential damage to buildings, structures and underground utilities.

NOTE 2 In rock, water can sometimes scour out fissures and fractured ground, resulting in increased water inflow. Water following along behind the shaft or tunnel lining can also create a hazard by scouring out cavities.

NOTE 3 Build-up of water pressure can cause deformation in lined tunnels. This can be a particular problem in brick-lined tunnels.

During excavation, water in the ground surrounding a shaft or tunnel should be managed in one or more of the following ways.

a) By dewatering the ground externally around the shaft or tunnel.

b) By dewatering the ground internally ahead of the shaft or advancing tunnel face.

c) By excluding it using ground treatment, compressed air or by use of a closed-face tunnelling machine and sealed lining.

d) By allowing it to flow in under control.

Measures should be taken to prevent the presence of water in a shaft or tunnel from creating unsafe working conditions, and also to prevent changes of the phreatic regime from causing problems elsewhere.

*NOTE 4 Methods of managing water are described in **9.1.2, 9.1.3, 9.1.4, 9.1.5, 9.1.6, 9.1.7** and **9.1.8**.*

9.1.2 External dewatering

*COMMENTARY ON **9.1.2***

The water table can be lowered by the drainage of water external to the shaft or tunnel. This can be achieved by deep wells, well-pointing from the surface or by drainage sumps in a shaft or pit, possibly combined with drainage headings. A piled cut-off, toed into an impermeable layer can be constructed if there is a well-defined local source of water.

The system should be designed to avoid uplift of any shaft base or tunnel. The consequences of settlement, loss of fines and depletion of any aquifer should also be considered.

9.1.3 Impermeable cover

Where an open-faced tunnel is separated from water-bearing ground by an apparently impermeable stratum, the thickness and competence of this stratum around the excavation should be proved. This can be achieved by probing ahead, supplemented by other techniques as appropriate. Suitable precautions should be taken to control possible inflow if there is any likelihood of breaching the impermeable stratum. Probe holes should be securely sealed.

9.1.4 Ground freezing

Groundwater should be excluded by freezing.

*NOTE Details of this specialized process are given in **7.13.1**.*

9.1.5 Ground treatment

Groundwater should be controlled by reducing the permeability of the ground using a ground improvement technique.

9.1.6 Slurry and earth-pressure balance machines

In slurry or earth-pressure balance machines (see **7.6**), water should be excluded from the tunnel by a pressure bulkhead.

9.1.7 Compressed air

Water should be controlled by use of compressed air (see Clause **11** for details).

9.1.8 Controlled inflow

*COMMENTARY ON **9.1.8***

Where the flow of water is small, it might be preferable to control the inflow rather than to exclude it. In an open-face tunnel, a sub-drain below invert level can be used to draw down the level of the water table. Water flows might be accepted and piped through any lining so that pressure is not allowed to build up. Ultimately, such piped flows can be sealed up and backgrouted, or they can be accepted as permanent water inflow, according to circumstances.

Before sealing inflows, consideration should be given to the water flow paths and the need for backgrouting. Backgrouting should be engineered for the specific location and should take account of the resulting applied grouting pressures and the development of strength of the lining.

9.2 Handling of groundwater

9.2.1 Tunnel gradient

Under wet conditions a tunnel should be driven on an ascending gradient because all water flows back from the face. Unless the tunnel is dry or drains satisfactorily by gravity back to the portal, a system of sumps and pumps should be installed.

9.2.2 Sumps

Invert sumps are liable to be submerged and constitute a hazard to persons walking along the tunnel, therefore they should be either securely covered, or signed and barriered. If they are covered, the cover, which should be hinged, should normally be kept closed and should provide a secure foothold without substantial gaps. The cover should be fixed so that it cannot float up when submerged.

9.2.3 Pumping capacity

In all shafts and tunnels where there is a risk of flooding, there should be adequate pumping capacity to meet abnormal conditions. All tunnels on a downgrade are at risk of flooding, and adequate standby pumps for emergency use should be available. Pumps sited near the face should be submersible so that access to the face can be recovered after flooding.

NOTE Float switches operating audible and/or visual alarms can be fitted in sumps to give warning of pump failure.

9.2.4 Subdrains

If subdrains beneath the tunnel invert are used to interconnect sumps or assist in lowering groundwater, they should be grouted up solid when no longer required, unless there is good reason to the contrary.

9.2.5 Handling water under compressed air

*COMMENTARY ON **9.2.5***

When work is being carried out under compressed air, water at the face can usually be cleared by a "snorer" or air lift, using the air pressure to discharge the water and slurry through a pipe leading out to free air.

9.2.6 Watertightness of lining

In determining the methods to be used to establish water-tightness of the completed shaft or tunnel, the nature of the ground, the water pressure, the methods of construction, chemical reactions and movements due to stresses or temperature should be considered.

Water entering the tunnel through a segmental lining should be eliminated by hydrophilic or elastomeric gaskets fitted to the segments before installation; other measures include:

- annulus grouting;
- fixing of water tight grout plugs;
- grummeting of bolts;
- caulking of joints;
- repair of cracked segments.

If hydrophilic gaskets are to be used, the groundwater should be tested for salinity, which can affect the seal's performance.

In the case of in-situ or sprayed concrete linings, pipes should be embedded to allow passage of water through the lining during concreting. Thereafter, inflows and cavities behind the lining should be sealed by grouting, through the embedded pipes and via holes drilled through the concrete.

NOTE The use of an impermeable membrane can assist in the control of water.

10 Inundation

10.1 General

*COMMENTARY ON **10.1***

*This subclause gives guidance on means that can be used to manage the risk of inundation by large volumes of water, often at high pressure. The management of water under general conditions in shafts and tunnels is described in Clause **9**, and in compressed-air working in **11.6**.*

The risks associated with inundation should be evaluated at all stages of planning.

NOTE 1 These stages include the initial investigations, the design process, the development and implementation of methods of work and the preparation of contingency plans.

In all cases where there is a risk of inundation, planned means of escape should be prepared, along with measures to secure the tunnel.

NOTE 2 In the event of an inundation, there is a serious risk of persons being trapped by the water. If the tunnel rises from a flooded shaft, persons could be cut off and unable to escape. If the tunnel descends from the shaft towards the face, the water will accumulate there.

Walkways should be built at as high a level as space permits.

10.2 Inundation at the tunnel face

10.2.1 Identification of risk

NOTE 1 In an open-face tunnel driven below bodies of water or below the water table, there is a risk of inundation arising from, or accompanied by, loss of ground at the face. Inundation can also be initiated by breaking into faults, fissures, buried channels, abandoned mine workings or other geological features that connect to underground water sources. Breaking into man-made structures such as wells or culverts can also result in inundation.

The presence of such features should be determined by careful geological and geophysical studies and systematic exploratory borings.

*NOTE 2 See Clause **5** and the "Site Investigation in Construction" document [9].*

Borehole surveys alone are not always sufficient to confirm the location of localized features such as buried channels. Where such features are likely to occur, additional measures such as advance probing during tunnel construction should be taken.

Any inadequately sealed boreholes can constitute a hazard. These might have been part of a site investigation for works other than the tunnel. They should always have been fully sealed after use, but research should be carried out to determine their likely presence so that they can inform the risk assessment.

In the event of a sudden inundation it is unlikely that measures can be taken in time to stem the flow of water, and contingency plans should be in place to address this possibility.

If there is a possibility that water flowing back through the tunnel could flood surrounding land or endanger third party assets, precautions should be taken to prevent this from happening.

10.2.2 Precautions

Where the risk of inundation is identified in soft ground, a closed face machine should be used. This should also be used in hard rock.

The guidance and recommendations for ground support given in **7.2** should also be followed closely in subaqueous work. Water inflow (see Clause **9**) should be managed to prevent it from developing into an inflow of water and ground.

NOTE If an inflow of ground occurs, a mass of material can accumulate and form a plug that can be unstable and give way without warning.

When there is a risk of inrush of saturated ground, sand tables should be fitted to tunnelling shields as a precaution (see **7.6.1**).

During subaqueous tunnelling, where cover beneath a body of water is found to be inadequate, a layer of clay or other impermeable material should be deposited across the line of the tunnel as a precautionary measure. The objective should be to form a cohesive impermeable blanket between the water and the tunnel.

If tunnelling is at or near sea level, tide tables should be studied and, if possible, warnings arranged from port and harbour authorities. Tide gauges should be installed and used in appropriate circumstances.

River levels should also be monitored. The relationship of water levels at the tunnel site to the river levels and flood records should be studied in advance. Arrangements should be made to obtain any flood warnings from the relevant authority, e.g. the Environment Agency (for England and Wales), or from any organizations or local sources, such as power stations or factories which themselves monitor river levels.

Where rainfall, snowfall, or melting snow is a significant factor in flood risk, meteorological forecasts should also be regularly obtained and studied.

10.2.3 Shaft protection

The shaft should be properly lined and all openings at the top of the shaft, and other openings to the tunnel, should be situated above the highest foreseeable flood water level. In addition, any surrounding protective banks should be constructed and maintained at a safe level and should be protected against erosion.

When openings into the shaft below the highest foreseeable floodwater level are essential, the planning of any such openings should include the provision of appropriate materials and equipment and the provision of instructions to personnel about closing the openings at times of risk. Such protective works should be built at an early stage of shaft construction and be maintained for as long as the risk remains (see also **20.6**).

Watertight bulkheads should be installed where the driving of more than one tunnel takes place from a shaft. However, their installation could give rise to a risk of entrapment in the isolated sections, and strict procedures should be adopted to prevent this occurrence.

10.2.4 Precautions when flooding threatens

Shafts and tunnel workings should be provided with a communication system to make flood warnings effective. Immediate action if the shaft is threatened with flooding should include:

a) withdrawal of all persons from below ground, if necessary;

b) closure of all working openings situated below possible flood level, after all persons have been withdrawn;

c) arrangements for continuous monitoring of water levels, with inspection of any points of risk;

d) strengthening of any vulnerable points, using sandbag protection where appropriate;

e) preparation and putting into use of, as appropriate, emergency pumps, or any other standby plant;

f) preparation of isolation of the electrical supply to the threatened workings.

10.3 Remedial action

The cause of inundation should be established and steps should be taken to prevent further inundation before re-entry to the tunnel is considered. Re-entry procedures should include:

- ensuring the tunnel is structurally stable;
- that the atmosphere is fit for respiration and free from potentially explosive gases;
- ensuring that plant and electrical equipment are safe;
- as early as practicable, all strutting, timbering and supports in the tunnel, together with walkways, stairways and gantries. These should be inspected and made safe.

After submergence, all machinery and plant should be carefully inspected and reconditioned. Electrical cables and equipment, in particular, require special care in drying out, and should be tested prior to use. If the danger of flooding is persistent, compressed air should be used, instead of electricity, for power in the tunnel.

Clay, preferably plastic but firm, should be deposited by grab rather than dumped as a large mass from a hopper, which might dangerously disturb existing ground. Sufficient time should be allowed for the deposited blanket to consolidate before tunnelling commences beneath it.

NOTE 1 This is also a possible remedial measure in the event of a breach.

NOTE 2 There could be an added advantage in such a blanket providing loading that allows higher air pressure to be utilized safely.

10.4 Flooding of the tunnel from a shaft or adjoining tunnel

10.4.1 Identification of flood risk

The risk that a tunnel will be flooded from an access shaft, other passage or adjoining tunnel should be considered in advance.

NOTE Possible sources of floodwater include river floods, high tides or burst water mains overtopping or undermining any protective works.

The risk of flooding should be considered as part of the design and planning of the project. In this case there is no immediate risk of the tunnel face collapsing, although flood water entering from a shaft could cause serious damage to a TBM and ultimately the collapse of an inadequately supported face.

Periods of high flood risk should be identified and sources of risk monitored, particularly during those periods.

If tunnelling is at or near sea level, tide tables should be studied and, if possible, warnings arranged from port and harbour authorities. Tide gauges should be installed and used in appropriate circumstances.

River levels should also be monitored. The relationship of water levels at the tunnel site to the river levels and flood records should be studied in advance. Arrangements should be made to obtain any flood warnings from the relevant authority, e.g. the Environment Agency (for England and Wales), or from any organizations or local sources, such as power stations or factories which themselves monitor river levels.

Where rainfall, snowfall, or melting snow is a significant factor in flood risk, meteorological forecasts should also be regularly obtained and studied.

10.4.2 Shaft protection

The shaft should be properly lined and all openings at the top of the shaft, and other openings to the tunnel, should be situated above the highest foreseeable flood water level. In addition, any surrounding protective banks should be constructed and maintained at a safe level and should be protected against erosion.

When openings into the shaft below the highest foreseeable floodwater level are essential, the planning of any such openings should include the provision of appropriate materials and equipment and the provision of instructions to personnel about closing the openings at times of risk. Such protective works should be built at an early stage of shaft construction and be maintained for as long as the risk remains (see also **20.6**).

Consideration should be given to the installation of watertight bulkheads where the driving of more than one tunnel takes place from a shaft. However, their installation could give rise to a risk of entrapment in the isolated sections, and strict procedures should be adopted to prevent this occurrence.

10.4.3 Precautions when flooding threatens

Shafts and tunnel workings should be provided with a communication system to make flood warnings effective. Immediate action if the shaft is threatened with flooding should include:

a) withdrawal of all persons from below ground, if necessary;

b) closure of all working openings situated below possible flood level, after all persons have been withdrawn;

c) arrangements for continuous monitoring of water levels, with inspection of any points of risk;

d) strengthening of any vulnerable points, using sandbag protection where appropriate;

e) preparation and putting into use of, as appropriate, emergency pumps, or any other standby plant;

f) preparation of isolation of the electrical supply to the threatened workings.

10.4.4 Remedial action

The cause of inundation should be established and steps taken to prevent further inundation before re-entry to the tunnel is considered. Re-entry procedures should include:

a) ensuring the tunnel is structurally stable;

b) that the atmosphere is fit for respiration and free from potentially explosive gases;

c) ensuring that plant and electrical equipment are safe.

d) as early as practicable, all strutting, timbering and supports in the tunnel, together with walkways, stairways and gantries. These should be inspected and made safe.

After submergence, all machinery and plant should be carefully inspected and reconditioned. Electrical cables and equipment, in particular, require special care in drying out, and should be thoroughly tested prior to use. If the danger of flooding is persistent, the use of compressed air, instead of electricity, for power in the tunnel should be considered.

10.5 Precautions when drilling

The following precautions should be taken when drilling out from the face or lining. An assessment of the risk of meeting water, gas or obstructions including unexploded ordnance should be made before drilling starts. Where necessary, drilling should be through a stuffing box.

11 Compressed-air working

*COMMENTARY ON CLAUSE **11***

*The use of compressed air to manage groundwater, as described in **9.1**, presents hazards to both individuals and structures. The health of individuals is particularly the subject of The Work in Compressed Air Regulations 1996 [2], which govern work in compressed air and are accompanied by guidance document L96 [24]. They are referred to hereafter in this clause as the Regulations and the Guidance respectively. The Regulations and Guidance apply to the construction stage for which the principal contractor for works using compressed air is required to appoint a compressed-air contractor who is responsible for compliance with virtually all aspects of the Regulations and is required to make statutory notifications. Employers and employees also have specific responsibilities.*

11.1 Structural considerations

11.1.1 General

When the use of compressed air is envisaged, consideration should be given during the design and tender stages to the risks involved in its use and to its safety in relation to civil engineering, as detailed in this subclause.

11.1.2 Maximum working pressure

The pressure used in design should be based on the maximum head of water likely to be encountered.

An initial estimate should be made of the pressure needed at the lowest point of excavation, allowing for any surcharge above free water level due to flow from higher ground and the effects of tidal conditions.

NOTE In exceptional circumstances, sensitive clays can act as a liquid and the pressure to be resisted is a multiple of the bulk density of the clay rather than that of the water.

To allow for errors and variations in the functioning of equipment and for errors in the initial estimate, the estimate should be increased by 10% to establish the maximum working pressure for the purposes of design.

Airlocks and bulkheads should be designed in accordance with BS EN 12110.

NOTE See L96 [25] for more information on the design of airlocks and bulkheads.

11.1.3 Ground strength

The ability of the ground to sustain air pressure from within a tunnel and/or shaft can limit the pressure used. This should be determined by an assessment of the overburden at all parts of a tunnel and/or shaft system at all stages of construction. The assessment should include testing.

Although the ground is immersed, only its dry density should be used in the calculation, because the passage of air will tend to dry out the ground. In the case of a tunnel, the restraining force of the ground should be taken as the weight of a vertical column of the soils above the tunnel in the same plan area.

The strength of the tunnel lining or jacking pipes should not determine the ability of the ground to resist bursting due to air pressure (see **11.1.4**).

NOTE When lack of ground strength limits the pressure that can be used, other methods of groundwater management can reduce the air pressure needed.

Protection against overpressure should be provided as recommended in **11.4.2**.

11.1.4 Bulkheads for airlocks in tunnel linings

The design of a bulkhead (in either steel or concrete) includes its connection to the tunnel lining and should take into consideration the stability of the lining in its vicinity, as this can be subject to any movements of the bulkhead under pressure variations.

NOTE 1 When airlocks are created by building bulkheads within linings, these linings are subject to frequent pressure changes.

The design of the linings should allow for such changes.

*NOTE 2 Hydrostatic conditions at the commencement of tunnel construction do not always require the "maximum working pressure" determined as described in **11.1.2**, which means that the ground conditions might be unable to sustain that pressure.*

When the lining is designed to sustain air pressure, it should be designed to withstand the maximum working pressure entirely by itself, or provision should be made for another bulkhead under greater cover for when the pressure needs to be raised.

11.2 Physical effects of compressed air

11.2.1 Hydrostatic balance

NOTE 1 In tunnelling through water-bearing ground, one means of reducing the volume of water which flows in at the face is to provide within the tunnel a counterbalancing air pressure. At any tunnel face, the head of water will be greater at the invert than at the crown. If too high an air pressure is used, the danger of a "blow" or "blow-out" arises, in which the escaping air opens an enlarged passage through the overlying ground, resulting in a sudden and critical loss of air pressure and inflow of soil and water. If too low an air pressure is used, the inflow, particularly at the invert, can be excessive, leading to a collapse of the face unless the face is otherwise adequately supported.

The pressure needed should be assessed when working with shallow overburden or working towards free air, as when meeting a shaft or a tunnel at lower pressure. In addition, it should be noted that trapped water pockets can give false impressions of the air pressure necessary.

NOTE 2 The hydrostatic balance is thus inherently unstable. In a wholly fluid medium, balance is impossible; it can only be achieved where the strata have some cohesion and some resistance to the flow of water and air. The greater hazard is probably from excess air pressure.

To minimize the air pressure used, the balance level should be fixed at the minimum depth practicable.

NOTE 3 In some circumstances it could be appropriate to set the balance level above the crown of the tunnel, accepting the consequent wet conditions in the tunnel and providing appropriate face support. Where a TBM of very large diameter is in use and the cover to the crown of the tunnel is shallow, the large variation in pressure across the face can be a hazard.

Where a tunnel constructed under compressed air is to be connected to a shaft, tunnel or structure that cannot be pressurized, special measures should be taken, such as the stabilization of water-bearing strata by grouting or by lowering of the water table.

Pressures should not be raised simply to provide more comfortable working conditions at the face without full consideration of other possible effects.

NOTE 4 L96 [24] states that the person in charge ought to be responsible for the designation of persons to be in charge of determining the pressure of air in the working chamber.

11.2.2 Supporting pressure

Where compressed air is used in impervious ground it exerts a supporting pressure on the ground; this can be relied upon in designing immediate ground support but precautions should be taken to prevent ground instability in the event of loss of air pressure.

Where a tunnel is not actually in water-bearing strata but could penetrate such ground, as when clay cover is very shallow, compressed air should be introduced at a low pressure which can be increased quickly when needed, or at least to a bulkhead and compressed-air equipment should be installed.

11.2.3 Ground loading

Where a tunnel is being driven under shallow cover, the provision of ground loading should be considered, to reduce the danger of a blow-out.

NOTE This could include the building of a low embankment over the tunnel at the surface or the deposition of a blanket of material on the seabed or on a riverbed.

11.2.4 Consequence of a blow-out

*COMMENTARY ON **11.2.4***

The consequence of a blow-out can be failure of the tunnel face or shaft and possible damage to surface infrastructure. This is particularly serious when operating in pressurized plenum chambers where sudden loss of air can result in the rapid and total inundation of the chamber.

11.2.5 Behaviour in permeable non-cohesive ground

NOTE 1 Where tunnelling is through permeable water-bearing gravel or sand, compressed air can be used to reduce inflow of water and stabilize exposed material. Air can escape at the upper part of the face, displacing water in the interstices of the gravel and thereby progressively making easier the path of escape of air so that an increasing volume of air has to be supplied. At the same time, inflowing water at the lower part of the face tends to carry with it fine silt and sand and to open up channels, thereby increasing water inflow. Continuous progress of the face into undisturbed ground can counteract these tendencies, but when conditions are difficult it is advisable to provide timbering and clay, bentonite, grout or other materials for sealing off escapes of air.

These measures should be taken if forward progress is interrupted or stopped for any reason.

Silts and fine sands have a useful measure of cohesion when damp, but their moisture content should be recorded.

NOTE 2 Dry silt can crumble away, while wet silt becomes fluid.

Water should be controlled (see **9.1**), but this no substitute for close support, which should be provided where water is present.

NOTE 3 Clay is almost impermeable to air and water, but can be fissured or excessively soft, plastic and sensitive. Some silts and fine sands are of such low permeability that they can act as an impermeable material.

NOTE 4 In soft rock, such as chalk, compressed air could be used to control the entry of water through joints and fissures, but other means of water control are sometimes needed to supplement its use. In chalk, particularly near the top of a stratum, there is an increased risk of a blow-out arising from the presence of soft "putty chalk" and from old swallow holes infilled with gravel.

11.2.6 Air losses

*NOTE 1 In some ground conditions, leakage of air at the face and through the lining behind the face can be substantial. The escaping air can be detrimental to adjacent structures and, if it accumulates under an impervious layer, uplift can result. Additionally, the passage of air, displacing water, can weaken foundations, cause settlement of piles and interfere with sewers and drains. The loss of air ought to be reduced to a minimum. Heavy-gauge plastic sheeting can be highly effective as a temporary measure to staunch major air leaks through the face. Sprayed concrete or bentonite can also be used. Should air input become negligible, ventilating might be necessary (see **11.3.2**).*

NOTE 2 Compressed air is occasionally used in a tunnel which has a sprayed concrete lining, but its use is generally confined to tunnels lined with segments of cast iron or precast concrete, erected as closely as possible behind the excavation so as to cover any exposed ground.

Air losses through segmental linings should be reduced by a sealing system.

NOTE 3 Elastomeric gaskets can virtually eliminate leakage, particularly when used with self-sealing grout valves. Hydrophilic material is only wholly effective after exposure to clean water and can allow leaks of compressed air. An effective remedy is to wet the gasket by reducing air pressure while the face is secured.

To avoid leaks, the lining should be constructed with particular care to ensure that segments are not damaged, gaskets are not displaced, grouting is adequate, and when reliance is placed on caulking, grummets are in place around bolts. Residual leaks should be sealed by caulking and pointing.

These measures are usually adequate to sustain the water pressure when the air pressure is reduced and further movement of the lining takes place. Any excessive or prolonged loss of air should be investigated and not merely compensated for by additional air supply.

11.2.7 Depressurizing of working chamber

Depressurizing should be gradual to allow the air trapped in the surrounding ground to disperse outside the works (see also **11.3.4**). It should be noted that rapid depressurizing of working chambers can result in residual external pressure on the linings of shafts and tunnels.

11.3 Shaft sinking (see also Clause 20)

11.3.1 General

NOTE When shafts are sunk using compressed air, the following two positions of the air deck are possible:

a) at or close to surface;

b) some way down the shaft.

The design of the shaft lining should allow for loads from the expected air pressure, the ground and any kentledge.

The shaft lining and the kentledge distribution should be designed to withstand the tensile forces imposed on the shaft lining by the uplift on the underside of the air deck and by the radial pressure. The final air pressure required to complete construction of the shaft and subsequent tunnel (if any) should be allowed for. This is particularly important where the air deck is close to the surface and where the escape of air through the shaft lining joints (and later through those of the tunnel) could weaken the ground support immediately behind the lining. The lining should therefore be of adequate strength to allow for this.

When the pressure in the shaft is reduced to atmospheric, in position (a) the lining below the air deck should sustain the weight of the air deck and kentledge above it, and in both positions (a) and (b) the air deck itself should sustain the full weight of the kentledge. The lining should be anchored accordingly.

In all cases, the applied loading on the air deck should be sufficient to prevent uplift loading at maximum air pressure. Flanged segmental linings should be assumed to be unable to sustain longitudinal tensile forces and should therefore be in compression at all times, unless the joint connections are specifically designed to withstand such forces.

Water should only be used as air-deck kentledge when the structure above the air deck is watertight. Conversely, the situation when the shaft above the deck can become inadvertently flooded should be taken into account when designing the deck.

11.3.2 Underpinning

11.3.2.1 General

When a shaft is sunk by underpinning, particularly in loose ground, care should be taken to ensure that ground lost behind the lining is always replaced with grout.

NOTE If ground loss is not controlled, the lining can become stressed, causing fractures and allowing air to escape, which can endanger persons working at the bottom of the shaft.

11.3.2.2 Caisson construction

During caisson sinking of a shaft the lining cannot be grouted in place until sinking is complete. To prevent loss of air around the cutting edge and through the lining into the bentonite annulus behind it the cutting edge should be kept buried or at least below the point of hydrostatic balance and an airtight lining should be built for the shaft. The descent of a caisson should be controlled.

The design should establish the extent to which the weight of a caisson can be supported by the ground at the cutting edge.

NOTE 1 This determines the method of excavation around the cutting edge and the amount of support the caisson needs during excavation.

NOTE 2 Hydraulic cylinders can be used to aid sinking and to control its movement and inclination. Hazards that arise from the uncontrolled lowering of a caisson and the consequent reduction of working space include over-pressurization and entrapment.

A risk assessment should be carried out to establish when persons should be withdrawn from the working chamber.

NOTE 3 As caissons, by their nature, are generally employed in wet conditions, there is a risk to personnel from flooding.

Depressurization of the working chamber should not be used to aid sinking unless personnel are withdrawn beforehand.

NOTE 4 This can lead to uncontrolled movement of the caisson.

11.4 TBMs and compressed air

11.4.1 General

TBMs used in compressed air should be designed for this purpose in accordance with BS EN 12110 and BS EN 12336. When a TBM designed for use in free air is to be used in compressed air, the design should be verified as suitable for such conditions by the TBM designer or other appropriately qualified person (see **7.6.4**).

11.4.2 TBM with pressurized plenum

NOTE 1 The use of a sealed bulkhead within a shield enables compressed air to be applied in the plenum, without persons being continuously under pressure during the construction cycle. Spoil is conveyed through the bulkhead by means of slurry pipework or an auger conveyor.

NOTE 2 As access to the plenum of these machines is needed for periodic maintenance and repairs, they are usually fitted with a small airlock for personnel. Owing to the restricted space available, these airlocks are constructed to suit each machine.

When maintenance is carried out within the plenum of a slurry TBM, the manufacturer's handbook should be consulted on a safe method of work. Good communications should be kept at all times and the crew inside should be provided with the means to prevent rotation of the head.

The airlock should allow for the passage of a casualty from within the plenum chamber.

NOTE 3 For smaller-diameter tunnels, a temporary airlock sometimes needs to be attached to the portal of the tunnel or installed within the tunnel.

An airlock is particularly vulnerable in the event of fire; consideration should be given to its protection by the provision of insulation or of a water-cooling system that would operate in the event of a fire.

11.4.3 Entire TBM in pressurized atmosphere

NOTE 1 A tunnel can be driven using a TBM where a length of tunnel is pressurized. This allows the benefits of compressed air (ground support and water control) to be coupled with a safe and controlled excavation technique.

*NOTE 2 The guidance for open-face work given in **11.2.1, 11.2.2, 11.2.3, 11.2.4, 11.2.5, 11.2.6** and **11.2.7** applies equally where TBMs are used in this way.*

When carrying out front-end repairs to a TBM, the ground should be supported ahead of the cutter head and water inflow should be controlled by using compressed air over a short length of tunnel. When such operations are undertaken, an assessment of the hazards involved should be made and a detailed method statement drawn up. Plans should be drawn up for emergency rescue from the most inaccessible areas of the operation.

11.5 Air supply

*NOTE See also Clause **15**.*

11.5.1 Quality

NOTE Air quality can be measured at the point of delivery from the compressor to the working chamber or at any point in the working chamber. For the air as delivered, only 10% of the short-term exposure limit for any contaminant is advised by the Guidance [25]. This is to allow for subsequent pollution of the atmosphere by work in the chamber (see paragraphs 61 to 65 and 74 of the Guidance).

The atmosphere in the working chamber should be monitored regularly, at a frequency determined by project-specific duties and hazards. Monitoring equipment employed in pressures above atmospheric should be carefully selected and used (see Annex 2 of the Guidance [25]). Electronic gas monitors should be recalibrated and acclimatized in the workings in accordance with the manufacturer's recommendations.

Detector tubes give an enhanced reading in pressurized atmospheres, and to give an equivalent reading at atmospheric pressure, readings should be factored down by following the manufacturer's instructions.

The limits for the proportions by mass of gaseous contaminants present at pressures higher than atmospheric should be reduced from the free-air value, in proportion to the absolute pressure. No change should be needed for dust contaminants.

11.5.2 Quantity

NOTE 1 In order to maintain quality of compressed air in the working chamber, the Guidance [25] recommends that fresh air be supplied at the rate of at least 300 L/min per person at working pressure. In practice, a higher rate is usually required for other purposes. In granular soils, losses of compressed air through the face and lining, together with discharge through airlocks, are likely to exceed the recommended minimum supply rate.

In some compressed-air tunnels where the quantity of air needed for hydrostatic balancing is not sufficient for ventilation, further quantities of fresh air should be supplied directly to working areas, particularly in clay or organic strata or when grouting in small-diameter tunnels.

NOTE 2 Heat from machinery and from hydration of cement in grout, and dust and fumes from rock excavation and from grout mixing, all call for ventilation. This can be achieved by ducting the incoming supply to the working area or, more effectively, by venting to atmosphere via a "snorer" pipeline, which can be controlled at its inlet.

11.5.3 Compressed-air plant

NOTE Attention is drawn to The Pressure Systems Safety Regulations 2000 [26], which are relevant to compressed-air working, compressors, receivers, coolers and filters (see Annex 1 of the Guidance [25]).

It should be noted that reliability of the compressed-air supply is an essential safety feature.

11.5.4 Deoxygenated air

COMMENTARY ON ***11.5.4***

Deoxygenated air is a hazard indirectly associated with compressed-air working. Any reduction of air pressure can draw back deoxygenated air from the ground. Deoxygenated air can also be driven into a free-air tunnel by the pressure from an adjacent compressed-air tunnel, or by the effect of a fall in barometric pressure. During depressurisation, deoxygenated air can be forced into the compressed air tunnel from the surrounding ground.

Ventilation should be provided (see Clause **15**) and the oxygen content of the air should be constantly monitored.

11.6 Bulkheads, airlocks and associated compressed-air equipment

11.6.1 Design and construction

Bulkheads in tunnel linings and airlocks should be designed in accordance with BS EN 12110 and should have at least the following features.

- Airlocks and bulkheads should be strong enough to withstand any air pressures (internal or external) to which the structure could be subjected in use and in an emergency.
- Dimensions should be adequate for the maximum number of persons likely to use the airlock at any one time

  NOTE See L96 [25].
- The anchorage of the airlock should resist the thrust imposed by air pressures on the ends of the airlock and should be designed to carry all loads safely.
- The airlock itself should be airtight and satisfactory devices should be provided for sealing the doors, even at low pressures.
- All materials used in the construction of airlocks should be non-combustible when tested in accordance with BS 476-4, or fire-resistant when tested in accordance with BS 476-21 or BS 476-22.
- Pressure-relief valves.

11.6.2 Testing of the installation

A programme of testing the compressed-air installation should be performed as follows.

a) All mechanical equipment, e.g. compressors, coolers, filters, receivers, valves, gauges and pipework, should be verified as adequate before installation for rates of flow and limits of pressure embodied in the design.

b) After installation and prior to commencement of tunnelling operations, the whole of the installation up to the entry to the airlock(s) and bulkhead, including the equipment listed in (a), should be verified by introducing compressed air from the compressors gradually to a pressure no higher than the tested capacity of the lowest-rated component. This can be done by sealing the ends of the supply pipes and pressurizing the entire supply system.

c) After the installation of the bulkhead and airlocks and the testing of the mechanical equipment, as detailed in (b), and prior to commencement of pressurized tunnelling operations, the whole of the installation should be tested. Where the design permits, the maximum working pressure (see **11.1.2**) should be used. However, as the working pressure can vary (usually upwards) during the course of the work, the test to the maximum pressure may be delayed until ground conditions at the tunnel permit. Meanwhile, tests at appropriate working pressures should be carried out. This is particularly important when a shaft is being sunk, because the working pressure that is safe at the start can be inadequate at greater depths.

NOTE 1 In the case of a shaft with an air deck and airlocks provided for use when driving the tunnel, the test to the maximum working pressure can only be carried out after the construction of the shaft and the break-out from the shaft is completed.

For the purposes of work up to that time, the test should be to the pressure expected for that work and may have to be in stages according to the strength of the construction relative to its depth.

The workings and individual airlocks should be protected from overpressure by means of one or more safety valves that are able to maintain pressure in the event of a control problem. Tests should be carried out to verify the effectiveness of these valves. Hearing protection should be worn during the tests.

NOTE 2 L96 [25] gives recommendations, and BS EN 12110 specifies requirements, for the setting of these safety valves.

Pressure tests should be carried out under supervision.

At no time should the working pressure exceed the pressure to which an installation has been tested.

11.7 Fires and rescue in compressed air

NOTE Paragraphs 211 to 229 of L96 [25] give details of emergency and contingency planning.

11.7.1 Special hazards

Compressed air provides a greater mass of oxygen and therefore increases all fire risks. All the preventive measures described in Clause **13** and Clause **14** should be strictly observed and appropriate precautions should be taken.

NOTE 1 Materials that are flammable in free air burn more vigorously in compressed air. Materials that are comparatively safe in free air can become flammable in compressed air. Timber is an essential material of construction, but in compressed air, even heavy timbers, including those treated with flame retardant, can ignite and burn, rather than merely become charred. Airborne sparks can more readily ignite oily rags or waste. Synthetic fibres flare up rapidly and can stick to the skin. Many plastics give rise to dense smoke, often with toxic properties. Flame spread rates also increase.

Hydraulic plant containing oil at high pressure can be particularly dangerous in two ways: a pinhole leak can produce a fine spray of oil, readily ignited; or an oil hose exposed to fire or otherwise damaged can burst, releasing a large volume of flammable oil; for these reasons, low-flammability (HFDU) hydraulic oils should be used. In addition, it should be noted that timber can become saturated with oil, and steel platforms and walkways can become slippery.

Batteries should not be charged within compressed-air workings. If this is necessary, in exceptional circumstances, special local ventilation should be provided.

The use of burning, welding or grinding gear in compressed-air workings is inherently hazardous and should only be undertaken when cold work is impracticable. When hot work is essential, hot-work permits should be drawn up detailing precautions to be taken, such as the removal of all combustible debris, exposed oil and grease, the use of fire blankets and extinguishers and the appointment of a fire-watcher. Lone working should not be permitted and this should be taken into account when organizing the hot work and subsequent decompression. A fire-watcher should remain in position for the duration of the hot work and for at least 1 h after the work is finished (see also **13.2.1**).

NOTE 2 In some circumstances, fire-watching can be carried out by remote observation.

When oxyacetylene or oxypropane burning equipment is used, the smallest size of cylinder needed for the job should be employed.

NOTE 3 Particular requirements apply to the use of acetylene at elevated pressures. Acetylene may be used at pressures of up to 2.5 bar absolute, provided that the conditions stipulated in Certificate of Exemption No. 2 of 1989 (The Explosives Act 1875 [27]) are conformed to.

It should be noted that the outlet pressure indicators on regulators show gauge pressure not absolute pressure; for instance, in compressed air at a pressure of 1 bar gauge, an outlet pressure reading of 0.5 bar is equivalent to 2.5 bar absolute.

NOTE 4 1 bar = 105 N/m^2 = 105 Pa.

11.7.2 Fire at timbered face

NOTE When air is escaping at the tunnel face, supporting timber has a continuous supply of oxygen and is therefore particularly susceptible to fire.

Access to the seat of a fire can be difficult and the structural strength of the face support can be at risk. The fire should therefore be blanketed with grout, clay pug or a similar material and the air pressure should be reduced to the lowest value considered safe, in order to reduce the air supply and to admit more water.

11.7.3 Fire-fighting equipment

Water is the principal resource for controlling a fire in compressed-air workings. It should be noted that a fire apparently extinguished can brighten and re-ignite in compressed air. The site of any fire should therefore be cooled and wetted with water and, where it is safe to do so, kept under continuous observation until it is determined that the emergency is over.

NOTE 1 Paragraph 218 of L96 [25] recommends a fire main running throughout the airlock and tunnel.

Normally pressurized fire extinguishers cannot be relied upon to function effectively in elevated ambient air pressure, unless they have been specifically proved to be adequate for the actual conditions. It should be checked with the supplier that the extinguisher is suitable for use in a hyperbaric atmosphere.

NOTE 2 Extinguishers developed for use in the diving industry can be suitable.

Breathing apparatus for use in smoke and fumes should be employed only by those trained in its use. Only self-contained compressed-air breathing apparatus (of a type that does not have an air cushion seal to the mask) should be used. Manufacturers should be consulted concerning the duration of sets at the working pressure in the chamber.

The suitability of self-rescuers for working at enhanced pressures and their duration should be verified.

Pure oxygen should not be breathed at a partial pressure greater than 2 bar.

11.7.4 Special training

Contingency planning on site should include an analysis of the types of fire possible in the workings and the persons best placed to tackle the fire. Training (both theoretical and practical) should be given to selected fire-fighters who should then have periodic rehearsals. These persons have a key role in fire incidents and should be trained to issue instructions and to clear non-essential personnel from the workings.

The fire service, HSE and local accident-and-emergency hospitals should be informed of the use of compressed air and should be invited to participate in contingency planning. As a general rule, the fire service should not undertake operations in compressed air. A clear understanding of the services that can and will be provided in the event of a fire should be reached (see **14.1**).

Fire service personnel who agree to work in compressed air should be given training in the operations of locking-in and locking-out and should be advised of the special fire hazards.

NOTE Even when its personnel do not enter compressed air, the fire service is sometimes prepared to provide supporting services and equipment.

Whether or not fire service personnel are available to fight fires in compressed air, early action should be taken, and a site fire squad should be designated and trained for fire-fighting (see **13.4**).

11.7.5 Methane

The likelihood of methane being present should be assessed by detection and measurement. When any likelihood is established, additional safety precautions should be implemented (see Clauses **12** and **15**).

NOTE 1 When tunnelling work in compressed air penetrates any strata where methane is likely to occur, there is an increased risk of fire or explosion. In particular, compressed air within coal seams increases the risk of combustion.

The outflow of air through any coal seams should therefore be minimized or eliminated by sealing them off as soon as possible.

NOTE 2 Methane can occur at high pressures and form a potentially explosive mixture with the compressed air in the working chamber. Methane can leak out through the strata or be found, in solution, in groundwater entering the tunnel. It can also be drawn back into the tunnel on reduction of tunnel air pressure.

11.7.6 Rescue when shaft sinking with vertical airlocks

When a shaft is to be sunk using a vertical airlock, the method of removing an injured person from the working chamber should be given consideration.

The normal way to enter such an airlock from the chamber is by climbing a ladder through a hatch and into a small chamber in which it is only convenient to stand. An alternative means of egress for an injured person should therefore be provided.

NOTE The most common way is to provide a man-riding cage that can be lowered through a muck lock, into which the injured person can be lowered in a special emergency sling. The man-riding cage can be covered with a hood or mesh so that no part of the person being rescued can be trapped in the guides and doors.

Access to the airlock should be tested to verify that it is adequate for persons wearing breathing apparatus.

11.7.7 Rescue in tunnel and from machines

In addition to the hazard of fire, rescue of persons injured by falls and other accidents should be considered; this is especially important in the case of a tunnelling machine that uses compressed air in the cutter-head chamber. Lock-keepers and workers should be trained in the routine for rescuing a person injured in the working chamber (the cutter-head chamber). They should also be familiar with the manufacturer's instructions for operation of the airlock(s) on the machine.

NOTE When there is a loss of pressure in the cutter-head chamber there could be a problem in closing the door from there to the airlock in order to recompress the persons in the airlock.

11.8 Inundation

11.8.1 Precautions

In compressed-air tunnelling, an increased risk of inundation arises (see **11.2.1**) if air escaping through the ground erodes a channel of increasing area through which there could ultimately be an uncontrolled loss of air pressure. Precautions should include:

- use of the minimum practicable air pressure;
- constant inspection for air leaks at the face and surface;
- sealing off any leaks, using bentonite, cement grout, plastic sheeting, bags or other means of choking the airflow.

Specific boxing-up and inspection procedures, preferably by remote means, should be implemented at weekends and other stoppages.

Special care should be taken with TBMs that use compressed air in small compartments at the face.

11.8.2 Escape

In compressed-air working, escape routes should be carefully planned to give access to airlocks. In small-diameter tunnels, airlocks at higher level, accessed by ladders in trunking, and affording a better place of safety than airlocks at tunnel level should be used.

12 Methane

12.1 General

NOTE 1 The principal danger from methane is explosion.

Where methane is present or there is a risk that it could be present, precautions should be taken to prevent ignition. Equipment for monitoring the presence of methane should be available on site at all times. All machinery and equipment used should be designed to minimize the danger of sparks and high temperatures.

*NOTE 2 Both mechanical and electrical equipment might have to be explosion-protected (see **25.3.7**).*

Where methane is found to be present, it should normally be dispersed by dilution using forced ventilation.

NOTE 3 Extraction ventilation might be preferred where excessive quantities of dust have to be removed.

*NOTE 4 For further references to methane and ventilation, see **11.7.5, 12, 15.4.3.4** and **15.4.4**.*

12.2 Occurrence

The following information on the occurrence and properties of methane should be considered when designing or constructing tunnels.

a) Methane (CH4) is a potentially explosive gas produced in nature by the decomposition of organic matter. It is commonly found in, or near to, carboniferous rocks, more particularly coal seams, shales and oil-bearing strata, and in other porous or bedded strata above methane-producing rocks. It is also found in peat and organic silts, and wherever organic matter decays in wet conditions. The presence of methane can be influenced by groundwater movements. The gas can travel laterally for considerable distances along joints and fissures or through porous rock.

b) Accumulations of gas can occur under lakes and waters if trapped by overlying impermeable strata. In urban areas the gas can occur in refuse dumps, under landfill, in sewers or sewage sludge, or by leakage from gas mains. Methane can also enter excavations from biological sources, e.g. by migration from landfill disposal sites, and from microbiological decay of organic material such as could be present in silt or sludge in drains, sewers and culverts.

c) Methane can appear in an excavation as a steady infiltration, a heavy emission or in a sudden influx when a pocket of gas under pressure is penetrated, e.g. in faulted ground. Methane infiltration can also b influenced by changes in tunnel atmospheric pressure due to fluctuations in barometric pressure or by the use of extraction ventilation systems. Methane dissolved in groundwater can enter tunnel works and the gas can subsequently be released into the tunnel atmosphere.

d) Methane can form layers in the crown of the tunnel and can migrate from the source of entry to a point some distance away, especially up an incline, and this can occur against the normal flow of ventilation. Thus, an explosion can be caused some distance from the source of entry of the methane, when mixing subsequently takes place.

e) Methane can occur with carbon dioxide and other gases that can affect its density, resulting in mixtures that are neutrally buoyant or even denser than air. Thus layers can form at the base of excavations and migrate down inclines.

f) The methane layers can be dispersed by various methods of turbulent mixing, e.g. by high-velocity airflow in the tunnel or by directing a flow of air to the crown of the tunnel by means of local air movement devices.

12.3 Explosion characteristics

*COMMENTARY ON **12.3***

The danger from methane is that it is potentially explosive when mixed with air. Following research in Europe, the lower and upper explosive limits (LEL and UEL) were changed some years ago and are now accepted as approximately 4.4% and 17% by volume respectively (see also BS EN 1127-1). The density of pure methane is approximately 0.6 times that of air and, consequently, it tends to accumulate at the tunnel crown, forming persistent layers if undisturbed. When thoroughly mixed with air, it does not again separate and can therefore be safely handled in a ventilation system if diluted.

When tunnelling through coal measures, the build-up of coal dust should be prevented, as an explosion of methane can initiate a coal dust explosion (see **16.1**).

12.4 Detection and monitoring

Where the presence of methane at any concentration is foreseeable, the air in the tunnel should be continuously monitored using fixed monitoring equipment, supplemented by the use of portable monitoring equipment. The detection system should be coupled to an alarm system in the tunnel to indicate when predetermined alarm levels are exceeded. On activation of the alarm, emergency procedures should be implemented. BS EN 60079-29-1 should be consulted for advice on the choice and use of monitoring equipment.

The presence of methane or any potentially explosive gas should be reported to the tunnel designer and the client as soon as it is detected. When the presence of any potentially explosive gas is indicated, the nature and source of the gas should be determined, and the intensity of the inflow should be specifically measured.

Effective and regular maintenance and calibration of the gas-detection equipment should be carried out. It should be borne in mind that such equipment only measures the gas concentration at or near the sampling head.

Monitoring should be carried out using fixed monitoring equipment in the pit bottom, along the crown of the tunnel, on excavation machinery at the tunnel face and in extraction ventilation ducts. This should be supplemented by monitoring, possibly using portable equipment, at the following locations:

- along the invert;
- in the general body of the air within the tunnel;
- at low-level points such as sumps and pits;

- where methane layering is suspected;
- in voids above crown level;
- upwind of tunnel machinery, electrical switchgear and transformers.

Data on current methane concentrations, obtained from the monitoring system, should always be available to site managers on the surface and at the tunnel face.

Written, printed or electronic records should be kept showing the following:

- calibration of the equipment;
- the results of routine monitoring;
- abnormally high concentrations of methane;
- atmospheric pressure;
- position of sampling;
- time of day;
- date;
- air quantity flowing at each sampling point.

Atmospheric monitoring equipment used for detecting methane should conform to BS EN 60079-29-1. Care should be taken in instrument selection as many instruments are intended for use only in the range 0%–100% LEL only (0%–4.4% methane by volume) and can fail at higher concentrations.

12.5 Danger levels

If concentrations of methane cannot be kept consistently below 5% LEL (0.22% by volume) in the general body of the air, all mechanical and electrical equipment in use in the tunnel should be explosion-protected (see **12.7**). In particular equipment deemed essential for safety, including lighting, emergency lighting, communications equipment and fire detection, alarm and extinguishing systems, should be of an explosion-protected type so that it can remain operational at all times.

If concentrations of methane cannot be kept consistently below 10% LEL (0.44% by volume) in the general body of the air, no explosives, cutting and welding equipment, abrasive disc cutters and non-explosion-protected locomotives should be used, and non-explosion-protected mechanical and electrical equipment should be shut down or disconnected.

Whenever a methane concentration of 25% LEL (1.1% by volume) or above is measured, either in the tunnel or in an extraction ventilation duct, persons other than those essential for the safety of others should be withdrawn from all parts of the tunnel, and all non-essential explosion-protected mechanical and electrical equipment should be disconnected until the concentration has been reduced to below 20% LEL (0.88% by volume). Only persons essential for safety should remain in the tunnel if the lighting, emergency lighting, communications equipment and fire detection, alarm and extinguishing systems are of an explosion-protected type.

If the methane concentration exceeds 40% LEL (1.76% by volume), all persons should be withdrawn from all parts of the tunnel and electrical power isolated by means of switchgear at the surface, apart from the power supply to atmospheric monitoring equipment, which should be left in operation. Such equipment should be designed accordance with BS EN 60079-11.

12.6 Sources of ignition

NOTE 1 Any flame or hot spot, or any spark or electric arc can ignite a potentially explosive gas mixture. Hot spots can be generated by friction in machinery (including braking), by overloaded or inadequately cooled electric cables or lamps, by faulty earthing and current leakage to earth, or by metal cutting and grinding.

Sparks can be produced by violent contact between metals and rock. Cutting machines and similar equipment should therefore be operated at low speeds and be cooled with water sprays or jets. Aluminium and other light metallic alloys can produce intense sparks when struck by other metals or rock. These alloys should be completely excluded from use in a tunnel where the presence of methane is foreseeable (see BS EN 60079-14:2008, Clause **14**).

Electric arcs arise in making and breaking contact in a live circuit and from loose contacts. It is because of such arcing that explosion-protected equipment should be used when operating in any atmosphere known to contain methane at a concentration above the limits in **12.5**.

NOTE 2 Electric sparks can be generated by static electric charges that build up on insulating materials subject to friction, such as rubber belting, nylon and other non-metallic materials. Static charges are also produced, for example, when compressed air is used for the pneumatic handling of dry materials (see BS 5958-1).

12.7 Explosion protection (see also 12.5)

The use of electrical apparatus/equipment and systems (both explosion-protected and non-explosion-protected) under conditions where a hazard could arise from the presence of a potentially explosive atmosphere, e.g. due to the presence of methane, should only be permitted after a full assessment of the risks involved.

NOTE 1 Attention is drawn to The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2002 [28], which specify requirements for explosion-protected equipment. The regulations apply to both mechanical and electrical equipment.

NOTE 2 See BS EN 60079-10-1 and BS EN 60079-14 for the selection, installation and maintenance of electrical apparatus in potentially explosive atmospheres for applications other than mining.

Where explosion-protected equipment is being used, all switchgear, cables and joints associated with the equipment but not part of it, should also be appropriately explosion-protected.

NOTE 3 Where Group I Category M1 [2)] equipment is not available, Group II Category 2 [2)] equipment may be substituted provided that it is suitable for the gas or gas group likely to be encountered.

NOTE 4 The definition of mining ought to be taken as in S180 of the Mines and Quarries Act 1954 [29].

NOTE 5 Attention is drawn to The Dangerous Substances and Explosive Atmospheres Regulations 2002 [30].

NOTE 6 Tunnelling which complies with the recommendations on potentially explosive atmospheres in tunnelling of this British Standard is regarded by HSE as likely to achieve conformity with the relevant parts of The Dangerous Substances and Explosive Atmospheres Regulations 2002 [30].

NOTE 7 BS EN 1889-1 specifies requirements for rubber-tyred vehicles and locomotives.

In general, equipment that is likely to produce flames, hot spots or sparks as described in **12.6** should not be used.

2) As defined in The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2005 [28].

Advice from a specialist in explosion protection should be sought on the suitability of equipment for use in compressed-air working.

When explosives are being used where the presence of methane is possible, specialist advice should be obtained.

12.8 Work in potentially explosive atmospheres

NOTE 1 The Dangerous Substances and Explosive Atmospheres Regulations 2002 [30] specify requirements or work in potentially explosive atmospheres. The Regulations do not apply to work in a compressed air tunnel.

NOTE 2 Oxygen resulting from the discharge of gas from a manlock and giving rise to enrichment of the tunnel atmosphere, is an "oxidizing agent" and consequently falls within the definition of "dangerous substance" in The Regulations [30].

NOTE 3 Any dust which can form an explosive mixture with air or an explosive atmosphere and any naturally occurring gas such as methane would be considered a "dangerous substance". While diesel and hydraulic fluid would not be considered dangerous when stored as bulk liquids, they could be considered "dangerous" if leaked as an atomised spray.

Where the potentially explosive contaminant is kept below 100% LEL by means of ventilation, an "explosive atmosphere" is not present. Consequently the guidance in this standard on work in potentially explosive atmospheres should be strictly adhered to (see **12.7**).

13 Fire and smoke

13.1 Storage of materials

13.1.1 General

In the confined space of a tunnel, materials likely to ignite or assist in the development of fire should be eliminated or controlled, for example, the amount of combustible material (e.g. timber, straw, paper, rubber), flammable liquid (e.g. oils, chemical solvents and primers, paraffin) and compressed gas in a tunnel should be kept to a minimum.

Any materials not required imminently (generally those not needed during the working shift), should be removed to a surface storage area, except items such as emergency face timbers and, in some cases, straw needed for safety purposes.

Smoking and the carriage of smoking materials constitute a fire hazard, and should be prohibited below ground and only permitted in designated areas on the surface away from combustible materials.

NOTE The FPA publication, "Fire Prevention on Construction Sites" [31], gives further useful information on the prevention of fire.

13.1.2 Combustible materials

Combustible materials stored in a tunnel should have suitable fire-fighting equipment conspicuously located nearby (see Table 4 and Table 5). Storage areas for combustible materials should have well-placed notices warning of the fire risk. Whenever practicable, the storage areas should be isolated from the general working area. They should not be in, or in the vicinity of, any shaft or tunnel opening, or on any escape route, and should be protected by some form of construction that has a fire-resistance period of not less than 30 min when tested in accordance with BS 476-20, BS 476-21 and BS 476-22. Surface structures and buildings at, or close to, any shaft or tunnel opening should be constructed from non-combustible materials wherever practicable.

In any place where the use of timber is likely to introduce a special hazard, whether by reason of the location's vulnerability, or because the consequences of fire are particularly serious, steel should be substituted if possible.

Straw should not be used. However, if it is stored for emergency stuffing at the face, it should preferably be kept in bales in a damp condition and stored in a metal container. Substitutes such as rockwool should be used wherever possible.

Table 4 **Provision of fire extinguishing equipment**

Location of fire	**Extinguishing medium**				
	Water (jet)	**Water (spray)**	**Foam**	**Inert gas**	**Powder**
Tunnel – general	F		P	P	P
TBM – general			P	P	P
TBM – hydraulics			F		F
TBM – electrics				F	F
Diesel plant			F		F
Battery locomotives				F	F
Fuel store			P		P
Battery charging					P
Compressed-air workings	F	F	P		
Timber headings, break-outs, etc.	F		P		

NOTE F = Fixed P = Portable.

Table 5 **Portable fire extinguishing equipment**

Class of materials involved	**Extinguishing medium**
Fires involving solid usually of an organic nature, in which combustion normally takes place with the formation of glowing embers	Water extinguisher
Fires involving liquids or liquefiable solids	Foam extinguisher, CO_2, dry powder
Fires involving gases	Water spray to cool cylinder, foam to extinguish any fire when valve has been closed
Fires involving metals	Dry powder, dry sand
Electrical equipment (if live)	Inert gas, dry powder, dry sand

NOTE The flammability of timber can be reduced by treatment with a fire-retardant, although its effectiveness can deteriorate.

13.1.3 Flammable liquids

Flammable liquids should always be contained in tightly sealed and properly labelled metal containers, which should be stored in a cupboard or bin that is fire-resistant when tested in accordance with BS 476-20, BS 476-21 and BS 476-22, and such a bin or cupboard should be locked when materials are not in use. Such liquids should be stored apart from other combustible materials and at safe distances from areas of high activity, electrical installations and explosive magazines. Not more than one day's supply of such liquids should be kept in a tunnel.

Means should be provided to contain spillage of the entire contents of containers of flammable liquids.

Drip pans should be provided to catch any leakage from containers, and these pans should be emptied as necessary to prevent spillage on to the floor. The floor around drip pans should be covered with sand or similar non-combustible material, which should be replaced as necessary.

The products generated by the fluid on combustion should be considered when selecting a hydraulic fluid.

13.1.4 Compressed gases

Below ground, cylinders containing oxygen should be segregated from cylinders of flammable gas (e.g. acetylene, propane and butane), except when in use. Under no circumstances should oxygen cylinders be allowed to come into contact with any form of grease. All cylinders of compressed gases should be kept away from flammable liquids and combustible materials. The cylinders should be of the smallest size practicable for the operation to be undertaken, and should remain underground only for the period of the operation.

All cylinder valves, including the screw thread into the neck of the cylinder, should be regularly checked for leaks. Any cylinders found to be leaking should be removed to open air immediately.

NOTE 1 Gas cylinders are liable to damage from mechanical impact, which could cause leakage from valves or cylinder rupture, leading to explosion.

Cylinders should therefore be protected by suitable containers during handling, storage and use, and protected against any risk of impact by falling or being struck by other plant or equipment. Cylinder valves and a fire extinguisher should be immediately available.

NOTE 2 HSE publication HSG139 [32] gives information on the safe use of compressed gases.

13.1.5 Handheld blowpipes

Handheld blowpipes should conform to BS EN ISO 5172 and should be fitted with non-return valves at both gas inlets, and with flame arrestors with cut-off valves at the gas supply outlets. All safety devices should conform to BS EN 730-1 and BS EN 730-2. Hoses should conform to BS EN ISO 3821, and pressure regulators to BS EN ISO 2503. Transportable acetylene containers should conform to BS EN 1800. Containers for other fuel gases should conform to BS EN 12862 or the appropriate standard in the BS 5045 series.

13.1.6 Lighting fixtures

Any lighting fixtures in storage areas for combustible materials or flammable liquids should be constructed, located and maintained so that combustible materials cannot be ignited by the heat that the fixtures produce (see Clause **17**).

13.1.7 Accumulation of refuse

All combustible refuse should be removed from a tunnel as frequently as practicable, at least once per shift, to prevent the build-up of a fire hazard. Such material should preferably be removed in the normal process of working. Combustible refuse should not be deposited close to any other combustible materials.

Any combustible refuse that cannot be removed should be stored in metal bins with close-fitting lids, and away from naked lights and other fire hazards. These refuse storage areas should have suitable fire-fighting equipment nearby (see **13.4**).

13.1.8 Low flammability hydraulic fluid

Low flammability hydraulic fluids such as those classed as HFDU in BS EN ISO 12922 should be used in TBM applications. In addition, these fluids should also be used in the hydraulic and transmission systems of all plant and equipment used in tunnels. The advice of the plant manufacturer and fluid supplier should be sought over the selection of the appropriate fluids for these applications.

13.2 Welding and cutting (burning)

13.2.1 General

There is a high risk of fire from welding and cutting (including disc cutters) and greater hazards are created in tunnels than in the open air; whenever possible, such work should be undertaken at the surface or cold processes should be adopted.

*NOTE In pressurized workings, the risk of fire is significantly increased, as all combustible materials ignite more easily and burn more fiercely, making fire-fighting more difficult (see **11.5.1**).*

In tunnels where explosive gases are present, hot work should be prohibited. If there is potential for these gases to be present, atmospheric monitoring should be carried out before work commences and continued throughout the work period (see **11.5.5**, **12.4** and **12.5**). In the event of an explosive atmosphere being detected, all hot work should cease immediately.

A "permit to work" system should apply to any underground welding or cutting. This should specify the conditions for storage, transport and use of equipment, and the fire precautions. The "permit to work" system should also cover the return of the equipment to surface storage. "Permits to work" should have specific dates, as an open-ended permit can be abused. No work should be carried out on fuel or oil tanks until they have been purged and certified gas-free.

On completion of the operation, the area should be inspected to check that nothing is smouldering. A fire-watcher with fire hose or extinguisher should be in attendance during the operation and for at least 1 h after its completion.

No person carrying out welding or cutting should be allowed to work alone, as they might fail to notice a fire developing or be unable to extinguish it successfully. However, all unnecessary personnel should be excluded from the work area.

Fumes are generated by many welding and cutting operations, and so good ventilation should be provided (see Clause **15**). When worked, galvanized steel produces toxic fumes that should not be inhaled. Local exhaust ventilation, air lines and air movers should be employed in order to disperse local concentrations of fumes.

13.2.2 Electric arc welding and cutting

Petrol-driven generator sets should never be used underground. Electrically-powered transformer or rotary converter sets should preferably be used as the power supplies for the generation of electric arcs. If diesel sets are used, adequate ventilation is essential (see **15.7**), and additional fire precautions should be taken and proper arrangements made for the storage and handling of fuel (see **24.4**). Carbon electrodes may be used for arc-air gouging provided that there is adequate ventilation.

Arc welding plant, equipment, accessories and installations should conform to BS 638-4, BS 638-5 and BS 638-7.

13.3 Fires involving electrical equipment

NOTE 1 Electrical installations and equipment can cause fires by overheating, by arcing or by sparking. On mechanized drives, a fire can occur on power packs, inside electrical panels or cable ducts. Fire can develop rapidly and produce dense smoke.

NOTE 2 If equipment is capable of carrying the requisite loads, with a margin for overloads, and is properly installed, used and maintained, it is unlikely to cause a fire, except as a result of accidental damage or penetration by water.

If a fire involving electrical equipment does occur, the electrical supply should be disconnected before fire-fighting commences.

*NOTE 3 Recommendations for cabling and wiring and for equipment are given in Clause **25**.*

The special hazard of fumes and smoke from burning PVC or similar cables should be taken into account.

Because of the restricted space in tunnels and the usually very damp conditions, defective cables or equipment should be carefully isolated so that persons are not exposed to the hazards of electric shock and electrocution.

The network of cables should be planned so that essential fire-fighting resources, including pumps, lighting and ventilation, are not cut off in the process of isolating overheated equipment, and so that signals and communications are maintained.

Electrical fittings in areas where gas cylinders are stored should be protected so that they do not present a possible ignition source.

13.4 Fire precautions

13.4.1 General

NOTE Fire safety is regulated by the Regulatory Reform (Fire Safety) Order 2005 [33].

The HSE is responsible for enforcement of both general fire precautions and process fire precautions on construction sites; their advice and that of the local fire service should be sought before the quantity, type and position of fire protection equipment is decided. In addition to fire-fighting to save life, account should be taken of the consequences of fire damage to the tunnel structure and the hazards associated with any remedial work required.

13.4.2 Fire mains and hose connections

A fire main conforming to BS 5306-1, providing water for fire-fighting, should be available throughout the tunnel, with hydrant outlets at intervals not exceeding 50 m. Such outlets should be clearly marked and should be readily accessible.

The water supply should be sufficient in volume and pressure for the operation of fire hoses, water sprays or other fire-fighting equipment, and the advice of the fire service should be sought regarding this. Equipment should be located strategically in accordance with the progress of the tunnel, and should be regularly tested and properly maintained.

13.4.3 Fire extinguishing systems

All TBMs should have fixed fire extinguishing systems covering the high-risk areas of the machine.

NOTE 1 High-risk areas include hydraulic pumps, motors and oil storage tanks, significant electrical switchgear enclosures, electric motors and transformers. Foam extinguishing systems can be used for protection of hydraulic and electrical systems.

All TBMs should be fitted with a water spray curtain at their outbye end, to cool and control smoke to aid escape of persons.

All plant used underground should be fitted with fixed extinguishing systems giving direct injection of extinguishant into the engine compartment. On rubber-tyred plant, the extinguishing system should cover the tyres also.

Portable fire extinguishers conforming to BS 7863 and to the appropriate part(s) of BS EN 3-10 should be provided. They should be selected and installed in accordance with BS 5306-8 and maintained in accordance with BS 5306-3. They should be sited so that they are readily accessible by personnel.

The effects of the extinguishing medium on the tunnel atmosphere should be taken into account in the selection process. Table 4 and Table 5 indicated suitable extinguishing media for a range of fire locations.

NOTE 2 BS 5306-0 gives guidance on the selection of appropriate systems. Recommendations concerning the application of fixed or portable installations are given in Table 5.

13.4.4 Routine testing and maintenance of fire protection equipment

All equipment should be maintained in good working order, and this should be verified by routine testing in accordance with the manufacturer's instructions.

13.5 Vulnerable items and locations

Certain items and locations are particularly vulnerable to fire, whether by reason of high flammability, or because a fire would be especially difficult to extinguish, or because the consequences of a fire could be catastrophic. Items such as the following, and their locations should be identified and protected.

a) Timber in headings and face.

b) Stores or accumulations of:

   1) timber and scrap timber;

   2) paper cement bags;

   3) straw;

   4) oily rags and hemp;

   5) flammable liquids and gases.

c) Conveyor belts.

d) Cables and wiring.

e) Electrical installations, including transformers and switchgear.

f) Hydraulic (oil) systems.

g) Flame cutting and welding areas.

h) All areas of compressed-air working.

i) All methane-bearing strata.

j) Storage areas for explosives.

k) Shafts and all openings to the tunnel.

l) Coal seams liable to spontaneous combustion.

13.6 Escape routes

All escape routes underground should be clearly signed. Blind headings should be marked as such. Consideration should be given to the provision of places of relative safety where appropriate such as in long tunnels (see **14.12**).

14 Response to emergencies

14.1 Emergency services and operational capacity

During the planning stages of construction, renovation or repair work, the cooperation of the emergency services should be sought in making arrangements for fire-fighting and rescue and for summoning of the emergency services and for emergency response.

An assessment should be carried out during the planning stage of the tunnel project, in consultation with the police, fire and ambulance services, to establish their operational capacity and to establish details of any additional facilities and equipment required for operations beyond that capacity. A desktop exercise of the plan should be carried out as part of the planning stage.

NOTE 1 Because of the extended distances that occur in tunnel operations, special arrangements and facilities might be necessary to assist emergency services in dealing with incidents occurring in tunnels during the construction stage. Fire service operational capacity in tunnels is based on the principle that fire service personnel are able to take equipment to the scene of an incident, deal with the incident and return to ground level safely. For tunnels in remote locations or in challenging environmental conditions the involvement of other emergency services such as mountain rescue might be require. Planning for casualty evacuation by helicopter might also be necessary.

Equipment and other issues that should be taken into account when planning a response to emergencies include some or all of the following points.

a) Provision of a control room (see **14.2.1**) and/or a bridgehead location(s) (see **14.2.2**) from which resources and operations can be controlled close to the incident.

b) Underground transportation of personnel and equipment to the incident or bridgehead.

c) Lighting, communications, ventilation and smoke control.

d) Underground transportation of casualties and personnel back to the surface.

e) Fixed installations, e.g. water mains, fire suppression systems, fire-fighting hose.

f) Portable fire-fighting equipment.

g) Provision of extended-duration breathing apparatus.

h) Training, and site familiarization for fire service personnel.

NOTE 2 Additionally, because of the remote location of some tunnel sites, special arrangements might be necessary for transportation of emergency personnel or their equipment to site and evacuation of casualties to hospital. This might involve the use of helicopter transport.

In all such circumstances the effects of adverse weather on the contractor's emergency response arrangements should be considered and alternative arrangements should be made.

Following an assessment of operational capacity, the emergency services might be unable to provide an assurance that their personnel can deal with all incidents within the tunnel; in this event, the emergency services should be asked to formally notify the contractor and give details of their reduced operational capacity for the particular tunnel or stage of the tunnel construction. Thereafter, the contractor should make their own arrangements for emergency response.

14.2 Emergency control facilities

14.2.1 Control rooms

On larger sites, and where requested by the emergency services, an emergency control room should be provided, from which the senior officers of the emergency services can control their response to an incident. Such a room should be equipped with ex-directory telephone lines, site radio communications and drawings showing the up-to-date layout of the underground workings.

Where practicable, an emergency control room should be provided at the top of each shaft or other point of access. If this is not possible, an up-to-date weatherproof drawing showing the depths of shafts, layout of tunnels and location of fire-fighting and other emergency equipment should be displayed at these locations. It should also give details of where and how to notify the emergency services.

On multiple-contractor projects, or once multiple access points or exits are established, control rooms should be interlinked. In larger tunnels, and where requested by the emergency services, a "leaky feeder" communication system compatible with their radio systems should be provided for use underground.

Full particulars of the ventilation system in use, including details of all fans and ducts, and of any apertures and doors, should be kept available for use by the fire service officers or other responsible persons. A suitably qualified member of the contractor's staff should also be made available to the fire service to operate the ventilation system, should this be necessary.

Details of all "permits to work" relating to the use of hot cutting/burning equipment should be available to the fire service and in the emergency control room.

14.2.2 Bridgeheads

A forward control point, or "bridgehead", should be provided in situations where it might be necessary for breathing apparatus or other operations to be started up at a distance from the original point(s) of entry to a hazardous area, while remaining in a safe-air environment.

14.3 Raising the alarm

Adequate arrangements should be made for raising the alarm and calling the emergency services in the event of an incident underground. It should be borne in mind that a fire at the surface level could endanger those working underground. The nature and operation of the emergency alarm system should be related to the scale, layout and nature of the works, and to the nature and extent of known fire and other underground hazards. The fire alarm system should be extended and modified as the tunnelling work proceeds.

The alarm should be clearly perceptible to all persons in the workings, and to key personnel above ground.

NOTE Warning arrangements can include any of the following, as appropriate:

a) voice warnings;

b) telephone communications;

c) hand-operated or electrically operated bells or sirens;

d) special flashing lights;

e) flashing of the main lighting circuits.

The locations of the alarm devices should take into account the layout of the working areas underground, the adverse nature of the working conditions (especially high noise levels) and the transient nature of the working locations. Where single-alarm systems are used, wiring should conform to BS 6387:1994, meeting a minimum category rating of AWZ [i.e. the lowest performance category for resistance to fire (A), resistance to fire with water (W), and the highest performance category for resistance to fire with mechanical shock (Z)].

A separate and distinct signal to order the total evacuation of the workings should be provided. The emergency alarm systems should be regularly tested and properly maintained.

14.4 Alarm procedures

14.4.1 Consultation and planning

Particular procedures should be pre-arranged for each site, for example, the contractor should consult the HSE and the emergency services for advice on fire and evacuation. Planning should cover matters such as arrangements for fire-fighting, rescue and evacuation of casualties, and the management controls necessary to effect this.

Protocols for calling the emergency services should include instructions to switchboard/security staff on which service(s) should be called, how 999 calls are to be made, and the information that is to be passed to the emergency service control. (See also **14.3**.)

14.4.2 Action at point of discovery of an incident

All personnel should be given the following set of instructions to follow on the spot when there is an incident underground including a fire or suspicion of fire in the tunnels or underground workings.

a) Raise the alarm in the tunnel and attack the fire only if it is safe to do so.

b) Report the incident, stating the following:

- nature of the incident, e.g. fire, injury, illness, collapse, atmospheric contamination;
- where the incident is;
- what assistance is required;
- whether evacuation is in progress;
- any other relevant information e.g. surface evacuation required.

14.4.3 Action on receiving the alarm

The person on site receiving the alarm should immediately undertake the following actions.

a) Summon the relevant emergency service, giving a precise rendezvous point, and arrange for a responsible person to meet them on arrival.

b) Inform the senior site manager or emergency coordinator.

c) Activate the site emergency plan.

14.5 Site training

All underground personnel should be trained in the care and use of fire-fighting equipment.

NOTE Some fire services are able to assist in this training.

All site personnel should be made familiar with the site emergency procedures prescribed. Emergency drills including evacuation should be held at regular intervals to familiarize all personnel with the practical working of the systems.

14.6 Access

Access to the site, and the provision of, and access to, hard standing for fire appliances and ambulances is of vital importance and should be covered in the site emergency procedures, following consultation with the local fire service and ambulance services.

Access to the shaft and workings should be available for the emergency services at all times. The surface of any walkways in the tunnel should be maintained in a safe condition so that they can be used safely by fire-fighters, even in conditions of nil visibility.

Where appropriate, helicopter landing areas should be designated in accordance with the requirements of the helicopter operator.

14.7 Lighting

Adequate emergency lighting should be maintained at all times, particularly at fire points, escape routes, emergency exits and tunnel access points (see Clause **17**).

14.8 Smoke control

*COMMENTARY ON **14.8***

Smoke is a major danger in fire, as it can cause asphyxiation. It can interfere with visibility, resulting in disorientation and possibly panic. The hazard can be reduced by using the ventilation system to the best advantage.

Smoke control should be studied in advance in conjunction with the fire service. The aim should be to configure the airflow so that it clears the heat and smoke without spreading the fire.

NOTE 1 Valved discharge points can be provided at intervals on an air line along a tunnel to provide air for persons trapped by fire and smoke.

Persons should be made aware that in a smoke-filled atmosphere they can find movement easier if they crawl under the smoke.

Self-rescuers and breathing apparatus should be provided, as these are necessary in severe conditions of smoke.

NOTE 2 The use of a water spray curtain at the outbye end of a TBM can control the spread of smoke from a fire on the machine or adjacent to it.

14.9 Rescue facilities

First aid equipment, including stretchers, should be available as described in **6.5.9**.

Rescue equipment, including full breathing apparatus, should be provided and maintained so that it is readily available in an emergency.

All rescue equipment should be stored in containers designed to provide protection from adverse conditions likely to be encountered in the workings. In many tunnels, a dedicated rescue skip or train should be provided for quick response by a site rescue team and/or emergency services.

14.10 Self-rescuers

All persons underground should have immediate access to a self-rescuer which provides the user with a supply of oxygen for at least 20 min while walking. Where such oxygen supplies are likely to be needed for longer periods, stockpiles of additional rescuers should be provided at intervals, e.g. in long tunnels.

Self-rescuers should normally be worn by persons underground on a belt, but may be stored in racks that are immediately accessible for use in an emergency. Where alternative escape routes are available, racks of self-rescuers should be provided for each escape route. If self-rescuers are stored on racks, there should be a maintenance and inspection system to check that a sufficient number are always available and that they are always in full working order.

Smoke hoods incorporating a built-in oxygen supply, such as from a chemical oxygen-generating cartridge, are quick to don and might be provided as self rescuers. They can be too large to wear on the belt but should be made immediately available for use in an emergency. As they can be of less than 20 min duration, they should be supplemented by stockpiles of additional self-rescuers as necessary.

NOTE 1 Oxygen self-rescuers are designed to be used in normobaric conditions only but can be used at up to 1 bar pressure provided the risks from hyperbaric oxygen breathing are addressed. A prototype hyperbaric self-rescuer has been developed for use up to 3.5 bar. Open circuit air-breathing apparatus can be used in hyperbaric conditions but its duration will be significantly reduced.

The highest standard of cleanliness should be maintained in situations where oxygen is used. Specialist advice should be sought on how this is best achieved.

*NOTE 2 For guidance on the use of self-rescuers in compressed air, see **11.5.3**.*

14.11 Accounting for personnel

There should be a system for accounting for site personnel in an emergency. The system should accurately indicate the number and location of persons underground at all times. This information should be supplied to the emergency services in the event of an underground fire or other emergency.

NOTE If the works have a single entrance/exit, a simple tally board might be adequate.

For works with multiple entrances/exits, a more sophisticated system should be used. Whichever system is used, it should be supervised and monitored, and all persons using the system should be instructed in its correct use.

If the tunnelling operations form part of a multiple-contractor project, then the system used for accounting for personnel should be uniform across the entire extent of the underground works, and should be built into the contract and safety case. The system should allow persons to be accounted for across the entire project site, irrespective of the entrance or exit by which they enter or leave.

14.12 Refuge chamber

A refuge chamber is a place of relative safety in a tunnel. The number and location of refuge chambers provided should be determined by an assessment of the risk to those working underground and the options for escaping to a place of relative safety. It should be noted that not all tunnels are large enough to accommodate a chamber or long enough to require one.

The chamber, which should be of robust steel or concrete, should provide occupants with a long-duration breathing-air supply along with protection from atmospheric contamination in a pressurized and thermally controlled environment which is lit, is in communication with the surface and contains basic food, water, welfare and first-aid provisions.

NOTE Experience has shown that fungal infections due to lack of proper washing facilities and poor dental hygiene can be problems for persons confined to warm, damp refuge chambers over long periods of time.

A refuge chamber should be capable of providing those in it with a breathable-air supply, preferably through connection to a compressed air main in the tunnel. This main should be protected from mechanical damage and heat, such as by burying it in the tunnel invert. Where such a main cannot be provided, the air supply should be from cylinders. Alternatively, the chamber should have an on-board oxygen system supplied from cylinders located adjacent to the chamber, along with a scrubbing system to remove carbon monoxide and carbon dioxide from the chamber atmosphere. There should be a further chemical oxygen supply to the chamber for emergency use. The duration of supply from cylinders should be 24 h and from the chemical supply 4 h.

There should be an air conditioning system or water cooling in the chamber capable of maintaining an internal temperature of 28 °C when the ambient temperature outside is 50 °C.

The chamber should be under a slight positive pressure when in normal use.

There should be a porthole at least 150 mm in diameter in the door or in the chamber wall adjacent to it. The door should provide a seal to prevent entry of atmospheric contaminants. There should be an emergency escape hatch in another wall of the chamber remote from the door.

The chamber should be connected to a mains power supply. The power supply should be protected against mechanical damage and heat. In addition there should be an emergency power supply of 30 h duration. Lighting intensity in the chamber should be 100 lux at floor level but this can be reduced to 10 lux when powered by the emergency power supply.

The internal chamber walls and all internal fixtures and fittings should be chosen to minimize fire risk.

The chamber should be linked to the tunnel voice communications system by means of a connection which should be protected from mechanical and fire damage.

The chamber should have seats for three visitors along with all persons normally working at that location in the tunnel and be clearly marked with its capacity. It should be fitted with external warning lights to indicate when someone is using it and to an audible device to facilitate its location in poor visibility,

A water or foam fire extinguisher should be provided internally.

Refuge chambers on TBMs should comply with the requirements of BS EN 16191 [3)].

[3)] In preparation.

15 Ventilation

15.1 General

*NOTE 1 Attention is drawn to The Construction (Design and Management) Regulations 2007 [1] for requirements on the supply of fresh or purified air for safety. The Regulations give no figures for minimum requirements for the fresh air supply (see **11.3.2** and **15.2**).*

NOTE 2 The object of ventilation in a tunnel or shaft is to provide fresh air or to extract pollutants, in order to achieve an acceptable environment. The quantity of fresh air supplied is usually determined not by breathing requirements but by the need to dilute pollutants and to provide cooling.

The design and installation of the ventilation should be overseen by a competent person.

NOTE 3 Ventilation requirements differ substantially according to whether or not dust and/or various toxic, asphyxiant or explosive gases are present and require dilution or removal, and depend also on the extent to which conditions of heat and humidity require amelioration.

NOTE 4 High humidity is characteristic of tunnels. Increased air temperatures can result from any plant working in a tunnel, from the use of explosives and from grouting and concreting operations. The natural ground temperature also greatly influences the air temperature.

NOTE 5 The efficiency of a ventilation system can be seriously impaired by poor duct design and/or maintenance, so for example, lack of rigid bends at major changes in duct alignment can cause the duct to flatten, impeding airflow.

Any leaks in a damaged duct should be sealed.

Procedures should be set out for regularly testing the operation and efficiency of each ventilation system and for its regular maintenance, particularly in long tunnels. The tests should also determine whether the system continues to meet operational requirements, taking account of changes in tunnel length or configuration since the previous check. Appropriate repairs and modifications should be made as necessary.

Procedures should also be set out for the withdrawal of personnel where necessary. These procedures should be rehearsed periodically.

15.2 Guidelines for fresh air supply quantities

Fresh air should be distributed to all working areas. A fully controllable balanced ventilation system should be designed in advance, with the capacity and flexibility to allow growth and adaptation as excavation progresses. In more complex or hazardous contracts, specialist advice should be sought.

Each situation should be treated individually, taking account of all factors such as:

- workforce number;
- tunnel size;
- ambient conditions;
- amount and type of plant.

Particular care should be taken where dangerous dust or toxic gases are present or foreseeable, and actual pollution levels should be measured systematically.

A minimum fresh air supply of 0.3 m^3/min. per person should normally be sufficient to maintain a respirable atmosphere. Additional ventilation should be provided where construction is to be used, to mitigate the effects of exhaust emissions and/or heat generated. An additional supply of at least 3.0 m^3/min. per working kilowatt is recommended for machines with stringent emission controls (see **24.4.1**). This additional ventilation supply should be designed to maintain atmospheric contaminants within acceptable levels and will depend on the type and capacity of construction plant being used. Stringent controls on emissions and the adoption of other good practices should reduce the volume of air required.

If methane or another potentially explosive gas is present, different considerations apply; in this case the danger of explosion is of primary importance and the air supplied should dilute the gas, wherever it appears, to levels significantly below the LEL (see **12.5**).

Recommended minimum air velocities in the tunnel should be 0.5 m/s to contain dust, and 2.0 m/s to prevent layering of methane.

NOTE Local air movers or brattices can help to achieve velocities of the latter order.

15.3 Quality of air

NOTE 1 Fresh air contains approximately 20.9% oxygen, 79.0% nitrogen and 0.03% carbon dioxide by volume. The remainder includes argon and other gases.

The tunnel atmosphere should be considered as oxygen-deficient when the concentration of oxygen falls below 19%.

The important physical aspects of air quality are temperature, humidity and velocity. The air as supplied should be as cool and dry as is reasonably practicable, as during its passage into the tunnel its temperature tends to become that of the tunnel walls and take up moisture in the tunnel.

Wherever possible, the wet-bulb temperature in any working area should not be allowed to exceed 27 °C.

NOTE 2 A higher temperature can impair working efficiency. Lower temperatures, e.g. 15 °C to 20 °C, can contribute greatly to comfort and efficiency.

If strenuous physical effort, e.g. hand excavation, is required in conditions of high temperature and humidity, the risk of heat stress should be assessed and medical advice sought on appropriate remedial measures.

*NOTE 3 Deoxygenated air is a potential asphyxiant. It can occur where the oxygen in normal air has been absorbed into porous organic deposits. Other types of ground, e.g. glauconitic sands, can also deoxygenate air (see **11.3.4**).*

Precautions should be taken where these strata are encountered in not fully saturated conditions, as fluctuations in tunnel pressure either as a response to changing meteorological conditions or when compressed air in use in the vicinity is removed or reduced in pressure, can result in deoxygenated air being released from the ground into the tunnel.

*NOTE 4 Attention is drawn to The Health and Safety at Work, etc. Act 1974 [12] and to The Control of Substances Hazardous to Health Regulations 2002 [34], which require levels of airborne contaminants (as defined in Guidance Note EH40 [35]) to be reduced as low as reasonably practicable. Attention is also drawn to the workplace exposure limits for airborne contaminants set out in Guidance Note EH40 [35]. (See **15.4**.)*

Continuous monitoring of the oxygen concentration should be undertaken by instruments conforming to BS EN 50104. Fixed monitoring equipment should be used and supplemented by the use of portable monitors as necessary. Only fresh air should be used for ventilation to improve the quality of air in the tunnel.

15.4 Dangerous gases

15.4.1 General

*COMMENTARY ON **15.4.1***

Gases are dangerous if they are toxic, flammable/potentially explosive or asphyxiant. The monitoring and control of such gases in a tunnel atmosphere can be difficult because the concentrations rarely remain constant throughout a working day. Guidance Note EH40 [35] deals comprehensively with airborne contaminants and sets out maximum exposure limits and workplace exposure limits for a wide range of contaminants at atmospheric pressure. It includes a full explanation of the terms "maximum exposure limit" and "workplace exposure limit".

Expert occupational health advice should be sought in assessing the effects of complex mixtures not dealt with in Guidance Note EH40 [35].

Individuals vary greatly in their sensitivity or susceptibility to toxic substances, and the factors controlling this variability are not well understood. Therefore it should not be assumed that conditions that are safe for some individuals will be safe for all.

*NOTE 1 Although serious injury as a result of exposure to the workplace exposure limit concentrations is considered unlikely, it is a statutory requirement to maintain concentrations of all atmospheric contaminants as low as is reasonably practicable (see **15.3**).*

*NOTE 2 Electronic atmospheric monitoring equipment can be used to monitor for the presence of methane (see Clause **12**), other hydrocarbon gases and a range of toxic gases.*

15.4.2 Simple asphyxiants

*COMMENTARY ON **15.4.2***

Certain gases and vapours, when present in air in sufficient quantities, act as simple asphyxiants. Without other significant physiological effects, they reduce the oxygen concentration by dilution to such an extent that life cannot be supported. Some simple asphyxiants also present an explosion hazard, e.g. methane.

The concentration of asphyxiant e.g. carbon dioxide, should be monitored directly and not by reliance on monitoring the oxygen concentration alone, because the asphyxiant displaces both oxygen and nitrogen in the air in proportion to their volumetric concentrations and, as there is approximately four times as much nitrogen as oxygen in air, a gross underestimation of the asphyxiant concentration can result if direct measurement of its concentration is not undertaken.

*NOTE Nitrogen gas vented from ground-freezing operations is hazardous if allowed to accumulate (see **7.13.1**).*

15.4.3 Atmospheric contaminants most commonly encountered in tunnelling

*COMMENTARY ON **15.4.3***

The workplace exposure limit quoted in this subclause are those specified in Guidance Note EH40 [35].

NOTE Relevant information on these gases is summarized in Table 6.

15.4.3.1 Carbon monoxide (CO)

COMMENTARY ON ***15.4.3.1***

Carbon monoxide is highly toxic and rarely occurs naturally. It is always produced during the burning of carboniferous materials, especially in fires with restricted air supply. It can appear in a tunnel environment owing to slow combustion of coal and timber or, more seriously, from spontaneous combustion. Its most common source is from internal combustion engines.

Petrol engines should not normally be used in tunnels under construction, as their exhaust fumes can contain up to 10% carbon monoxide (see **24.4.2**).

NOTE 1 Diesel engine exhaust fumes usually have a much lower concentration, the amount depending upon the size of the engine, its state of maintenance and its mode of operation. Diesel engines can be used underground, but see the guidance in ***24.4.1****.*

Explosives used in blasting generate carbon monoxide and care should be exercised in the choice of explosive, and in the use of proper stemming and means of detonation.

NOTE 2 The long-term (8 h time-weighted average) workplace exposure limit is 30 ppm,[4] but short-term (15 min) exposures of up to 200 ppm are permissible (see Table 6).

Any indication of carbon monoxide in a tunnel should be investigated by site management and work suspended if necessary. It should be noted that carbon monoxide is potentially explosive in concentrations of between 12.5% and 74.2%.

15.4.3.2 Carbon dioxide (CO_2)

COMMENTARY ON ***15.4.3.2***

Sources of carbon dioxide include ones occurring naturally, particularly where igneous rocks penetrate carbonaceous strata and where acid water acts on limestone or other calcareous rock. Other sources include the exhaust from internal combustion engines, in the combustion of carbonaceous materials and from the detonation of explosives.

Carbon dioxide is heavier than air and thus accumulations should be expected in low areas and sumps.

NOTE Carbon dioxide often acts as a simple asphyxiant (see ***15.4.2****). The long-term workplace exposure limit is 5 000 ppm, but short-term exposures of up to 15 000 ppm are permissible. Where carbon dioxide occurs naturally underground, it is often associated with oxygen deficiency (known as "blackdamp" in mining). "Blackdamp" is defined as an atmosphere containing higher concentrations of carbon dioxide and nitrogen than normally occur in air.*

The concentration of carbon dioxide should always be measured directly and never inferred from the oxygen concentration.

15.4.3.3 Nitrogen oxides

COMMENTARY ON ***15.4.3.3***

The principal oxides of nitrogen encountered are nitric oxide (NO) and nitrogen dioxide (NO_2).

[4] 1 ppm = a mass fraction of 1 x 10^{-6}

Table 6 **Summary of most commonly encountered atmospheric contaminants**

Contaminant		Relative density	Hazard	W.E.L [A]		Explosive limits		Principal sources
				Long-term limit [B]	Short-term limit [C]	Lower %	Upper %	
Carbon monoxide	CO	0.97	Toxic	30 ppm	200 ppm	12.5	74.2	Explosives, engines
Carbon dioxide	CO_2	1.53	Asphyxiant	5 000 ppm	15 000 ppm	N/A	N/A	Natural, engines, welding explosives
Nitrogen oxides	NO NO_2	1.04 2.62	Toxic Extremely toxic	25 ppm 3 ppm	35 ppm 5 ppm	— —	— —	Explosives, engines Welding
Methane	CH_4	0.55	Explosive and asphyxiant	—	—	4.4	14	Natural
Hydrogen sulfide	H_2S	1.19	Toxic and explosive	10 ppm	15 ppm	4.3	45.5	Natural
Sulfur dioxide	SO_2	2.26	Toxic	2 ppm	5 ppm	—	—	Natural
Propane Butane Acetylene		1.55 2.05 0.91	Explosive and asphyxiant	— 600 ppm —	— 750 ppm —	2.2 1.5 1.5	9.5 8.5 100	Leakages Leakages Leakages
Ammonia	NH_3	0.59	Toxic	25 ppm	35 ppm	15.0	28.0	Organic material
Volatile organic compounds	vari-ous	—	Toxic and explosive	—	—	approx. 1.0 [D]	—	Contaminated land
Organic solvents	vari-ous	—	Toxic	—	—	—	—	Industrial discharge
Oxygen deficiency	O_2	1	Asphyxiant	—	< 19% O_2	—	—	Natural, induced
Oxygen enrichment	O_2	1	Increased fire risk	—	> 23% O_2	—	—	Stored oxygen in tunnel, airlocks
Petrol/diesel vapour	—	> 2.0	Explosive	—	—	approx. 1.0	7.5	Spillage
Ozone	O_3	1.66	Toxic	—	—	—	—	Welding
Radon	Rn	—	Radioactive	N/A	N/A	—	—	Natural

[A] Workplace exposure limits (see Guidance Note EH40 [35] for further information).

[B] 8 h, time-weighted average.

[C] 15 min.

[D] Dependent on constituents.

N/A = Not applicable.

Sources of nitrogen oxides which should be considered include blasting fume, welding and engine exhaust fumes. Both oxides are highly toxic, particularly nitrogen dioxide, which attacks the lung tissue insidiously without major preliminary symptoms, but can cause collapse shortly afterwards, with symptoms of acute broncho-pneumonia.

Nitrogen dioxide, because of uncertainty over its chronic pulmonary effect, currently has no long-term workplace exposure limit, however, HSE recommends that long term exposure should be controlled to 1 ppm.

NOTE The long-term workplace exposure limit for nitric oxide is "as low as reasonably practicable" and industry research has indicated that a long-term limit of 5 ppm may be acceptable in tunnelling with short-term exposure not exceeding 15 ppm. Nitrogen monoxide converts to nitrogen dioxide, slowly but spontaneously in air. However these changes are unlikely to be significant in normally ventilated tunnels.

15.4.3.4 Methane (CH_4) and other hydrocarbon gases

*COMMENTARY ON **15.4.3.4***

Methane is a potentially explosive gas which occurs naturally in coal seams and other carbonaceous strata, and in peat. It can also be found in porous reservoir rocks or dissolved in water. It can also be generated in any ground containing organic material such as river silts and from the biological decomposition of organic waste, e.g. domestic refuse. Methane is released into the ground from fractured domestic gas mains. In mixtures with other potentially explosive gases, particularly hydrocarbons, it is also known as "firedamp".

Methane is not toxic, but care should be taken as it can become an asphyxiant by diluting the oxygen concentration of the air.

*NOTE The primary hazards are of fire and explosion, more fully described in Clause **12**. Other hydrocarbon gases such as natural gas or LPG can occur due to leakage or spillage into the ground.*

15.4.3.5 Hydrogen sulfide (H_2S)

Hydrogen sulfide is highly toxic and has a characteristic smell (rotten eggs). It should be noted that exposure to high concentrations of the gas, i.e. > 150 ppm, reduces the sensitivity of the olfactory nerves. It should also be noted that it is flammable and at concentrations of between 4.3% and 46.0% can be explosive, although these concentrations are unlikely under normal tunnelling conditions.

NOTE Hydrogen sulfide occurs naturally as a product of the decay of organic material containing sulfur or as a result of the action of acid water on pyrites. The gas is a respiratory and eye irritant, causing bronchitis and conjunctivitis respectively. It can cause unconsciousness and subsequently death through respiratory paralysis. The long-term workplace exposure limit is 10 ppm and the short-term standard is 15 ppm.

15.4.3.6 Sulfur dioxide (SO_2)

*COMMENTARY ON **15.4.3.6***

Sulfur dioxide is a toxic gas, attacking the lungs. Sources of the gas include natural occurrence in volcanic areas and also in the fumes from engine exhausts and burning fuels where these contain sulfur. In industrial areas, sulphur dioxide is a common air contaminant. It is easily detected by most people by its characteristic odour and later by its taste as the gas is absorbed.

The long-term workplace exposure limit of 5 ppm should be respected in order to prevent respiratory tract irritation in most persons exposed and that has only a minimal effect on persons who are sensitive to irritant gases.

15.4.3.7 Cutting and welding gases

*COMMENTARY ON **15.4.3.7***

Propane, butane and acetylene are used for cutting and welding.

These gases can form potentially explosive mixtures in air, and care should be taken, since cylinders containing them can burst if subjected to heat or impact.

NOTE 1 Acetylene cylinders can explode if subjected to heat, owing to the exothermic decomposition of the acetylene. This danger can persist for a substantial period after the cylinder is removed from the heat source.

Acetylene cylinders in particular should be isolated and cooled with water for at least 24 h.

*NOTE 2 A particular risk from propane and butane is that as they are heavier than air leakage can accumulate at low spots in tunnels (see **13.2**).*

*NOTE 3 Guidance on the use of acetylene in compressed air can be found in **11.5.1**.*

15.4.3.8 Fumes from cutting and welding

*COMMENTARY ON **15.4.3.8***

Fumes from cutting and welding are usually toxic. The composition and quantity depend on the alloy being welded and the process, but major constituents are oxides of nitrogen, ozone, argon, carbon dioxide, carbon monoxide, metal oxides and fluorides.

Local exhaust ventilation systems should be installed. These should not be of the type which recirculate filtered air, unless sufficient general ventilation is supplied to prevent accumulation of harmful gases.

*NOTE Unprotected persons might have to be withdrawn temporarily (see **13.2**).*

15.4.3.9 Petrol/diesel vapours

*COMMENTARY ON **15.4.3.9***

Petrol or diesel vapours present toxic, fire and explosion hazards. Petrol and diesel residues in the ground can be found in the vicinity of current or former fuel handling or storage facilities not associated with the tunnelling work.

The handling of diesel fuel in the tunnel should be at points where spillages can be contained and where ventilation is provided to the air outside the tunnel.

15.4.3.10 Ammonia

*COMMENTARY ON **15.4.3.10***

Ammonia can arise from the use of certain chemical grouts and has also been reported in tunnels driven through estuarine organic silts, possibly as a result of chemical reaction between cementitious grouts and the soil.

15.4.3.11 Volatile organic compounds (VOCs)

*COMMENTARY ON **15.4.3.11***

A range of volatile organic compounds (VOCs) is frequently found in contaminated ground associated with industrial processes such as gas, coke or tar production. VOCs include benzene, toluene, xylene and related compounds.

Care should be taken since they are hazardous to health, some VOCs being carcinogenic, and their LELs are relatively low at around 1% by volume. When VOCs are encountered in a tunnel, expert advice on both the occupational hygiene risks and the explosive risks should be sought.

15.4.3.12 Other toxic gases

*COMMENTARY ON **15.4.3.12***

Other atmospheric contaminants can occur but are not commonly a significant hazard in tunnelling.

A hazard that should be avoided is the one deriving from toxic gases (e.g. hydrogen chloride, hydrogen cyanide and toxic isocyanates) evolved during the combustion process, especially when burning plastics materials.

NOTE 1 Leakage from sewers can result in organic solvents entering a tunnel.

NOTE 2 For further information on these gases, see Guidance Note EH40 [35].

15.4.3.13 Alarm settings for atmospheric monitoring equipment

NOTE Guidance on exposure limits is given in publications such as HSE's EH40 [35]. In tunnels where the risk assessment shows that sudden change in levels of atmospheric contamination are unlikely to occur, a 2-stage alarm system can be adopted. Modern electronic atmospheric monitoring equipment has the facility to indicate the gas giving rise to the alarm condition as well as for multiple level alarms to be given.

While there should be no ambiguity about the point at which evacuation occurs and the action to be taken to achieve this, supervisory staff in tunnels should be made aware of developing unsafe situations by the use of monitoring equipment with the capability to give multiple level alarms so that an investigation can be carried out and corrective action can be taken before evacuation becomes unnecessary.

The alarm settings and responses in Table 7 should be considered. Where the atmospheric monitoring equipment does not have the capability for multiple level alarms the alarm settings and response should be as for Level 2 Alarms in Table 7.

Table 7 **Alarm settings and responses**

Hazard	**Level 1 Alarm (Warning)**	**Level 2 Alarm (Evacuation)**
Oxygen (deficiency)	19.5% by volume	19% by volume*
Oxygen (enrichment)	22% by volume	23% by volume
Flammable gas	5% LEL	10% LEL
Toxic gas	50% STEL	100% STEL*
Interpretation of alarm and response	Be aware there is a threat to safety from the atmosphere but it remains safe without donning a self-rescuer and evacuating. Action should be taken to ascertain the cause of the threat and put mitigating measures in place.	There is an atmospheric problem. Tunnel should be evacuated in accordance with emergency plan.

*NOTE For conditions marked * (oxygen deficiency or the presence of toxic gas), self-rescuers should be worn immediately.*

15.4.4 Limits for potentially explosive gases where no specific guidance is given

Where flammable or potentially explosive gases such as those listed in **15.4.3** (other than methane), or gas mixtures, occur, and no specific guidance is given in **15.4.3** or any other standard reference material, the principles stated in Clause **12** should be observed. In particular, the recommendations given in **12.5** relating to specific concentrations of the gas, in terms of percentage of LEL, should be followed.

15.4.5 Radon

*COMMENTARY ON **15.4.5***

Radon, an inert radioactive gas, is one of the naturally occurring products of uranium.

Any rock or material containing uranium should be treated as a source of radon.

NOTE 1 Traces of uranium are present in many rocks, but the concentration of uranium is not a guide to the likely concentration of radon. Radon is readily soluble in groundwater, from which it is released on contact with free air, and can be transported significant distances through the ground from its source by this means.

It should be noted that radon activity is not confined to any particular area of the UK, although some areas are more radon-active than others.

NOTE 2 Exposure to radon comes within the scope of The Ionising Radiations Regulations 1999 [36], and the associated guidance document L121 [37].

The absence of recorded radon activity in an area should not be taken as an indication that radon is not present.

The HSE should be notified if the level of exposure at a workplace exceeds the limit specified in these regulations.

NOTE 3 The risk to human health from exposure to radon arises mainly from inhalation of its radioactive decay products, the daughters of radon. The effects of cellular damage, particularly to the lungs, consequent upon exposure to these substances are not immediately life-threatening but can increase the risk of cancer developing later in life.

NOTE 4 Specialist advice is given in guidance document L121 [37] and can be sought from the HSE.

Research into the radon potential of the ground through which a tunnel is to be driven should form part of the desk study and site investigation, in order to determine before work commences whether monitoring during construction is required and whether measures to deal with radon emission and its effects on personnel should be included in the health and safety plan.

If the pre-construction-stage investigation indicates a risk of radon emission into shafts and tunnels, representative measurements of the concentration of radon for all readily accessible places should be taken during construction.

Causes of local variation in the concentration include the use of compressed-air tools and the operation of ventilation systems. The concentration can also be influenced by short-term and seasonal weather changes. All of these influences should be borne in mind when measurements are taken to determine a representative concentration. If old mine workings or tunnels are encountered in areas of radon activity, they should be treated with caution, as high concentrations of radon or its decay products can be present.

All records of radon activity should be used to assess the likelihood of emissions of the gas into the completed works. A summary of that information should be included in the health and safety file. Tunnel owners should be advised accordingly and appropriate operational procedures should be recommended to protect the health of all persons using the tunnel, e.g. during travel within it or while carrying out maintenance work.

15.5 Unoccupied tunnels and stagnant areas

NOTE Toxic gases, mixtures deficient in oxygen, or explosive mixtures can accumulate in areas where there is little circulation of air, such as unventilated tunnels, shafts, sumps or headings. Gases denser than air, such as carbon dioxide, tend to flow to low points and remain there. Methane is less dense than air but, when mixed with other gases, can accumulate at any level in a tunnel. The risks are particularly high when disused or abandoned tunnels or shafts need to be entered, but they are also present when a tunnel or shaft is re-entered after a brief shutdown, such as a weekend.

No one should enter an unoccupied tunnel unaccompanied, or without being in possession of atmospheric monitoring and personal protective equipment, or without first establishing that a ventilation system is working and that the return airflow has been tested and is safe. Additional personnel should be on call and such operations should be planned on a "permit to work" basis. Factors that should be considered include:

a) the competence of the personnel;

b) whether the passages to be entered can form a gas sump;

c) the nature of the ground and its potential for harmful or explosive gases;

d) the length of time during which the tunnel has been unoccupied;

e) the natural ventilation of the tunnel;

f) the difficulty of rescue.

Sewers, whether in use or abandoned, can be particularly hazardous and should be entered only with the approval of the local water and sewage undertaker.

15.6 Cooling

It should be recognized that the need for cooling in tunnels near the surface arises most often from high ambient temperatures above ground.

NOTE 1 Heat is generated in the tunnel by mechanical and electrical plant and the hydration of cement when it cannot be absorbed by the ground sufficiently quickly in the vicinity of the advancing face.

The air temperature therefore rises and a sufficient flow of air should be provided to keep the temperature within acceptable limits. In determining the volume of fresh air required for cooling purposes, the total heat balance should be examined carefully (see also **15.3**).

NOTE 2 At great depths cooling is important, owing to the high ground temperature.

15.7 Ventilation systems and plant

15.7.1 General

The methods of ventilation adopted should be in accordance with the magnitude of the problems presented by each tunnelling situation. Factors that should be considered include:

a) the numbers of face workers;

b) the length, size and gradient of drive;

c) the presence of water, dust or fumes;

d) the presence of methane or other contaminants;

e) whether drilling and firing will be taking place;

f) contaminants emitted by mechanical plant;

g) the amount of waste heat generated by mechanized tunnelling operations.

NOTE 1 In a soft ground tunnel advancing as a single face, a direct fresh air supply to the face is likely to be sufficient but in a complex tunnel system, as in underground transport projects or in hydroelectric schemes, there can be many areas of work and the arrangement of passages and ducts are likely to change as work progresses, and so the requirements for the supply of fresh air and dilution or removal of contaminants might vary.

Conventional forcing, exhausting or overlap systems are employed in most tunnels, and the particular machinery and environmental conditions should determine which is the most suitable.

Where it is necessary to mix or dilute contaminants e.g. potentially explosive gas at roof level, local air movement devices such as hydraulically powered fans fitted to a tunnelling machine or shield should be used.

Where dust is a major problem, the system should be designed to control dust and should incorporate filters to clean the dusty air before readmission to the general body of airflow.

NOTE 2 Where mechanical plant is being used in dusty conditions, there can be a conflict between having a sufficient flow of air to dilute exhaust emissions and restricting the flow of air to prevent siliceous dust being picked up by the airflow.

NOTE 3 The effect of heat added to the air from installed machinery, and the increase in humidity from natural and introduced water, can be reduced by using forcing systems having high local air velocities and by carefully controlling the amount of water used for dust suppression.

The ventilation system should be designed to be moved forward or extended with the progress of tunnelling. After breakthrough the layout of the ventilation system should be re-assessed.

NOTE 4 Ventilation systems can include one or more of the following:

- *a forced supply of fresh air, exhaust being through the tunnel and access ways;*
- *extraction of polluted air from the tunnels, fresh air being drawn into the tunnel due to the reduction;*
- *in-pressure caused by the exhaust ventilation;*
- *alternation of supply and exhaust;*
- *more complex systems combining supply and exhaust, such as overlap systems, which can include filters;*
- *controlled recirculation;*
- *air movers to assist locally and to eliminate stagnant pockets.*

If air movers are used locally, they should not cause recirculation, which can vitiate the air.

*NOTE 5 These systems are described briefly in **15.7.2**, **15.7.3**, **15.7.4**, **15.7.5**, **15.7.6** and **15.7.7**.*

15.7.2 Supply ventilation

Ducted forced ventilation to the working face provides fresh air for face workers and should therefore be the preferred system for most tunnels.

NOTE As the air passes back along the tunnel it becomes progressively more contaminated. Where explosives are in use, the ventilation flow carries back a plug of heavily polluted air, which gradually diffuses into the main body of air, but which can still be potentially dangerous.

In long rock tunnels or for particularly long clearing periods, local refuges furnished with a fresh air supply for use by face workers during a particularly long clearing period, should be provided.

15.7.3 Extraction ventilation

*COMMENTARY ON **15.7.3***

A duct extracting air from a point close to the face can be used directly to remove hazardous dust produced during tunnelling and also any fumes arising from the use of explosives. The extraction process draws in air supply along the tunnel, but this air accumulates contaminants, including dust and heat, and increases in humidity during its passage.

Extraction ventilation is only effective for a short distance around the duct entrance and therefore the duct entrance should be sited close to the point where the extraction of contaminants is required. Extraction ducts should be relocated as frequently as is necessary to keep them close to the source of contamination and close to the face.

These ducts, being at reduced pressure, should be of rigid or spirally reinforced flexible construction.

NOTE It can be more effective to site the fan in the tunnel, close to the face, and to force air from the fan to the surface.

An extract system can draw increased quantities of methane from the source and, when this is foreseeable, the air in the duct should be monitored to ensure that a potentially explosive gas mixture does not form.

15.7.4 Alternating ventilation

*COMMENTARY ON **15.7.4***

Forced and extraction ventilation systems are sometimes combined by the use of reversing fans so that dust and fumes can be extracted for a period after blasting, and fresh air can then be supplied to the face during the rest of the cycle.

The system is complex and not efficient, and should only be used in a short tunnel.

15.7.5 Overlap systems

An overlap or recirculatory system of combined supply and extraction ventilation is sometimes necessary and should normally include filters to remove dust from the extract duct.

The duct layout should be designed to maintain a circulating flow at all workstations. The use of curtains to control airflow should also be considered.

Where methane is present, care should be taken as additional risk can arise from:

- exhaust systems;
- layering due to low air velocity;
- static electrical discharge.

*NOTE See **15.2**, **15.7.3** and **15.7.9**.*

15.7.6 Controlled recirculation techniques

Ventilation systems should be designed to prevent the recirculation of air. However, controlled recirculation could be used where dust is a problem in long tunnels or where there are excessive amounts of dust in mechanized tunnelling. Filters should be provided to remove dust from the extract duct.

15.7.7 Other systems

Where the tunnelling system is complex, it should be studied as a whole and at every stage of the programme to check that there is a supply of fresh air to every working area.

NOTE Both supply and exhaust fans on the surface are sometimes needed, with booster fans in the system and bulkheads or air doors to control the airflow. It can be necessary to control ventilation flows by means of curtains.

15.7.8 Siting of fans

Air intake fans on the surface should be sited away from sources of contamination. Air exhaust fans should be sited away from working areas.

15.7.9 Earthing

NOTE The movement of dust and gases through a ventilation system can cause a dangerous build-up of static electricity.

All ducts, fan bodies, casings and support structures should be properly bonded to each other and to an adequate earth. Air movers and venturi devices should also be earthed.

15.7.10 Methane in duct

Where an extraction ventilation system is in use and there is a risk of methane being encountered, the design and construction of the system should take into account the hazard of methane passing through fans and fan motors. The methane concentration in the ducts should be continuously monitored. If the concentration of methane is likely consistently to exceed 0.25% by volume (5% of LEL) in the general body of the air, the fans should be explosion-protected (see **12.5**).

NOTE 1 Methane concentration in the tunnel is likely to increase when the ventilation system is shut down.

NOTE 2 Explosion protection of the extract system in many cases involves the use of bifurcated fans with non-incendive impeller rings.

16 Dust

16.1 General

NOTE Dust in tunnelling arises principally from the process of breaking rock and of spraying concrete linings.

Dust generated should be suppressed at source as far as is practicable. Its spread should be controlled by methods such as water spraying, water infusion and extraction ventilation. Certain dusts, e.g. coal dust, are potentially explosive when mixed with air, and any electrical apparatus present should conform to and be selected in accordance with BS EN 61241 (all parts).

16.2 Sources of dust

16.2.1 General

*COMMENTARY ON **16.2.1***

Dust can be generated directly at the tunnel face by the processes of drilling or breaking up of rock, even when wet. Where drilling and blasting are employed, dust production is intermittent. Machine excavation tends to produce dust more continuously. In soft-ground tunnelling, there is little direct production of dust, but clay and chalk that have dried out can be dusty. The loading, transport and tipping of spoil is likely to produce further dust, particularly at transfer points and in stockpiling. Dry cement for use in a process such as grouting, concreting, sprayed concrete and caulking, produces dust in handling.

Special precautions should be taken when handling powder additives to cement.

16.2.2 Asbestos

NOTE 1 Attention is drawn to The Control of Asbestos Regulations 2006 [38] which prohibit the use of asbestos or materials containing asbestos.

NOTE 2 Many segmentally lined tunnels built prior to the early 1980s could have been caulked with materials containing asbestos.

When materials containing asbestos are encountered in the course of the work, e.g. during maintenance or repair, they should be removed by an asbestos removal contractor licensed by the HSE.

When asbestos is encountered in tunnels under compressed air, the primary decontamination unit should be set up inside the working chamber. While the miners can be trained to handle asbestos materials, at least one experienced asbestos operative should be in the working chamber to oversee the handling of asbestos materials.

16.3 Effects of dust

16.3.1 Physical effects

*COMMENTARY ON **16.3.1***

The physical effects of dust include the following.

- *Reduced visibility, which increases the risk of accidents related to moving machinery and equipment.*
- *Increased wear and tear on plant and equipment.*

Coal dust creates a special hazard because it becomes potentially explosive when airborne, and, consequently, stone dust barriers should be installed in roadways where coal dust is deposited, in accordance with mining practice.

16.3.2 Physiological effects of mineral dusts

*COMMENTARY ON **16.3.2***

The exposure of persons to various kinds of mineral dust can produce a variety of lung conditions. Among the more serious conditions is pneumoconiosis, a term used to describe any lung disease that is of a chronic character and where parts of the lung have become fibrotic, i.e. inelastic and inefficient.

One of the most serious causes of pneumoconiosis is silica, and the condition produced is described as silicosis; as a result, dusts containing silica should be considered a serious hazard, especially where they contain crystalline silica in proportions exceeding 1%.

NOTE 1 The respirable fraction of dusts (broadly those particles having an effective size of less than 5 µm, which enables them to enter the finer airways of the lungs) can be eliminated by the natural processes of the body. However, continued exposure to excessive dust concentrations can result in permanent damage.

NOTE 2 The incidence of bronchitis is increased by working in dusty atmospheres.

NOTE 3 The medical effects of inhaling asbestos dust can include asbestosis, which is a form of pneumoconiosis, and various cancers, including bronchial carcinoma and diffuse mesothelioma.

16.3.3 Occupational exposure standards

NOTE Attention is drawn to the Control of Substances Hazardous to Health Regulations 1994 [34] and to Guidance Note EH40 [35] which require that the exposure of any person to airborne dusts does not exceed the appropriate occupational exposure limit.

The occupational exposure limit for any respirable dust of no known specific hazard, including dusts containing less than 1% crystalline silica, should be 5 mg/m^3. The long-term maximum exposure limit (MEL) for respirable crystalline silica dust should be 0.1 mg/m^3.

16.4 Sampling

In cyclic tunnelling operations, the average exposure can be difficult to assess, hence individual exposure should be measured over a period by special personal samplers through which the air from the wearer's breathing zone is drawn at a known flow rate by means of a small battery-driven air pump carried on a belt or special harness.

NOTE Conditions at the face are likely to be unacceptable immediately after blasting, but at that time personnel are not present.

After blasting, no one should be permitted to return to the face until concentrations of atmospheric contaminants and airborne dust have fallen to an acceptable level. This should be determined by monitoring the tunnel atmosphere.

In continuously dusty conditions, regular sampling should be carried out so that excessive exposure can be prevented.

16.5 Control and removal of dust

High-pressure water jets at the point of rock fracture should be used to suppress dust.

NOTE 1 While these jets can reduce visible dust, they do not necessarily reduce respirable dust. In drilling, hollow bits with continuous water feed can substantially reduce dust.

Cutter heads in tunnelling machines should be wetted with high-pressure jets of water at predetermined rates.

NOTE 2 A solid cone spray is sometimes preferable to a jet, and the addition of emulsifying and wetting agents to the water can enhance its effectiveness. Water curtains can be appropriate in severe conditions.

NOTE 3 Respirable dust that has become airborne cannot be controlled by water sprays. However, these can be used while handling spoil to suppress dust by preventing it from becoming airborne.

In dusty conditions, extraction ventilation and possibly filtration should be considered essential. Extract points should be kept close to the face, and should be moved forward as frequently as is necessary to maintain effective control. Dusty air is likely to be very erosive, and fans and ducts should be designed accordingly and be properly maintained.

NOTE 4 Air suction points can be fitted to TBMs.

Dust hoods, in the form of enclosures with extraction, should be fitted to known dust sources, such as at conveyor transfer points and shotcreting machines.

NOTE 5 For drilling and blasting, extraction ventilation for a period following the blast can be effective in reducing dust concentrations in the tunnel.

To prevent dust particles migrating back against the main body of airflow, the air velocity in any section of tunnel should be not less than 0.5 m/s. Ventilation calculations should use this as a minimum value.

The efficiency of the ventilation system should be tested periodically and any deterioration in performance should be remedied.

Where extraction ventilation is necessary to control dust emissions and methane could be present, the guidance in **15.7.10** should be followed.

16.6 Respiratory protective equipment

NOTE Attention is drawn to The Control of Substances Hazardous to Health Regulations 1994 [34] and The Personal Protective Equipment at Work Regulations 1992 [39] which set out requirements for respiratory protective equipment.

Respiratory protective equipment should not be used for permanent protection from respiratory hazards. It should only be used as a last resort where, for short periods, control measures cannot effectively limit dust levels at places where persons need to work. Such equipment should be provided and worn while the hazard is present.

Equipment should be selected in accordance with BS EN 529. Once issued, the equipment should be used in accordance with the manufacturer's instructions, paying particular attention to proper storage, maintenance, cleaning and training.

17 Quality of illumination

17.1 General

NOTE 1 Attention is drawn to The Construction (Design and Management) Regulations 2007 – Regulation 44 [1].

Good lighting contributes greatly to safety in tunnels under construction, as well as during maintenance, renovation and repair, and lighting levels should be such that any hazards on walkways and tracks can easily be seen.

Personnel should be required to wear high-visibility clothing. Higher lighting levels should be provided locally, particularly on TBMs, at the face and other working areas.

*NOTE 2 Depending on the size and use of the tunnel, general lighting can be desirable as a permanent installation, particularly on pedestrian access routes. The design and installation of lighting are covered in **17.2, 17.3, 17.4, 17.5** and **17.6**, while guidance on electrical matters associated with lighting is given in **25.7**.*

Fixed lighting is normally required and, in the exceptional case where it is not, hand lamps or cap lamps should be provided.

Where it is foreseeable that potentially explosive gas could enter the tunnel, the lighting installation should be explosion protected so that in the event of an evacuation of the tunnel due to the presence of potentially explosive atmosphere, the evacuation can be undertaken with the main tunnel lighting system operational (see **12.5**).

17.2 Level of lighting

*COMMENTARY ON **17.2***

The lighting level at a surface is expressed in lux. In a tunnel, the lighting level is basically a function of the output and location of the light fittings (luminaires), the dimensions of the tunnel, the light absorbency of the surrounding surfaces and also tunnel atmospheric conditions. Light absorption is less in tunnels that have light-coloured smooth walls than in similar tunnels having dark irregular surfaces.

Lighting levels can be measured with a lightmeter and should be as high as is practicable, taking into account the work to be undertaken in the area. The recommended mean lighting levels should be as set out in Table 8.

Table 8 **Mean lighting levels**

Area	**Lighting level**
Walkways and tracks	30 lux at walkway level
General working areas	100 lux at working surfaces
Tunnel face, excavation areas, crane lifting points	100 lux illuminated from at least two widely separated sources to avoid shadows

The ratio of the maximum illuminance (lux) measured directly under the luminaire to the minimum illuminance measured mid-way between luminaires should not be more than 3:1.

The presence of dust or mist in the atmosphere can also have a very significant effect on lighting levels; under these conditions, the number of luminaires should be increased to meet the values in Table 8.

NOTE Misting-up of the atmosphere generally occurs where there are pressure variations in the atmosphere or at locations where cold air meets moist warmer air in the tunnel ventilation system. It is particularly common in compressed-air workings and deep shafts.

Regular maintenance, including cleaning of the luminaires, should be carried out to maintain the light output and the area lighting level. The luminaires should therefore be as easily accessible as possible.

17.3 Type of lighting

The lighting scheme should be designed to minimize glare. Fluorescent and incandescent luminaires produce less glare than floodlights. The type of luminaire should be selected to minimize fire risk through the use of "cold" lights where reasonably practicable.

Where colour recognition is an important factor, the type of light source should be carefully considered.

NOTE For example, sodium lighting can present problems in colour discrimination.

Protective covers over lamps should be maintained, especially mercury discharge lamps which can emit high levels of ultraviolet radiation if damaged.

Where no other form of lighting exists, pedestrian access to worksites in existing tunnels should be fitted with suitable portable lighting (see **17.6**). Temporary fixed lighting should be considered for longer-term works.

Exceptionally, in sections of tunnel under construction where pedestrian access is prohibited and all transportation, including that of personnel, is vehicular, fixed lighting may be omitted provided that all transport vehicles use headlights. Consideration should, however, be given to providing minimal emergency lighting. Worksites for persons carrying out essential inspection, maintenance, renovation, and repair in tunnels that are not fitted with permanent lighting should be appropriately lit by temporary lighting.

Trackside warning lights and/or lookouts should be used to warn oncoming drivers of the presence of personnel.

17.4 Siting of luminaires

All luminaires (see **25.7.3**) should be fixed to provide maximum uniformity of lighting and minimum vulnerability to damage, consistent with their purpose and accessibility for installation, routine maintenance and repair.

Glare from high-intensity light sources should be minimized by proper siting and the use of diffusers and screening. Floodlights should be located at a suitable height to light areas from above and should not be directed horizontally. They should be arranged so that their fields overlap.

On access routes accommodating both pedestrians and vehicles, lights should be sited to minimize shadows cast on walkways or workplaces by obstructions or plant and vehicles.

17.5 Emergency lighting

Because tunnelling is wholly dependent on artificial light, lighting systems should be made as secure as possible and should be provided with battery back-up or uninterruptible power supplies.

Separate emergency lighting appropriate to the scale and scope of the project should be provided if the lighting system does not already incorporate adequate back-up power.

NOTE 1 Battery-powered emergency luminaires can be used to provide standby lighting. Advice on the use and installation of such systems is given in BS 5266-1.

The capacity of the batteries should be sufficient to maintain the lights for enough time to allow persons in the area to take appropriate action without danger.

Emergency luminaires should be installed along the tunnels intervals of not more than 50 m to allow safe egress from the tunnel, and should be positioned so that it is possible to see at least two emergency fittings from any location. They should also be installed at the following locations:

- fire and first aid points;
- escape routes;
- emergency exits;
- tunnel access points;
- electrical substations;
- control and communication points;
- locations where particular hazards (e.g. stairs or ladders) exist.

The condition of the emergency luminaires should be regularly checked and any faults immediately rectified. The proper functioning of the emergency lighting system should be functionally tested at intervals not exceeding 3 months. Allowance should be made for the fact that the batteries require a certain time to recharge following restoration of the supply after a prolonged power cut.

NOTE 2 As flames, smoke and hot gases tend to build up in the tunnel crown in the event of a fire, damage to the emergency lighting installation can be minimized by locating it below crown level.

Where potentially explosive atmospheres exist, emergency lighting should be explosion-protected (see **12.7**).

NOTE 3 Alternative mains supplies or standby generation can also be used to provide emergency lighting. (Such supplies are sometimes needed to maintain other essential services in the event of mains failure.)

Where the emergency lighting is dependent on an alternative supply or standby generator supply, the wiring should be adequately protected. It should conform to BS 6387:1994, meeting a minimum category rating of AWZ [i.e. the lowest performance category for resistance to fire (A), resistance to fire with water (W), and the highest performance category for resistance to fire with mechanical shock (Z)]. It should also be protected against mechanical damage (see **25.4.5**).

17.6 Hand lamps and cap lamps

Where hand lamps or cap lamps are used, management procedures should be put in place and facilities should provided for their proper storage, charging, distribution, use, and maintenance. Where potentially explosive atmospheres exist, hand and cap lamps should be explosion-protected.

18 Operating communications

18.1 General

*COMMENTARY ON **18.1***

Good communications throughout the site are fundamental to the safety and efficiency of all aspects of a tunnel project, in particular to the passing of information and instructions, the monitoring of systems, the control of lifting operations, the transportation of persons, materials and plant and in the management of emergencies.

The communication system should link major workplaces, tunnel boring machine, tunnel portal or shaft top and bottom, refuge chamber, site offices and safety critical locations on site, e.g. first aid room or emergency control room. Means of contacting the emergency services from the site should be available at all times.

For a small and simple job employing few people, unaided voice communication can be adequate, but normally some combination of signalling systems, telephones, radios and CCTV should be provided for safety.

NOTE On more sophisticated tunnelling projects, electronic digital data transmission systems such as SCADA (Supervisory, Control And Data Acquisition) are used for transmitting control, monitoring and alarm information between a central control room and various tunnel locations. This information includes a variety of safety-related items such as machine condition monitoring, instrumentation monitoring, atmospheric monitoring and fire detection and alarms.

18.2 Communication systems

18.2.1 General

NOTE 1 Attention is drawn to HSE publication L96 [25] for guidance on communication that applies to working in compressed air.

Means should be available whereby the person in charge of a workplace can communicate requirements for materials and equipment, give warning of unexpected hazards and receive instructions. While the system adopted should depend on the size, length and complexity of the tunnel, the number of persons in the tunnel, and on the system of tunnelling employed, its potential hazards and the speed of operations, voice communications systems should be considered the norm.

NOTE 2 A system of signalling by bells or by coloured lights can be appropriate for routine communications, such as controlling train movements or requesting that lining segments or other materials be sent forward.

Details of any signal code adopted, whether audible or visual, should be posted at the top and bottom of each shaft or incline and in clear view of the operator.

A voice communications system should be robust enough to withstand the tunnel environment, and should be maintained in good working order. It should be brought forward as the face is advanced. Tests, and any necessary adjustments, should be made to ensure that messages can be clearly transmitted and that sufficient protection against environmental noise is provided. Suitably soundproofed enclosures should be provided as necessary. The system should be independent of the tunnel power supply and installed so that destruction of one unit will not interrupt the use of the other units in the system. All wiring, especially that used to transmit warnings in an emergency, should be fire-hardened and protected against mechanical impact. All communications cables should be installed and protected in accordance with **25.4.5**. Those needed to transmit warnings in an emergency should have increased integrity under fire conditions by conforming to BS 6387:1994, meeting a minimum category rating of AWZ [i.e. the lowest performance category for resistance to fire (A), resistance to fire with water (W), and the highest performance category for resistance to fire with mechanical shock (Z)].

Radio communications should be used in conjunction with leaky feeder cable systems for propagating the signals in the tunnels. The leaky feeder system should be designed to give coverage throughout the tunnel system. It should be capable of linking into the normal site emergency system. Where a leaky feeder system is to be installed, the contractor should discuss with the emergency services the potential for compatibility with their requirement (see **14.2**). The system is particularly useful for maintaining continuous communication links between control points, persons and vehicles operating within range of the cable.

Radio communication procedures with call signs and channel allocation should be adhered to.

At all working shafts, a standby means of communication between ground surface and the shaft bottom should be available.

18.2.2 Precautions where explosives are in use

Radio communication equipment on sites where blasting is being carried out should only be used in accordance with predetermined procedures.

All radio communications equipment that is intended to be brought on to the site should be assessed in accordance with BS 6657 for its possible hazardous effect on electro-explosive devices; this includes mobile phones and any such equipment that is a component of mobile plant coming on to site. A system should be put in place to ensure that any equipment coming on to site that emits any electromagnetic waves is not going to affect the operation of any electrical, electronic or similar equipment on the site. Details of the frequencies and power of such equipment should be made available.

Modifications to site radio equipment should not be made without first assessing the resultant hazard and ensuring safe working in accordance with the guidance in BS 6657.

18.2.3 Use of mobile phones underground

*COMMENTARY ON **18.2.3***

Mobile phones are radio devices which emit increasingly strong signals when unable to find a base station as can occur underground. There is evidence of interference with wireless control or communications systems used underground. On some projects repeater stations are installed to facilitate the use of mobile phones underground.

The contractor should have a policy and procedure for managing the use of mobile phones underground.

18.3 Signals

18.3.1 General

NOTE Attention is drawn to The Health and Safety (Safety Signs and Signals) Regulations 1996 [40], which require employers to use a safety sign where a significant risk to health and safety cannot be avoided by the implementation of engineering controls.

18.3.2 Audible signals

Audible signals by bell, whistle, air horn or other device should be considered for routine operations such as hoisting and lowering in a shaft, or for winch operation on an incline.

Any signal should be distinctive and sufficiently loud to avoid confusion with any incidental or accidental noises.

The recommended codes should be:

- stop: one signal;
- lower: two signals;
- hoist: three signals;
- hoist personnel: four signals;
- emergency: continuous.

The codes for both audible and visual signals should be displayed at strategic locations for the banksmen and operators.

18.3.3 Visual signals

Signals to machine operators should normally be given only by banksmen or other persons authorized to do so, but all persons involved in the operations should be made familiar with the code through induction training and/or other means such as toolbox talks.

For crane operation in circumstances where the operator can clearly see the banksman giving the signal, the signal code detailed in CP 3010 should be employed. However, it should be noted that shafts can present certain special difficulties (see Clause **20** for further information).

If light signals are used, they should employ a number of lamps and should utilize the same signal code as for audible signals (see **18.3.2**).

NOTE Alternatively, lamps of three colours with a suitable prescribed code, or the direct illumination of key words on a signal panel, might be used.

18.4 Closed-circuit television (CCTV)

CCTV with or without sound, should be used to assist an operator to monitor or control operations remotely or from a place of safety.

NOTE Common uses of CCTV in tunnelling are on TBMs, on locomotives, on cranes and in the pit bottom.

Particularly on locomotives, CCTV systems should have the capability to operate in both colour and infra-red modes.

19 Noise and vibration

19.1 General

NOTE 1 Attention is drawn to The Control of Noise at Work Regulations 2005 [6], which require employers and the self-employed to reduce the risk of hearing damage from exposure to noise to the lowest level reasonably practicable.

NOTE 2 Attention is drawn to The Supply of Machinery (Safety) Regulations 2008 [41], which set out information about noise limit (displayed on the equipment) and on the level of noise emission.

Effects of noise which should be taken into consideration include:

a) immediate effects on hearing, e.g. temporary shift of individuals' hearing threshold, tinnitus, permanent hearing loss;

b) failure to hear some sounds because of hearing damage, causing poor intelligibility of speech;

c) impairing both communication and the perception of warning alarms and signals;

d) distracting persons from following safe systems of work.

NOTE 3 The effects of noise are intensified in tunnels because the confined space increases the reverberant sound field that can be developed by noisy plant and equipment, tools or processes. This is especially problematic if persons have to work close to, or use, noisy tools, e.g. pneumatic pick).

NOTE 4 BS 5228-1 gives guidance on how noise arising from worksites affects site personnel and others living and working in the neighbourhood. It contains information on noise emission from tools, plant and equipment that could be useful at the planning stage in reducing noise and procedures for the control of noise.

NOTE 5 BS 5228-2 gives guidance on legislation covering the control of noise and vibration, and BS 5228-4 gives recommendations for controlling noise and vibration that apply specifically to piling operations.

19.2 Noise emission and exposure

19.2.1 General

A competently executed noise assessment should provide sufficient information to enable the production of a construction-phase health and safety plan describing engineering measures to control noise at source. This plan should specify means of minimizing noise emissions by incorporating low noise tools and processes at the outset, as it might be impossible to install them later.

In situations where it is not reasonably practicable to control noise at source, e.g. by the use of measures such as silencers or damped picks, operators and bystanders, depending upon their level of exposure or by request, should be supplied with personal hearing protection as an interim means of reducing the level of noise. This should reduce the noise to below that associated with the SAL.

NOTE Guidance on the selection and care of hearing protection is given in HSE publication L96 [25], as well as in BS EN 458.

19.2.2 Tunnel face

All machines and tools should be selected to be of low noise emission, taking account of operator and other personnel.

19.2.3 Access routes

If possible, noisy plant and equipment should be sited away from tunnel access routes and workstations. Otherwise it should be located within an appropriate noise enclosure.

A noise assessment should include journeys in the man-rider.

19.2.4 Noise sources

NOTE 1 The principal sources of noise in a tunnel vary according to the method of working and the stage in the cycle of operations.

Major sources which should be considered include machines, tools, ventilation equipment and air leaks.

NOTE 2 Other sources of noise include high-pressure compressed air, airlock discharge pipes, pumps, materials handling, conveyors, hoists, winches, diesel plant, diesel locomotives, concrete pumps and placers and compressors.

Noise emission at source should be reduced by silencing or by the use of acoustic screening.

NOTE 3 In hand tunnelling, pneumatic tools are the principal source of noise.

Silenced tools, including the use of acoustically damped moil points or spades, should be considered.

NOTE 4 In rock tunnels, drilling, blasting and spoil removal all generate noise, each with its own characteristics. Blasting produces peak sound pressures that can exceed the PAL.

Measurements of peak sound pressure should be used to indicate whether withdrawing persons from the face, and/or the use of hearing protection, can reduce exposure to below the PAL.

Care should be taken since noise from tunnelling machines can arise from several sources.

a) On TBMs (**7.6.4**), the ground-breaking operation does not always produce high levels of noise and the machine operation is often the dominant source of noise. Noise reduction measures, such as the enclosure of noisy components including pumps and motors, vibration isolation to reduce structure-radiated noise, and damping of large radiating surfaces, should be incorporated into the TBM.

b) On hard-rock TBMs (**7.6.4.4**), ground breaking produces significant levels of noise. Consideration should therefore be given either to vibration isolation to minimize transmission through, and noise radiation from, the framework, or to the use of an acoustically deadened steel framework (where possible), or both. Where space on the machine permits, a ventilated noise refuge for the operator should be incorporated into the design of the machine.

c) On part-face cutting machines, e.g. cutter boom or other mechanical excavator shields (see **7.6.2**), excavation is across the face by means of a smaller cutting element which cannot normally be enclosed to reduce the cutting noise. Even if the machine has a noise refuge/control cabin, face workers should still use hearing protection.

NOTE 5 Requirements for noise reduction for TBMs are included in BS EN 12111 and BS EN 12336. Information on noise levels for a particular machine can be found in the instruction handbook for that machine.

19.2.5 Noise reduction

Noise should be controlled by using plant and equipment that has been designed to eliminate or reduce the noise at source. This should form part of the initial planning strategy of the project and in purchasing specifications. This proactive approach should be used to minimize the costly operation of retrospectively designing and fitting noise controls when work is in progress.

A noise assessment should be undertaken in order to:

- confirm the adequacy of the noise controls specified; and/or
- identify residual noise sources that significantly contribute to personal noise exposure.

Equipment should undergo regular maintenance checks, with noisy or defective parts being replaced or repaired.

19.2.6 Communication

NOTE 1 Noisy environments can impair a safe system of communication. Frequency characteristics and the level of workplace noise can make communication difficult, e.g. by interfering with speech and by masking warning alarms.

Consideration should be given to the use of communications head-set/hearing protection combinations, which allow conversation in noisy areas without temptation to remove hearing protection.

The effectiveness of audible alarms and warning signals should be assessed using BS EN ISO 7731. These alarms and signals should be audible when hearing protection is worn.

NOTE 2 See also Clause ***18****, Clause* ***20*** *and Clause* ***21****.*

19.3 Vibration

19.3.1 General

COMMENTARY ON ***19.3.1***

Exposure to whole-body or hand–arm vibration resulting from the use and/or operation of tools, plant and machinery can give rise to a significant risk to health.

Vibration should be controlled by using plant and equipment that has been designed to eliminate or reduce the vibration at source. This should form part of the initial planning strategy of the project and in purchasing specifications. This proactive approach should be used to minimize the costly operation of retrospectively designing and fitting vibration controls when work is in progress.

NOTE Attention is drawn to The Control of Vibration at Work Regulations 2005 [7], which require employers and the self-employed to control the exposure to both hand–arm vibration and whole-body vibration so far as is reasonably practicable. The Regulations set a daily exposure limit value of 5 m/s^2 A(8) and a daily exposure action value of 2.5 m/s^2 A(8) for hand–arm vibration. For whole-body vibration, the daily exposure limit value is 1.15 m/s^2 A(8) and the daily exposure action value is 0.5 m/s^2 A(8).

19.3.2 Vibration emission and vibration exposure

19.3.2.1 Level of vibration

The level of vibration declared by a manufacturer can be lower than that measured under "in-use" conditions. Therefore care should be taken, as using the manufacturer's information for the purpose of assessing exposure could underestimate the level of risk.

19.3.2.2 Whole-body vibration exposure

It should be noted that exposure to whole-body vibration (WBV) can give rise to serious health effects.

NOTE 1 Any part of the body can be injured by exposure to a sufficient magnitude of vibration. The parts of the body most likely to be injured during exposure to WBV depend on the distribution of motion/energy within the body, and this in turn depends upon the vibration frequency, axis of motion and body-coupling to the vibrating source. It is not yet possible to provide an adequate dose–effect relationship between vibration exposure and injury and damage to health. Subjective data concerning magnitudes of vibration causing discomfort and pain can give some indication of the possibility of injury for various conditions, although it is recognized that sensations do not always correlate with pathological damage.

NOTE 2 BS 6841 recommends methods for quantifying vibration exposure and gives guidance on repeated shocks in relation to human health, interference with activities, discomfort, the probability of vibration perception and the incidence of motion sickness.

19.3.2.3 Level of hand–arm vibration exposure

*COMMENTARY ON **19.3.2.3***

Vibration is transmitted to the hands and arms of persons when operating vibrating tools or vibrating machinery, and/or operating in vibrating workplaces. Persons who regularly use tools with a high level of vibration, resulting in a high level of exposure, can suffer from several kinds of injury to the hand/arm, e.g. finger blanching, numbness and tingling sensations, and carpal tunnel injury, which are collectively known as hand–arm vibration syndrome (HAVS). Included in HAVS is the injury referred to as vibration white-finger (VWF), which is a painful and reportable injury under The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 [13].

NOTE The Control of Vibration at Work Regulations 2005 [7] and HSG61 [5] give information for assessing vibration exposure and designing a system of health surveillance.

When an assessment identifies a need, actions which should be taken to reduce vibration exposure could include:

- job rotation;
- purchase and use of low-vibration tools and equipment;
- limitation of exposure period by task rotation;
- health surveillance.

20 Shafts, pits and piles

20.1 General

NOTE 1 In this Clause rectangular pits and hand excavated piles are referred to as shafts.

Shaft construction should be considered a safety-critical aspect of tunnelling because:

- their often have a relatively small cross-section compared to their depth;
- their depth means that even small objects falling can cause serious injury, e.g. hard hats;
- of the interface between personnel having to work in the shaft while lifting operations take place;
- of the lack of space to provide effective protection from falling objects;

- of the remoteness from those in control of surface operations;
- of a lack of awareness by those on the surface of the vulnerability of those in the shaft;
- heavy loads are sometimes hoisted for which no protective structure can be built.

NOTE 2 Categories of shaft include:

a) a permanent shaft, designed and constructed solely to meet the requirements of permanent works;

b) a permanent shaft, designed to meet the requirements of permanent works but constructed to allow for the construction of further underground works, before its own completion, by the addition of temporary works or changes to its own detail (e.g. a pipejacking drive shaft);

c) a temporary shaft, designed and constructed for the sole purpose of facilitating the construction of further underground works and which is finally filled in;

d) a shaft designed and constructed initially to provide for the construction of further underground works, but with a design that allows for the subsequent construction within it of permanent works ((e.g. a working shaft later converted into a pumping station).

NOTE 3 The same categories apply for vertical or inclined shafts (see also ***20.3.3*** *on escalator shafts).*

20.2 Design

Design considerations for shafts should take into account the factors listed in **20.1**. Shafts of 6 m diameter or less (or of similar cross-sectional area) present particular difficulties in respect of protection against falling objects. For this reason shafts of 6 m or less should, preferably, be constructed as caissons (see **20.3.1.3**).

Shafts can be permanent or temporary, vertical or inclined. Their design should be checked for all loading conditions, both temporary and permanent, e.g. thrust load from TBM during launch, surcharge from construction plant, change of hydrostatic loading due to dewatering.

The temporary loading condition can exceed the permanent condition, in which case the shaft should be designed for the temporary loading condition. If a shaft is to be built using temporary structural support, it should be treated as temporary work as in Clause **6** and Clause **7**.

The designers should include in the design considerations the working space required for the type plant likely to be needed to excavate the shaft, taking account of the ground conditions.

NOTE 1 This is particularly necessary for shafts of up to 6 m diameter.

If the shaft bottom is to be plugged with concrete, reinforced if necessary, full account should be taken of any possible hydraulic uplift or any possible heave of the formation, or materials which could swell when in contact with water. Clause **9** should be referred to for guidance on the construction of sumps.

NOTE 2 Guidance on shaft design and thrust loads on shaft linings can be found in the PJA design guide [18] and in the BTS "Tunnel Lining Design Guide" [24].

20.3 Shaft sinking

20.3.1 Construction techniques

20.3.1.1 General

NOTE 1 Shafts can be constructed by a variety of means, depending on cross-section, depth and ground conditions.

NOTE 2 The shaft sinking operation can have an impact on the general public, and can affect adjacent structures both above and below ground.

Particular care should be taken in designing and locating shafts to minimize disturbance outside the site. Both safety and environmental factors should be considered.

20.3.1.2 Underpinning

*COMMENTARY ON **20.3.1.2***

*Underpinning is a well-proven technique in firm self-supporting soils or rock. At the base of the shaft, excavation is followed by the installation of ground support. Support can be provided by the use of pre-formed concrete elements or by sprayed concrete (see **7.10**).*

The amount of excavation that can be carried out prior to erection of the support lining depends on ground conditions and should be assessed.

NOTE There is a trend towards shaft units of 1.0 m or 1.5 m in depth which leaves a greater amount of ground unsupported prior to grouting, and increases the risk of sidewall failure.

Grouting should be carried out as required by the ground conditions but as a minimum at the end of every shift.

20.3.1.3 Caisson construction

*COMMENTARY ON **20.3.1.3***

In order to maintain continuous support in non-self-supporting ground or water-bearing ground, a form of caisson construction is often adopted. This can utilize either in-situ concrete or precast concrete elements.

In suitable ground conditions caissons can be excavated by grab without the need for persons to be present within the shaft during construction. For this reason this method of shaft construction should be used for shafts of 6 m diameter or less (see **20.2**).

Hydrostatic balance should be maintained in water-bearing ground to avoid ground movement around the shaft.

Consideration should be given to how new units are placed on the top of the shaft and how suitable shaft perimeter edge protection can be provided and maintained. Externally bolted segments or one-piece lining rings should be used. Where necessary, purpose-made building cages or stages within the shafts should be used to allow good access to internally bolted segment joints.

NOTE 1 Unless the primary lining is very heavy, additional load might be required to maintain penetration of the cutting edge. The use of kentledge weights stacked on steel frames is a traditional system for sinking, but placing or removing these weights can put persons at risk. An alternative form of caisson construction is by the use of jacks.

Jack frames and their supports should be designed for the anticipated loads to be imposed, and the jack pressure should be limited to that specified in the design of the jacking frame and its supports. If shoes or spacers are used they should be secured so that they cannot fall into the shaft in the event of jacks becoming slack.

NOTE 2 A fluid such as a bentonite suspension could be used to support the ground and reduce friction during caisson sinking.

When a combined system of caisson construction followed by underpinning is used, the caisson should be secured before underpinning commences. Work under cutting edges should not take place unless the shaft lining has been secured.

20.3.1.4 Shafts with pre-installed linings

NOTE In some circumstances it is preferable to install the shaft lining before shaft excavation takes place. Lining types include contiguous bored or driven piles, sheet piles, diaphragm walls and secant piles.

Additional support should be placed as excavation proceeds if required by the design. Loose material should be cleared from the internal surface of the lining as excavation proceeds to avoid it becoming dislodged by vibration or drying out when exposed.

In principle, sheet piles, secant piles and diaphragm walls should form a watertight shaft lining.

The design should provide for adequate toe-in to ensure stability of the base of the excavation.

20.3.1.5 Drill-and-blast

Drill-and-blast technique should normally only used in rock as it can present environmental problems in urban areas. The risk of flying debris and vibration should be addressed in relation to both structural damage and personal injury. It should be noted that underground services can be at greater risk of damage (see **7.8**).

Different types of detonators and explosives should be selected for shaft sinking, to suit the type of ground, water conditions, and possible stray electrical currents from buried cables. Careful checks should be made for potentially explosive gases before blasting.

NOTE The use of 0.5 s delay detonators is not always appropriate in shaft sinking due to re-compaction.

20.3.1.6 Raise bored shafts

Raise bored shafts should not need any lining. If the ground investigation identifies a need for a lining, a different construction method should be used.

20.3.2 Shafts under construction

Normally, mechanical means of excavation should be used and that measures should be taken to ensure the safety of all personnel. The number of persons in the shaft bottom area should be kept to a minimum while operations are in progress. Procedures should be set up to avoid persons being underneath suspended loads wherever possible. In small-diameter shafts, particular care should be taken due to the limited scope for refuge, and all persons should be alerted (see **20.8**) to any loads being sent down.

Shafts of less than 6.0 m diameter which cannot be excavated mechanically should be avoided. In shafts of less than 6 m diameter where only hand excavation is reasonably practicable, appropriate mitigation measures to address the risks from manual handling, heat stress, noise and vibration should be put in place.

All skips used in shafts should have positive fixings so that they cannot tip while being hoisted. Other risks, such as that from material falling off the top due to overfilling, or loose material becoming stuck to the bottom, should be assessed and minimized.

Larger shafts are often excavated by a 360° hydraulic excavator working within the shaft and measures should be taken to minimize the risk of persons being struck or trapped by moving plant.

In many shafts ventilation is required to maintain air quality and should be provided where the air quality cannot be assured.

When handling loads with a crane or hoist, it should be ensured that:

a) the load or skip does not swing or twist, causing it to strike the lining of the shaft or other structure;

b) the load or skip does not catch a ledge, either in lowering or in hoisting, causing it to tip over and spill out its contents (whether persons or materials);

c) the rope does not become slack when the load is resting on the bottom or on a stage and catch in some part of the shaft structure, with resultant damage when tightened.

All plant regularly transferred down the shaft should be designed for hoisting and should be tested and certificated for such a purpose.

As a standard procedure in lifting, the load should be lifted a short distance then stopped, steadied and inspected before hoisting continues.

As excavation proceeds, the shaft should be fitted with skip guides or partitioning to protect personnel, e.g. an enclosed ladder bay.

20.3.3 Inclined shafts and escalator shafts

NOTE Due to the steep angle used on escalator drives, they are invariably classified as shafts rather than adits. Excavation, ground-support, and transport systems, however, all tend to follow tunnelling practice.

To minimize the dangers presented by the steep gradient, special attention should be given to preventing unintentional movement of plant and equipment on the sloping invert.

The design of the face support system and access stages should be given particular care to check that the correct transfer of face loads takes place. Detailed method statements, and thorough personnel training, should be provided at the commencement of the shaft.

Shafts should be driven downhill wherever possible. If, at the beginning of the construction stage, the shaft has to be raised uphill, a pilot should ideally be driven before enlarging from above using the pilot for the transport system. Uphill drives should be planned in such a way as to minimize the risk from overhanging ground falling away. Transport systems on uphill drives should be limited to overhead (monorail) types, which can be rope, rack or friction operated. Very careful advancing techniques should be used, as the safety features need to pace with the moving face as the shaft is constructed.

Personnel access should be by stairs or walkways with gripper battens.

20.3.4 Transport systems for downhill drives

20.3.4.1 Monorail

*COMMENTARY ON **20.3.4.1***

In a monorail transport system, the load is suspended from a roof-mounted beam, and moved by rack and pinion, rope haulage or friction wheel drive.

A fail-safe system should be put in place to prevent or limit runaway.

NOTE Systems used can include speed-applied grips, double-drum, double-braked winches with double ropes, and regular "dodgers" or pawls that are released in turn manually.

20.3.4.2 Invert rail mounted system

NOTE 1 In an invert rail mounted system, wagons are winched from fail-safe winch units at the head of the shaft located in a level marshalling area.

A visual and/or audible warning system should be installed to warn face workers when the haulage system is in use. The winches should be selected to operate well below the rated maximum hoist load, to ensure reliable operation of the rope and braking systems. A fail-safe braking system should be fitted. Rope fixings onto the wagons should be secure to prevent uncoupling, and only rope fixings manufactured specifically for this purpose should be used.

Safety gates should be fitted on the incline, and interlocked consecutive gates should be installed, one of which is always closed.

NOTE 2 As the shaft progresses, more gates may need to be added to limit the maximum possible runaway energy to be contained by a gate.

Special care should be taken in the initial stages where there is insufficient space for the full gate installation.

Hoist operators should be trained and issued with certificates.

All plant and safety mechanisms on transport systems should be examined and serviced regularly, and records should kept.

20.4 Disused shafts

20.4.1 Permanently disused

When a shaft is to be decked over on completion of its use, the decking used should be specifically designed for that purpose and should be installed for its intended use. Although a shaft is permanently disused access should still be provided for asset management and maintenance purposes. Traceable records should be kept of all disused shafts giving details of the shaft or tunnel and the method of capping or filling.

20.4.2 Temporarily disused

When a shaft is temporarily disused following sinking, it should be securely covered to prevent unauthorized access, e.g. by children. However, a lockable opening should be maintained in the cover in order to enable escape or to allow access for inspection purposes. The cover should be vented.

20.5 Tunnel eye

A shaft through which any opening is to be formed should be designed to facilitate the safe construction and use of that opening. The use of a soft eye or of glass fibre reinforcement in the shaft lining should be considered to facilitate the breakout from the shaft. Before breakout the ground water level and pressure outside the shaft should be checked.

When a tunnel eye is to be provided through which the tunnel or heading is to be formed, the shaft structure should be supported as for a tunnel opening (see **8.4**).

The actual operation of breaking out should be carried out with the utmost care because the ground is inevitably disturbed by the sinking of the shaft, and it is probable that water has followed down the side of the shaft, however carefully the grouting has been done. Immediate close support of all ground should therefore be considered essential.

Where TBMs are entered through the tunnel eye (EPBMs or slurry shields), the tunnel eye should be fitted with an appropriate seal to prevent ground or slurry loss. A sealing system should also be used to contain lubricant or annular grout for use with pipejacking systems. Consideration should be given to a similar system at the reception chamber.

In bad ground the first setting of a heading should be fixed, or the first ring of iron or concrete be built within the shaft.

NOTE Alternatively, a small heading can be driven out of the shaft, from which a break-up for the full size access tunnel is constructed at a safe distance in undisturbed ground, the heading or tunnel being subsequently enlarged back to the shaft.

20.6 Shaft top layout

The layout and detail at the top of the shaft should be designed to facilitate the delivery, unloading and handling of materials as well as to prevent the accidental fall of persons, plant, spoil or material into the shaft.

The area immediately around each shaft should be level, clear of obstructions and drained. It should provide a safe working area and should be adequately lit (see Clause **17** and Table 8).

Stacking and storage of materials should be arranged at a distance from the shaft top so that excessive ground pressures are not imposed on the shaft.

The shaft should be guarded using, for example, additional segmental rings or substantial steelwork and mesh, which should reach a height of at least 1.2 m above adjacent ground level. A solid barrier should be provided, reaching a height of at least 225 mm above ground level.

Facilities should be provided for the shaft top banksman to have a clear view into the shaft from a place of safety.

Surface water should be excluded from the shaft by the provision of barriers and by drainage and pumping if necessary. Special precautions should be taken against inundation (see **10.3**).

Mobile plant poses a particular hazard; either it should be physically prevented from working near a shaft, or barriers should be erected that are robust enough to prevent the equipment from falling into the shaft.

Services in the shaft fed from the surface should be fixed to the shaft wall and protected from impact by swinging loads.

20.7 Personnel access

Personnel access in shafts should be by fixed access equipment such as a mast climbing hoist or man-riding crane where it is reasonably practicable to provide such equipment.

In all cases where the normal means of access is by mechanical means (hoist or crane), there should be a secondary means of egress to cover plant breakdown. The secondary means should be available within a reasonable period of time, to be determined according to the level of risk on each job.

NOTE This allows for the use of a second crane, for example, which can be located a short distance away, or a davit hoist when a second crane is not available on site. The use of cranes and hoists is covered in Clause ***21****.*

Fixed access should be provided in every shaft as early as possible, and in any case on completion, except where an alternative route provides safe pedestrian access to the base of the shaft. Fixed access includes stairways, ladderways or vertical ladders with protective hoops and it should be designed in accordance with BS 5395-3 and with BS 4592-1, BS 4592-2, BS 4592-3 and BS 4592-5.

Stairways should be used whenever possible as the preferred option, as these allow persons to carry hand tools and similar equipment.

Where used, timber ladders should conform to BS 1129 and should be fixed to form an inclined ladderway. Every ladder should be securely fixed at its base and at the upper landing. It should extend at least 1.1 m above the upper landing unless other adequate handhold is provided.

Vertical ladders fixed to shaft walls should be made of steel (rather than light alloy or timber). Vertical ladders should have protective hoops and straps fixed above a height of 2.5 m from a landing.

The foothold at every rung on all ladders should be unobstructed. Landings should be at intervals not exceeding 6 m. They should be solidly constructed with hand rails, guard rails and toe boards. Openings for ladders should be as small as is practicable and sited clear of the foot of the upper ladder. Every landing should be adequately lit (see Clause **17**).

Stair bays and ladder bays in shafts should be protected by substantial barriers against swinging loads being handled in the shaft.

All means of access including hoists should be inspected weekly, and maintenance carried out where necessary.

Standard provision should be made for the safety of persons working at a height.

Allowance should be made for recovering stretcher cases, either in ambulance cages or by special emergency slings.

20.8 Communication

A means of communication should be provided between persons at the shaft top, and those working in the shaft, which allows for difficulties caused by background noise, obstructed vision, etc.

NOTE 1 A voice communication by radio or visual signalling can usually cover all needs.

*NOTE 2 See also Clause **18**, Clause **19** and Clause **21**.*

21 Lifting equipment

21.1 General

NOTE 1 Attention is drawn to The Lifting Operations and Lifting Equipment Regulations 1998 [42] and supporting Approved Codes of Practice which carry information on the use of lifting equipment in tunnelling and associated operations. They are referred to hereafter in this Clause as the Regulations. The Regulations include requirements for inspection and thorough examination, which involve testing of lifting equipment and accessories for lifting.

Any examination scheme prepared under the Regulations should take into account the severely corrosive conditions that can occur in below-ground works.

BS 7121-1 should also be followed in the erection, use and dismantling of cranes for which the principal installation recommendations are secure support and anchorage, safe clearances and clear visibility.

NOTE 2 Attention is also drawn to The Provision and Use of Work Equipment Regulations 1998 [43].

21.2 Cranes

21.2.1 Cranes at shaft

The types of crane which should be considered as most appropriate for tunnel and shaft construction are crawler cranes, mobile cranes and gantry cranes. They should also be seen as more suitable for shallow shafts than for deep shafts because of the progressive difficulty of control. Due to the length of hoist rope needed, standard cranes should not be used for deeper shafts.

NOTE Crane operations include both routine hoisting during tunnelling and the lifting of one-off heavy loads such as parts of TBMs or tunnel excavators.

The surface layout should be designed to ensure that crane positions have the least possible adverse effect on other site activities or on any surrounding urban environment and 24-hour working should be considered where appropriate.

When siting a crane in the vicinity of any shaft, care should be taken to ensure the imposed ground loads from the crane do not adversely affect the proposed shaft or tunnel works or that shaft sinking does not affect crane stability. A platform for siting a crane should be designed and constructed in order to minimize settlement, to spread crane loads as widely as possible, and to avoid excessive lateral thrust from the ground against the shaft lining.

With mobile cranes that are not restricted to predetermined locations, loadings imposed upon the ground should be kept within safe limits.

Rope lengths should be checked to confirm that at least two full turns of rope remain on the hoist drum when the hook is at full depth in the shaft bottom, including any sumps.

21.2.2 Clearances

Where adequate personnel clearance around a crane cannot be provided, access to areas of restricted clearance should be prevented while the crane is operating.

21.2.3 Long loads or complex lifting operations

NOTE Long loads might need to be slung vertically because of restricted space.

For such lifting operations the slinging arrangements should be devised to ensure the stability and security of the load. Where possible this should be done by providing properly designed lifting points. The load under suspension should be secure at all times and the lifting speed controlled to prevent the load from swinging out of control.

The shaft should be cleared of persons other than any essential to the hoisting operation while the lift is in progress. These persons should be safely positioned.

Complex lifting operations such as lowering a TBM which involve tandem lifting should be specifically planned and supervised.

21.2.4 Lifting accessories

Suitably certified (according to LOLER requirements) chains, slings, rope slings and lifting equipment, marked with their safe working loads, and hooks of a safe type should be used. Copies of current test certificates should be held on site.

Suitable lifting accessories should be provided for all loads. Systems should be developed for handling segments, pipes, rails, etc. with no risk of load displacement.

21.3 Winches

NOTE Winches are used extensively in tunnelling operations, e.g. for hoisting skips.

Only winches intended for lifting and fitted with powered-off brakes, should be used for hoisting loads.

Where winches or snatch blocks are used, their safe working load and that of their mountings should be clearly marked and strictly adhered to. Their mountings or anchorage points should be specifically designed and tested.

A system for inspection and maintenance of winches and associated equipment should be instituted, and records of those inspections should be maintained.

Tunnel lining bolts and their sockets should not be used as anchorage points unless their safe load-carrying capacity has been specifically ascertained.

21.4 Materials hoists

Fully automatic materials hoists should be enclosed with guards or barriers at all points of their length of travel where persons could have access or be struck by moving parts of the installation or by falling materials. Interlocked gates should be provided at all landings. Further protection should also be provided to prevent the hoistways being fouled by rails, pipes or other materials being handled in the vicinity.

For operator-controlled hoists, the operator should be able to observe the load at any point of its travel.

NOTE Banksmen or visibility aids can be required. This can also involve the use of pendant controls.

21.5 Communication

Good communication between the surface and the working level should be kept both for control of all hoisting and lowering operations and for the exchange of information on loads being handled.

Slinger/banksmen should be designated, and should have undergone specific training. The movement of loads by lifting equipment other than fully automatic hoists should be, at any stage, under the control of one person.

*NOTE 1 See also Clause **18**, Clause **19** and Clause **20**.*

Care should be taken because the plant operator might not have an uninterrupted view of the load while it is within the shaft.

There should be a safe system of work in place to allow the operator to see and control the load and/or be instructed in moving the load.

NOTE 2 This can include the use of:

a) radios;

b) banksmen;

c) CCTV;

d) signal lights;

e) audible signals; and

f) remote control of the crane by the operator.

NOTE 3 For some parts of routine lifting operations in tunnelling such as the self-tipping of skips, a slinger/banksman might not be required for that part of the operation.

When more than one signaller is responsible for directing the lifting operation, the transfer of responsibility should be clearly defined.

The visual system of crane signals in BS 7121-1 should normally be used, except where the signaller is viewed from a position where normal crane signals could be misinterpreted, such as by a person in the bottom of the shaft. In this case, a clear code, including transfer of responsibility, adapted to the particular site, should be devised and made known to all responsible. Fail-safe systems should be as detailed in BS 7121-1. Where the code is audible, it should be in accordance with **18.3**.

NOTE 4 The use of CCTV, linking the plant operator at the surface to the shaft bottom, can enhance safety and allow the operator to view the hook and load.

Where appropriate there should be a hand-over between the signallers at the pit top and pit bottom as the load moves into and out of camera view.

CCTV should be used to enhance operator visibility rather than replace normal visual checks of shaft operations by the banksman.

Hands-free radio sets (head sets with fixed microphones) provide an effective means of communication with the plant operator and should be considered for use in busy locations.

Verbal instructions should be given at normal voice level to allow the signaller to simultaneously guide and signal a load into position.

21.6 Carriage of persons

21.6.1 General

A crane or hoist should be used for the carriage of persons only if it was constructed for that purpose.

*NOTE Attention is drawn to **21.1**.*

21.6.2 Use of crane

When a crane is used for the carriage of persons, it should conform to BS 7121-1.

A cage should be used, constructed to enclose the passengers fully, with an inward opening gate. The cage should be rated and tested for the maximum load and a notice should be prominently placed specifying the maximum number of persons that can be accommodated.

Exceptionally, a purpose-built open-topped man-riding skip or basket is used for working in shafts; such a skip or basket should be specifically designed and constructed for man-riding. The safe working load (SWL) and maximum number of occupants should be marked.

21.6.3 Use of hoist

If for any reason the gate cannot be operated, the cage should have an emergency escape opening panel, or other device for use in an emergency. Gates should be interlocked by mechanical and electrical devices.

21.6.4 Injured persons

Safe and secure means of lifting out injured persons should be provided, such as a basket stretcher capable of lifting a person in a horizontal position. Slings to secure the patient without making worse any injury should be used under the control of qualified first aid personnel familiar with the system.

22 Access

22.1 Walkways

Pedestrian access should be properly identified and provided by walkways in the tunnel. Every tunnel should have a safe pedestrian route from face to pit bottom, with escape routes properly signed, and thence by ladder or stair tower to the surface.

NOTE 1 In shafts and tunnels where man-riding is carried out, a walkway might be required only for maintenance access or for emergency evacuation.

NOTE 2 Attention is drawn to The Construction (Design and Management) Regulations 2007 [1] and The Work at Height Regulations 2005 as amended [44].

NOTE 3 See also ***13.6****.*

The pedestrian route should be clearly delineated and signed as appropriate. Where practicable, a walkway should be provided within a minimum clear space of 2 000 mm high and 900 mm wide, with a walking surface not less than 430 mm wide. Where reasonably practicable, a walkway should be physically separated from an adjacent traffic route, otherwise precautions should be taken to safeguard any persons using it during the passage of vehicles, unless the simultaneous passage of pedestrians and vehicles is prevented. Extra clearances should be allowed for side-throw, end-throw and sway of vehicles.

Where continuous clearance with the recommended minimum dimensions is not practicable, refuges should be provided at intervals related to visibility, the curvature and gradient of the tunnel and to traffic speed.

Care should be taken as the visibility of both vehicle drivers and pedestrians can be adversely affected by dust or humidity in the atmosphere. Refuges should therefore be clearly illuminated and should comprise:

a) recesses constructed outside the general line of excavation;

b) robust barriers between the safe position and the haulage route;

c) stages raised clear of any possible hazard.

Refuges should also be provided where there is no space for a segregated pedestrian walkway and man-riding is not in use. In addition, a safe system of work (including a permit to work) should be implemented to protect persons who are required and authorized to work within the tunnel from the danger of tunnel transport.

The walkway surface should be maintained in good condition, should provide adequate grip and be free from hazards such as irregularities, sudden changes in level, loose boards, obstructions, etc. which could cause slipping, tripping or falling.

NOTE 4 The walkway could be used by the emergency services in conditions of nil visibility.

Elevated walkways from which a fall is possible should be provided with suitable guard rails and toe boards. Hand rails or similar should be provided on inclined walkways. All stairways should be provided with guard rails and toe boards.

Water should not be allowed to stand or accumulate at or above walkway level at any point. Any accidental spillage of muck or other material on a walkway should be cleared away promptly.

NOTE 5 Recommended illumination levels are set out in Clause ***17****.*

Lighting should be provided along a walkway, not only to assist pedestrians, but also to allow haulage drivers to see pedestrians clearly. The lights should be located so that they are not obscured by moving vehicles.

In tunnels which are normally unlit, and where only occasional access is required for inspection and maintenance, refuges should be identified by reflective material. As necessary, reflective signs indicating escape routes should also be posted. Persons entering unlit tunnels should be equipped with a suitable hand/cap lamp and appropriate means of communication (see Clause **18**).

Access on foot should not be permitted in a tunnel while a winch haulage is in operation, unless there is adequate protection to the walkway.

22.2 Access for maintenance

Where access in tunnels is required for the purposes of maintaining the tunnel or to carry construction equipment through the tunnel, the safe system of work should address:

a) minimum dimensions for access. These should be in accordance with the BTS/PJA/HSE table [5)] (but see also **22.1** and **7.14.1**);

b) adequate ventilation;

c) gas detection equipment;

d) rescue procedures with due allowance made for the reduced number of personnel on site, and obstructions in the tunnel;

e) necessary rescue equipment with due allowance made for self-rescue sets, the type of breathing apparatus and stretcher availability;

f) avoidance of lone working;

g) communication equipment.

For major maintenance consideration should be given to the removal of machinery to the surface, the construction of a dedicated maintenance shaft or the excavation of a maintenance chamber underground.

22.3 Gradients

NOTE Up to a slope of approximately 30°, pedestrian access can be achieved on a properly constructed stairway.

Special equipment, such as a bucket conveyor, should be used for any access tunnel steeper than 30°. In the steeper tunnels protection should be provided against falling material.

22.4 Temporary tunnels

Temporary tunnels which are specially built for access purposes should be built to be as safe as permanent tunnels.

22.5 Working at height in tunnels and shafts

Where work at height is required in tunnels and shafts, the system used should be fit for purpose. For work such as the installation of bolts in tunnel linings or mesh in sprayed concrete linings, mechanical access equipment should be used. Fixed ladders and access platforms or permanently installed moveable platforms should be provided where work at height is regularly required at the same location, e.g. to place and tighten tunnel lining bolts on TBMs.

NOTE For short-duration work at height, ladders are acceptable, provided that they can be properly grounded and secured.

Mobile access towers should not normally be used for work at height, given the rigours of the tunnel environment.

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5) See www.pipejack.org.uk for information on the table.

23 Transport and loading

23.1 Rail haulage

23.1.1 General

The use of railborne plant should be planned and safe operating procedures agreed. It should be noted that factors affecting the choice of system are:

- gradients;
- length of main haul;
- rate of muck removal;
- clearances;
- total mass of trains;
- whether passing points are required;
- size and availability of haulage system.

A risk assessment should be carried out for all rail operations. It should be the responsibility of site management to give instructions on the maximum loads that can be hauled and the maximum speeds that are allowed on the tunnel gradient(s). Locomotive drivers should be authorized in writing by the site management after their training, testing and the issue of a "training certificate".

NOTE 1 The braking performance of the haulage system (whether locomotive, rope or manpower) determines the mass of train or skip that can be transported safely.

The recommended retardation for steel-tyred locomotives should be 2% g (0.196 m/s^2). Where this cannot be achieved, the absolute minimum service braking effort should be 16% of locomotive weight. When hauling up a gradient, a locomotive should never be used to haul a load greater than that which it is capable of safely braking when travelling down that gradient, without recourse to engine braking. It should be possible to stop a train within the range of its driver's vision under the worst conditions. This distance should not exceed 60 m.

The correct locomotive for any application should be selected by careful calculation for which there are established formulae available from manufacturers. Manufacturers or plant hire companies should be consulted for advice. Preference should be given to trains with full or partial air brakes, which are inherently safer than trains that rely on braking by the locomotive only.

In particular, the conditions for starting uphill and for braking should be analysed. The adhesion between rail and wheel can vary from 25% in good dry conditions to 15% or worse in bad conditions caused by muck spillage or oil. Steep or long gradients can require extra measures to prevent accidents. Where wagons do not have individual braking and are down gradient relative to the locomotive, they should have secondary couplings or safety chains. Locomotives fitted with power brakes that are not fail-safe should have a secondary manual system.

NOTE 2 There is a risk of train runaway if the driver exceeds the permitted speed, or train loading, for a given locomotive on a given gradient.

Where the consequences of overspeeding, identified by the risk assessment, would be serious (collision or derailment), automatic warning equipment should be fitted. Automatic overspeed brakes should be considered for the steepest gradients. Where a train is required to operate on steep gradients (2% or steeper, and more than 50 m long), the braking efficiency should be checked by full safe testing as the tunnel progresses.

Appropriately qualified and experienced engineers should be given specific responsibilities for the continued safe operation of a railway system. These include:

- the selection and training of drivers;
- the enforcement of site safety procedures;
- regular auditing of maintenance procedures for both track and rolling stock, and keeping maintenance records;
- specifying and checking the haulage system relative to loads, distances and gradients.

NOTE 3 Attention is drawn to The Construction (Design and Management) Regulations 2007 [1], which give statutory requirements for transport during the construction process.

In the case of operational railways, the advice of HM Railway Inspectorate should be sought.

23.1.2 Clearances

Methods of working should be adopted that prevent persons being in hazardous areas during train operation, e.g. a ban on walking or working in the tunnel, provision of continuous walkways with handrails separating the walkway from train operations, or pedestrian refuges at regular intervals not exceeding 50 m, restricting access around machinery, and providing man-riding cars and suitable access routes. In most cases, pedestrian access to the face along the track should not be considered safe.

Track maintenance should not be attempted during train operations. In exceptional circumstances, when other work in a tunnel is required adjacent to live train operations, a safe system of work should be adopted which includes adequate refuge space, a nominated lookout, and flashing warning lights being placed at either end of the section of track affected. Locomotive drivers should be made aware of the work in progress.

*NOTE 1 Further information on illumination is given in Clause **17**, and on communications in Clause **18**.*

Locomotives should be provided with driver-containment cabs to avoid possibility of striking equipment within the tunnel.

NOTE 2 Particular areas of concern include TBM back-up systems, where loading conveyors, ancillary plant and equipment are located very close to the train vehicles.

Locomotives used in smaller tunnels (less than 2.5 m diameter) should be selected to allow clearance for personnel, and to leave room to manoeuvre a stretcher past an immobilized locomotive.

23.1.3 Propelling

The additional risks to persons in the tunnel from propelling (or breasting) trains (where a locomotive pushes a train from the rear) due to problems of poor driver visibility, should be considered.

In addition to the locomotive lights (see **23.1.4.1**), the train should be equipped with a warning light on the lead vehicle. The train should be propelled only where the driver can see sufficient of the track ahead of the train to be able to stop within his field of view (see **23.1.1**) or where the train is under the control of a banksman who is in a safe position.

Trains being propelled into the backup equipment on a TBM should be under a controlled signalling system and persons should be kept off the tracks when the train is moving.

NOTE Where trains remain marshalled for production, CCTV can be used to allow the driver a good view ahead.

Visibility from the driver's cab should be sufficient to avoid the need for the driver to lean out of the locomotive and risk striking obstructions within the tunnel (see **23.1.4**).

Where locomotives are attached to both ends of a train, a system of work should be adopted to ensure that the train is controlled from the lead locomotive only. The driver should move off only after checking that all persons are clear, or safely aboard.

23.1.4 Locomotives

23.1.4.1 General

Any self-propelled railborne vehicle should be classed as a locomotive. Any new locomotive should comply with BS EN 1889-2.

NOTE PUWER require that drivers are provided with adequate protection against impact injury caused by accidental contact with external objects.

The design of cab or driver-containment enclosure should allow reasonable freedom of movement for the driver. Visibility should be adequate for safe driving of the train. It should be possible for the driver to be able to leave the locomotive when in a section of tunnel where one or other side is adjacent to the wall and while coupled to a train.

A daily functional brake check should be carried out by the regular drivers, supplemented by brake testing in accordance with a maintenance programme at a frequency determined by project-specific duties and hazards.

Locomotives should be checked and, if required, serviced at least weekly when in use. This should follow the manufacturer's service schedules, and the work should be logged.

In addition to the requirements in BS EN 1889-2 for lights on a locomotive, the lights should automatically show white in the direction of travel and red to the rear of the locomotive when a travel direction is selected.

23.1.4.2 Fuelling

*NOTE The storage and handling of diesel fuel can give rise to fire hazards (see **13.1.3, 13.4.3** and **15.4.3.9**).*

A design of locomotive should be chosen in which the fuel tank is located as far as reasonably possible from hot engine components, and where the tank is below the fuel pump (to prevent spillage in the event of leaking pipework). The quantity of stored fuel should be kept to a minimum, which is normally taken to be one day's supply. All fuel connections should be of good quality robust pipework. Where high-pressure fuel leaks can spray onto a hot exhaust system, baffles should be fitted.

Fuelling operations should, wherever possible, be outside the tunnel, but where underground fuelling points are unavoidable, particular attention should be paid to local drainage and the provision of fire extinguishers in the vicinity that are appropriate for the type of fuel being used. No welding, cutting or any other hot work should be carried out within 10 m of the fuelling point or at any height vertically above the fuelling point.

The area in which fuelling operations are carried out should be designed to facilitate the containment and removal of spilt fuel and should be kept clear of combustible waste. The fuel store should be constructed from materials that are non-combustible when tested in accordance with BS 476-4, and any waste material such as rag and paper should be removed promptly. All tanks should be bunded. The fuelling plant should be used only by designated persons. At least one person should be designated to be responsible for the fuelling area and to monitor its safe use.

23.1.4.3 Battery locomotives

An area should be designated for the safe charging of batteries that is well ventilated (to disperse the hydrogen given off during charging) and that is near a supply of clean water (to wash off spilt acid).

BS 6133 gives guidance on minimum local ventilation requirements.

The lids on battery boxes where the design allows accumulation of hydrogen within the box should be lifted. The correct type of charger should be used for each battery to eliminate heating and possible explosion of cells. Defective chargers should be repaired by an electrician as soon as a fault is evident. Smoking and naked flames should not be permitted within 10 m of the charging point and lighting should be intrinsically safe.

NOTE HSE publication INDG139 [45] provides additional useful advice.

Battery locomotives should be fully isolated by disconnecting the main battery plug when left unattended as this prevents battery overheating and gassing caused by any double earth fault on the locomotive.

23.1.4.4 Locomotives with external current collection

NOTE In exceptional circumstances locomotives with external current collection can be used.

Special precautions should be taken when using locomotives with external current collection from catenary wire, third rail, or conductor bars, where the voltage exceeds 110 V. These precautions should either protect persons from physical contact with the conductor (e.g. by the use of barriers, by locating the conductor out of reach or on a separate route to normal travel, or by the use of prominently placed warning signs), or take the form of approved earth leakage systems.

23.1.4.5 Potentially explosive atmospheres

NOTE BS EN 1889-2 specifies requirements for locomotives for use in atmospheres containing potentially explosive gases (e.g. methane, or hydrocarbon fumes). Further guidance can be obtained from BS EN 60079-10-1 and BS EN 60079-14.

Where the risk is low, monitors detecting low levels of potentially explosive gases should be used in order to stop locomotive operations before 5% of the LEL of the gas is reached (see **12.5**).

23.1.5 Rolling stock

NOTE Muck skips are usually designed for either tipping or hoisting.

When skips are hoisted, they should be regarded as a piece of lifting equipment (see Clause **21**) and should be designed and used accordingly. Periodic examination and testing should take place as for lifting tackle. When skips are tipped, provision should be made to lock them during travelling.

Purpose-built skips and materials bogies should incorporate restraint of the intended load to prevent, for example, a box or stack of segments from sliding off and fouling walkways. The vehicle should be inherently stable when loaded, even on poor track and with rough handling.

Personnel should only be transported if purpose-built man-riding cars are used. These should be attached as near the locomotive as possible with a safety chain in addition to the coupling. A man-riding car should be constructed with proper seats, side bars and a crash cage. It should be constructed to contain passengers within the vehicle while in motion and to withstand derailment with minimum injury to passengers. The largest practical wheel size should be used with a suspension system on man-riding cars.

23.1.6 Couplings and buffers

NOTE 1 The correct type of coupling to be used depends upon the combination of vehicles involved but can either be a rigid bar with pin type connections, or a loose link coupling working in tension only.

The loose link type of coupling should allow safe propelling of a train without uncoupling or jamming. The links should not jump off skip-towing pins. Where solid link couplings with long slotted holes are used instead of the classic three-link coupling, they should be free-fitting to avoid jamming.

Couplings should be designed to accept the maximum snatch load on start-up or during braking. Adequate allowance should be made for wear due to prolonged use. By using link-type couplings constructed to conform to lifting gear regulations it should be possible to select ready-made safe designs.

NOTE 2 Automatic self-coupling devices are fitted to many of the larger rail vehicles and provide a safe system of train coupling and should be used where feasible.

Rigid bar type couplings should be used for vehicles with large overthrow to avoid buffering problems when propelling round curves or on uneven track. Manufacturers' recommendations should be followed.

When propelling with link-type couplings, buffers or buffing beams should be matched on adjacent vehicles so that the heights are the same and the overthrow (distance from the nearest axle) is similar.

NOTE 3 Failure to match can result in jamming and side thrust on curves, possibly leading to derailment.

Secondary couplings or safety chains should be used between the locomotive and unbraked vehicles.

All couplings should be subject to an inspection and maintenance regime to detect excessive wear, bending, or overloading. Damaged couplings should be replaced.

23.1.7 Track

Track should be properly supported and secured against displacement in the tunnel. Rails should be of adequate section, laid to gauge on an even surface and jointed with bolted fishplates, or by other equivalent means.

NOTE 1 The following list gives an indication of suitable rail section to use with sleeper spacing not exceeding 900 mm.

a) 9.92 kg/m (20 lb/yard) – 1.5 tonnes axle load.

b) 17.36 kg/m (35 lb/yard) – 3.0 tonnes axle load.

c) 24.80 kg/m (50 lb/yard) – 4.5 tonnes axle load.

Flush fitting, tapered-edge fishplates with four bolts should be used for a tight, smooth joint. The rail ends should be saw cut and fishplate holes drilled.

NOTE 2 Due to the specification of the rail steel, any cutting or welding of rail can cause minute shrinkage cracks which spread if stressed, eventually leading to fracture.

For this reason cutting and welding should be avoided, and cold sawing, drilling and clamp-type connections should be used instead. If hot work is to be carried out, the rail should be preheated and cooled under controlled conditions.

NOTE 3 Poor track laying can lead to gauge spread, slack joints, and violent slewing. In unlined tunnels the track can suffer from sinking and rolling. These problems can be avoided by provision of suitable base materials to allow safe laying and maintenance of the track.

A designated person should be responsible for the maintenance of the track.

To avoid derailments, turnouts and crossings should be laid on a sound base to accurate gauge and maintained with adequate guide rails and close fitting switch blades. The radii should allow the largest vehicle to pass without flange jamming and jumping.

Sidings for the storage of unbraked skips should be constructed on the level. Scotches should be used to prevent accidental movement.

23.1.8 Winch haulage

Where the gradient is such that winch haulage has to be used, special precautions should be taken to anchor the winches securely, to control the ropes and to check the brake operation of the winch.

The vehicles and rail tracks should be fitted with devices such as automatic brakes, catch points, and protection gates (e.g. Manchester gates) to arrest runaway vehicles (see also **20.3.4.2**).

23.2 Rubber-tyred vehicles

Rubber-tyred vehicles should conform to BS EN 1889-1 unless they are earth-moving machinery conforming to BS EN 474 (all parts) or road-going diesel-powered vehicles.

NOTE 1 In larger tunnels, rubber-tyred vehicles (also known as free-steered vehicles) can be used to transport materials.

Larger clearances should be present between the vehicles and persons, equipment, or the side of the tunnel than for rail vehicles.

Reversing or turning vehicles presents particular risks to pedestrians, and vehicles should not be operated on steep gradients without prior assessment of ground conditions and the capability of the vehicles.

Planning of operations should include consultation with the suppliers. Vehicles should not be employed on gradients steeper than 12.5% unless they have been specified as suitable for that purpose.

Level loading areas should be provided and discharging should be on level ground with kerbs to locate the wheels and a stop barrier where a drop occurs.

Each vehicle should be provided with the following equipment, functional at all times.

a) An audible warning device.

b) Two white front headlights visible at 60 m.

c) Two red rear lights visible at 60 m.

d) A braking system, preferably fail-safe when the design allows, which can be operated instantaneously by the driver.

e) A parking brake capable of holding the vehicle fully loaded on the steepest slope likely to be encountered.

f) Sprays or jets for cleaning windscreens if fitted.

Vehicles should be fitted with visual and/or audible reversing warning systems. Each vehicle driver should have received site-specific training and should carry a valid certificate authorizing them to drive that vehicle and should be certified medically fit.

A safe system of work underground should be prepared and adherence to this should be the responsibility of one or more members of the site management team. The procedures should encompass training and clear marking and notices underground. When several vehicles are in use, the regulation of movements should be the duty of supervisory personnel underground, each of whom should be in charge of a particular section.

NOTE 2 Attention is drawn to The CDM Regulations 2007 [1], which require that procedures are established to protect persons from moving vehicles by separation wherever reasonably practicable.

23.3 Crawler-tracked vehicles

NOTE It can be preferable to use crawler-tracked vehicles for mucking operations if the floor conditions are soft and where there would be stability risks for rubber-tyred vehicles.

The same general recommendations as for rubber-tyred vehicles (see **23.2**) should be applied to the construction, use and control of crawler-tracked vehicles. However, the ability of a crawler vehicle to "sprag", i.e. lock one track to turn the machine on the spot, should be kept in mind when controlling pedestrian access, as standing next to a working crawler poses the risk of being knocked or trapped as the tracks skid sideways.

Particular care should be taken to prevent electrically powered crawlers that use a supply cable from running over their own cable, as the sharp track edges can easily cut through cable insulation.

23.4 Tyred skips or trolleys in pipe jacking

NOTE As pipes have smooth internal surfaces, skips or trolleys equipped with tyred wheels can be operated directly on them and banked by winches located in the thrust pit.

Winches should be checked at a frequency determined by project-specific duties and hazards to ensure that the winch ropes are in good condition and are adequately guarded. Tyred wheels should also be regularly checked because uneven wear or misaligned wheels can cause a trolley or skip to ride up the side of the pipe and overturn.

Personnel should be prevented from entering an area while such tyred skips or trolleys are being moved by winch.

23.5 Conveyors

23.5.1 Belt conveyors

*COMMENTARY ON **23.5.1***

Belt conveyors can be used to significantly reduce the frequency of traffic movements in tunnels and the train size. However a conveyor in a confined area such as a tunnel is potentially hazardous to persons working alongside unless safe by position or properly guarded.

When belt conveyors are used, measures should be taken to minimize the risk to persons working in the vicinity by ensuring that all chains, sprockets, gears, belts and in-running nips are fully guarded. In particular, pinch points between the conveyor belt and the drum should be securely guarded.

NOTE 1 Pinch points occur at each loading and discharge point and at any tensioning device that is fitted. The BS 5667 series specifies requirements, and BS EN 618 and BS EN 620 provide guidance on applicable safety standards.

Idlers on the underside of the conveyor should be guarded if they are accessible to persons walking past the conveyor.

Pull cords should be provided on either side if necessary, throughout the length of the conveyor. These should be inspected regularly and maintained in serviceable condition. Alternatively, emergency stop buttons should be provided at suitably close intervals along accessible lengths of the conveyor belt.

Starting of the conveyor should only be possible from a single position, normally the main operator's position, but this might be on the instructions of the conveyor operator. An audible signal should be given and a safe interval allowed to elapse before start-up.

NOTE 2 BS EN 12336 gives requirements for audible signals.

Fire prevention measures should be taken (see **13.3** and **13.4**), especially at all drive, transfer and tail-end locations. Adequate ventilation of electric motors should be maintained and motors should be protected against spillage. Fire-resistant belting should be used wherever practicable. Fire extinguishers should be located nearby.

The conveyor should have sufficiently high sides to prevent spoil spilling over. Care should be taken as not only can spillage result in an untidy workplace, but large pieces loaded on to the conveyor can strike and injure operators or damage machinery. Oversize material should be prevented by means of a gating device from travelling up conveyors.

Inclined conveyors, other than short lengths, should be fitted with anti-runback devices to prevent the belt running backwards in the event of a power failure.

Man-riding should not be permitted on a conveyor. It should be noted that on some TBMs access to the cutter head is only possible along the conveyor. This should be done only in accordance with the manufacturer's instructions.

When dry spoil is being handled and dust presents a problem, effective dust control measures should be taken (see Clause **16**).

The safe use of conveyors depends largely upon thorough inspection (at least once each working shift) and maintenance, and worn or damaged parts should be replaced as soon as is practicable. The build-up of spoil on belts and rollers should be controlled as this is likely to result in spillage and motor overloading. Maintenance such as greasing bearings, adjusting belt positioning, cleaning belts, etc., or repair work should not be undertaken while the conveyor is in motion. A lock-out switch should be used on such occasions.

23.5.2 Belt weighers

Where the spoil is transported out of the tunnel by conveyor, one or more belt weighers should be fitted to conveyors on the TBM and in the tunnel as part of a spoil reconciliation system (see **7.17**).

NOTE The belt-weighing equipment ought to comply with "Document OIML R 50-1" [46], Accuracy Class 0.5.

The accuracy of the belt weighers should be ±0.5% of the load weighed.

23.5.3 Vertical conveyors

When spoil is transported out the tunnel by conveyor, consideration should be given to the use of vertical conveyors for spoil handling in the shaft, thus reducing the number of lifting operations required.

Vertical conveyors should be designed and constructed to contain the material on them and not allow material being transported to fall into the shaft.

23.6 Slurry pumping

23.6.1 General

*COMMENTARY ON **23.6.1***

*Slurry pumping for tunnelling purposes generally comprises the use of fluid mixed with the material excavated by a tunnelling shield which is pumped out of the tunnel (see **7.6.4.2**).*

The slurry system should comprise as a minimum:

- a mixer which will mix the components of the slurry;
- an injection device to inject the slurry into the tunnelling machine;
- a discharge pump to pump the slurry from the machine;
- pipework to deliver the slurry to the point of discharge; and
- a separation plant to remove spoil from the slurry.

All power supply to mixing and slurry plant should be subject to the normal safety requirements (see Clause **25**) for remotely operated mechanical plant.

NOTE Attention is drawn to The Control of Substances Hazardous to Health Regulations 2002 [34].

23.6.2 The mixing system

NOTE 1 Slurry is a mixture of water, bentonite or long-chain polymers and, possibly, other additive materials.

Storage and handling advice supplied with the materials should be followed. Persons likely to come into contact with slurry should be appropriately trained. An eye wash station should be located near the mixing plant, and facilities provided for washing and changing of clothing.

Mixing systems should be established in order to avoid any manual contact with moving parts. If there is any possibility of splashing, tanks should have covers. Any spillage should be cleaned up to avoid contaminating working areas.

NOTE 2 Attention is drawn to The Control of Substances Hazardous to Health Regulations 2002 [34] when handling bentonite and any other caustic chemical additives.

23.6.3 The slurry pumping system

NOTE In slurry systems pumping pressures can be high and connections between pipework and pumps can be subject to some movement.

Where high pressures exist, warning signs should be displayed providing sufficient data about the pressures to guide safe working practice. Advice should be sought from the equipment supplier on what pressure will be generated in use and whether this is likely to require special attention.

Where pumps are in confined spaces or in spaces where entry of personnel is forbidden, special procedures for the isolation of the power supply should be in place. Signs should be posted to identify isolation points.

For any maintenance work, a "permit to work" system should be enforced with a suitable isolation and lock-off procedure to immobilize plant before maintenance work commences.

Where power cables to the pump have to be regularly connected and disconnected for the purpose of pipe installation or segment installation, the cables should be supported so that connections cannot become contaminated by any fluids within the tunnel or access shafts. There should be a clear system indicating when lines can be disconnected and reconnected such that no live cable is accidentally handled.

A monitoring system should be used on power plugs and couplers to isolate the system in the case of an accidental disconnection.

23.6.4 The piping network

The slurry pipework should be able to withstand the pressures and abrasion caused by the spoil carried in the slurry. Where supported on the tunnel wall or in the shaft, carrying brackets should be strong enough to allow for alignment problems causing some brackets to carry double the predicted load. Anchorage should be designed to resist surge loading as valves are opened and closed, particularly adjacent to bends. Where telescopic pipes are used adjacent to a TBM, the design should allow for surge reaction forces. Where flexible hoses are used, they should be of a suitable design to resist the pressures and should be positioned so as to cause no injury if there is a burst.

All slurry pipework should be inspected to ascertain its suitability for use. Special attention should be paid to pipe connections.

All valves and multiple pipework installations, such as bypass systems, should have suitably designed supports. Where pipework is extended or pipes are opened for the purposes of pipe jacking installation, there should be a system in use to minimize spillage of the pipe contents, as this can lead to slipping accidents and untidy and contaminated facilities.

Valves should be installed at regular intervals in advancing pipework.

NOTE For larger pipes, it is sometimes possible to insert inflatable stops through pipe sockets.

Personnel should release any pressure from the pipeline before joints are disconnected.

23.6.5 Intervention procedures

TBMs with man-entry facilities to a normally flooded slurry chamber should have an extensive documented procedures to ensure safety for personnel. Compressed air should normally be employed to maintain face support (see Clause **11**). The following additional safety precautions should also be employed.

a) A "filter cake" (a skin of slurry material) held by compressed air on the tunnel face should be created and established.

b) During work on the TBM, a constant watch should be kept to detect deterioration of the face.

c) Minimum air pressure necessary to maintain face stability should be applied.

d) If conditions appear unfavourable, the crew should be withdrawn and the chamber reflooded.

e) Adequate harnesses and fall-arrest equipment should be used for personnel safety.

f) There should be an agreed method for removing injured persons from the front of the machine through the airlocks.

Simultaneous maintenance should not be carried out on the rest of the system. The slurry plant, pumping system and TBM should be kept in a state of readiness in order to be able to excavate one cycle so that tunnelling forward into undisturbed ground can quickly recommence.

23.6.6 General operating procedures

NOTE 1 High pressure on the face of a TBM during driving can result in high pressures at the rear of the shield. This can affect the installation of segments and can present hazards to segment-handling personnel.

There should be a procedure to identify when hazards due to high pressure on the face of the TBM occur so that suitable reduction of the slurry pressure on the face of the machine can be carried out.

NOTE 2 During the launch of a shield from a shaft, high slurry pressure can cause discharge into the shaft.

A shaft seal system should be employed to prevent loss of slurry and ground into the launch chamber.

NOTE 3 A similar system might be required at the reception chamber.

23.6.7 Slurry separation

*COMMENTARY ON **23.6.7***

Slurry separation can be carried out by the use of separation plant, settlement tanks or lagoons.

Separation plant and settlement tanks should be secured safely with adequate foundations and support. Where there is any risk of falls into a tank, the tank should be covered with a grating.

Where separation plant is employed, in addition to the protection of tank facilities, all moving parts should be guarded. An isolator should be installed to enable a qualified operator to shut down the plant. As with any fluid handling, matters can go wrong quickly, and emergency procedures should be set up in advance.

All maintenance and adjustments should be carried out in accordance with the manufacturer's instructions.

Where lagoons are employed, there should be adequate fencing, and warning signs identifying the depth of the lagoon and the nature of the contents.

Removal of slurry from a site should be managed with due recognition of the nature of the contents. Slurry should be pumped into suitable tanks and tankered off site.

23.6.8 Personal protective equipment

Any site on which slurry is being employed should have facilities that incorporate, at a minimum, eyewash facilities, and fluids for cleaning both skin and eyes if contaminated with slurry. Equipment should include masks, goggles and gloves and, where necessary, protective overalls.

23.7 Tipping and disposal

NOTE 1 The disposal of excavated materials off site is subject to local and national waste disposal legislation.

The location of any on-site tip or disposal area should be carefully chosen and due consideration should be given to engineering requirements for tip siting and formation, e.g. method of construction, drainage and compaction. It should not be positioned to surcharge future tunnel excavations unless it can be established that the soil or rock is able to withstand these additional loads.

In tipping areas, reasonably level and properly maintained roadways should be provided using ballast or hard-core, as necessary, to allow proper traction and stability of haulage and tipping vehicles. If tipping is to be carried out down a slope, a robust "stop" should be provided to prevent any overrun of the haulage vehicle.

Dust control measures (see Clause **16**) should be put in place during the tipping and storing of rock and spoil to minimize risks to health and the environment.

NOTE 2 Attention is drawn to road traffic regulations for off-site tipping. It is often necessary to provide facilities for cleaning wheels, etc., before the vehicles go on to the public highway. The legal requirements for this are generally the subject of local by-laws.

Since a further hazard with pumped slurry storage is the possibility of flooding, the flood protection at each shaft should be well above any possible slurry lagoon level.

24 Tunnel plant

24.1 General

NOTE Due to the confined space in a tunnel, when a hazard occurs, the severity of outcome is likely to be greater. Safety aspects specific to tunnelling are described in ***24.2, 24.3, 24.4, 24.5, 24.6, 24.7*** *and* ***24.8****.*

Before attempting any work on powered machinery, the power source should normally be isolated (see Clause **25**), except where it is necessary to operate parts of the machinery in a specifically selected maintenance mode. This applies equally to electrical, mechanical and pneumatic plant, and suitable instruction and training should be given, backed up by notices on the machinery advising on the steps to be taken.

24.2 Pneumatic plant

NOTE 1 Pneumatic plant includes vacuum plant.

Care should be taken since flexible hoses and couplings are a hazard if they fail in use due to the violent whiplash effect caused by escaping air.

They should be protected and routed clear of possible impact or cutting damage. Hoses and couplings should be regularly inspected for wear or damage, and discarded if no longer fit for use.

NOTE 2 Site repairs can be made provided properly matched bolted clamps are used.

It should be noted that several different outside diameters are available for a given internal diameter of hose, and different clamps will apply. Where hoses are of 19 mm internal diameter or larger, whip restraint wire loops should be attached at each end.

Air-driven machinery, whether percussive hand tools, air motors, or reciprocating pumps, should be silenced. Care should be taken as the level of noise produced by air driven machinery prevents effective communication and is a hazard to health. Silencers should be of a type which does not cause excessive restriction of the air flow. The exhaust air should be directed away from the operator. If the air supply is very wet, water traps should be used in the air line feeding the plant to minimize exhaust mist.

Vacuum lifting plant should meet the requirements of BS EN 12336.

24.3 Hydraulically operated plant

The following precautions should all be taken as far as practicable.

a) Fire-resistant or low flammability fluids should be used in the system.

b) Effective oil coolers should be incorporated to maintain oil temperatures below 70 °C. Temperature switches should automatically shut down overheated circuits.

c) Fixed fire extinguishing systems should be installed covering major systems such as oil storage tanks, pumps, motors, etc.

d) Pipe runs should be routed to minimize the possibility of oil sprays reaching hot objects.

Hydraulic systems should be regularly maintained, at a frequency determined by project-specific duties and hazards, to prevent leaks. Damaged components should be replaced. Hoses should be pressure-rated to allow for transient pressure spikes in use.

Segment erectors should comply with BS EN 12336.

Face and forepole cylinders should be able to relieve hydraulic pressure automatically during shield shoving to avoid overpressure in the cylinders.

NOTE These recommendations apply to all plant including plant on short-term hire.

24.4 Internal combustion engines

24.4.1 Diesel engines

NOTE Attention is drawn to type approvals for diesel engines under EC Directive 97/68/EC [47].

In order to meet stringent limits on atmospheric concentrations of nitrogen oxides, the guidance in the BTS publication, "*Occupational Exposure to Nitrogen Monoxide in a Tunnel Environment: Best Practice Guide*" [N1] should be followed.

Engines of more than 37 kW-rated output should conform to BS EN 1679-1. This should prevent the emission of exhaust gases likely to cause excessive levels of particulates in the tunnel, and ensure that the engines are designed to minimize fire hazards.

Ventilating air should be sufficient to dilute toxic gases to safe levels, and reduce smoke and odours to acceptable levels (see Clause **15**).

To avoid local concentrations of dangerous levels of contaminants, some form of exhaust conditioning should be used on engines not complying with Euro III or higher.

NOTE 1 Conditioning can take the form of a fume diluter or catalytic converter.

Advice on correct matching should be sought from the suppliers of any conditioning device.

NOTE 2 Diesel particulate filters can be incorporated, but the duty cycles on locomotives can cause fouling up.

NOTE 3 Engines conforming to Euro III or higher already incorporate exhaust conditioning.

Engines for underground use should be "clean burn" types, which produce minimum particulate emissions, with virtually no visible exhaust emissions.

In addition, adequate provision should be made for the storage and handling of fuel (see **13.1.3** and **23.1.4.2**).

Explosion-protected equipment should be used whenever there is the risk of the presence of explosive gases.

24.4.2 Petrol engines

The use of petrol engines underground should be avoided except in an emergency when alternatives are impracticable. In this case the following measures should be taken.

a) The numbers of persons underground should be restricted to the minimum required.

b) Ventilation should be sufficient to dilute the fumes (see **15.4**).

c) The time of operation should be kept to a minimum.

d) The equipment should be returned to the surface as soon as possible on completion of emergency operations.

e) Gas monitoring should be carried out to ensure carbon monoxide concentrations do not rise above permitted levels.

24.4.3 Siting of engines

Internal combustion engines on the surface should be sited so that exhaust fumes cannot enter the ventilation system or compressed-air intakes, or enter the tunnel by any shaft or other opening.

Static plant used underground should be electrically powered whenever possible. If diesel-powered, it should be located down wind of any operatives.

24.5 Concreting plant

24.5.1 Concrete pumps

Pumping should be carried out in accordance with BS 8467. Concrete delivery pipes should be installed and maintained to pump manufacturers' guidelines.

NOTE These pipes can move with the pump strokes and that reaction forces are generated at every bend.

Furthermore, the full pipeline can be heavy and should be supported, particularly in shafts.

Wear on bends and reducers can cause complete failure under pressure and these areas should be checked regularly. Whenever possible, pump lines should be cleaned by pumping water through them. When cleaning out a concrete pump ("blowing out") using compressed air, the cleaning ball or sponge is likely to exit with considerable velocity and should be caught in a basket at the end. The delivery hose should be securely restrained before "blowing out" takes place to prevent whiplash. The pipework used with the concreting plant should be correctly matched to the performance of the pump and its condition checked. Care should be taken since incorrect pipe and couplings could rupture in use.

Procedures should be agreed in advance for dealing with blocked pipelines as this can entail splitting pipes which can be under pressure and for blowing out the line section by section.

24.5.2 Shotcrete plant

The mixing plant should be set up to minimize exposure to hazardous substances by those operating it. Mixing plant, pump and delivery lines should be maintained in good condition to minimize the release of dust into the tunnel atmosphere.

24.6 Water drainage pumps

Reliability of the drainage system, and adequacy of pumps, should be considered critical for the safety of personnel where flooding could occur.

Consideration should be given to duplicate pumps and pipework, along with an independent back-up power supply and to good accessibility to the pumps for regular servicing or changing-over.

Submersible pumps should be suspended so that they can be progressively lifted clear of silt in the pump sump. Pump performance should be checked regularly to detect wear or blockage.

NOTE Pipework in tunnels is prone to progressive silting up in use. A second pump line could be used to allow cleaning of the blocked pipes.

24.7 Drilling and piling rigs

24.7.1 General

Drilling and piling rigs used in any operation associated with tunnel construction should conform to BS EN 791 and BS EN 996 respectively.

NOTE Typical drilling equipment in tunnels include:

- *"jumbo" for blast hole drilling or rock bolting;*
- *drill mounted on TBM for probing or bolting;*
- *geotechnical drilling rigs (Pt2 machines) taken into to the tunnel;*
- *drill mast attachments on 360° excavators;*
- *hand-held drilling for blast hole drilling bolting etc.;*
- *spiling/face bolting rigs.*

24.7.2 Operation

The operation of drilling or piling rigs and their ancillary equipment should be carried out in accordance with established safe working practices, such as those set out in:

- *Codes of Safe Drilling Practice* [N2];
- *Guidance Notes for the Protection of Persons from Rotating Parts and Ejected or Falling Material Involved in the Drilling Process* [N3];
- *Notes for the Guidance on PUWER (Regulations 11 and 12) in Relation to Guarding and Cleaning of Augers on Piling Operations* [N4]; and
- *Guidelines for the Safe Investigation by Drilling of Landfills and Contaminated Land* [N5].

Drilling and piling rigs should be maintained in accordance with the instructions in the manufacturer's handbook.

24.7.3 Specific recommendations for drill rigs

The rig and in-hole equipment selected for a specific operation should be suitable for its intended use. Consideration should be given to site, operational and environmental conditions.

Some drilling operations require access to the area around the rotating drill string and guarding or protective devices should be fitted to the rig to prevent persons working near the drill string from accessing dangerous rotating parts.

Machine ratings should be compatible with anticipated drilling conditions to prevent overloading of a machine.

The drill rig should be set up so that it forms a stable, safe drilling platform with adequate working space for operators.

Any limitations on ambient temperature for which the rig is designed should be adhered to.

Minimizing noise emissions and vibration should be a factor in selecting the drilling equipment.

24.8 Grouting equipment

Grout mixers employing rotating paddles should be designed so that any dangerous parts are guarded. Removal of the guard should isolate the power source automatically.

Grout pumps used for either transferring bulk grout or injecting at the point of use should be matched to the method of work.

NOTE 1 The potential pressure of some piston pumps is very high (100 bars) whereas air-operated diaphragm pumps tend to produce lower pressures (6 bars).

Pressures should be monitored and all hoses, pipe fittings and injection nozzles (grout guns) should be matched to the maximum pressure rating of the pump and inspected regularly for damage and wear. Care should be taken as high-pressure grout blow-outs can cause serious injuries and damage to tunnel machinery. Where transfer distances are great, an effective means of communication should be in place between the source and the point of delivery.

All grouting equipment should be regularly inspected and maintained and any grout build-up removed. Whip restraint wire loops should be provided for both the feed air and the grout transfer hoses.

NOTE 2 Potential hazards arising from grouting equipment include the following:

- *bursting of the grout feed hose through damage, inadequate maintenance or improper connection, or solidification of the grout. Cleaning and maintenance to a high standard is therefore essential;*
- *blow-out at the point of injection where a screw connection or other pressure retaining device ought to have been provided;*
- *back-flow of grout after injection. A stop valve might be necessary to retain the grout until it has set;*
- *damage to lining or to surface installations due to excessive pressure.*

25 Electrical

25.1 Planning, management and control of the electrical system

The challenging environments associated generally with civil construction work, and the need for safe use of electricity, mean that electrical installations should be properly planned, managed and controlled. This should be considered especially important in tunnelling operations, where environmental conditions can be very severe and where high-voltage (HV) power distribution frequently has to be used.

*NOTE 1 With regard to the appointing of electrical personnel, attention is drawn to the requirement of The Electricity at Work Regulations 1989 [47] that all persons are competent to carry out their duties without danger to themselves or others and in terms of objectives to be achieved, i.e. goal setting (see also **6.5.7**). This covers all stages of the process including planning, management, operation and maintenance.*

It should be noted that persons competent to work on low-voltage (LV) systems are not, without the necessary additional knowledge, training and experience, competent to do so on HV systems.

An authorization system should be put in place, with certificates issued to competent persons which clearly define the range of electrical equipment they are authorized to work on and the extent of their duties. No person should be allowed to carry out work on any systems and equipment for which they are not authorized.

A safe system of work should be in place addressing as a minimum:

- permit to work;
- sanction to test;
- switching schedule;
- limitation of access.

There are inherently greater risks associated with HV systems than with LV systems and therefore their management and control should be tighter and even more structured. The "permit to work" system is a major control procedure that should be used in conjunction with operational procedures carried out on HV systems, either to eliminate or to control and minimize risks.

During the planning stage and before any work starts on site an Electrical Duty Holder should be appointed for the project.

NOTE 2 The Duty Holder is responsible for ensuring the safety and standards appropriate (e.g. Electrical Safe System of Work) for the project are adhered to.

In order to provide and maintain a safe electrical system, procedures that address the following subjects should be formulated and put into operation.

- Electrical safety rules.
- Authorization certificates.
- "Permit to work" system.
- Training, including resuscitation techniques.
- Testing, maintenance and inspection, including appropriate documentation.
- Liaison with appropriate regional electricity company.
- Preparation of system drawings.
- Updating of records.
- Dealing with emergencies.

NOTE 3 Further guidance on aspects of safe working on electrical systems can be found in HSE publication HSG85 [49], which includes a typical example of a "permit to work" form.

Site electrical installations should conform to BS 7671. All work up to 1 000 V a.c. should conform to BS 7671:2008 with specific reference to section 704.

NOTE 4 The IEE have produced a series of Guidance Notes [6)] which contain detailed advice on how to conform to BS 7671.

NOTE 5 BS 7671 and BS 7375 are applicable to surface work, including site offices and construction plant and equipment.

NOTE 6 Specific challenges occur when designing and installing the tunnelling distribution network where various other standards and conditions apply, e.g. The Dangerous Substances Explosive Atmospheres Regulations [30].

NOTE 7 BS 7375 gives further guidance and recommendations of specific relevance to electrical installations on construction sites.

25.2 Mains supply connection

Care should be taken as the safety of persons and works can be dependent on the continuity of power supplies, particularly in respect of:

a) lighting;

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6) See http://electrical.theiet.org/books/guidance-notes/index.cfm.

b) pumping;

c) atmospheric monitoring equipment and ventilation;

d) compressed-air working;

e) signalling and communications;

f) alarms and shutdown systems.

The importance of each of these, and the time for which interruption of supply can be tolerated, should be determined. This should depend on the particular tunnel and its method of construction.

In planning mains power supplies, these matters should be fully examined and discussed with the Distribution Network Operator.

Essential standby power should be provided by a second independent mains connection or generator. Switchgear and circuits should be planned so that essential circuits are not broken when other circuits are disconnected or fail.

In some safety critical cases, installations for essential services should be duplicated to maintain power at all times.

The electrical protection should be designed so that, as far as is practicable, only the faulty circuit is disconnected in the event of a fault. Also, secure means of isolation should be provided for all circuits, which can include appropriate protective switching devices, so that extensions, maintenance and repairs can be carried out safely on dead electrical equipment with minimum disruption to other circuits.

25.3 Site installations

25.3.1 General

Installations on construction sites should conform to BS 7375 for the distribution of electricity on construction and building sites, together with BS 4363 for distribution units.

It should be noted that for tunnelling installations, additional safeguards might be necessary because:

a) HV systems are frequently required for economic power distribution;

b) space in tunnels is restricted, requiring electrical installations to be as compact as possible to allow adequate access and room for installation, operation and maintenance;

c) wet conditions and high atmospheric humidity can frequently be encountered;

d) hazards from smoke and fumes are intensified in the event of fire;

e) potentially explosive atmospheres can be present;

f) power supply cables to the working face have to be continuously extended;

g) there is high risk of mechanical damage to equipment;

h) oxygen-rich atmospheres can be encountered.

25.3.2 Voltage

NOTE See BS EN 60204-1.

25.3.2.1 High voltage

NOTE HV supplies, i.e. those above 1 000 V a.c., can be used to transmit power economically to transformer substations or very high-powered electrical plant.

Since tunnelling necessarily utilizes a greater proportion of HV distribution equipment than other parts of the construction industry, this increased risk should be managed by tight control of the installation, operation and maintenance of HV systems by persons who are competent to work at these voltages (see **25.1**).

While voltages should be kept as low as reasonable practicable for the system in question, nominal voltages for HV systems are likely to be 11 kV or higher, 3-phase 50 Hz.

25.3.2.2 Low voltage

NOTE 1 LV supplies, i.e. those between 50 V a.c. and 1 000 V a.c., are generally used to supply the majority of electrically powered tunnel plant.

The recommended nominal voltages for LV systems should be 550 V or 400 V, 3-phase 50 Hz (550 V is widely used for mining plant).

NOTE 2 LV systems of up to 1 000 V can be required in long tunnels.

230 V single-phase supplies should not be used except to supply fixed equipment through armoured cables.

25.3.2.3 Reduced low voltage

NOTE 1 Reduced low voltage supplies, i.e. 110 V, 50 Hz, are used for lighting or hand-held portable tools. The supplies are derived from centre tap earthed (CTE), single-phase or 3-phase transformers.

The single-phase version should be used as this limits the voltage to earth to 55 V, compared to the 63.5 V for the 3-phase unit. Overcurrent protection suitable for the circumstances should be installed in each pole of the outgoing supplies.

NOTE 2 Reduced low-voltage systems, particularly when equipped with residual current devices (RCDs) for additional earth leakage protection, are, with proper maintenance, safe in all but the most hazardous conditions.

Where lighting or tools are being used in wet or confined or conductive conditions (such as inside a metal pipe), an extra low voltage system (**25.3.2.4**) should be considered necessary.

NOTE 3 Battery-operated tools are a safer alternative in adverse environments.

25.3.2.4 Extra low voltage

*COMMENTARY ON **25.3.2.4***

Extra low voltage supplies, i.e. those not exceeding 50 V (a.c. or d.c.), between conductors or conductor and earth, are used for:

- *portable tools and lighting in damp or confined locations. In these circumstances the supply ought to be limited to 25 V and derived from a CTE transformer;*
- *control circuits for electrical plant. These supplies for control circuits ought to be derived from a single-phase transformer with one pole earthed and the other pole containing a protective device, e.g. a suitably rated fuse.*

CTE transformers should not be used for supplying control circuits as their use could lead to dangerous malfunction of the plant when earth faults occur in the control circuit.

25.3.3 Fault ratings

Electrical equipment should be selected according to the circuit fault level and in all cases should be capable of withstanding the full fault rating for 3 s. Actual fault levels should ideally be reduced by the use of high-impedance transformers and neutral earthing resistors supplemented by high-speed protection.

NOTE The following nominal fault levels are common for industrial equipment:

- *11 kV, 250 MVA;*
- *6.6 kV, 150 MVA;*
- *3.3 kV, 50 MVA;*
- *1.1 kV, 50 MVA;*
- *400 V, 30 MVA.*

25.3.4 Earthing

25.3.4.1 General

All electrical installations and equipment should be earthed and bonded in order to reduce the likelihood of dangerous voltage rises and to rapidly clear any faults by installed circuit protection.

NOTE 1 For further advice on earthing see BS 7430 and BS 7671.

Due regard should be given to designer's and manufacturer's recommendations and to good industrial practice, for fuse ratings and the settings of protection devices. Account should be taken of actual fault levels as the basis for earthing, circuit protection and discrimination.

NOTE 2 BS 7671:2008, Section 604, details requirements for earthing and electrical protection. However, they are more relevant to commercial situations than to industrial ones.

25.3.4.2 System earthing

NOTE On both HV and LV systems, the neutral connection at the supply source might be connected either solidly to earth, or via a suitable limiting device that can be installed to limit the prospective earth fault current.

If the latter is used, the integrity of the limiting device should be constantly monitored with suitable alarm and indication functions, as otherwise the failure of the limiting device could result in an unsafe condition continuing unnoticed.

25.3.4.3 Circuit protective conductors

NOTE It is normal practice to utilize the armouring of power cables as the circuit protective conductor. On longer tunnels the installation of additional separate single core copper earthing conductors might be necessary to limit the total earth impedance path, thus limiting the voltage rises that can occur in the earthing system under fault conditions to a safe level.

Additional point earthing should also be considered, especially for HV to LV distribution within the tunnel where protective multiple earthing (PME) or TNCS earthing could be advantageous.

In addition the earth fault impedance should be checked each time a cable is extended or altered, to ensure the appropriate discrimination can be maintained.

25.3.4.4 Lightning and static electricity protection

To avoid dangerous touch voltages arising as a result of a lightning strike, extraneous metalwork such as rails and pipework should be bonded together to the electrical earthing system at the tunnel portal and to the circuit protective conductor at regular intervals along the tunnel.

NOTE For guidance on protection against lightning and static electricity see BS 5958-1 and BS EN 62305 respectively.

25.3.4.5 Protection of circuits against electrical shock and overcurrent

The main protection against electrical shock and overcurrent should be provided by the combination of the following in accordance with BS 7430, BS 7375 and BS 7671:

- suitable voltage;
- suitable and sufficient enclosure of live parts;
- correctly rated circuit breakers and fuses;
- properly designed earthing;
- equipment capable of withstanding the harsh environment.

Additional protection against electric shock should be provided by the use of residual current devices (RCDs) (see **25.3.5**).

25.3.5 Residual current devices (RCDs)

25.3.5.1 General

RCDs should be used to provide supplementary protection against earth leakage currents as they are able to detect much lower levels of earth fault current than circuit breakers or fuses and enable the fault to be isolated very rapidly. However, as these devices are neither fail-safe nor particularly robust, they should be used only to supplement other protective measures, and should not be used on their own. In order to guarantee their reliable operation they should be put in sealed enclosures in accordance with the advice of the RCD manufacturer and regular use of the "test" push-button and regular testing of the RCDs should be carried out as part of a planned maintenance scheme, and these results recorded.

RCDs should conform to a recognized standard such as BS IEC 1008-2-2 or BS EN 61008 and associated standards.

25.3.5.2 RCD sensitivity and discrimination

NOTE 1 RCDs can provide supplementary protection to guard against:

- *direct-contact electric shock caused by persons touching a live conductor;*
- *indirect contact caused by persons touching exposed metalwork, such as the casing of electrical equipment, which has become live through insulation failure of an electrical component within the equipment.*

For protection of persons sustaining direct contact electric shock, an RCD should have a rated residual operating current not exceeding 30 MA and an operating time not exceeding 40 ms when subjected to an earth fault current of 150 MA. This level of protection should be used in low-powered circuits supplying portable tools, hand-held lighting and mobile plant.

NOTE 2 RCDs used for protection against indirect contact might be less sensitive and might also have time delays to provide satisfactory discrimination. On both HV and LV circuits, discrimination is important to ensure minimum disruption of supplies to healthy circuits in the event of an electrical fault. When RCDs are fitted, series discrimination in respect of earth faults can be enhanced by suitable selection of the operating times of the devices. This necessitates the provision of RCDs with adjustable time delays on some circuits.

On main switchboards supplying fixed points through fixed cables, RCDs with adjustable time delays up to 2 s should be installed on the incoming circuit and/or on each of the outlets, but all final circuits supplying fixed plant, mobile plant, portable equipment and all plugs and sockets should be protected with RCDs having no deliberate time delay.

NOTE 3 The sensitivities in Table 9 are considered to be normal safe practice.

Devices with more sensitive settings should be used wherever practicable but the additional hazards that could be caused by increased spurious tripping should be taken into account.

Table 9 – Earth leakage protection

Circuit voltage	Earth leakage protection	Time delay feature
High (1 000 V a.c. and over)	A protection device with a rated trip current not exceeding 5 A or 15% of maximum earth fault current	A time delay of around 0.4 s should be considered as part of the network design. Additionally a grading survey of the HV protection devices should be carried out by an electrical engineer
Low (50 V a.c. to 1 000 V a.c.)	Residual current device (RCD) with a rated trip current not exceeding:	
	750 MA on incoming circuit	Yes
	300 MA for outgoing circuits to fixed equipment	Yes
	100 MA for mobile equipment	No
	100 MA for fixed lighting	No
	30 MA for 16 A socket outlets	No
Reduced low (110 V a.c.)	30 MA for portable lighting and hand tool	No

25.3.6 Waterproofing and dustproofing

Account should be taken of the anticipated working environment when selecting materials to be used in the construction of switchgear, control gear, motors and other equipment. In particular, in saline conditions, aluminium alloys should not be used unless adequately protected against corrosion. Aluminium alloys should not be used in situations warranting the mandatory use of explosion-proof enclosures.

Ingress of water and dust into enclosures of electrical equipment can impair the operation and safety of the equipment and the enclosures should therefore limit this ingress in order to protect the equipment and prevent any harmful effects.

NOTE A system of classifying the degree of protection is described in BS EN 60529.

For electrical equipment to be used in tunnels in a non-explosive but dusty and moist atmosphere, including compressed-air working, the equipment should, wherever possible, provide protection not less than IP 65 in accordance with BS EN 60529. It is recognized that this might be impracticable to achieve in certain circumstances (e.g. for air-cooled transformers), in which case alternative external measures should be used to protect the equipment from the conditions.

25.3.7 Flammable or potentially explosive atmospheres

NOTE 1 Explosion-protected electrical equipment is used to prevent danger when operating in explosive atmospheres.

Classification of Hazardous Areas should be undertaken in accordance with BS EN 60079-10-1 for potentially explosive gases and BS EN 60079-10-2 for combustible dust.

NOTE 2 A range of British Standards have been issued to cover the various categories of explosion-protected equipment and the general requirements for all are contained in BS EN 60079-0.

The three categories that should be used in tunnelling are as follows.

- "Intrinsically safe" equipment designed to limit the ignition spark energy to below that which will ignite potentially explosive gas. This category should be used for low-powered equipment such as telephones, signals, communications, metering, control and monitoring, and can be used in Zone 0 environments where an explosive atmosphere is continuously present for long periods (more than 1 000 h per year).

NOTE 3 See BS EN 60079-11 for further details.

- "Increased safety" equipment designed to prevent any ignition from occurring by ensuring no normally sparking components are used and other components reduce the risk of causing a fault that may cause ignition. This category should be used for low-powered equipment as listed above for the intrinsically safe category, and may also be used in Zone 1 environments where the explosive atmosphere is likely to occur for between 10 h and 1 000 h per year.

NOTE 4 See BS EN 60079-7 for further details.

- "Flameproof" equipment designed with its electrical components contained within FLP enclosures that prevent flame or gas emissions hot enough to ignite the external atmosphere. This category should be used for equipment that is too high-powered to be designated as "intrinsically safe" or "increased safety", and may also be used in a Zone 1 environment.

NOTE 5 See BS EN 60079-1 for further details.

Where there is a likelihood of encountering dangerous levels of methane or other flammable or potentially explosive gas, explosion-protected electrical equipment should be used (see **12.5** and **12.7**).

Non-explosion-protected electrical equipment can be used, in which case the following conditions should be fulfilled.

- Ventilation, coupled with atmospheric monitoring, is used to control the concentration of potentially explosive gas in the general body of the air, below 5% LEL, to protect against explosion.
- A power interlock is installed between the ventilation system and non-explosion-protected electrical equipment such that unless the ventilation and atmospheric monitoring systems are operational and the concentration of gas is at a safe level (see **12.5**), the power supply to the non-explosion-protected equipment is disconnected. The switch used for the power disconnection should be either flameproof or a non-explosion-protected type located in an atmospherically safe area.
- Any failure of the atmospheric monitoring or ventilation equipment automatically disconnects the equipment.

All items of electrical equipment deemed essential for safety, including lighting, switchgear, control and monitoring equipment, telephones and ventilation fan motors, unless located and operating in safe atmospheric conditions at all times, should be of the explosion-protected type.

Supplies to non-essential explosion-protected equipment should be disconnected when the flammable or potentially explosive gas concentration reaches 25% LEL.

NOTE 6 Useful information regarding good practice can be obtained from HSE publication L128 [50].

25.3.8 Explosion-protected equipment in compressed air

Explosion-protected equipment is not necessarily suitable for use where explosive atmospheres occur in compressed-air workings; the equipment manufacturer should be consulted for guidance on suitability.

25.4 Cables

25.4.1 General

Cables should be selected after full consideration of the conditions to which they will be exposed and the uses for which they are required, including the effects of hydraulic fluids, oils, grease and water.

NOTE Aluminium sheathing requires a high degree of protection against corrosion in the humid and possibly saline conditions in a tunnel.

Power cables should be of the low smoke-emission and fume-emission types. PVC-sheathed power cables should not be used because of their flammability and the toxic nature of the products of combustion released.

For increased integrity during fire conditions, fire alarm and emergency lighting cables should conform to BS 6387:1994, meeting a minimum category rating of AWZ [i.e. the lowest performance category for resistance to fire (A), resistance to fire with water (W), and the highest performance category for resistance to fire with mechanical shock (Z)].

25.4.2 Power supply cables

Power supply cables should be fire-retardant and should produce low smoke and fumes (especially halogen gases) when involved in a fire.

NOTE 1 Various designations are used to indicate the low smoke and fume, especially halogen gases, from cables involved in a fire, including LSF, LSOH, LSZH, LSHF and OHLS.

The choice should be discussed with the manufacturer/supplier to ensure that the type chosen is the most appropriate for the conditions in which it is going to be used.

Cable accessories, i.e. cleats, joints, cable glands etc., should have similar fire survival and/or low smoke- and fume-emission characteristics as the cables to which they are attached.

For HV and LV power supplies, the following cables should be used.

a) For voltages above 3.3 kV: low smoke and fume type, 3-core, screened with single wire armouring and cross-linked polyethylene (XLPE) insulation, conforming to BS 7835.

b) For voltages of 3.3 kV and below: low smoke and fume type, 3-core or 4-core, with single wire armouring and cross-linked polyethylene (XLPE) insulation, conforming to BS 6724.

NOTE 2 These cables might be used in situations where the cable is continuously extended but once extended is not subjected to continuous movement. For example, they might be used as power supply cables to a TBM stored in a "figure of eight" configuration at the back of the machine, and paid out on to brackets on the tunnel wall as the machine advances. When the full length of the cable has been run out, a new length is delivered to the machine, laid in "figure of eight" configuration, connected between the machine and the end of the existing cable, and the process is repeated as the machine continues its advance.

Armoured cables should not be used.

NOTE 3 Flexible power cables may be considered once the minimum bending radius has been evaluated.

All power supply cables operating at above reduced low voltage should be of a type having a metal sheath and/or screen which should be continuous and effectively earthed.

25.4.3 Trailing and flexible cables

For trailing and flexible cables the following should be used.

a) For heavy mobile plant such as roadheaders, three power cores, pilot and earth conductors, EPR/CSP insulated, screened, PCP inner sheath, pliable armoured, PCP outer sheathed, conforming to BS 6708:1998, type 321 or 331.

b) For mobile plant such as grouting or shotcreting equipment etc., three power cores, pilot and earth conductors, EPR/CSP insulated, screened, PCP sheathed, conforming to BS 6708:1998, type 7, 14 or 16.

Cable types should be given careful consideration as new insulating materials become available from time to time. All cables should be checked to confirm their suitability for use and should not be easily scored or damaged.

25.4.4 Fire risks involving cables

NOTE 1 In the event of fire, cable insulation can ignite and spread the fire, itself producing fumes and smoke.

The special vulnerability of grouped cables in a vertical shaft should be noted and essential circuits, such as fire alarms and emergency lighting (see **14.3 and 17.4**), should be segregated from other circuits where possible in order to reduce the risk and consequences of spread of fire. In vertical shafts the cables should meet the requirements of BS EN 60332-3 (all parts).

NOTE 2 Damaged insulation can allow arcing or sparking with consequent fire and electric shock hazards

NOTE 3 See IEE's Guidance Note 4 [51].

It should also be noted that circuit overloading or poor connection can cause heating, with damage to insulation and subsequent breakdown.

All cables should be stored on drums, or coiled in a "figure of eight" if no drum is available. They should be free from twists. Where current is passed through a coiled cable, particular care should be taken to guard against heating effects (see **13.3**), and the cable should be appropriately de-rated. Guidance on the latter point should be sought from the cable manufacturer.

25.4.5 Installation of cables

Cables should be located along the side wall of the tunnel at an elevated position to be clear of water and accidental contact by moving vehicles. They should be protected against mechanical damage, fire and water. Where HV cables are to be used, high standards of insulation and mechanical protection should be considered necessary, coupled with a high standard of workmanship in their installation.

Cables should be installed clear of passing traffic and should be adequately supported and secured while in use, preferably in a position where they are visible to persons working in the vicinity. Screening should be provided where cutting or welding is to be carried out in the vicinity of cables (see **13.2**).

As far as is practicable, cables should not be sited where they might be submerged. Cables entering a cubicle or other enclosure should be brought in from below to prevent ingress of water.

Top entry of cables into enclosures should not be carried out because of the problems that can be presented by ingress of water falling on the equipment from above.

Formal cable handling procedures for the mobile plant should be put in place. Cables supplying mobile plant and equipment should not be moved by personnel while they are energized. Such cables should only be moved or relocated when the associated circuits have been proved dead and isolated.

All non-utilized cable entries into electrical equipment should be sealed to prevent ingress of water, dust or other materials.

25.4.6 Joints

Power supply cables need to be extended periodically to match the progress of the tunnelling operations, and the distance between joints should be as large as practicable.

Joints should have similar fire survival and/or low smoke- and fume-emission characteristics as the cables to which they are attached.

NOTE 1 Attention is drawn to The Electricity at Work Regulations 1989 [48], which require joints and terminations to be both electrically and mechanically suitable.

The cable sections should be joined together by either:

- utilizing proprietary jointing kits installed in situ in the tunnel forming permanent joints; or
- using barrel type bolted half couplers, complete with connector pins, gasket and connecting bolts.

NOTE 2 The latter is the recommended method as it allows the new cable to be terminated into half couplers in a clean and dry environment before it is sent into the tunnel.

The supply should then be extended simply by bolting the half couplers of the new and existing cables together.

NOTE 3 This method also gives the added advantages of allowing the cables to be easily split into sections for fault finding, and simplifying cable recovery and reuse at the end of the job.

The continuity of the protective earth conductor should be maintained across the cable joints and couplers. All power cables should be subjected to an earth continuity test at 3-monthly intervals and immediately after any alterations, extensions or damage to the cable concerned. Details of all tests carried out should be recorded, including date of test, voltages recorded etc. Earth continuity should be maintained across bolted couplers by means of an external earth bond, as appropriate, clamped to the armouring on each side of the coupler.

Couplers for non-flexible HV 3-core low smoke and fume type/SWA/XLPE cables should have the cable armouring securely clamped to its outer metallic shell.

Couplers for type 321 and 331 flexible, pliable armoured trailing cables, should have an internal earth fitting to terminate the earth screens.

In potentially explosive or flammable atmospheres, all couplers should be of the flameproof type (see **25.3.7**).

In pipe jacking, operations cables should be frequently connected and disconnected in the thrust pit to allow for additional pipe sections to be installed. The cable connectors and the system of work used should allow this to be done safely and easily. Pilot operated circuits should be used and qualified electricians should carry out this work. For cables operating at above 1 000 V the persons responsible for this work should be competent to work on HV systems.

25.4.7 Cable terminations

Low voltage cable connections should be in accordance with BS 7375.

Cables should be terminated into electrical equipment utilizing appropriate cable glands that provide a mechanically sound installation and maintain the integrity of the earthing system. Gland shrouds should not be used, unless they are required for additional environmental protection, as regular visual inspection of armouring/gland/equipment interface is essential.

The type of glands used should maintain the integrity of the IP rating of the apparatus (see **25.3.6**) and should be installed with correct seals, washers and also shrouds (where necessary) to prevent water ingress.

All spare cores in cables should, wherever practicable, be connected to earth.

Special junction boxes or termination boxes should be provided with feeder protection cables.

NOTE This is to allow for cross-connexion of cores in order to minimize capacitance.

Protection cable cores within power cables should be avoided.

25.4.8 Location when explosives are being used

For the safe siting of electrical plant and installations, to prevent stray current activation of electrically operated explosive initiating systems, the comprehensive recommendations given in BS 5607 should be followed.

25.5 Transformers and switchgear in tunnels

25.5.1 Standard types of transformers

The growing use of tunnel construction plant dependent on electrical power supplied through transformers, sited as close as is practicable to the plant, means that standard ranges of the most suitable safe types should be employed. The temporary nature of tunnel construction operations and the very limited space normally available should be considered when selecting transformers.

Transformers in tunnels should be located as follows:

- in fixed substations in tunnels, generally remote from working areas;
- as temporary installations to suit mobile machines;
- fixed to, or forming an integral part of, a machine.

In tunnels, only transformers employing air cooling (preferable), or appropriate fire resistant synthetic insulating/cooling liquids should be used. Such synthetic liquids should not contain PCBs or other hazardous ingredients and should not emit, in a fire, the quantity and type of smoke and fumes that could be considered hazardous to personnel.

The liquids should be synthetic organic esters as specified in BS EN 61099 or silicone-based fluids manufactured in accordance with BS EN 60836.

Mineral-oil-filled transformers should not be used in any underground location.

The transformers should be in accordance with BS EN 60076-1.

The transformers should be designed to have segregation between each phase winding and should be fitted with inter-phase barriers to minimize the possibility of severe inter-winding faults. If the transformers are to be of the cast resin type, care should be taken in assessing the loads to be applied, as this type generally is not able to withstand very much overload. This should be taken into account at the design stage, and correctly designed electrical protection should be used to provide a further safeguard. Cast resin transformers should not be used in situations where there is a risk of combustible dust.

Where high levels of protection against ingress of water or dust are necessary, and in situations where high humidity could cause problems due to condensation, the use of dry type, hermetically sealed, pressurized nitrogen-filled transformers should be considered.

The means of isolation of the primary side of any power transformer should be by air break, vacuum or gas-filled type switchgear, which is preferably integral to the transformer, or alternatively by similar, separate, immediately adjacent switchgear.

The vector grouping of HV/LV transformers (details of the options are given in BS EN 60076-1) should be considered during the design of the electrical distribution scheme to:

- make provision for earthing the system at appropriate points in order to prevent the voltage in any part of the system rising to a dangerous level with respect to earth;
- avoid circulating currents;
- provide a "star" point on the load side of the transformer;
- effect safe parallel operation;
- suppress, where necessary, harmonics generated by thyristor-controlled motors.

Any external tap change selector handle should have a padlocking facility and should be securely padlocked in the selected position. Automatic tap changers should only be considered for transformers mounted above ground.

25.5.2 Siting of transformers

Transformers should be sited such that risk of damage is minimized and that they are protected from moving objects, water and debris. Safe means of access and adequate space and lighting (see Clause **17**) should be provided for inspection, maintenance and emergency purposes.

25.5.3 Switchgear

Switchgear should be provided, wherever necessary, to isolate and protect cable runs, transformers, other distribution units and the equipment and plant for which the power is required.

All switchgear should conform to the standards appropriate to the system voltage and to the circuit loadings, and should be fully protected against the foreseeable risks and expected hazards particular to its situation, which can include:

a) fault currents;

b) entry of water and dust (the minimum degree of protection as categorized in BS EN 60529:1992 should be IP 65);

c) methane or other flammable gas;

d) damage from moving plant and vehicles or other mechanical sources;

e) damage from blasting operations.

Oil-filled switchgear should not be used underground, principally because of the fire risk. Air break, vacuum or gas-filled switchgear should be used.

25.6 Electrical plugs and sockets

It should be possible for flexible trailing cables to high-powered mobile plant such as power loaders, roadheaders, etc. to be switched off and disconnected easily and quickly. The plug and socket system used on the cables should be of the restrained type which prevents the plug from accidentally being pulled out of the socket with the power on and should be robust enough to withstand rough handling. The plug and socket should accommodate the power cores and the earth and, where necessary, pilot cores of the flexible cable. The control circuits of the associated switchgear should monitor the integrity of the pilot/earth cores and trip the supply in the event of an open or short circuit fault in these cores. The monitoring device should also automatically isolate the supply to the cable before the power circuit is opened, if a person tries to disconnect the plug with the power on.

For low-voltage applications rated 125 A or less, the plugs and sockets should conform to BS EN 60309-1, and for operating voltages above 110 V and current ratings above 16 A, the plugs and sockets should be fitted with either electrical or mechanical interlock to prevent disconnection while live.

In flammable or potentially explosive atmospheres plugs and sockets should be of the explosion-protected type (see **25.3.7**).

25.7 Lighting installations

25.7.1 General

Electrically powered lighting should be used in tunnel construction (see Clause **17**).

25.7.2 Voltages

Lighting circuits should be separate from other sub-circuits and should be designed in accordance with the recommendations in **25.3**. The preferred operating voltage for tunnel lighting should be reduced low-voltage 110 V single phase (see **25.3.2.3**).

Low-voltage 230 V single phase lighting should be used only when the lighting circuit is supplied from a fixed point and where the lighting fittings are fixed in positions out of normal reach and clear of danger of possible damage from foreseeable working operations.

In confined conductive locations such as small bore tunnels of nominal bore less than 1.5 m, temporary lighting installations should be supplied at extra-low voltage (see **25.3.2.4**).

25.7.3 Luminaires

Luminaires should have a protective enclosure that conforms to a rating of IP 54 in accordance with BS EN 60529:1992 where practicable. Where required, waterproofing and dustproofing of luminaries should be in accordance with **25.3.6**.

The use of explosion protected luminaries, typically rated Ex "e" or Ex "d", should be considered for underground locations where methane might occur.

Luminaires operating at reduced low voltage but incorporating a step-up transformer should be used only in fixed positions and should be accessed by authorized persons only.

NOTE 1 Fluorescent lighting is the preferred type for general lighting of the tunnel. Floodlighting might be more appropriate for access and task lighting, especially when large areas have to be lit.

NOTE 2 For illumination of access routes, moulded rubber fittings with tungsten lamps operating on reduced low voltage or below could be used, provided that the lamp-holder is shrouded in insulating material and permanently moulded or bonded in an equivalent manner to the cable sheath.

In addition, each lamp should be protected by a suitable mechanical guard or cover or placed out of reach.

25.7.4 Lighting cables

Cables supplying power to light fittings that are operating at above reduced low voltage should be of a type having a metal sheath and/or screen which needs to be continuous and effectively earthed.

25.7.5 Emergency lighting

Emergency lighting should be provided in accordance with **17.5**.

25.8 Electric motors

25.8.1 Types

Totally enclosed fan-cooled motors in accordance with BS EN 60034-5 should be used. Open ventilated motors should not be used.

25.8.2 Motor control and protection

Motors should be provided with overcurrent and single-phase protection and, in the case of HV motor starters, should additionally have instantaneous earth fault protection. Short circuit protection should be by high-breaking capacity motor rated fuses or moulded case circuit breakers where fault levels permit. Rewireable fuses should not be used because of their low fault-breaking capacity.

A switching device (which might be part of the starter) capable of breaking the stalled motor current should be mounted in a position convenient to the machine operator. When a switching device is used in conjunction with a starter, an interlocking device should be incorporated to prevent access to live parts, but provision should be made to enable control circuits to be tested with the switching device in the "off" position. Motor control circuits should operate at a voltage as low as practicable, but such circuits should never be supplied from a CTE system.

*NOTE 1 See **25.3.2.4**b) and BS EN 60204-1.*

Control circuits incorporating hand-held controls such as pendants should operate at a voltage not exceeding 50 V to earth.

The majority of TBMs are now fitted with programmable logic controllers, and care should be taken in the design of control circuits to ensure that safety is not compromised as a result of power failure or faults within the control system.

Control circuits should be designed to be fail-safe to prevent a hazard occurring when power is lost or restored.

Interconnection between the PLC and Motor control circuits should be by volt-free isolated contacts. Control voltage source via the PLC should always be from the motor control circuit. Fleeting contact systems should not be used.

Control circuits should also be designed to minimize the risk of inadvertent movement of any component through control circuit failure. Control cables should be protected against the risk of mechanical damage, and the use of control cables with screened cores should be considered in hostile environments.

NOTE 2 See also BS EN 60204-1 and BS EN ISO 13850.

All unused cores of multi-core cables used in control systems should be connected to earth while not in use, especially on applications where these cables are subject to continual movement, e.g. erector umbilical cables.

25.8.3 Emergency stops

All machinery should be provided with emergency stop controls readily accessible to operators and others. Emergency stops should incorporate reset facilities within the motor control circuit to prevent the motor restarting once the emergency stop is released.

NOTE See also BS EN 60204-1 and BS EN ISO 13850.

25.9 Laser products

25.9.1 General

*COMMENTARY ON **25.9.1***

Because of the wide ranges possible in wavelength, energy content and pulse length of a laser beam, the risks associated with laser use vary widely. It is considered impractical, therefore, to regard lasers as a single group to which common standards can apply.

The manufacturer's instructions and classification should be consulted as one practical means of evaluation and control of laser radiation risk.

A risk assessment should be carried out and a safe system of work developed.

NOTE 1 Laser products are certified as belonging to one of five hazard classes denoting the accessible emission limit of the laser. The recommendations for laser safety vary with the class of laser product in use.

Except for surveying instruments, two classes of laser products, namely Class 2 and Class 3A should generally be used in construction operations.

NOTE 2 Class 2M and Class 3R in the revised international standard IEC 60825-1+A2:2001 [52].

25.9.2 Class 2 laser products

*COMMENTARY ON **25.9.2***

Class 2 laser products are non-pulsed, low-power devices emitting radiation in the visible region (i.e. 400 nm to 700 nm). The output power of this class is limited to 1 mW (collected through a 50 mm limiting aperture). Safety from these lasers can be afforded by aversion response including the blink reflex.

The laser beam should, where reasonably practicable, be terminated at the end of its useful path. The laser should not be aimed at vehicles or personnel, and should be sited above eye level.

Beam propagation paths should be demarcated where practicable, and users should be instructed never to stare deliberately into the laser beam. Persons known to have impaired eye aversion responses should not use Class 2 lasers when unsupervised. This should also be applied to persons on certain types of medication affecting the blink reflex or under the influence of alcohol.

25.9.3 Class 3A laser products

*COMMENTARY ON **25.9.3***

Class 3A laser products are those that typically operate in the visible region (i.e. 400 nm to 700 nm) at an output power no greater than 5 mW (collected through a 50 mm limiting aperture) and are typically continuous wave rather than repetitively pulsed devices. The power density of the beam, through a limiting aperture of 50 mm, is also constrained to no greater than 25 W/m^2. Power density limit ensures that the eye can never be exposed to more than 5 times the Class 2 limit (i.e. 1 mW), even when magnifying viewing aids are used.

Direct intra-beam viewing with optical aids can be hazardous and therefore systems of work should always ensure that this is avoided.

25.9.4 Use of laser products

Class 2 laser products should be used in tunnelling operations wherever possible.

However, there are times when, for example, due to high ambient light levels, more power might be needed than is available from Class 2 laser products; Class 3A laser products may then be used, in which case the following additional precautions should be taken.

a) A Laser Safety Officer should be appointed whenever lasers above Class 2 are in use.

b) Suitable and appropriately trained persons should be assigned to install, adjust and operate the laser equipment.

c) Areas where such lasers are used should be treated as laser-controlled areas and should be posted with standard laser warning signs, and access thereto should be restricted to persons who have been advised on the precautions they should take.

d) Wherever reasonably practicable, mechanical or electronic means should be used to assist in the alignment of the laser.

e) Prolonged intrabeam viewing (0.25 s) can be hazardous and precautions should be taken to prevent persons looking directly into or inadvertently gaining access to the beam. Direct viewing of the beam with optical instruments, unless fitted with special filters, can be especially hazardous and should not be permitted, unless specifically approved by the Laser Safety Officer after detailed assessment.

f) If the beam irradiance at the boundary of the controlled area exceeds the maximum permissible exposure level (MPE), under any viewing conditions including the use of 8 mm viewing optics, the laser beam should be terminated within the controlled area.

g) The position of any laser beam path should, where reasonably practicable, be either well above or well below eye level.

h) Precautions should be taken to avoid the laser beam being directed intentionally at reflecting surfaces such as mirrors, lenses, etc. Any such reflecting surfaces should be stopped from being accidentally introduced into the beam path.

i) When not in use, the laser should be stored securely, so that unauthorized persons cannot gain access to the equipment.

26 Maintenance, renovation and repair

26.1 General

Many of the recommendations in other clauses of this code of practice should be considered as applying equally to the maintenance, renovation and repair of tunnels as to the construction of new tunnels.

In addition, the guidance in CIRIA Report RP712 [N6] should be taken into account.

26.2 Asset management

A formal asset management system should be established for all tunnels. Detailed inspection and recording of defects in the tunnel lining should be carried out at pre-determined regular intervals, starting with a formal handover inspection on completion of construction.

A standard reporting procedure should be established with appropriate checklists to enable correlations with subsequent inspections. Before each inspection, reference should be made to the records of any previous inspection, copies of which should be retained and available on site. There should be provision within the asset management system for identifying and prioritizing remedial works and for recording significant repairs to the lining.

NOTE 1 In the majority of cases the rate of deterioration of tunnels is slow and the development of defects is accompanied by visible signs of distress. The safe and successful maintenance, renovation and repair of tunnels depends on an understanding of the original design, the correct diagnosis of the cause of the defects, the development of the most appropriate remedy and the decision on when and how to carry out the work.

It should be noted that points which are likely to require attention are:

- degradation and spalling of the lining material or exposed rock faces;
- loss of mortar in lining materials;
- deformation and cracking;
- location and quantity of ingress of water and solids;
- chemical and thermal effects.

In certain tunnels where the presence of gases poses a danger, a scheme should be drawn up for the regular assessment of the gases (see **15.4** and **15.5**).

NOTE 2 Guidance is available from the HSE and other published sources of information on this subject.

Those areas of the tunnel lining that have deteriorated the most should undergo more detailed inspection and monitoring.

NOTE 3 In addition to normal inspection procedures, specialized techniques that can be employed include:

- *CCTV inspection;*
- *installation of monitoring studs for the accurate measurement of deformation;*
- *strain gauges;*
- *profiling, e.g. photogrammetry, laser measurement techniques;*
- *water sampling;*
- *geophysical, e.g. ground penetrating radar, thermography.*

NOTE 4 A computer-based system to analyse and manage the profile data could be desirable.

*NOTE 5 Some of the further investigations listed under **26.3** can be carried out instead at this stage.*

26.3 Preparation for renovation or repair

26.3.1 Desk study

Detailed historical research should be carried out to identify particulars of original construction and associated temporary works such as construction shafts and adits. This research should also determine whether any subsequent construction or modification has been carried out. Documents that should be located and studied include:

- geological reports and site investigation reports prepared prior to the original construction work;
- any mining records;
- reports written by the original engineer;
- works-as-executed drawings, reports and diaries kept by the original resident engineer;
- engineering papers and old repair reports;
- records held by local libraries;
- health and safety file.

*NOTE 1 See The Construction (Design and Management) Regulations 2007 [1] and see Clause **4**.*

Locating these reports and drawings can take a long time, as over the years they might not necessarily have been passed from the original client to subsequent owners. Nevertheless, every effort should be made to find them, as the alternative would mean site investigations.

*NOTE 2 The works-as-executed drawings are particularly valuable (often they have been microfilmed). Moreover, the more information is produced by the historical research, the less might be required for the forthcoming site investigation (see Clause **5**).*

26.3.2 Site investigation

A site investigation should be carried out (see Clause **5**) to identify the ground conditions (if this is not already known) and the extent of the voids or defects behind or within the tunnel lining. The location and delineation of voids behind the tunnel lining is vital and should be determined.

NOTE Trial holes could be required to establish, for instance, the general integrity of the tunnel lining in the area of the proposed work, whether a structural invert is present or to establish the groundwater regime behind the lining.

Among the procedures that should be considered are core and soil sampling, drilling holes for the use of endoscopes, cutting access windows, and geophysical or imaging techniques.

Special care should be exercised in identifying inherent imperfections in existing structures, old shafts and joints between length work on old brick tunnels.

26.3.3 Design

*COMMENTARY ON **26.3.3***

The engineering properties of the ground or of the structure itself could have changed as a result of the action which has prompted repair (e.g. water leakage, solids transport, general weathering effects) and this could have affected the structural behaviour and load-bearing capacity of the ground/structure complex. The work to be carried out can itself impose local or widespread loading on the structure (e.g. grouting pressures). Even minor intrusions, such as drilling for grouting, can affect structural behaviour. Major intrusions, e.g. for partial reconstruction, are likely to have greater effect.

The design of the existing structure should be assessed for any changes in the ground or tunnel lining since it was built.

The design assumptions made and the limitations on working should be clearly stated in the health and safety plan, and the contractor should made aware of the dangers and be enabled to design appropriate temporary works and emergency procedures.

26.3.4 Information to be included in tender documents

The following information should be made available for inclusion in tender documents.

- The findings of any historical research or relevant local experience.
- "As built" drawings.
- Health and safety files for previous works.
- Ground investigation reports.
- Information from the condition survey.
- Previous in-house experience.

If a "permit to work" system is obligatory, details should be included. Other contractual arrangements should be subject to the same information provision.

If the client has requirements for working practices and safety procedures, these should be set out in the health and safety plan.

26.3.5 Preparation of a safe system of work

A detailed method statement, developed from the health and safety plan, should be prepared for the tunnelling work. Statutory authorities and other bodies should be consulted as appropriate and their consent obtained if necessary.

26.4 On-site procedures for renovation and repair

26.4.1 Documents to be held on site

The principal contractor should ensure that site-based representatives of all parties to the contract have access to the following documents.

- Health and safety plan and method statements with access to the health and safety file;
- Relevant "as built" drawings.
- Details of the latest condition survey.
- The site investigation report.
- "Permit to work" forms as appropriate.
- Relevant parts of any by-laws, wayleave stipulations, etc.

- Other reports, drawings, etc. located during the historical research.

26.4.2 Emergency procedures

Before renovation or repair work commences, a site meeting of all relevant parties should be held to discuss emergency procedures (see Clause **6**). Further meetings should be held as necessary during the course of the work.

26.4.3 Ventilation and testing for gases

Ventilation should be provided in accordance with Clause **15**; the procedures for ventilation during construction are equally applicable to the maintenance, renovation and repair of tunnels.

NOTE 1 Gases, particularly methane, can fill voids behind tunnel lining or enter the tunnel dissolved in groundwater.

NOTE 2 Attention is drawn to the relevant provisions of the "Guidance on the Health Hazards of Work Involving Exposure to Sewage" [53].

26.4.4 Fire precautions

The recommendations of Clause **13** and Clause **14** should be applied equally to tunnel maintenance, renovation and repair.

26.5 Work in shafts

26.5.1 Lifting operations

Cranes may be used for raising or lowering inspection cages but should not be used for supporting working platforms. Particular care should be taken to prevent sudden crane movements.

NOTE Attention is drawn to The Lifting Operations and Lifting Equipment Regulations 1998 [42].

26.5.2 Environment

Following the completion of work carried out within a shaft, but before re-entry, the environment within the shaft and within the tunnel at the bottom of the shaft should be checked to ensure that it is still safe.

NOTE 1 Closing a shaft can result in a changed environment within the tunnel and therefore due regard should be given to ventilation, atmospheric pressure effects, means of escape, etc.

NOTE 2 This can also result in a shaft becoming a confined space.

Build-up of water and debris on the temporary cover, decking or working platform should be controlled.

26.5.3 Access control

A substantial barrier with dedicated access point(s) should be installed at the top of the shaft to control access and to prevent materials or debris falling on to persons working in the shaft.

For work of limited duration within the shaft, access to the tunnel at the bottom of the shaft should be fenced off.

NOTE 1 For work of longer duration or where necessitated by the nature of the work being undertaken, it might be necessary to install a temporary cover, decking or working platform within the shaft. This generally protects the area within the tunnel at the bottom of the shaft.

NOTE 2 Rope access techniques can be used for access within shafts, where appropriate. The IRATA publication "Guidelines on the Use of Rope Access Methods for Industrial Purposes" [54] provides important information.

26.5.4 Working platforms

Any working platform should have a substantial roof with a trap door.

NOTE This gives protection against wet conditions and small objects falling down the shaft.

The working platform should be secured to the shaft wall during use and the maximum platform loading should be clearly displayed. Platform suspension systems should be designed to withstand the heaviest loading to which it is envisaged that the platform will be subjected.

A secondary escape facility from the platform should be provided. A means of communication with the working platform or inspection cage should be in place at all times. Communication should be both oral and visual wherever possible.

Unless working from a properly guarded fixed working platform, suitable individual safety harnesses should be worn.

26.6 Temporary works

Before work on site commences, the contractor should submit to the client's professional adviser for approval all details of temporary works, including proposed methods of working.

26.7 Record of work

All work carried out should be recorded in the health and safety file so that it can be available for future inspection and repair work.

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