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BS 6164:2019

Health and safety in tunnelling in the construction industry − Code of practice

DRAFT

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Contents

List of tables

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 October 2019. It was prepared by 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This British Standard supersedes BS 6164:2011, which is withdrawn.

Information about this document

This is a full revision of the standard, and introduces the following principal changes:

- reference to the current versions of European Standards relating to tunnelling machinery and manlocks;
- reference to the ITA guidelines for refuge chambers in tunnelling;
- setting out formal procedures for design checking including the resolution of differences between a designer and a design checker;
- Clauses 23 and 24 have been extensively restructured and extended, particularly in respect of fire, MEWPs, use of plant underground and rail operations;
- recommendations for undertaking high pressure compressed air exposures;
- material on SCL and exclusion zones; and
- information on real time dust monitoring.

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at bsigroup.com/standards, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Use of 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 2015 [1] and the guidance in 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 BS 6164:2011. Clauses contain recommendations for and guidance on health and safety practices in shaft sinking and tunnelling. However, the text has been extensively 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.

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 of 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.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

The word “should” is used to express recommendations of this standard. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the Clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

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.

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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 construction aspects of maintenance, renovation and repair of shafts and tunnels.

The recommendations in this British Standard 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) and machinery for use underground are currently under development or revision.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions 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.

Standards publications

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 4211, *Specification for permanently fixed ladders*

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

BS 4727-1: Group 01:1983, *Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms – Part 1: Terms common to power, telecommunications and electronics – Group 01: Fundamental terminology* (now withdrawn)

BS 5045 (all parts), *Transportable gas containers*

BS 5306-3, *Fire extinguishing installations and equipment on premises – Part 3: Commissioning and maintenance of portable fire extinguishers – Code of practice*

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BS 5306-8, *Fire extinguishing installations and equipment on premises – Part 8: Selection and positioning of portable fire extinguishers – Code of practice*

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 ground investigations*

BS 5975:2019, *Code of practice for temporary works procedures and the permissible stress design of falsework*

BS 6031:2009, *Code of practice for earthworks*

BS 6100-3:2007, *Building and civil engineering – Vocabulary – Part 3: Civil engineering – General*

BS 6387:2013, *Test method for resistance to fire 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 of rated voltages of 600/1 000 V and 1 900/3 300 V for fixed installations, having low emission of smoke and corrosive gases when affected by fire – Specification*

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 7212:2016, *Code of practice for the safe use of construction hoists*

BS 7375, *Distribution of electricity on construction and demolition sites – Code of practice*

BS 7430, *Code of practice for protective earthing of electrical installations*

BS 7671, *Requirements for Electrical Installations – IET 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 8460, *Code of practice for the safe use of MEWPS*

BS 8467, *Protective clothing – Personal protective ensembles for use against chemical, biological, radiological and nuclear (CBRN) agents – Categorization, performance requirements and test methods*

BS 8476:2007, *Code of practice for the safe use of concrete pumps*

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 169, *Personal eye-protection – Filters for welding and related techniques – Transmittance requirements and recommended use*

BS EN 206:2013+A1, *Concrete –Specification, performance, production and conformity*

BS EN 352 (all parts), *Hearing protectors – Safety requirements and testing*

BS EN 361, *Personal protective equipment against falls from a height – Full body harness*

BS EN 377, *Lubricants for applications in appliances and associated controls using combustible gases except those designed for use in industrial processes*

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BS EN 388:2016, *Protective gloves against mechanical risks*

BS EN 397, *Industrial safety helmets*

BS EN 474 (all parts)*, Earth-moving machinery – Safety*

BS EN 529, *Respiratory protective devices – Recommendations for selection, use, care and maintenance – Guidance document*

BS EN 618, *Continuous handling equipment and systems – Safety and EMC requirements for equipment for mechanical handling of bulk materials except fixed belt conveyors*

BS EN 620, *Continuous handling equipment and systems – Safety and EMC requirements for fixed belt conveyors for bulk materials*

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 14973, *Conveyor belts for use in underground installations – Electrical and flammability safety requirements*

BS EN 16228 (all parts), *Drilling and foundations equipment – Safety*

BS EN 1800, *Transportable gas cylinders – Acetylene cylinders – Basic requirements, definitions and type testing*

BS EN 1889-2, *Machines for underground mines – Mobile machines working underground – Safety – Part 2: Rail locomotives*

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 and continuous miners– 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 13157, *Cranes – Safety – Hand powered cranes*

BS EN 13463 (all parts), *Non-electrical equipment intended for use in potentially explosive atmospheres*

BS EN 13501-1, *Fire classification of constructions products and building elements – Part 1: Classification using data from reaction to fire tests*

BS EN 13794, *Respiratory protective devices – Self-contained closed-circuit breathing apparatus for escape – Requirements, testing, marking*

BS EN 14116, *Tanks for transport of dangerous goods – Digital interface for product recognition devices for liquid fuels*

BS EN 14502-1, *Cranes – Equipment for the lifting of persons – Suspended baskets*

BS EN 14530, *Workplace atmospheres – Determination of diesel particulate matter – General requirements*

BS EN 16191, *Tunnelling machinery – Safety requirements*

BS EN 16228 (all parts), *Drilling and foundation equipment – Safety*

BS EN 50104, *Electrical apparatus for the detection and measurement of oxygen*

– Performance requirements and test methods

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BS EN 50110-1, *Operation of electrical installations – General requirements*

BS EN 50110-2, *Operation of electrical installations – National Annexes*

BS EN 62305 (all parts), *Protection against lightning*

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 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*

BS EN 60079-10-2, *Explosive atmospheres – Part 10-2: Classification of areas – Explosive dust atmospheres*

BS EN 60079-11, *Explosive atmospheres – Part 11: Equipment protection by intrinsic safety "i"*

BS EN 60079-14:2014, *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 *Degrees of protection provided by enclosures (IP code)*

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

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

BS EN 61099, *Insulating liquids – Specifications 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 340, *Conveyor belts – Laboratory scale flammability characteristics – Requirements and test method*

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 3449, *Earth-moving machinery – Falling-object protective structures – Laboratory tests and performance requirements*

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 8030, *Rubber and plastics hoses – Method of test for flammability*

BS EN ISO 11117, Gas cylinders – Valve protection caps and valve guards – Design, construction and tests

BS EN ISO 11611, *Protective clothing for use in welding and allied processes*

BS EN ISO 11925 (all parts), *Reaction to fire tests – Ignitability of products subjected to direct impingement of flame – Single-flame source test*

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BS EN ISO 12922:2012, *Lubricants, industrial oils and related products (class L) – Family H (Hydraulic systems) – Specifications for hydraulic fluids in categories HFAE, HFAS, HFB, HFC, HFDR and HFDU*

BS EN ISO 20344:2011, *Personal protective equipment – Test methods for footwear*

BS EN ISO 20345:2011, *Personal protective equipment – Safety footwear*

BS EN ISO 20471:2013+A1:2016, *High visibility clothing – Test methods and requirements*

BS EN ISO 22721, *Conveyor belts – Specification for rubber- or plastics-covered coveyor belts of textile construction for underground mining*

BS EN IEC 62485-1, *Safety requirements for secondary batteries and battery installations – Part 1: General safety information*

BS IEC 1008-2-2, *Implementation of IEC 1008-2-2:1990 – Specification for residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCCBs) – Part 2-2: Applicability of the general rules to RCCBs functionally dependent on line voltage*

BS ISO 12482, *Cranes – Monitoring for crane design working period*

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.

[N7] GREAT BRITAIN. The Electricity at Work Regulations 1989. SI 1989/635. London: The Stationery Office.

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 (now withdrawn).

NOTE Terms relating to duty holders under CDM 2015 [1] are defined in the regulations.

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4 The control of risk

4.1 From hazard identification to safe systems of work

*COMMENTARY ON **4.1***

Risks arise from hazards. Hazards (such as unstable ground, water, noise, dust, compressed air, moving machinery and electricity) have the potential to harm persons, the tunnel or the surrounding environment including third party assets. Sometimes the hazard arises from the third-party assets e.g. flooding from a nearby water main or sewer.

The risk associated with a hazard is the product of the likelihood of occurrence, 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 construction activity, and precautions against the risk of falling are well understood and easily implemented.

4.1.1 General

NOTE 1 The achievement of good health and safety performance on site, and the avoidance of "adverse events" including accidents, cases of ill health, incidents and losses, requires the effective identification of hazards and control of risks.

Identifying hazards and risks, along with determining the level of risk and how it is to be controlled, should be a continuous process that starts at the procurement, planning and design stages and is continued by the contractor and designer through the construction stage of the project into the operation and maintenance stage of the asset.

Low frequency but high consequence tunnelling events can occur (such as substantial ground collapses, or underground fires). Their consequences for the client, designers, contractor, employees and others (e.g. members of the public and third-party asset owners) can be very severe and these low probability high consequence events should be considered and mitigated as part of the overall hazard and risk management system. In addition, there can be insurance, political or regulatory outcomes which can affect the wider tunnelling industry.

NOTE 2 Adverse events which have occurred in similar tunnels, in similar ground conditions or in nearby locations, could all impact on the project in hand.

A structured approach should include the following stages.

a) Project specific identification of the possible hazards that could be encountered during construction and maintenance. Generic approaches to the identification and evaluation of risk can result in an incomplete picture.

b) Elimination of hazards should begin at the design stage and continue throughout the construction stage.

c) Evaluation of the residual hazards that cannot be eliminated.

   NOTE 3 Certain hazards in tunnelling can give rise to several risks. For example, ground contaminants such as benzene, toluene and xylene pose the risk of fire or explosion and are themselves carcinogenic.

d) An assessment of the risks should be carried out in order to prioritize the necessary risk-control measures. Risks that are identified as trivial should be noted as such and 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 measures should be developed during the design and construction stages and the information generated together with information on any additional hazards identified should be passed to all relevant parties to the contract.

   NOTE 4 The ultimate aim of this process is to devise project-specific safe systems of work.

   NOTE 5 For further information see the ITIG Code of Practice for Risk Management of Tunnel Works [3].

4.1.2 Devising safe systems of work

Achieving 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. Worker consultation and input can also be useful.

NOTE 1 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. The potential in tunnelling for high consequence events should never be underestimated.

NOTE 2 A team approach that harnesses the knowledge and experience of all concerned has many benefits. Input from experienced designers, contractors 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 phase plan, that addresses the risks identified in the information provided, together with any additional risks the principal contractor identifies. 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)

*COMMENTARY ON **4.2***

Emergencies are adverse events, the occurrence of which can result in irrecoverable situations and require urgent assessment and action to address them.

Specific contingency response plans should be developed for dealing with foreseeable hazardous occurrences on the project.

Contingency plans deal with events which might or might not occur. An example is the degree of variability of the ground or water conditions. Plans should be prepared to address such factors and the speed of recovery through application of the plan should also be assessed.

NOTE 1 For example, 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 together with an emergency power supply capable of running safety critical systems.

The first consideration should be to identify the types of possible emergencies in the context of the project. Those who draw up a list of possible emergencies should have as wide a knowledge and experience of tunnelling as possible and should be prepared to undertake research to supplement knowledge derived from their own experience.

NOTE 2 Foreseeable emergencies 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, for example, breach of a flood defence.

Planning for emergencies should harness the skills and experience of those experienced in dealing with such situations.

The nature of possible emergencies should be discussed with the public emergency services.

Emergencies arising from the tunnelling activities can adversely affect persons and infrastructure not directly involved in the works and this should be recognized in emergency planning; however, a single emergency plan is unlikely to adequately address the range of emergencies which could occur.

As part of emergency planning a comprehensive information pack should be prepared which can be handed to the emergency services on their arrival on site, containing information about the tunnel layout, tunnel access locations and shafts, location of fire and other emergency equipment, location of refuge chambers, communication arrangements, and location of hazardous materials stored underground. The pack should be kept up to date.

NOTE 3 This pack is referred to as a "grab bag" by some fire and rescue services.

*NOTE 4 Recommendations for managing emergencies involving flooding and inundation are given in Clause **10**, and for managing fire emergencies, in Clause **13** and 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 and welfare

4.4.1 Health surveillance

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

As part of the overall control of risk, occupational health and welfare should be managed during construction on site.

As part of an adequate health risk management system, all workers should understand the symptoms of the health conditions which might occur under the particular conditions of work and know what to do if they occur, so they can access occupational health advice. The importance of early reporting of symptoms should be included as part of this. A clear system of accessing occupational health advice should be devised and communicated.

Some activities can require a greater level of fitness such as plant operation, spraying of shotcrete, working in protective clothing in contaminated ground and site rescue team members. Occupational health advice should be taken on appropriate fitness to work assessments in respect of performing additional tasks such as these. There are statutory requirements for fitness for work in compressed air.

NOTE 2 Health surveillance can be required by statute as part of the mitigation measures limiting the risk from exposure to physical hazards such as noise and vibration.

As tunnel workers are a peripatetic group, often living away from home and with limited access to community health services, general community health services should be provided as necessary.

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

Where 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.

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

Accident category	**Examples**	**Precautions and/or principal references**	**Other references**
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	**17**, **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 (fresh)	Restrict access for personnel, tests prescribed to confirm structural stability, safe zones identified on construction sequence drawings	
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, purpose designed transport	**20.6**
Injury from fall of ground	Collapse of open face	See Clause **7** and Clause **8**	
	Rock fall, Sprayed concrete lining (SCL)	Barring down loose rock; immediate support, exclusions zones	**7.7**
Flooding or inrush of water	Broken sewer or water main, groundwater inrush, river breach, 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 **23.3**	
Vehicles	Locomotives and rolling stock	See **23.2.8** and **23.2.9**	
	Rubber-tyred vehicles	See **20.12.4**	
Electrical installation	Electrocution	See Clause **25**	**13.4**
Fire and explosion	Burns, concussion	See Clause **12**, Clause **13** and Clause **14**	**11.5**, **25.7.7**
Atmospheric pollution	Atmospheric contaminants	See Clause **12**, Clause **15** and Clause **16**	**11.3.2**
Handling hazardous materials	Soil conditioners	Avoidance of spillage and contact. Adherence to manufacturer's data sheets. Suitable PPE. Health surveillance	

Accidents associated with TBMs		See BS EN 16191	

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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 on the HSE website: http://www.hse.gov.uk/health-surveillance/index.htm [5].

Risk assessment of occupational health risks should be undertaken early in the process. All workers should understand what these risks are and how they are controlled.

Site managers, supervisory staff and designers should be able to recognize and respond appropriately to occupational health hazards associated with tunnel construction work activities.

Supervisory staff should have training in and an awareness of the symptoms of common occupational illnesses. Workers should also be made aware of the symptoms of relevant health conditions.

There should be access to occupational health professionals as necessary. On larger sites there should be access to an occupational health nursing service on site with periodic support from an occupational health doctor. It should be ensured that the occupational health provider understands the occupational health risks of working in a tunnelling environment and has previous relevant experience. Support from an occupational hygiene service should be provided particularly where high levels of dust, noise or vibration occur.

Appropriate controls should also be in place to prevent skin exposure to irritant or caustic substances.

4.4.3 Provision of information

Information on exposure levels and associated risk control measures should be made available to employees.

Employees should also understand the occupational health risks relevant to their role and what to do should they develop symptoms.

4.4.4 Record keeping

*COMMENTARY ON **4.4.4***

Attention is drawn to the 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 Regulatory Reform (Fire Safety) Order 2005 [6], the Control of Noise at Work Regulations 2005 [7] and the Control of Vibration at Work Regulations 2005 [7] and the Working Time Regulations 1998 (as amended).

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

4.4.5 Washing facilities and potable water

There should be welfare provision on site with potable water, toilet, washing, messing and clothes drying/storage facilities. Good personal hygiene should be maintained, particularly where work involves contact with contaminated ground and with irritant or caustic substances. Skin care facilities should be provided to mitigate the risks from contact with cementitious materials and irritant chemicals.

Underground workers should have ready access to potable water, toilet, washing and messing facilities.

4.4.6 Mitigation measures

4.4.6.1 Noise

Steps should be taken so far as is reasonably practicable to reduce noise exposure, including substitution by less noisy equipment or by placing machinery in noise enclosures. For example, the seating area of tunnel personnel transport should be insulated from noise so that noise levels do not exceed 80 dBA.

NOTE 1 Health surveillance might also be required.

NOTE 2 See the Control of Noise at Work Regulations 2005 [7].

4.4.6.2 Manual handling

Risks involved in manual handling should be reduced, for example, 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

Selection and maintenance of tools along with 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 professional experienced in HAVS.

NOTE See the Control of Vibration at Work Regulations 2005 [7] and BTS Guide on HAVS [9].

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Table 2 – Principal occupational health hazards

Physical			
Hazard	**Occurrence**	**Possible symptoms and/or consequences**	**Clause reference**
1 Noise	Prolonged exposure to high noise levels. Pneumatic tools such as clay spades or rock drills. Machinery.	Irreversible hearing loss, tinnitus.	**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 lower back pain and restricted body movements that can lead to permanent disability. Prolapsed disc. Muscle/tendon damage.	**4.4.3, 8.3, 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 (Hand arm)	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. Vibration induced carpal tunnel syndrome. 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, 4.4.6.4, 19.3**
4 Vibration (whole body)	Operators of ride-on machinery lacking appropriate seating	Damage to internal organs, back pain.	**24.1.8**
5 Heat	Hand excavation in conditions of high temperatures, high humidity, or low rate of air movement. Exacerbated by working in compressed air.	Heat stroke, heat exhaustion. Increased heart rate and body temperature and sweating and salt imbalance. Fainting.	**4.4.5**, **4.4.6.5**, **Clause 11.1.1, note 1**, **15.3, 15.9**
6 Cold	Working in a cold environment due to altitude, working in artificially frozen ground.	Hypothermia	**9.2.1.1**
7 Hyperbaric atmospheres	Work in compressed air.	Decompression illness, barotrauma, bone necrosis. Signs and symptoms can include: Acute: Limb joint pains, skin rashes, itching, mottling, numbness, tingling, weakness, paralysis, visual disturbance, unconsciousness, and convulsions. Chronic: Bone necrosis.	**11**

8 Fatigue	Poorly planned shift patterns, excessive work demands, lack of suitable rest periods, poor/restricted working environment, noise and chemical exposure, lack of sleep or existing health issues.	Fatigue can result in excessive tiredness and a reduced ability to perform work effectively. A fatigued person might be: • less alert • less able to process information with reduced risk perception • take longer to react and make decisions • more prone to error • less interested in working	**4.4.6.9**
		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 and/or allergic dermatitis.	**4.4.5, 4.4.6.6, 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, silicosis (acute, subacute, chronic), lung fibrosis, chronic obstructive pulmonary disease (COPD), lung cancer.	**4.4.2, 4.4.3, 4.4.4, 4.4.6.7, 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. Lung fibrosis, lung cancer, COPD, asthma.	**4.4.6.7, 6.7, 16**
4 Solvents	Skin contact, contamination of tunnel atmosphere. Contaminated land.	Principally skin irritation including dermatitis, absorption into body causing effects on brain, blood etc. Nausea and giddiness.	**4.4.3, 15.6.3.10**
5 Hydrocarbons	Particulates and gases from diesel engine exhaust emissions including NO_x and CO.	Irritation of eyes and respiratory tract. Might be a link with cancer (cause unclear).	**15.6.3, 24.8.1**
6 Spray membranes	Spray applied concrete linings	Irritation of respiratory system, dermatitis, asthma, sensitisation.	**16.2**
7 Ground contamination	Tunnelling under sites of former industrial activity	Exposure to carcinogenic organic compounds, irritants, etc.	**5.3.2**
8 Asbestos	Caulking in precast concrete linings built pre 1990s	Asbestosis, mesothelioma, lung cancer.	**16.3**
9 Lead	Caulking in old cast iron segmental linings	Lead poisoning	**16.11.7**
		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. Salmonella.	**4.4.3, 4.4.5, 26**

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4.4.6.5 Heat stress and exhaustion

Mechanization, ventilation, air chillers, cool breaks and job rotation should be used 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. Consideration should be given to the avoidance of products that are harmful to health, to the use of remotely operated equipment, and to the use of personal protective equipment (PPE) such as gloves and overalls. An appropriate skin care regime should be provided for workers. When contact has occurred, contaminated skin should be washed immediately with clean warm water and cuts covered with waterproof dressings. Pre-work (barrier) creams should be used, as well as moisturizer creams to replenish skin oils.

Use of gloves can result in dermatitis and this also needs to be considered as part of the risk assessment/health surveillance programme. 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 recognised as an important health risk in tunnelling, especially where sprayed concrete lining is being used.

NOTE Risk from dust exposure is dealt with extensively in ***16.1*** *and* ***16.2.***

The risk assessment should also consider the need for appropriate health surveillance in respect to dust (including RCS) exposure.

Mitigation measures should include reduction of emissions at source, exhaust ventilation and the use of water sprays. Mix design along with wet-mix shotcrete should be used to reduce the amount of dust generated in sprayed concrete lining applications.

4.4.6.8 Diesel engine exhaust emissions (DEEEs)

Exposure to diesel engine exhaust emissions (DEEEs) should be recognized as a health risk in tunnelling if diesel plant is being used.

Mitigation measures which should include replacement with non-diesel plant or diesel plant producing lower emissions, or use of specialist clean burning fuels.

4.4.6.9 Fatigue

NOTE 1 Fatigue does not have a clear scientific definition but is generally considered to be "a state of perceived weariness that can result from prolonged working, heavy workload, insufficient rest and inadequate sleep". Specifically, a fatigued person will be less alert, less able to process information, have slower reaction times, be more prone to human error and have less interest in working compared to a person who is not fatigued. In addition to the safety implications of fatigue, there is the potential for issues with some workers' health when they are persistently fatigued e.g. where they have underlying health conditions.

NOTE 2 Attention is drawn to the HSE "Fatigue and Risk Index Calculator": http://www.hse.gov.uk/research/rrhtm/rr446.htm.

To mitigate fatigue, a risk assessment should be undertaken and acted upon that assesses, as a minimum:

a) Work demands:
   1) Use of plant, machinery and equipment to eliminate or reduce excessive physical demands.
   2) The introduction of a variety of tasks throughout the shift to minimize physical and mental demands and assist in maintaining alertness during a shift, particularly in night work.
   3) The design of plant and equipment to reduce both the mental and physical demands and hence reduce error and violation opportunities.
   4) Manage overtime opportunities to ensure suitable rest breaks are maintained and do not adversely increase fatigue levels.

b) Work environment:

1) Provide suitable facilities for rest, meal breaks, toilet facilities, etc.
2) Avoid physically demanding work during extreme temperatures or other environmental conditions (e.g. hyperbaric interventions) or increase the frequency of breaks/task rotation.
3) Use heating/cooling devices in extreme temperatures and/or provide appropriate work clothing and shelter.
4) Install local ventilation/cooling devices in hot, confined work environments.
5) Monitor and control exposure to noise, temperature and chemicals.

c) Work scheduling/planning:

1) Avoid excessively demanding contract programmes.
2) Tunnel bonus scheme, if in operation, should be designed to ensure there are no incentives to finish tasks more quickly than is safe.
3) Include adequate breaks and ensure rest opportunities are provided through the work shift.
4) Ensure workers are not placed under excessive demands.
5) Fill vacant positions as quickly as possible to ensure enough workers are available to complete planned activities.

d) Non-work factors:

1) Brief workers on fatigue risk factors and their responsibility to manage their sports and social commitments to ensure they are fit-for-work.
2) Check workers are fit-for-work and encourage them to self-identify unfitness where appropriate.
3) Following up when a worker self-identifies difficulties they may have with such issues as rostering arrangements, health conditions, and family/carer responsibilities.
4) Encourage workers to seek medical advice to manage both temporary illnesses and chronic health conditions which may cause fatigue.
5) Monitor leave to ensure workers do not accrue excess annual leave.
6) Monitor sick leave to make sure that workers affected by fatigue are identified and managed appropriately.
7) Refer workers who are fatigued due to personal issues or medical conditions (e.g. sleep apnoea) to an occupational health specialist.
8) Ensure workers' temporary residential accommodation arrangements are conducive to restorative sleep (quiet, dark and cool) when workers need to work away from home and ensure travel distances are appropriate.

NOTE See the Work Time Regulations 1998 (as amended), HSE Guidance document 'Managing Shift Work' (HSG 256) and HSE Human Factors Briefing Note No. 10: http://www.hse.gov.uk/pUbns/priced/hsg256.pdf.

4.4.6.10 Shift length

Consideration should be given to the effects of shift length and shift pattern on health and safety performance through their effects on worker physical and mental wellbeing and the prevention of fatigue, as both are comparatively complex being influenced by historical working patterns, the transient nature of tunnelling, worker expectations and labour availability. Factors which should be considered when determining shift length include travel time between pit bottom and face, hand over at face or not along with travel time to and from living accommodation. Shift pattern is more complex as the pattern of days working/days off has wellbeing consequences affecting life style and family time. The importance of physical and mental wellbeing and personal preferences should be recognized including impact on earnings and distance of home from site as this determines the opportunities for spending time with family and undertaking recreational activity.

5 Investigation and information gathering

5.1 General

The safety of tunnelling works is critically dependent on adequate ground and site investigation information being available for undertaking detailed design and construction. All 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, along with identification of gaps in the information, to those responsible for the design, planning and 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.

NOTE 1 This could include on-site design involvement during the site investigation contracts to ensure the quality of the information obtained is suitable and to adapt the site investigation to address any issues identified in the investigation.

The recommendations set out in **5.2** and **5.3** should be treated as a basic checklist, and not a comprehensive specification.

NOTE 2 BS 5930 deals with site investigations in detail.

Particular reference should be made to the *Tunnelling and pipejacking addendum* in the *Specification for ground investigation* [20]. Ground investigations should be designed and scoped to reflect the requirements of Eurocode 7(BS EN 1997 series).

Where necessary, further ground investigation should be undertaken, after the contractor has been appointed.

5.2 Preliminary studies

5.2.1 Topography

Ordnance Survey maps and plans normally provide sufficient detail for the preliminary studies and 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 Many statutory undertakers and public bodies such as London Underground, Network Rail and Local Authorities have historical records of assets and inspection and assessment records.

NOTE 4 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; local port or harbour authorities can 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-reference 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 quality checks should be made on accuracy, applicability and relevance.

Records of relevant aquifers that could affect the tunnel during construction and in operation should be obtained.

5.2.3 Hydrology

Relevant records of surface water and potential sources of flooding should be obtained, e.g. from the Environment Agency. The potential for flooding from burst sewers or water mains should also be assessed.

Consideration should be given to tidal variations where the tunnel passes under estuaries or the sea.

5.2.4 Existing structures, services, old workings and unexploded ordinance

Knowledge of all structures, buildings, foundations and earthworks within the potential zone of influence of ground movements associated with construction (including tunnels and shafts) 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 groundwater 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. The presence of test piles separate from the building footprint should also be considered. Tunnelling works should not take place within the zone of influence of ground anchors without their impact on the anchors being assessed and any required mitigation measures implemented.

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, e.g. transport operators. Where appropriate, the actual location of these services should be verified. Drawings should not be relied upon unless verified, as they might be incomplete or insufficiently accurate.

NOTE 2 Trunk mains and services might be the responsibility of national, rather than local, utility providers.

Where there is a foreseeable risk from unexploded ordnance, the guidance on assessing the risk from unexploded ordnance published by CIRIA [10] should be followed.

A comprehensive walkover survey of the proposed tunnel alignment should be undertaken.

Owners of existing underground assets such as Network Rail, London Underground and other metro operators, Royal Mail, telecommunications companies, the National Grid, water authorities should be identified and consulted. When tunnelling close to existing assets, condition surveys are often required together with assessment of the impact of construction and consent from the asset owner.

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 along with the Tunnelling and pipejacking addendum in the *Specification for ground investigation* [20].

5.3.2 Boreholes

Boreholes (vertical, horizontal or inclined) should be sited to provide information specific to the tunnel or pipe jack 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 or adversely impact tunnel construction.

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 or a closed face tunnelling machine is used. The siting of a borehole where a shaft is to be sunk makes correlation possible between the borehole data and the actual ground encountered. This can be a risk if there is a water table below the shaft.

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 For more information, see: https://www.sepa.org.uk/media/34618/decommissioning-redundant-boreholes-and-wells.pdf.

NOTE 3 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 two 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 per kilometre of tunnel specifically for correlation of the stratigraphy of the site geology should be sunk.

As with information logging, drilling operations should be supervised by an experienced geologist 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. Borehole cores and samples of rock, subsoil and groundwater should be properly identified, labelled, and photographed where necessary, sealed and stored for further examination if required.

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

Where ground contamination is encountered, sufficient ground investigation should be undertaken to allow the nature of the contamination, concentration of contaminants and the spatial extent of the contamination including any groundwater plumes of contamination to be determined. The occupational and environmental impact of the contamination on the proposed shaft, tunnel or pipe jacking works should both be considered.

5.3.3 Information logging

The following techniques for information logging should be considered:

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

All information should be provided in accordance with the format recommended by the Association of Geotechnical and Geoenvironmental Specialists (www.agsdataformat.com) to allow dissemination and processing of information.

The experience of the logging geologist should be in accordance with the recommendations in the Site Investigation Steering Group publications at www.ags.org.uk/business/bestsi.cfm.Wherever possible additional information should be obtained from local exposures of strata or from large auger boring. For exposures in rock, this allows detailed information on joints and discontinuities in the rock including, persistency, orientation, degree of weathering, joint roughness and any infill to be obtained that supplements the borehole information. Chalk exposures are important for characterizing the material and engineering properties including the presence of flints.

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 field and laboratory testing programme should be undertaken to provide design parameters and information 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. Reference should to be made to the CIRIA Report C562 [11].

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

NOTE 2 In urban areas the use of geophysical methods might not be appropriate because of the interference from existing services and structures. However, 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.

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, the location of any underground structures, including piles and foundations, should be accurately determined where possible to enable the proximity to the proposed tunnel alignment to be calculated. 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; and
- 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, special hazards that could result should be carefully examined and appropriate precautions should be taken. This may include drilling of additional boreholes and geophysical testing to determine the depth of a pile, for example.

5.3.7 Structural survey

All buildings and structures that could be adversely affected by the tunnel construction should be surveyed to determine their condition prior to and after the proposed tunnelling operations. There is a wealth of empirical information that allows the zone of impact and assessment of the impact on adjacent properties to be determined from which the risk of damage category should be determined. Particularly sensitive buildings should also be monitored during tunnel construction.

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, pumping tests in boreholes sunk specifically for the purpose should be carried out.

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 prior to, and during, tunnelling work should be undertaken.

Water levels in boreholes should be recorded, and any perched water tables or artesian supplies should be identified. In water-bearing ground, permeability tests in boreholes should be considered as they 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 undertaken for salinity, acidity or pollution and/or the presence of chemicals or dissolved gases of natural or artificial origin.

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

The proximity of any contaminated groundwater that could be mobilized by dewatering should be considered.

5.3.9 Gas

The ground gas regime 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.

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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 or the Lambeth beds;

d) permeable strata where air has been introduced by previous compressed-air workings;

e) areas where the lowering of the water table has caused deoxygenation; and

f) limestone areas with acidic water.

It should be remembered that groundwater can travel considerable distances into tunnelling works and that gas can be dissolved in water and therefore enter a tunnel with any water ingress.

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 attenuation characteristics of the ground at that site.

5.4 Ground investigation during construction

5.4.1 General

*COMMENTARY ON **5.4.1***

As part of the validation of the design, it might be necessary to continue ground investigation during the construction stage to validate the ground investigation.

Face logging should be undertaken to correlate actual ground conditions with the ground investigation reports. 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 open face tunnelling methods are being employed.

5.4.2 Probing ahead

*COMMENTARY ON **5.4.2***

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 carried out depends on the likely hazards.

Probing should normally be carried out ahead of the face but this can be difficult in closed face machines unless the provision of drilling ports has been specified by the user. However in extremely bad ground conditions, probing to the side or above/below the tunnel can also be necessary, and in some conditions combined with ground treatment.

Care should be taken when drilling, to avoid uncontrolled penetration of any suspected aquifers above or below the tunnel construction (see Clause **9**). This is particularly important in open faced tunnels where it might be necessary to keep a buffer zone of probed ground for stability to confirm the ground conditions and presence of water in advance of tunnel excavation. Where necessary, de-pressurization or ground treatment can be undertaken to limit inflows to an acceptable level together with re-probing to confirm the effectiveness of the ground treatment.

5.4.3 Pilot tunnel

Consideration should be given to whether a pilot tunnel (either located within the cross-section of the intended tunnel or adjacent to it) might be the appropriate method for ascertaining the nature and behaviour of the ground in advance of the main tunnel construction. Findings from the pilot tunnel should be used to determine the need for possible special construction, ground treatment or ground support. Provision of a pilot tunnel as a means of settlement control and reduction should also be considered. It should not be forgotten that the pilot tunnel can be a significant structure in its own right.

6 Detailed planning for health and safety

6.1 Integral nature of design and construction

The interdependence between design and construction and their appropriateness for the ground and environmental conditions is fundamental for the safety of construction of underground works.

There should be shared understanding and agreed intent throughout the stages of planning, investigation, design and construction. If change is required, the shared understanding should be maintained, and a new intent agreed so that fragmentation of the planning, design and construction processes is avoided. There should be input from the designer during the construction phase to ensure the works are constructed and are behaving in accordance with the design intent. Reference should also be made to *A code of practice for risk management of tunnel works* [3], prepared by The International Tunnelling Insurance Group.

6.2 Pre-construction stage organization

Clients are responsible for ensuring and facilitating the establishment of a culture which enables good health and safety performance to be established. They should appreciate that this is in everyone's interest, and involves competence, cooperation and coordination along with the provision of adequate resources in terms of time and finance.

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 in conjunction with the designers on the residual risks. It should be prepared by persons who are suitably experienced in the tunnelling operations along with the types of plant and equipment to be used.

Contractors should carry out an assessment of the risks posed to their employees and all those who could be impacted by construction of the works. 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 along with channels of communication on engineering safety matters. This is particularly important, for example, in the choice of ground-support systems and decisions concerning safety at the tunnel face.

The principal contractor should plan, manage and monitor the construction phase and coordinate matters relating to health and safety during construction.

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

Where tunnel size permits, there should be welfare facilities located underground, including on tunnel boring machines (TBMs) as close as practical to the location of workers.

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 apply to individual work activities. Administration and enforcement are 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 2015 [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 and Road is the enforcement authority that should be consulted.

NOTE 2 Office for Nuclear Regulation is the enforcing authority for licensed nuclear sites.

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 2013 [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 3 Inspection of a shaft or tunnel by a competent person is a statutory requirement of the Construction (Design and Management) Regulations 2015 [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 4 The use of remote monitoring systems, including remotely-monitored instrumentation used together with 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, inspection and RESS meetings

All tunnelling operations should be subject to appropriate engineering supervision. Making informed engineering judgements and taking action in response to varying ground conditions should be done in order to maintain safe working conditions. The client should ensure that appropriately qualified and experienced persons monitor all site activities and assist in the overall promotion of health and safety. A proportion of both activities should be undertaken by persons independent from production responsibility. In tunnels and particularly those without a segmental lining routine, RESS (Required Excavation and Structural Support) meetings should be held.

NOTE RESS meetings are also referred to as Daily Review Meetings (DRM).

6.4 Safety of permanent and temporary works

6.4.1 General

*COMMENTARY ON **6.4.1***

Temporary works in tunnelling range from simple foundations and bases for static plant to primary lining of tunnels and caverns, the failure of which has the potential to result in a low probability high consequence event. In some forms of tunnelling, parts of the ground support installed initially as temporary works can later become incorporated into the permanent works.

The procedures for coordinating temporary works design and construction are set out in BS 5975. Specific requirements for tunnelling temporary works are set out in this standard.

The structural safety of temporary works should be considered as important as that of permanent works and their design and execution should be undertaken accordingly. Consequently, the design check procedures set out below apply to both permanent and temporary works.

All parties of the tunnelling project, including the client, should appoint their respective designated individuals (defined in BS 5975) to take responsibility for overseeing the design and execution of temporary works in accordance with BS 5975:2019, Table 22.

The designated individuals should collectively agree the scope of the checks required for temporary works and in the event of disagreement, the (CDM) principal designer's designated individual should make the final decision.

A temporary works register for the project should be prepared and maintained in accordance with BS 5975:2019, Clause **13**.

The execution of the temporary works should be subject to supervision and inspection in accordance with the requirements of BS 5975.

NOTE *PAS 8811 might also be relevant to clients.*

6.4.2 Design checks

The category of design checks for permanent and temporary works should be established on the basis of risk. The categories of design checks set out in BS 5975 should be followed. Design checks on works should be proportional to the risk of failure of those works and reflect the risk inherent in their execution. Risk should include risk to third parties who would be affected by a failure.

Where a design is revised after a check has been completed, the checker should be consulted as to whether a re-check is required. The checker should either issue an amended check certificate to cover the revised design or perform a re-check.

The level of risk in the execution of permanent and temporary works should be assessed in accordance with BS 5975:2019, Table 2. Low risk works should be subject to category 0 or 1 checks. Medium or high risk works should be subject to category 2 or 3 checks. It is the engineering competence and the level of independence of the checker (BS 5975:2019, Table 3) which should be considered important in selecting the checker, and not whether the checker is considered a contractor or a designer.

NOTE *The purpose of design checking is to confirm whether the design satisfies the design requirements, is constructible and is safe; not to undertake a full redesign of the project. For tunnel linings, it is normally sufficient for the checker to identify one or more worst case scenarios and check them as being sufficiently representative of the whole tunnel to satisfy the check requirements. Openings, junctions, enlargements, etc. are checked individually. Sufficient time is allowed in the programme for checks to be carried out. This is particularly so where design programmes are challenging and checks involve mobilisation of staff that are not exclusively employed on the project.*

If unforeseen ground conditions are encountered, the design should be reviewed and further checking might also be required.

6.4.3 Ground support works

Any lining which at any time supports the ground should be subject to a check.

The design of all lining works should take account of the constructability of the works and any associated temporary works.

6.4.4 Organization

The management of temporary works should conform to BS 5975.

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.

The Temporary Works Coordinator (TWC) should have experience and qualifications relevant to the role which they will be undertaking. Temporary Works Coordinators should have a sound appreciation for and understanding of the principles of design and construction associated with tunnelling temporary works.

Temporary Works Supervisors (TWS) should be appointed to supervise the construction of temporary works on a day to day basis. This resource should be increased if shift working occurs.

Examples of temporary works associated with tunnelling which should be assessed and managed in accordance with BS 5975 include:

- Ground support;

- Plant access roads leading to tunnel and/or shafts including verification of plant to shaft and plant to tunnel ground pressure exclusion zones;
- Shafts and pits in temporary condition including thrust walls;
- Gantry crane and all mobile crane foundations or supporting ground;
- Temporary propping;
- Temporary railways (non-mechanical parts only);
- Temporary structural steelwork;
- Mobile and static plant foundations or ground that plant will be bearing onto;
- Pipe supports and thrust restraint;
- Walkways, scaffolds and staircases including barriers and restraints;
- Plant and pedestrian bridges;
- Plant and train swept path analyses;
- Lifting points including those bolted into the tunnel lining;
- Bolting into the tunnel lining and segment edge distance verification, following guidance from the tunnel lining designer;
- Conveyors for spoil handling (see also **23.3.4**);
- Bolted connections subject to vibration;
- Open Cut Tunnel slope stability as dig progresses;
- Temporary tunnel linings (e.g. SCL);
- Ventilation ducting and brackets;
- M&E service supports and restraints; and
- Temporary stability of reinforcement cages.

The above list is not exhaustive and all tunnel temporary works should be reviewed by the TWC in advance at the planning stage.

6.4.5 Management of temporary works

A design brief should be prepared for all items of temporary works in accordance with BS 5975.

The selection of the category of design check for primary and secondary tunnel linings should be in accordance with **6.4.2**.

All tunnels under construction should be subject to a weekly review by the Principal Contractor's Temporary Works Coordinator.

For repetitive items of temporary works, or items of temporary works which due to their nature might become loaded as soon as they are installed (e.g. timber headings, construction railways). The Temporary Works Coordinator should assess when it is appropriate to issue a Permit to Load for the structure. Where the permit cannot reasonably be issued prior to the structure being loaded, the inspection should be carried out at a time-based frequency appropriate to the risk.

Inspection of low-risk items of temporary works may be delegated appropriately. This can include:

- Walkways;
- Pipe brackets;
- Ventilation duct fixation; and
- Permissible edge distances and areas on segment for bolting items of temporary works to the tunnel lining in accordance with the tunnel lining designer's criteria.

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Complex and high risk items of temporary works should be inspected and signed off by the TWC or delegated TWS. These can include:

- Heavy plant surcharge loading of shafts and tunnels including surcharge exclusion zones;
- Deep excavations and supporting temporary works;
- Lifting points bolted into tunnel lining;
- Plant support frame installations;
- Raised rail decking supported by structural steel work such as for crossings; and
- Complex installations involving temporary propping.

For complex items of temporary works, installation and removal sequences should be agreed between TWC and TWD and then detailed on the design drawings.

Changes to temporary or permanent works should only be made after direct consultation with the appropriate designer and after the appropriate level of check

6.4.6 Technical considerations

The design of the permanent works should take account of the constructability of the works and any associated temporary works including any structural or space proofing interaction between the two.

For tunnelling temporary works vibration and the risk of bolt slackening from vibration should be included in the design brief prepared by the TWC and Temporary Works.

The design of temporary works subjected to repetitive motion or vibration should be checked for resistance to fatigue failures and such works subject to specific inspections as necessary.

6.4.7 Category 0 and 1 checks

The checking process should be overseen by the design team leader and any disagreements resolved by the team leader.

6.4.8 Category 2 and 3 checking

6.4.8.1 Competence of the checker

The checker should have knowledge and experience of the type of work and should be fully capable of undertaking independent design of similar work.

6.4.8.2 Scope of the independent check

A check on the design of tunnel structures that support the ground should include both the design concept and assumptions and the design details. For some forms of tunnelling, such as Sprayed Concrete Lining (SCL) or timber support, the installed support might vary according to the ground conditions encountered, therefore in order to avoid a need for continuous redesign and rechecking during the works the initial design and check should include a range of measures (sometimes called “toolbox” items) for use in response to the conditions encountered.

6.4.8.3 Information to be supplied to the checker

The checker should be provided with and should formally accept a written brief including a statement of the scope of check required. The brief should include a statement of the design requirements which the design is intended to satisfy. The checking organization should be provided with, as a minimum, relevant drawings of the design signed off by the designer. The checker should be provided with relevant ground investigation information from which it should deduce ground parameters. Analysis or design reports produced as part of the design process should not be provided to the checker.

6.4.8.4 Checking process

The checker should carry out such review, analysis and assessment as necessary to confirm that the design provided satisfies the design requirements, is constructible and is safe. The checker’s work should be independent of the designer and carried out without exchange of calculations or similar information.

If the checker requires additional information or clarification about the final design from the designer this should be communicated in a controlled process and again should not include any analysis or design reports.

6.4.8.5 Output from the check

Where the checker is satisfied that the design meets the design requirements, is constructible and is safe the checker should, as a minimum, provide a signed certificate declaring that the design provided satisfies the design requirements, is constructible and, in their opinion, is safe. The checker may also certify the drawings accurately reflect the design. Where the checker is satisfied, subject to caveats, that the design meets the design requirements, is constructible and is safe the checker should, as a minimum, provide a signed certificate declaring that the design provided satisfies the design requirements and, in their opinion, is constructible and safe despite the caveats but the existence of caveats should be noted on the certificate. The caveats themselves should be provided either on the certificate or as a separate document and these should also be passed to the principal designer and client for appropriate action to be taken to address the caveats. Where the checker is not satisfied that the design meets the design, constructability or safety requirements, the reasons for this should be reported to the principal designer and the client. This report may be used to assist resolution of the issue.

The designer of the works checked should also sign the certificate.

6.4.8.6 Resolution of disagreements

Where the checker is not satisfied that the design meets the design, constructability or safety requirements, dialogue between the designer and checker should be undertaken. This may include discussion of the design methodology employed. Where a dialogue of this nature is undertaken it should be with the full knowledge of the client and principal designer and should attempt to resolve the disagreements. Where the disagreement cannot be resolved, an independent party acceptable to the client, designer and checker and competent in the type of work should be appointed by the client to seek resolution of the issue. This independent party should ensure that further sharing of information between the designer and checker does not compromise overall risk management or the safety of the works. On resolution of the disagreements the independent party should pass a report to the client recording how the disagreements have been resolved.

6.4.9 Records and reports

Records of temporary works left in the ground and permanent works, for both new tunnel construction and repairs to existing tunnels, should be compiled. Such records should be part of the health and safety file.

6.4.10 Peer review

*COMMENTARY ON **6.4.10***

Peer review is a process in which an independent specialist or group of specialists reviews aspects of the concept, design, execution, monitoring and remediation of the works, as set out in their terms of reference. The scope of the review is determined by the party sponsoring it but that is normally the client or a funding organization. Peer review is separate from a design check.

On complex projects, a peer review group should be set up to provide an independent oversight of the project as necessary.

6.5 Recruitment of project personnel

The employers' company health and safety policies should address how health and safety issues are handled in the recruitment of personnel for a tunnelling project.

All persons working on tunnel construction should have a high standard of physical fitness. Pre-employment health screening should be carried out on prospective employees relevant to their job function.

6.6 Competence

6.6.1 Skills, knowledge, experience and training

It should be noted that the most vital contribution to health and safety in any tunnelling operation is made by competent supervision through having competent engineers, managers, workforce and front-line supervisors.

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.

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.

The duty holder appointed under the Electricity at Work Regulations [N7] 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 Employment of young persons under 18 is addressed in The Management of Health and Safety at Work Regulations (MHSWR) [4].

6.6.2 Information and training

*COMMENTARY ON **6.6.2***

It is a legal requirement for all persons at work to be given appropriate information on and training in health and safety requirements 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:

a) information on possible hazards, risks and health effects;

b) the devised safe methods of working to address the hazards and risks;

c) site rules imposed by the principal contractor and prohibited activities;

d) the provision, use and care of protective equipment;

e) site communications and procedures;

f) those with particular responsibilities for health and safety; and

g) actions in the event of any emergency, particularly raising the alarm, places of safety underground and egress from underground workplaces.

Persons new to the industry should undergo a probation period and be mentored until they have demonstrated the required experience and competence.

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 restricted to essentials, but allow for feedback and questions from those present, and for questioning and referring back, to confirm understanding. 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.

Casual visitors and tunnel tourism should be discouraged. A risk assessment should be undertaken prior to any visit and any tasks that would pose a risk ceased for the duration of the visit.

6.7 Personal protective equipment

6.7.1 General

Good health and safety performance is 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 considered standard practice. Functionality and user comfort along with compatibility between items should be the primary considerations to ensure user acceptance in selecting PPE. Branding and corporate image should be of secondary importance.

The use of PPE should be managed. Face fit tests for hearing and respiratory protection should be carried out. Users should be instructed in the correct use of PPE and its use should be supervised. Facilities for cleaning and storing PPE should be provided. Maintenance including cleaning and/or replacement should be managed with records kept for RPE other than filter facepieces.

6.7.2 Head protection

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

6.7.3 Foot protection

Boots, with mid-sole protective plates, toe protection and providing ankle support, conforming to BS EN ISO 20344:2011 and BS EN ISO 20345:2011, category S3 should be worn at all times. Footwear with non-metallic mid-sole protection should be worn for railway use.

6.7.4 Hand protection

Gloves conforming to BS EN 388:2016, performance level 3 or higher should be worn where a person is at risk from cuts, abrasions or puncture injuries. Gloves for protection against contact with corrosive or irritant substances should conform to BS EN 377.

Pre-work (barrier) creams should be made available and used by site personnel. Moisturisers and adequate facilities for good skin hygiene should also be provided.

6.7.5 Eye protection

Light eye protection conforming to BS EN 166 should be the minimum level of protection worn. Where eye protection is required to be worn throughout the working shift, optical quality 1 lenses should be used. Prescription glasses should be provided for users who routinely wear spectacles.

Safety goggles, face shields and fixed shields conforming to BS EN 166 should be worn by site personnel whenever there is a foreseeable risk of facial injury. This includes pressurized air and water cleaning, spraying concrete, grinding or chipping, metal cutting, grout mixing and placing, breaking, cutting or drilling concrete or stone or similar material, and by persons handling or injecting hazardous liquids under pressure. For protection whilst burning and welding, protection conforming to BS EN 169 should be used.

6.7.6 Whole-body protection

Any person working underground should wear flame retardant clothing conforming to BS EN 14116 and with integral high-visibility strips or panels conforming to BS EN ISO 20471:2013+A1:2016, class 2.

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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.

6.7.7 Respiratory protection

Where there is a risk of respiratory damage from dusts or diesel engine exhaust emissions (DEEEs), ventilation should be employed to extract (preferred) 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. There are numerous standards for respiratory protective equipment and an occupational hygienist should be consulted when advice on selection of equipment is required.

For work in chemically contaminated atmospheres, occupational hygiene advice should be obtained and followed. Fitness to work in such environments including use of the required RPE also should be considered.

6.7.8 Hearing protection

All persons underground should carry appropriate hearing protection and wear this when appropriate. Hearing protection should conform to BS EN 352. Some occupations such as locomotive drivers require to be in radio communication and hearing protection incorporating two-way communication should be issued to them (BS EN 352-6).

*NOTE Guidance on the selection and care of hearing protection is free to download at www.hse.gov.uk/pubns/books/l108.htm[1], and can also be found in BS EN 458. See also Clause **19**.*

6.7.9 Self-rescuers

All persons underground should carry an oxygen self-rescuer conforming to BS EN 13794. If the nature of the work is such that carrying a self-rescuer incurs a risk due to a confined working area then the rescuer can be located at a suitable place within easy reach of the operative’s work station.

*NOTE See also **14.10**.*

6.8 First aid provision and procedures

6.8.1 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. An adequate first aid needs assessment should be undertaken considering the likely emergencies that could arise. This is influenced by the specific activities undertaken as part of the tunnelling project.

NOTE 2 Considerable advance planning and coordination with public emergency services might be required if the tunnel is in a particularly inaccessible location. Special arrangements might be required to allow emergency services to access the tunnel or have specialist medical support on call.

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

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[1] Last accessed 14 January 2019.

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.

6.8.1.1 First aid facilities

First aid boxes should be provided at all work sites. 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. Boxes should be inspected regularly and replenished as necessary.

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

6.8.2 First aid rooms

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

A person trained in first aid should be in charge of the facility and both a first aider and the facility should be available during all working hours.

6.8.3 First aid training

NOTE Guidance on selecting a suitable first aid training provider is given in L74 [15] (http://www.hse.gov.uk/pubns/priced/l74.pdf) and GEIS3 (http://www.hse.gov.uk/pubns/geis3.pdf). Given the specialised nature of work in compressed air and the working environment, first aiders might need additional training beyond first aid at work. http://www.hse.gov.uk/firstaid/changes-first-aid-regulations.htm

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.

6.8.4 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 **21.6.6**).

6.8.5 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 and directions to the nearest hospital dealing with emergencies should be prominently displayed.

6.8.6 Transport underground

Where necessary, a dedicated rescue transport facility should be provided to expedite the rescue of casualties from tunnels.

7 Excavation and control of ground movement

7.1 Management of risk in the tunnel construction process

*COMMENTARY ON **7.1***

*As the excavation, control of ground movement 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

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

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:

a) providing continuous ground support as part of the excavation sequence (e.g. segmentally lined TBM driven tunnel); or

b) opening up only as much ground as is safely self-supporting (e.g. SCL tunnel) 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 rock with support as required, 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.

It should be recognized that the time intervals between excavation, immediate support and final lining are critical to the whole construction procedure since as soon as a volume of ground is excavated, there is a redistribution of stresses in the remaining ground which can initiate movement in the ground. This movement 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**).

It should also be noted that the stand-up times of unsupported ground range from seconds to days or weeks and consequently the nature of the necessary ground support varies from mere containment to support for full overburden and in situ stresses.

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) topography;

h) the proximity of surface and underground structures;

i) the construction of adjacent tunnels and other underground structures; and

j) vibration.

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 most types of TBM tunnelling, it is not 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 followed and these include operational parameters of the TBM, inspection of the excavated material, forward probing (assuming suitable facility within the machine) and ground radar.

The method of construction should cater for sudden changes in ground conditions and appropriate contingency methods should be developed and made immediately available.

In open face tunnelling, including incremental excavation and support techniques, continuous observation of the ground, ground movement, tunnel deformation and the ground support should be carried out. The results should be evaluated by the designer and contractor working in collaboration and an appropriate response formulated. Formal records should be maintained.

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] and while sprayed concrete lining 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

7.3.1 General

For all tunnels, especially those in urban areas, the control of ground movement is essential and should be a determining factor when deciding on the tunnelling technique to be adopted.

*NOTE Methods of ground movement control are set out in **7.3.2** and **7.33**.*

As the amount of ground movement around a tunnel is a function of the ground loss, stress relief and changes to hydrogeology, the excavation and support installation should be managed to minimize ground movement.

Monitoring of ground movement can give real-time results and should be used as part of the overall management of the construction process.

Pipe arches and spiles should be considered as a means of settlement control or ground support in soft ground tunnels without a segmental lining.

7.3.2 Settlement control – Mechanized tunnelling

In TBM-driven tunnels (see **7.6.2**), the volume of spoil removed should be reconciled against the volumetric advance rate on a routine basis (**23.3.3**). 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)** visual inspection of the overbreak should be undertaken.

NOTE 2 Reference ought to be made to the BTS report on closed-face working [18].

NOTE 3 See also the HSE report "The Risk to Third Parties from Bored Tunnelling in Soft Ground" [19].

7.3.3 Compensation grouting

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

Compensation grouting should be used as a method of countering ground movement affecting critical structures. It should not be taken as a substitute for control of ground loss or over excavation.

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 sufficiently close to the tunnel face or lining to impose excessive load on it 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.

The normal safety hazards of grouting, including drilling safety and proximity to high pressure fluids along with the health hazards of exposure to hazardous substances, should be addressed.

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**, and **7.4.4**) offer guidance on the general characteristics of various soil types. However 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.*

The tunnel horizon should avoid any soil/rock interface where possible; 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.

In granular soils the possibility of failure occurring from the following reasons should be considered:

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; or

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. 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, not only supports the sand and gravel but also negates the effects of the groundwater by equalizing the hydrostatic head. The same effect can be achieved by the application of compressed air or by dewatering if in sand.

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 of 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; and

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 appropriate tests should be carried out.

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7.4.3.2 Clay

*COMMENTARY ON **7.4.3.2***

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.

It should be noted that in soft clays, and in stiff clays where discontinuities (i.e. slickensides or "greasy backs") are present, it might be necessary to provide support, as soon as practicable to restrain movement.

NOTE 1 In open-faced shields, hydraulic struts might be used. These allow the shield to move forward while keeping 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 might be needed to seal the clay surface if the normal cycle of operations is interrupted.

7.4.3.3 Silt

The stability of silt can suddenly be lost due to vibration or to changes in water content and the face should be fully supported. 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.

The presence or absence of flints within the chalk mass should be considered to be of particular importance, as the presence of flints can result in rapid and excessive wear of parts of the TBM or mechanical excavator.

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 extent 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, whether the joint infill is of soft material, 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.

When tunnelling in rock, the following should be taken into account in the design and construction of the tunnel.

a) The arching action is accompanied by redistribution of stresses. There can be movement of blocks of rock and ingress of water acting as a joint 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.

b) Slabs of rock present in the crown can fail in bending.

c) Rock tunnels that break with a square crown should always be treated with caution.

d) The risk of breaking into faults, fissures or cavities should be recognized and assessed.

e) 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.

f) 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.

g) 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 nature, concentration and spatial extent of contaminants including heavy metals, hydrocarbons, solvents, bacteria and gases.

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 Tunnel excavation

7.5.1 General

Tunnels should usually be driven using mechanical excavation and support techniques. Hand excavation should only be used when the safe use of mechanical excavation plant is not possible.

7.5.2 Machinery used in tunnelling

*COMMENTARY ON **7.8.2***

"Tunnelling machinery" is defined in clauses 3.2 – 3.11 of BS EN 16191. The terminology and machine classification system used in the standard is European in origin and sometimes varies from that commonly used in the UK.

The safety of the tunnelling machinery should be considered an essential aspect of overall tunnelling safety. Tunnelling machinery should conform to BS EN 16191.

All machinery should be operated strictly in accordance with the manufacturer's instructions and in the manner intended by the manufacturer.

Where possible, provision should be made for assembly of the entire TBM prior to launch.

The designers of the tunnel should make adequate provision for removal of the TBM and backup.

NOTE Underground dismantling of a large TBM is inherently hazardous because of the restricted space and headroom, lack of lifting and load handling capability along with the fire and contamination risks from hot work.

Other machinery used underground in tunnelling includes excavators, drill rigs, dumpers, concrete truck mixers etc. Such machinery should include the recommendations of Clause **23** and Clause **24** in respect of safety of machinery used underground.

7.6 Tunnelling machines

7.6.1 Open-faced shields

*COMMENTARY ON **7.6.1***

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 *tailskin 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.*

No one should normally work 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 additional support. Mechanical support such as hydraulic poling plates that span between the shield cutting edge and the face timbering should be used in preference to support, which has to be placed manually such as crown and shoulder support in the form of headboards.

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 open-faced 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 held by hydraulic face jacks which maintain a given pressure on the face timbering and yield as the shield is jacked forward or other suitable means.

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

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 designed, constructed and guarded working platforms. 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 removed from the face on a belt or chain conveyor, the conveyor should be fitted with appropriate guards and emergency stop facilities (see **23.3.1** and **25.12.3**).

7.6.2 Tunnel boring machines (TBMs)

7.6.2.1 General

TBMs should comply with BS EN 16191. 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.

NOTE EN 16191 and 12110 are being revised at the date of publication of this standard.

7.6.2.2 Slurry machines

*COMMENTARY ON **7.6.2.2***

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 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.

7.6.2.3 Earth-pressure balance machines (EPBs)

*COMMENTARY ON **7.6.2.3***

Earth-pressure balance machines are shielded TBMs with a bulkhead separating the excavation chamber from the rest of the machine. They have a 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. Most EPB machines are provided with an airlock for face access under pressure.

The excavated material within the screw conveyor forms a plug to maintain face pressure. Pressure is dissipated along the screw so that excavated material is discharged at atmospheric pressure. 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.

Provision of a gate to seal off the discharge end of the screw should be considered.

NOTE The hazardous nature of the chemicals used for spoil conditioning is covered in Table 3.

7.6.2.4 Rock TBMs

*COMMENTARY ON **7.6.2.4***

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 groundwater inflow rates. Appropriate 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 groundwater.

Means of installing appropriate ground support should be immediately available behind the cutter head such as rock bolting equipment, mesh installation or arch erection.

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

7.6.2.5 Ground support for mechanised tunnelling

The segment and other lining erection equipment should conform to the requirements of BS EN 16191.

*NOTE 1 Whilst permanent ground support is covered in Clause **8**, the safety of segment handling and erection is an integral part of the excavation process on a TBM.*

*NOTE 2 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**) and enhanced risk mitigation measures are expected to be included in the current revision of EN 16191.*

The erector operator should have good visibility over the area of operation of the erector.

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.

7.6.3 Non-shield tunnelling

*COMMENTARY ON **7.6.3***

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

In soft ground, non-shield tunnelling depends extensively on the use of free-steered vehicles and the system of work should ensure adequate separation of vehicles and people. Clause **23** and Clause **24** should be referred to for guidance on free-steered vehicles.

Clause **7.8.1.2** should be referred to for guidance on drill and blast tunnelling.

Conveyors should be considered for the transport of spoil as they significantly reduce the number of vehicle movements (see **23.3**).

7.7 Control of ground movement when tunnelling in soft ground without a segmental lining

7.7.1 Construction risks

For tunnels in soft ground, the following major construction risks should be considered.

a) Instability of the newly-excavated ground, fall out of recently applied SCL and excessive ground movement or tunnel deformation creating risk to personnel in the tunnel or on the surface.

b) Ground movement can present a risk to buried utilities and subsurface or surface structures along with transport and third-party infrastructure.

To minimize ground movement and improve face stability, consideration should be given to the subdivision of the cross-section. The benefits of using a pilot tunnel should also be considered (see **5.4.3**).

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

Where necessary, the stability of excavated surfaces should be enhanced by techniques including shaping them appropriately, the use of glass fibre dowels or the application of a coat of sprayed concrete.

There should be a quality and assurance system to ensure that ground conditions, excavation and lining procedures, materials quality control and post-lining ground movements meet the designer's assumptions and requirements. Any deviations should trigger an immediate engineering reassessment of design and construction.

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.

No one in the tunnel should work under or adjacent to unsupported ground.

7.7.2 Initial support and profile control of SCL tunnels

As soon as possible after excavation, an initial layer of sprayed concrete should be applied to the excavated faces, to stop deterioration of the ground surface, secure any loose material and minimize changes in the self-supporting characteristics of the ground which can also lead to increased ground movement.

This layer should provide sufficient support to allow persons to work below it. It should be specifically designed for that purpose and constructed in accordance with the design.

Means of controlling the excavation and monitoring the sprayed concrete profile should be used to minimize over-excavation and ensure that the minimum design lining thickness is achieved everywhere without compromising the internal clearances. Lattice ribs, if used, should be installed in accordance with **7.8.2.1**.

7.7.3 Sprayed concrete

7.7.3.1 General

*COMMENTARY ON **7.7.3.1***

The term "sprayed concrete" covers all pneumatically applied mixes of cement, water, additive and aggregate, including "shotcrete" and "gunite", using wet or dry processes. It is widely used in soft ground tunnelling as temporary or initial ground support due, in part, to its high early strength. Increasingly it is used to form a permanent lining. Similar spray application techniques can be used to apply fire protection layers.

It should be noted that the addition to the mix of steel fibres to enhance the structural properties of the sprayed concrete has become a normal practice. Likewise, the addition of polypropylene fibres to enhance resistance to heat/fire damage is also common place. The risk of puncture injuries from protruding steel fibres should be addressed by the lining designer.

Chemical 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.

7.7.3.2 Safety precautions

An exclusion zone should be established during the excavation and the spraying operations to prevent people from accessing unsupported ground or sprayed concrete lining which has not reached adequate strength to support the loads acting on it. The extent of the exclusion zone should be defined by the lining designer.

Exclusion zones should keep personnel away from moving plant and equipment. For sprayed concrete lining it is advisable to introduce at least two levels of exclusion: the excavation or spray area where nobody should enter until the exclusion zone has been released and secondly, an area around the excavation and spraying plant where only essential personnel can access.

7.7.3.3 Health precautions

Sprayed concrete work should be carried out by wet-process spraying and, where possible, using remotely operated spraying equipment, thus reducing the risk to the operator from exposure to dust, rebound and hazardous materials. In wet conditions, a limited amount of dry spraying can be necessary.

The minimization of dust emissions should be an integral part of the mix design process and design of the spraying machine. Residual exposure should be controlled by extraction ventilation (see **15.7.4**) with dedusting.

NOTE 1 Respirable crystalline silica is now classified as a human carcinogen.

Whilst all reasonably practicable means should be taken to reduce exposure below statutory limits, for carcinogens a higher standard of control is required with exposure being reduced to a level as low as reasonably practicable.

PPE should be provided to prevent exposure of skin to hazardous materials. Full facilities for washing and clothes-changing should be provided.

*NOTE 2 Concrete pumping and cleaning of lines are covered in **24.10.1**.*

As 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.

7.7.3.4 Water proofing

*COMMENTARY ON **7.7.3.4***

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

Only membranes which can be classed as self-extinguishing when tested in accordance with BS EN 11925 or meeting the requirements of BS EN 13501-1 should be used. All normal precautions in the use of MEWPs in tunnels (see **24.15**) should be adhered to when installing sheet membranes.

Exposure to spray membrane materials is hazardous and should be avoided (see **16.11**).

7.8 Tunnelling in rock

7.8.1 Excavation techniques

7.8.1.1 Rock TBM

The requirements for rock excavation by TBM are set out in **7.6.2.4**.

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7.8.1.2 Drill-and-blast

Blasting patterns should be designed to reduce the risk of damage to the excavated surface and surrounding rock. Where appropriate, smooth blasting or pre-splitting techniques should be used.

The extensive guidance on the acquisition, transport and storage of explosives in BS 5607 and its bibliography should be adhered to. The use of explosives in tunnelling should be undertaken in accordance with BS 5607.

The main hazards associated with drill-and-blast techniques which should be considered include noise, vibration and dust from the use of drilling equipment; fumes and vibration from the explosives; and falls of ground. It should be noted that 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.

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

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

The system of work should be reviewed and modified where 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.

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

Depending on the type of drill rig used it should conform to BS EN 16228 or ISO 18758-2:2018.

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

Fly rock can easily damage tunnel machinery or services. Vulnerable plant and equipment should be protected from damage and checked before use.

7.8.1.2 Roadheaders and other part face machines

Roadheaders should comply with BS EN 12111. As roadheaders can be used in both strong and weak rocks, the recommendations in **7.6** and **7.8.1.1** have relevance and should be applied where appropriate.

7.8.2 Control of ground movement

7.8.2.1 Steel arches and packing

The erection procedure should be specified and clearly provide for safe handling and erection.

Mechanical erection equipment (which can often be mounted on excavating or drilling machinery) should be used and properly designed for the particular situation.

Access to the bolted joints and for packing should be from properly designed platforms, stagings or mechanical/hydraulic access equipment where required (see **21.6**).

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

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. An engineer, with the competence to assess changes in ground conditions, should always be present on site to select the appropriate support.

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

*NOTE 1 Recommendations related to scaling of rock surfaces are given in **7.7**.*

Arches should be founded on rock capable of sustaining the transmitted load, or footplates should be 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.

NOTE 2 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 in accordance with the design. All joints should be made in accordance with the design requirements. Arches 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.

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

This support is normally in the form of mesh, timber, steel sheets or concrete panels spanning between the arches. Steel lattice ribs should be installed in sections corresponding to the excavation stages, with bolted joints at the bench surfaces. Ribs should not be erected from under unsupported ground. Shadowing during spraying should be avoided.

7.8.2.2 Sprayed concrete

Control of sprayed concrete should be in accordance with **7.7.3**.

7.8.3 Rock bolting

*COMMENTARY ON **7.8.3***

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 to tie back individual 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 designed taking account of the ground investigation results and observation of exposed rock surfaces in the tunnel.

The anchorage should be of sufficient depth to be outside any area of disturbed rock. It should be designed to resist the full pull-out value of the bolt without slipping in the bore or crushing the rock locally. In-situ load tests should be carried out on a representative sample of bolts.

Bolt installation should be undertaken mechanically where practicable. A mechanical means of access should be provided as required. Precautions should be taken to prevent bolts falling out before the anchorage has gained strength.

NOTE Further guidance is available in BS 8081.

7.9 Hand excavation, headings and small tunnels

7.9.1 General

NOTE The knowledge and skills associated with the design and construction of hand excavated tunnels and headings are slowly being lost due to increasing mechanisation.

For the design of hand excavated tunnels, headings and small tunnels reference should be made to the PJA/BTS/HSE guidance for designers [20]. The minimum dimensions in that document should be adhered to.

In particular the notes following the tables in "Guidance for designers" should be adhered to. Those working under such conditions should be specifically trained in the hazards of this type of work. Emergency exercises should be carried out periodically.

7.9.2 Hand excavation

Hand excavation should be limited to works where mechanical excavation is not reasonably practicable. It should be noted at the design stage if mechanical excavation methods are not viable.

NOTE 1 Hand excavation, because of its adaptability in restricted spaces, can be used for short tunnel drives in appropriate ground conditions, including break-outs from shafts, short connections and back drives, cutter maintenance chambers and enlargements.

Accessibility during construction and the logistics for the transport of materials to the face should also be considered.

In hand excavations where timber supports are used, these should be tightly wedged into position with a system of timber or steel struts and wedges. Reference should also be made to the BTS publication "Traditional timbering in soft ground tunnelling": https://www.britishtunnelling.org.uk/?sitecontentid=90830502-84CB-4F6E-95F1-1470EE5CB9B0.

The hazards of this type of work which should be mitigated include confined space working, noise, hand–arm vibration, manual handling, dust, working at height and heat.

Short shifts and/or frequent rotation of persons around different tasks should be considered, with a view to limiting exposure to noise, vibration and manual handling risks. Adequate working space and, where necessary, proper working platforms should be provided (see **7.7.1**).

NOTE 2 Guidance on the mitigation of risk from vibration can be found in the BTS publication, THE MANAGEMENT OF HAND-ARM VIBRATION IN TUNNELLING - Guide to Good Practice [48].

7.9.3 Hand-driven segmentally lined tunnel without a shield

*COMMENTARY ON **7.9.3***

Occasionally tunnels or chambers are excavated and cast iron or precast concrete segmental linings 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 practical. 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. Mechanical erection or mechanical assistance in the erection of linings should be undertaken.

Where segmentally lined tunnels are built within an existing tunnel, consideration should be given to hydraulic forces from any grout infill.

7.9.4 Timber headings

Timber headings are generally temporary in character and should not be less than 1.2 m high by 1.0 m wide inside the frames. All timber should be treated with a fire retardant.

The guidance in Clause **7** of BS 6164:1990 along with the BTS timbering guide [Traditional timbering in soft ground tunnelling - a historical review] should be followed. 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. All timber should be free from defects that could reduce strength. All materials required for the heading should be readily available as close as is practicable to the face.

Grouting should be undertaken as necessary to reduce ground movement or ground loss.

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

NOTE Although referred to as timber headings, steel members can also be incorporated into the structure.

7.9.5 Back filling

Small headings which are no longer needed should be back filled with concrete and then backgrouted. Care should be taken when backfilling to ensure all voids are filled. Timber to be left in-situ should be treated with preservative before use.

7.9.6 Escape and rescue

Escape and rescue from small headings should be in accordance with the recommendations given in Clause **14**.

7.9.7 Ventilation of small tunnels

Ventilation should be in accordance with recommendations given in Clause **15** and Clause **16**.

NOTE Low-volume, high-pressure ventilation systems with silencers at the point of discharge to control noise emissions might be appropriate if there is a lack of space.

7.10 Pipe and box jacking

7.10.1 Pipe jacking

For information on pipe jacking, “An Introduction to Pipe Jacking and Microtunnelling Design” [21] and the “Guide to Best Practice for the Installation of Pipe Jacks and Microtunnels” [22] should be consulted. The guidance in this standard is equally applicable to pipe and box jacking.

7.10.2 Control of ground movement

Control of ground movement is equally important in pipe jacking as in tunnelling and measures should be taken during excavation to limit over excavation and hence limit ground movement.

Over excavation should be prevented when forming under track crossings. Network Rail standard NR/L2/CIV/044 ISSUE 3 *Planning, Design and Construction of Undertrack Crossings* should be adhered to.

7.10.3 Box jacking

COMMENTARY ON ***7.10.3***

Box jacking is similar in basic principles to pipe jacking. The major differences are the use of 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 [23].

Similar precautions to those for pipe jacking 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 minimized and maintained within acceptable limits.

Face stability should be maintained, and ground movement and ground loss should be controlled by using the shield tunnelling techniques in accordance with **7.6.1**. Where cover to the box is shallow, an anti-drag system in combination with an appropriate lubricant, such as bentonite, should normally be used to minimize ground movement induced by drag and to prevent possible disruption to surface infrastructure.

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.

7.11 Soil conditioners

*COMMENTARY ON **7.11***

Compounds such as bentonites, polymers and foams are widely used in slurry and EPB tunnelling to modify the ground in order to support the face in unstable ground conditions and to improve spoil characteristics for transport from the face.

They are also used in pipe or box jacking as lubricants to lower jacking forces. 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 risk assessment for the tunnelling process should take account of any health hazards resulting from the use of these compounds both as concentrates and in diluted form.

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 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.

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Table 3 – Soil conditioners

Material	Principal components	Typical use	Hazard
Bentonite	Sodium, potassium, Calcium Montmorillonite	As a slurry in slurry shields and to modify the soil in EPB machines or as a ground support and lubricating medium round jacked pipes and in TBMs	Respirable dust in dry state slippery when wet skin irritant
Polymers	Artificial: Polyacrylamides Polyacrylates carboxymethyl cellulose Natural: Starch Guar	Additives to bentonite to modify viscosity, as Lubricants	Generally considered to be non-toxic, but safety data sheets should be consulted for specific hazards and relevant control measures slippery when wet
Foams and foaming agents	Synthetic foams containing: synthetic detergents glycol ether foam Fluorocarbon Protein foams containing: protein foaming agent glycol based foam Booster	For modifying soils to improve handling characteristics	Toxic, irritant safety data sheets should be consulted for hazards and control measures
Other materials	Hexylene glycol	Solvent used as foam	Toxic irritant safety data sheets should always be consulted
	Ethylene glycol ether	Solvent used as foam	Toxic irritant safety data sheets should always be consulted
	Soda ash	Increase pH for use in conditions	Safety data sheets should always be consulted for hazards and control measures
	Lime	Possible modifier to improve characteristics at disposal state	
	Cement		
	Lignosulfonates	Dispersants, thinners in bentonite slurries	
	Complex phosphates		

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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, account should be taken of the investigations and information gathering undertaken in accordance with 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 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 at all stages of the segment's lifecycle should be considered as part of the segment design process, so that structural elements can be set in place without damage.

8.2 In-situ linings

8.2.1 Primary lining

The primary lining is the fundamental means of supporting the ground and as such, its design should minimize the risks to as low as reasonably practical.

The use of sprayed concrete for in-situ primary linings should conform with the recommendations for such work set out in **7.7**.

If arch ribs with lagging, or other systems, are employed as part of the permanent in-situ lining, they should generally be built in, possibly with additional ribs or reinforcement, as appropriate. The building in of buried untreated softwood timber should be avoided (see **7.8**).

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, compaction and spraying of concrete should be adhered to as it increases its durability and reduces maintenance and the risks associated with such work.

Concrete should be specified, produced, transported and tested in accordance with BS EN 206:2013+A1:2016.

Formwork should be designed in accordance with BS 5975 and constructed so that it can be moved along the tunnel and reused if required. 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 should not be struck until the concrete has gained the specified strength. Formwork erected by hand should be made as light and as easy to handle as possible.

The use of concrete pumps should be carried out in accordance with BS 8476:2007.

With sprayed concrete, the recommendations of **7.7.3** should be followed.

8.3 Prefabricated linings

8.3.1 General

COMMENTARY ON ***8.3.1***

Prefabricated linings are most commonly manufactured off-site and are commonly used for circular tunnels and shafts.

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

a) 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. These can be erected with or without bolts.

c) Jacking pipes or box sections (see ***8.3.4****).*

8.3.2 Segments

COMMENTARY ON ***8.3.2***

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

The loads arising from lifting, transportation, handling, storage and erection of the segments should be considered as part of the segment design process.

When considering ring length, the designer should be aware that the width available between the uprights of the gantry frames through which the segments have to pass, is limited by the need to provide access along the outside of the gantry in accordance with BS EN 16191.

NOTE 1 Ring length is also limited by the space available in the tunnel for trains carrying segments to pass safely and still remain clear of the walkway.

The designer should also be aware that the width and taper of segments can affect the risk of the TBM becoming ringbound on curves.

Segments should normally be handled and erected mechanically.

NOTE 2 The handling and erection of segments on the TBM is covered by BS EN 16191. Increasingly single segments are lifted using a vacuum pad whilst stacks of segments are lifted in purpose designed lifting frames.

Traditional quick-release attachments, such as segment lifting "fingers", should only be employed where pads or frames are not available and their design prevents the accidental displacement of the load. Improvised and poorly maintained equipment should not be used for handling segments.

Vacuum lifting should meet the requirements of BS EN 16191.

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.

A positive means of attachment or a specially shaped cradle 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.

For small-diameters, pipe jacking should be considered in preference to segmental lining (see PJA/BTS/HSE guidance [20]).

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 positioned or able to move to where there is a clear view of the whole operation (see BS EN 16191).

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 dowels on the trailing edge.

Erection gantries should be provided to form a safe place of work and means of access.

Lining erection is a hazardous operation. The requirements of BS EN 16191 should be applied.

8.3.4 Jacking pipes and boxes

8.3.4.1 Jacking pipes

Concrete jacking pipes should conform to BS 5911-1 as a minimum, but should be designed to meet more onerous requirements for superimposed loads where necessary. Jacking pipes should be designed to enable the jacking forces to be transmitted along the pipeline and through interjack stations, if used, without causing distress and without damaging the joints. Interjack stations, if used, and joints should be designed to produce the flexibility necessary for installing the pipeline to the required alignment and for accommodating any future ground movement. The joints should also provide a high degree of watertightness.

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.

Match casting should be considered an effective means of ensuring compatibility between adjacent joint surfaces on large cross-section boxes.

The joints 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 On most 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 as part of the excavation control procedure after consideration of the depth of overburden and the presence of underground structures or services.

Freshly mixed grout under pressure can leak especially at the point of injection and should be considered a hazardous material which can affect the skin and eyes. Relevant PPE should be provided.

Where the grout is injected through the lining, the injection nozzle should be positively attached to the lining by a threaded connection or an expanding rubber sleeve.

Substitution of less hazardous materials should be considered.

8.4 Construction of openings

In mechanized tunnelling, the tunnel designer should facilitate the formation of openings by designing opening sets.

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. The temporary works should be designed and supervised by engineers with experience of this type of work. Complete and even contact should be made between the temporary members and the permanent work with all struts tightened securely.

In sprayed concrete lined tunnelling, the designer should be able to demonstrate the stability of the excavation at every incremental step.

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 ground movement or tunnel convergence is particularly sensitive, frequent inspection of the finished lining should be carried out by an engineer suitably experienced 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, grout plugs and empty grout holes marked and noted. The significance of these events should be investigated.

NOTE 2 Settlement at the surface and near the foundations of adjacent structures or buildings can seriously affect their stability, 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. The results should be reviewed and any necessary remedial work undertaken.

Some ground movement around a tunnel excavation is inevitable and this should be managed through the design process and by management of the tunnel excavation sequence to minimize the impact.

NOTE 3 Differential movement between different parts of the same structure, building or utility can cause damage.

Routine checks on 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 ground movement, more elaborate monitoring might be appropriate, using instrumentation to detect and measure ground movement surrounding the structure.

Where compensation grouting is being used, reference should be made to **7.3.3**

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8.5.2 Inclined shafts and escalator shafts

To minimize the dangers presented by the steep gradient,

unintentional movement of plant and equipment on the incline should be avoided.

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

The design of the face support system and access stages should be checked to ensure that the correct transfer of face loads takes place.

Shafts should be driven downhill wherever possible. If, at the beginning of the construction stage, the shaft has to be raised uphill, ideally a pilot should be driven before enlarging from above using the pilot for the transport system.

Uphill drives should be planned in such a way so 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 keep 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

*COMMENTARY ON CLAUSE **9***

*This clause gives guidance on the management of water under general conditions in shafts and tunnels. Control of the risk of inundation by large volumes of water, which can be at high pressure, is described in Clause **10**, and in compressed-air working in **11.6**.*

9.1 Control of groundwater

9.1.1 General

The presence of water should be considered at all stages in the design, construction and maintenance of tunnels. Review of the impact on the groundwater regime from underground construction should focus on foreseeable changes to the regime in both the short term (typically the construction timescale) and long term (typically the design life of the structure being built).

NOTE 1 For example, changes to the groundwater regime also affect the generation, distribution and flow of ground borne gases and contaminants in both the short and long term.

A comprehensive risk assessment should be undertaken including hydrogeological input as appropriate, and should take account of the impact on other assets (both surface and subsurface) and their associated operations based on factual hydro-geological and geotechnical data and the ground model put in place for the project. There should also be a risk assessment addressing failure of the groundwater control system on the structure(s) under construction. If there is insufficient factual information, the risk assessment should identify the need for more in the mitigation measures. The risk assessment should identify sources, pathways and receptors for the risks identified.

In all routine provisions for handling water, the need for contingency measures to cater for inundation should be taken into account, and this should be an output of the risk assessment. Stabilizing an inundation is a very specialized procedure and expert advice should be sought.

*NOTE 2 For further guidance on addressing inundation and the precautions to take, see Clause **10**.*

The following aspects of groundwater inflow should be addressed:

a) Groundwater inflow can lead to the wash-out of fine-grained loose material, thereby altering the strength characteristics of the ground and thus 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.

b) In rock, water can sometimes scour out fissures in fractured ground, resulting in changes in the rock mass characteristics and increased water inflow. These can be difficult to identify in boreholes and therefore local face inspection is essential. Water following along behind the shaft or tunnel lining can also create a hazard by scouring out cavities.

c) Build-up of water pressure can cause deformation in lined tunnels. This can be a particular problem in SCL lined tunnels or whilst maintaining brick-lined tunnels.

d) Excessive leakage into completed tunnels should be prevented.

e) For underground structures being repaired an investigation should be carried out to ascertain whether the structure/s have been designed to leak to reduce hydraulic load on the structure, as making these watertight could have damaging consequences on the longer term stability of the structure.

During excavation, water in the ground surrounding a shaft or tunnel should be controlled to maintain the stability of the excavation. Examples of control methods include:

1) by dewatering or depressurizing the ground externally around the shaft or tunnel;
2) by dewatering or depressurizing the ground internally ahead of the shaft or advancing tunnel face;
3) by excluding it using ground treatment including freezing, compressed air or by use of a closed-face tunnelling machine and a watertight lining;
4) by allowing it to flow in under control; or
5) by sinking a shaft as a flooded caisson.

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. It should also be checked that once groundwater control measures are removed (particularly in the case of freezing or dewatering) there is no detrimental impact on the structures being built or third-party infrastructure. Special consideration should be given to confined aquifers as only small volumes of fluid are involved in changing groundwater pressures and this can result in the ground loads changing rapidly and significantly.

Where there is a risk that failure of the dewatering or depressurization system could result in the instability of the works, appropriate contingency measures should be put in place to ensure the reliability of the system. Instability of the works could result in a high consequence low probability event and the reliability of the system should be proportional to the consequences from failure.

The occurrence of ground source heat pumps and ground heat storage has increased in recent years and the effects of tunnelling on these systems should be considered where relevant not least because such assets can involve harmful fluids contaminating the ground or aquifer.

9.1.2 Dewatering, depressurization and control of groundwater

*COMMENTARY ON **9.1.2***

The water table can be lowered to stabilize the ground by the drainage of water from around 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.

Shafts can alternatively be sunk as flooded caissons to balance the groundwater pressure.

The presence of water should be considered at all stages in the design, construction and maintenance of tunnels.

Review of the impact on the groundwater regime from underground construction should consider foreseeable changes to the regime in both the short term during construction and the long term.

NOTE 1 For example, changes to the groundwater regime might also affect the generation, distribution and flow of ground borne gases and contaminants in both the short and long term.

A risk assessment should take into account the impact on other assets (both surface and subsurface) and their associated operations.

The main hazards which should be taken into account when installing and using dewatering systems are settlement at the surface due to lowering of the groundwater table and loss of fine material from the ground, or failure of the dewatering system while the tunnel is being driven.

NOTE 2 The latter causes the ground to revert to its former unstable condition and rapid and massive ground loss can follow.

The system should be designed to avoid uplift of any shaft base or tunnel. The consequences of settlement, loss of fines, depletion of any aquifer, impact on any existing abstraction points, ground heat systems and the mobilization of contaminants in the ground should also be considered by the design of such dewatering systems. The speed of recovery of groundwater pressure or levels should be ascertained along with the time to implement contingency pumping arrangements.

NOTE 3 To mitigate the potential settlement impacts arising from the widespread effects of external dewatering, recharge wells may be provided by design to permit the reinjection of groundwater to raise water levels away from the tunnelling works.

The control of reinjection rates and pressures should be managed to ensure excess pressure does not give rise to heave, floatation or structural overload issues or result in the introduction of contaminants.

Upon completion of dewatering all wells should be appropriately decommissioned. The location, depth and details of all abstraction and recharge wells should be recorded with the British Geological Survey, as the relic borehole linings of each well can pose a hazard to any future tunnelling or groundworks at each well site.

Consultation with third parties should also be carried out to ensure that groundwater levels remain within design levels of constructed assets (e.g. LUL have a “Guard-it map”).

The dewatering systems should have a level of redundancy appropriate to the consequences associated with a failure of the system, and surface pipework should be protected from accidental damage.

The loss of fines from the ground should be minimized and the consequences of settlement, loss of fines, depletion of any aquifer, impact on any existing abstraction points, ground source heat pump systems or the mobilization of contaminants in the ground should also be taken into account by the design of such dewatering systems.

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

NOTE 4 There is a risk of instability in an open face tunnel being driven in clay but close to an interface with water bearing material and it might be necessary to depressurize the water bearing material by pumping from boreholes or by well pointing to ensure stability.

9.1.3 Impermeable cover

A review should be undertaken of the geological setting and likelihood of discrete water bearing features (e.g. old river channels in the Lambeth Group). Where a non-segmentally lined 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.

NOTE This can be achieved by probing ahead, supplemented by other techniques as appropriate.

Probe holes created as part of the ground investigation should be securely sealed. Suitable precautions should be taken to control possible inflow if there is any likelihood of breaching the impermeable stratum. Pre-construction investigations should also be carried out for the likely presence of historical ground investigation holes which, if not properly sealed, could present a hazard to the works.

9.2 Geotechnical processes for water management and ground improvement

9.2.1 Ground freezing

9.2.1.1 General

*COMMENTARY ON **9.2.1.1***

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 might be impossible if there is an underground flow of water which brings in heat at a rate faster than the freezing process can extract it.

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 manage this.
After installation, all boreholes should be surveyed throughout their length to confirm their exact position. Boreholes that are out of position should be re-drilled.

It should be noted that ground heave can result from the expansion of water on freezing and from the build-up of ice layers. Heave can continue throughout the period of the freeze as groundwater is drawn into the ice layers. Care should be taken as this can be a hazard to overlying or buried structures and services and might impose additional loadings on tunnel supports.

The uncertainty over the thaw effects of a ground freeze should also be recognized.

The risk to personnel from cryogenic liquids and from substances used in the freezing process (calcium brine, ammonia, glycol or liquid nitrogen) should be taken into account along with the risk of post freeze leakage which can be a health and safety risk, particularly in combination with buried utility services.

Excavation should not damage any live freeze pipe.

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.

9.2.1.2 Liquid nitrogen

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 to minimize risk to personnel.

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 conducted 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, storage on site and discharge should be carefully assessed.

9.2.2 Ground injection

*COMMENTARY ON **9.2.2***

Cementitious or chemical ground treatment in advance of tunnelling can usefully enhance safety, particularly when a closed faced TBM is not being used, by improving the stability of the ground to be excavated by sealing off water, or strengthening the overlying or surrounding ground.

The design of a suitable grouting system and pattern for particular circumstances should take account of the potential impact on existing infrastructure.

The effectiveness of ground treatment should be ascertained before excavation works commence.

Where different types of grout are mixed, the compatibility of the grouts and their potential for ground heave, should be assessed.

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, and cohesive strength can be added. Where the tunnel is being driven under compressed air, the air losses 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 along with groundwater flow. Groundwater quality should be taken into account when designing the grout.

The permeability of the ground is rarely consistent and the possibility of meeting untreated pockets should never be ignored.

It should be noted that successful retreatment of previously grouted ground can be difficult to achieve.

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.

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.

Toxic grouts or grouts which produce toxic residues should not be used in the confined space of a tunnel. Measures should also be taken to avoid pollution and damage at the surface from spillage and waste discharge. It should be noted that excavation in ground previously impregnated with cementitious or chemical grouts can release toxic gases or vapours.

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.

9.3 Compressed air

Where compressed air is used to control groundwater and stabilize the face it should be undertaken in accordance with Clause **11.**

9.4 Drilling through the tunnel lining for dewatering, ground treatment or freezing

Any holes drilled through the lining should be done through a valved arrangement such that if the groundwater regime changes rapidly, there are options for the control of inflow.

Stuffing boxes should be considered for drilling depending on the groundwater pressure and flow due to the safety implications.

9.5 Risk from groundwater on entry to cutterhead

*COMMENTARY ON **9.5***

*In slurry or earth-pressure balance machines (see **7.5**), water is excluded from the tunnel by a pressure bulkhead.*

9.5.1 General

Prior to entering the excavation chamber in tunnel boring machines, groundwater conditions should be assessed, and this can be done by means of a camera or instrumentation on the TBM.

Ground treatment should also take into account the possibility of grout travelling to the TBM shield annulus which can cause the TBM to become stuck and introduce new risks to a project.

9.5.2 Controlled inflow

Where the flow of water is small, the inflow should be controlled rather than to excluding it.

NOTE In a tunnel without a segmental lining, 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, or they can be accepted as permanent water inflow, according to circumstances.

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Back grouting should be engineered for the specific location and account should be taken of the resulting applied grouting pressure and its impact on the tunnel lining along with any ground heave.

Any holes drilled through the lining should be done through a valved arrangement such that if the groundwater regime changes rapidly that there are options for the control of inflow.

Stuffing boxes should be considered for drilling depending on the groundwater pressure and flow due to the safety implications.

9.6 Handling of groundwater

9.6.1 Tunnel gradient

Under wet conditions, a tunnel should be driven on an ascending gradient where possible 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 and designed to address the worst credible rate of ingress.

The disposal arrangements of tunnel ingress water should include treatment of the discharge to meet the relevant environmental criteria place on discharge consents.

9.6.2 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.

9.6.3 Pumps

Issues such as bio-fouling of pump filters (common in dewatering wells) and its remediation can lead to anoxic conditions which should be addressed in the design and operation of such pump systems. The pump lines will be under pressure when in use and should have appropriate clamps and/or restraints appropriate for the pressures of the pump lines.

9.6.4 Pumping capacity

In all shafts and tunnels where there is a risk of flooding, there should be adequate pumping capacity to meet foreseeable flood conditions.

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

9.6.5 Subdrains

Historically, subdrains were constructed beneath the tunnel invert to remove water from the excavation and their possible presence should be considered when working adjacent to existing tunnels or cut and cover structures.

9.6.6 Handling water under compressed air

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

9.6.7 Waterproofing of the lining

The risks associated with the various methods for waterproofing tunnels, including gaskets, and sheet or sprayed membranes should be considered (see **7.7.3.4**).

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, which can be 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**. Response to an inundation emergency is addressed in **14.13**.*

All parties should ensure that the risk of inundation is managed during planning, design and execution of the works to reduce it to as low as reasonably practicable, taking account of construction techniques and constraints arising from the local environment and risk of flooding.

NOTE Where appropriate, a hydrogeological and geotechnical model can be prepared.

10.2 Reliance on geological information

The risk assessment for inundation should take account of the geological and hydrogeological information (see Clause **5**).

Borehole surveys alone are not always sufficient to confirm the location of localized features such as buried channels, therefore geophysical investigation techniques should also be considered as part of site investigation. Where such features are likely to occur, additional measures such as advance probing during tunnel construction should be undertaken.

Fissures in rock can be closed with material, which gives a false impression of the groundwater regime. The site investigation and testing schedule should be designed and specified to take account of such occurrences.

Man-made water paths (for example, poorly filled boreholes) that can promote inundation, even when the factual geological information shows the risk is low, should also be considered.

10.3 Other potential sources of flooding

If tunnelling is at or near sea level, tide tables should be studied and, if possible, warnings of exceptionally high tides arranged from port and harbour authorities. Tide gauges should be installed and used in appropriate circumstances. During construction, weather reports should be used to predict storm surges and abnormally high tides.

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.

NOTE 1 An adverse weather event which could affect a site might occur a considerable distance from it.

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

Existing tunnels or mine workings should also be considered as potential sources of flooding.

NOTE 2 Existing drainage systems can suddenly become overwhelmed particularly if subject to flash flooding.

10.4 Precautions for probe drilling

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.

10.5 Inundation during shaft and portal construction

The shaft/portal should be properly constructed and all openings should be located above the highest foreseeable flood water level. Where necessary, protective bunds or raised working platforms should be constructed and maintained at a safe level and should be protected against erosion.

When openings at the top of shaft/portal and located 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 **20.16**).

Where there is a foreseeable risk of inundation, the installation of watertight bulkheads should be considered. Where more than one tunnel is being driven from a single shaft, the risk of one tunnel inundating the other should be assessed and appropriate means of preventing the inundation provided. Additionally, the risk of entrapment in the isolated sections of the tunnel should be considered and procedures adopted to prevent this occurrence.

10.6 Inundation of a tunnel constructed with open faces (including backshunts and foreshunts)

In a tunnel without a segmental lining driven below bodies of water or below the water table, consideration should always be given to the risk of inundation arising from, or accompanied by, loss of ground at the face. Other factors which should be considered to initiate inundation include breaking into faults, fissures, buried channels, abandoned wells or mine workings or other geological features that connect to underground water sources as well as breaking into man-made structures such as culverts.

The presence of natural or man-made features which form water paths capable of causing inundation should be determined by careful historical, geological and geophysical studies and systematic exploratory borings, i.e. probe drilling.

*NOTE 1 See Clause **5** and the "Site Investigation in Construction" document [20].*

Inadequately sealed site investigation boreholes or wells can constitute a hazard hence 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 ingress of water and debris flowing back through the tunnel could flood surrounding land or endanger third party assets, precautions should be taken to prevent this from happening.

Where the risk of inundation is identified in soft ground, a closed face machine should be used where possible. A closed face machine can also be used in hard rock, but its use should be balanced against the risks of excessive wear on the cutterhead and tooling, together with the probability of success of ground treatment.

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

This clause should also be considered relevant in connection with cross-passage construction.

NOTE 2 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.

10.7 Inundation during Tunnel Boring Machine (TBM) launch

A suitably designed sealing system capable of withstanding the foreseeable groundwater pressures and grout pressures should be installed.

10.8 Inundation via the TBM during operation

The TBM should be designed with electrical, hydraulic and pneumatic connections located inside the bulkhead to ensure that even during maintenance the bulkhead doors can be shut in an emergency.

10.9 Inundation during face inspections of closed face TBMs

It should be possible to determine water levels in the excavation chamber remotely by means such as cameras, bulkhead sensors (for water level detection) or pump rates prior to allowing entry.

10.10 Dealing with inundation

Emergency Response Planning for inundation of the works should form part of the overall site emergency preparedness (see **14.13**). Response to inundation should be part of the induction protocols of the site prior to gaining access underground.

Access controls to any underground works at risk of inundation should be maintained and should ensure the number and location of personnel underground is known at all times so that personnel can be accounted for in the event of an inundation incident. This system should be integrated with the provisions required for fire response.

11 Compressed-air working

*COMMENTARY ON CLAUSE **11***

*The use of compressed air to manage groundwater and hence stabilize the ground, as described in **9.1**, presents hazards to both individuals and structures. The health and safety 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 a guidance document published by the British Tunnelling Society [24]. These are referred to 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.*

What follows in this document is more about the interaction between the pressurized structure and the ground. This British Standard and the Guidance are complementary.

The use of compressed air is now more typically associated with access to the pressurized excavation chamber of slurry or earth pressure balance TBMs for inspection or maintenance purposes in which it is only the manlocks and the chambers in front of the TBM bulkhead which are pressurized. The former practice of pressurizing whole lengths of tunnel, using bulkheads built into the tunnel lining, is now much less frequently used but guidance on its use is still provided in this British Standard.

Compressed air working has also been successfully utilized in a wide variety of bespoke applications in tunnelling and shaft sinking where groundwater control has been required, including facilitating repairs to or replacement of lining segments, replacement of damaged pipes during pipe jacking, breakouts to form junctions, eyes, sumps, cross passages etc. It has also been used to facilitate rebuilding of the TBM cutter head following catastrophic damage from excavating in flint, replacement of tailseal brushes and to access parts of a TBM not accessible via a TBM airlock, such as the muck auger, or slurry handling components. Compressed air can be used in conjunction with conventional tunnelling methods such as sprayed concrete lining.

11.1 Physical effects of compressed air

11.1.1 Hydrostatic balance

NOTE 1 In tunnelling through water-bearing ground with the application of compressed air, the normal means of reducing the volume of water which flows in at the face is to provide a counterbalancing air pressure within the tunnel. This air pressure is assumed to be constant across the tunnel face. 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. Conversely 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. In locations where water bearing sand lenses of finite volume occur, the use of compressed air can be counter-productive and can de-stabilize the face by forcing groundwater into the tunnel, e.g. Lambeth group sands.

The pressure needed should be continuously assessed and adjusted as necessary, particularly when working with shallow overburden or working towards free air, as when meeting a shaft or a tunnel at lower pressure. Where a large diameter TBM 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 particular hazard and should also be regularly monitored. 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 commensurate with adequately supporting the face. The BTS Guidance [24] states that the person in charge should be responsible for the designation of persons to be responsible for determining the pressure of air in the working chamber.

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 to remove the need for compressed air as the tunnel drive approaches the shaft etc, such as the stabilization of water-bearing strata by grouting, by lowering of the water table or backfilling the shaft with granular material.

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

11.1.2 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.

The capability of the ground above the tunnel to restrain the applied compressed air pressure should be checked (see **11.2.3**) and where necessary additional measures should be provided to control face stability and prevent loss of confinement (blow out). Whilst traditionally 1 bar air pressure for every 10 m of hydrostatic head was used as an approximation for initially determining support pressure, the use of more sophisticated methods of calculation which take into account the nature of the surrounding ground and the groundwater regime should be considered. However, any significant deviation from the hydrostatically derived figure should be reviewed to ensure major errors in calculation or assumptions on ground parameters have not been made.

Where a tunnel being driven in compressed air is not actually in water-bearing strata but could penetrate such ground, as when clay cover is very shallow, the air pressure applied to the works should initially be slightly below that required for equilibrium at the crown of the tunnel. This minimizes the possibility of blowout, and the lining of the tunnel is not subject to significant tensile loading. It should be possible to increase air pressure quickly when needed.

If initially air pressure is not required, at least a bulkhead should be installed and the compressed-air equipment kept readily available.

The factor of safety to be applied when calculating the required support pressure should be sufficient to ensure that the risk of loss of containment is balanced against the need to control face stability. Where necessary, measures in addition to compressed air should be provided to control face stability and prevent loss of confinement (blow-out). Any increase in support pressure to reduce the risk of face collapse can have a detrimental effect on prevention of loss of containment and vice versa.

Various approaches can be used to calculate support pressure and expert advice should be sought from experienced engineers, on which to select and the factors of safety appropriate. Whilst traditionally 1 bar air pressure for every 10 m of hydrostatic head was used as an approximation for initially determine support pressure, it might be preferable to derive the pressure required from detailed analysis of the type of ground exposed and, where available, groundwater pressures. However, any significant deviation from the hydrostatically derived figure should be reviewed to ensure major errors in calculation or assumptions on ground parameters have not been made.

11.1.3 Ground loading

Where a tunnel is being driven under shallow cover, the provision of ground loading (surcharge) 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.

11.1.4 Consequence of a blow-out

*COMMENTARY ON **11.1.4***

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

Given the potentially catastrophic consequences of a blow-out, commensurately extensive precautions should be taken to prevent its occurrence.

11.1.5 Behaviour in permeable non-cohesive ground

*COMMENTARY ON **11.1.5***

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, timbering and clay, bentonite, grout or other materials for sealing off escapes of air should be provided. These measures should be taken if forward progress is interrupted or stopped for any reason.

The phenomenon of increasing air loss would normally be observed as a slow increase, possibly over a number of shifts. Sharp increases in consumption during a single shift (more than 20%) should be taken as a warning that the situation is moving towards an unstable condition, and remedial action should be taken, such as reducing the air pressure and blanketing the exposed ground to reduce leakage paths. If using a TBM, personnel should be withdrawn from the cutterhead, the pressurized excavation chamber should be flooded or refilled with spoil and the TBM driven forward to better ground.

NOTE 1 Dry silt can crumble away, while wet silt becomes fluid.

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

NOTE 2 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 3 In soft rock, such as chalk, compressed air can 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.

11.1.6 Minimizing 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. 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.

The loss of air should be reduced to a minimum.

Air loss through segmental linings should normally be prevented by the gaskets around the segments. Consequently, the lining should be constructed with particular care to ensure that segments are not damaged, gaskets are not displaced and grouting is adequate. Where air loss through the lining continues it can be a sign of damage to the gaskets. Caulking of the lining should be undertaken. Any excessive or prolonged loss of air should be investigated and not merely compensated for by additional air supply. These measures are usually adequate to sustain the water pressure when the air pressure is reduced (see **11.1.7**) and further movement of the lining takes place.

NOTE 2 Elastomeric compression gaskets can virtually eliminate leakage, particularly when used with self-sealing grout valves. Hydrophilic material is only wholly effective after exposure to clean water but if dry or allowed to dry out can allow leaks of compressed air.

If air loss becomes negligible, ventilation should be provided as necessary (see **11.5**).

11.1.7 Depressurizing of working chamber

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

*NOTE For guidance on the risk of deoxygenated air entering the tunnel see **11.5.4**.*

11.2 Structural considerations

11.2.1 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.

11.2.2 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 maximum theoretical pressure needed at the lowest point of the tunnel excavation, allowing for any surcharge above free water level due to flow from higher ground and the effects of tidal conditions.

In exceptional circumstances, sensitive clays can act as a liquid and the pressure to be resisted should be 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 BS EN 12110 and the BTS Guidance [24] for more information on the design of airlocks and bulkheads.

11.2.3 Check on ability of ground to withstand air pressure

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, taking account of geotechnical parameters.

Although the ground is immersed, only its dry density should be used in the calculation, because the passage of air can 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 effect of variations in ground cover should be taken into account.

The ability of the tunnel lining or jacking pipes to withstand air pressure should not normally be taken into account unless explicitly designed to do so.

When the shaft or tunnel lining is designed to sustain air pressure, it should be designed to withstand the maximum working pressure entirely by itself without any consideration of ground restraint.

When lack of ground strength limits the pressure which can be used, it might be necessary to add a surcharge to the ground or river bed to withstand the air pressure, or other methods of groundwater management should be used to reduce the air pressure needed.

Protection against overpressure should be provided as recommended in **11.6.1**.

11.2.4 Bulkheads for airlocks in shaft or tunnel linings

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

When airlocks are created by building bulkheads within linings, these linings are subject to frequent pressure changes and the design of the linings and any lining/ground interaction should allow for such changes.

Hydrostatic conditions at the commencement of tunnel construction do not always require the “maximum working pressure” determined, as described in **11.2.2**. This means that if a bulkhead is located in an area of low cover it might not be able to sustain the pressure required to stabilize the ground at a location with higher water pressure. If necessary, provision should be made for another bulkhead or air deck under greater cover for when the pressure needs to be raised.

11.3 Shaft construction under compressed air (see also Clause 20)

11.3.1 General

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

a) at or close to surface; or

b) some way down the shaft.

The design of the shaft lining should allow for loads from the expected air pressure – hoop tension in the lining; the ground – hoop compression of the lining; loads from the air deck – an upthrust due to air pressure below the air deck and any kentledge or jacking loads – vertical downwards loading on the shaft lining. The various load reversals which can occur when air pressure is reduced or removed should also be considered.

The shaft lining and the kentledge distribution should be designed to withstand the forces imposed on the shaft lining by the uplift on the underside of the air deck and by the internal 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. Segmental linings should be assumed to be unable to sustain longitudinal tensile forces and should therefore be in compression at all times, unless the segments and 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.

Where the air deck is built on top of the shaft lining and is not secured to it, the kentledge should always exert a load at least 10% greater than the uplift from the internal air pressure.

11.3.2 Shaft sinking

11.3.2.1 General

When a shaft is sunk by underpinning, particularly in loose ground, the ground lost behind the lining should always be replaced with grout to prevent the formation of a path for air loss.

11.3.2.2 Caisson construction

During caisson sinking of a shaft, the lining should not 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. 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.

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A risk assessment should be carried out to establish the criteria and circumstances 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 as this can lead to uncontrolled movement of the caisson, ingress of material and flooding.

11.3.2.3 Access

When a vertical lock is being used, access to the base of a shaft used is normally down a ladder formed by channel sections in the trunking. Consideration should be given to the need for fall arrest equipment and harness for those using the ladder.

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 16191 with airlocks designed in accordance with BS EN 12110.

A TBM airlock should not be considered a refuge chamber.

11.4.2 TBM with pressurized excavation chamber

NOTE 1 The use of a bulkhead within a shield enables compressed air to be applied in the pressurized excavation chamber, 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 pressurized excavation chamber of these machines is needed for periodic inspection, maintenance and repairs, they are usually fitted with an airlock for personnel access. Owing to the restricted space available, these airlocks are constructed to suit each machine.

BS EN 16191 has requirements for machinery safety and control systems when maintenance is carried out within the pressurized excavation chamber of a TBM. The instruction handbook should be consulted on the safe method of work. There should be goog communicationat all times between the crew inside and the lock attendant's station.

The spoil in the pressurized excavation chamber should only be drawn down as far as is needed for the inspection, maintenance or repair to be carried out safely. Minimizing the extent of drawdown is particularly important on large diameter TBMs to minimize the imbalance between air pressure and groundwater pressure across the face.

The airlock should allow for the passage of a casualty from within the pressurized excavation 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.

As 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.

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 **7.9.2**). The enhanced fire risk should be taken into account when designing the onboard fire suppression system.

Despite the requirements of BS EN 16191, a TBM in a pressurized atmosphere should not be provided with a refuge chamber.

NOTE 2 A refuge chamber is only designed to operate in free air and withstand a nominal internal overpressure.

11.4.4 **Repairs to the front face of a TBM cutterhead**

When carrying out repairs to the front face of a TBM cutterhead, 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

11.5.1 Quality

NOTE 1 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.

The air as delivered should not be contaminated by more than 10% of the short-term exposure limit for any contaminant.

*NOTE 2 See Clause **15.***

NOTE 3 This is to allow for subsequent pollution of the atmosphere by work in the chamber (see paragraphs 61 to 65 and 74 of the BTS Guidance [24]).

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 [24]). Electronic gas monitors can be used in pressurized environments but should be recalibrated and acclimatized in the workings in accordance with the manufacturer's recommendations.

Detector tubes can be used in pressurized atmospheres but give instantaneous results only. To give an equivalent reading at atmospheric pressure, readings should be factored down by following the manufacturer's instructions.

Exposure limits under hyperbaric conditions should be obtained from HSE publication EH75/2 [25].

11.5.2 Quantity

NOTE 1 In order to maintain the quality of the compressed air atmosphere in the working chamber, the Guidance [24] 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, along with 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 [24]).

Reliability of the compressed-air supply is an essential safety feature.

11.5.4 Deoxygenated air

Deoxygenated air should be considered a hazard indirectly associated with compressed-air working.

NOTE 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 depressurization, 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.

a) 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.

b) Dimensions of airlocks should be adequate for the maximum number of persons likely to use the airlock at any one time

NOTE See BTS Guide [24].

c) The anchorage of the airlock or any bulkhead to which an airlock is attached, should resist the thrust imposed by air pressures on the ends of the airlock and should be designed to carry all loads safely. Bulkheads and their anchorage in the tunnel lining should be treated as major temporary works.

d) The airlock itself should be airtight and satisfactory devices should be provided for sealing the doors, even at low pressures.

e) An airlock should always be protected from overpressurization by an appropriately-sized pressure-relief valve.

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, 105% of 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 might 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.

d) A functional test of the air supply system should be undertaken to demonstrate air quality meets the requirements in BTS Guide [24].

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 might 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 BTS Guide [24] 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 95% of the pressure to which an installation has been tested.

11.7 Fires and rescue in compressed air

NOTE Paragraphs 211 to 229 of BTS Guide [24] give details of emergency and contingency planning. If no life, either underground or on the surface, is at risk from the fire no one enters the workings to fight it. Attention is drawn to reducing air pressure to flood the tunnel if this will not lead to ground instability.

11.7.1 Special hazards

Compressed air provides a greater mass concentration 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, only 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. The 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 oxygen/fuel gas burning equipment is used, the smallest size of cylinders needed for the job should be employed. The recommendations in **15.6.3.7** for information on the hazardous properties of both acetylene and propane should be followed. It should be noted that specific prohibitions apply to the use of acetylene in pressurized environments.

NOTE 3 Acetylene may not be used at pressures in excess of 0.62 bar(g). This prohibition is contained in the Acetylene Safety (England and Wales and Scotland) Regulations 2014 [27].

It should be noted that the outlet pressure indicators on regulators show gauge pressure relative to the pressure of the environment in which they are located.

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 BTS Guide [24] recommends a fire main running throughout the airlock and tunnel.

Normally-pressurized fire extinguishers can be used if it can be demonstrated that they function effectively in elevated ambient air pressure. Normally, however, extinguishers specifically designed for use in hyperbaric environments should be used.

NOTE 2 Extinguishers developed for use in the diving industry might 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. Allowance should be made for reduction in duration of open circuit breathing apparatus which will be reduced in proportion to the absolute pressure of the workings.

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 does not undertake operations in compressed air however 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 Clause **12** and Clause **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 within the coal.

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.

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11.7.6 Rescue when using vertical airlocks

When using a vertical airlock, a method of removing a casualty on a stretcher from the working chamber in a safe manner should be developed. If such a rescue cannot be demonstrated to be feasible, a T-lock configuration should be provided to give the capability of removing an injured worker on a stretcher. Key personnel should be trained, and rescue procedures rehearsed on site to demonstrate that rescue of the injured person can be successfully undertaken. This should include rescuers wearing breathing apparatus. 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, the 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 attendants 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.

11.7.8 Self-rescuers

Compressed or chemical oxygen self-rescuers can be used in pressurized workings but should not be used above 1 bar (g) to limit the risk from oxygen toxicity.

For work at pressures above 1 bar the contractor should seek specialist advice.

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; and
- 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 to prevent air loss and rapid decompression should be taken with TBM interventions.

11.8.2 Escape

In compressed-air working, escape routes should be carefully planned to give access to airlocks. Airlocks at higher level, accessed by stairs or ladders, and affording a better place of safety than airlocks at tunnel invert level should be used.

11.9 High pressure compressed air

Compressed air work at pressures above 3.5 bar comes within the definition of "high pressure compressed air" (HPCA) in the ITA/BTS "Guidelines for good working practice in high pressure compressed air" [International Tunnelling Association Report 10 revision 2 published 2018] and should be undertaken fully in accordance with these guidelines.

It should be noted that the application of compressed air at pressures above 3.5 bar is only permissible by exemption, granted by HSE, from the limit set in the Work in Compressed Air Regulations 1996 [2].

It should be recognised that HPCA requires the use of non-air breathing mixtures and the possible use of saturation techniques including transfer under pressure between a surface habitat and TBM manlock. Whilst the use of saturation techniques is a complex high risk operation and requires considerable plant, equipment and personnel it should be noted that the decompression risk can be significantly lower than for non-saturation techniques at similar pressures.

12 Explosive atmospheres

12.1 General

*NOTE 1 Explosive atmospheres can arise from the presence of flammable gas or flammable dust. Electrical or mechanical equipment can cause ignition and might have to be explosion-protected (see **25.7.7**).*

NOTE 2 The main source of explosive atmospheres underground is methane either from natural sources such as coal measures and mining or from man-made sources such as landfill or transmission pipework. Other less common sources include coal dust or spillage or leakage of hydrocarbon fuels.

NOTE 3 Where methane is present or there is a risk that it could be present, the system of work adopted will need to comply with the requirements of DSEAR 2002 [30].

Work places where an explosive atmosphere might occur should be classified into hazardous or non-hazardous zones. Zoning should only be carried out by a competent person familiar with the characteristics of methane in relationship to tunnelling. If methane is likely to be present in the ground its entry into the tunnel might not be well defined and a cautious approach to zoning should be taken.

Precautions should be taken to prevent ignition and equipment for monitoring the presence of methane should be available on site at all times (see **15.4.1**). All machinery and equipment used should be designed to minimize the danger of sparks and high temperatures. Reference should be made to BS EN 60079 for the requirements of electrical apparatus and to BS EN 13463 for mechanical equipment in accordance with the DSEAR 2002 [30].

Where methane is found to be present, it should normally be dispersed by dilution using forced ventilation. The ventilation should be designed to maintain the general body concentrations of methane below those outlined in **12.5** resulting in such areas being classified as 'non-hazardous'. However, where these areas include escape routes along which evacuation could take place the monitoring, communication and lighting equipment along these routes should be suitable for use in a Zone 2 hazardous area thus allowing the equipment to remain active in the presence of methane.

Consideration should be given to the use of extraction ventilation where excessive quantities of dust have to be removed. Extraction ventilation should be designed to maintain the general body concentration of methane below those in **12.5** but because of the lower air velocities around any duct inlet the mixing of methane from a source might not be as efficient as with forced ventilation.

*NOTE 4 For further references to methane and ventilation, see **11.7.5**, **15.6.3.2** and **15.4.3**.*

12.2 Occurrence

*COMMENTARY ON **12.2***

Methane (CH_4) is a potentially explosive gas which can occur in nature in sedimentary strata including rocks of carboniferous origin or by decomposition of organic matter. Methane when pure has a density of about 0.6 that of air whilst methane from other sources e.g. landfill, is often mixed with carbon dioxide and the mixture can have a higher density than air.

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

a) Methane is commonly found in, or near to, carboniferous rocks, more particularly coal measures, shales and oil-bearing strata, and in other porous or bedded strata above methane-bearing rocks. In the UK it is found in sandstones, siltstones, mudstones and limestones. It is also found in peat and organic silts. The presence of methane can be influenced by groundwater movements as methane is soluble in water. The gas can travel for considerable distances along joints and fissures or through porous rock. Superficial deposits such as glacial till or clay can prevent the methane from escaping to the surface.

Accumulations of gas can occur under lakes and waters if trapped by overlying impermeable strata.

b) Methane from leakage from gas mains has a high degree of purity. Odour compounds (mercaptans) are added to piped gas to aid leak detection and discrimination between sources.

c) Methane from biological decomposition can occur around refuse dumps, under landfill, in sewers or sewage sludge or wherever organic matter decays in wet conditions such as peat bogs and flood plains. Methane can enter excavations 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.

d) 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 be influenced by changes in tunnel atmospheric pressure due to fluctuations in barometric pressure. It can also be affected by pressure fluctuations caused by the ventilation system.

e) Methane dissolved in groundwater can enter tunnel works and the gas can subsequently be released into the tunnel atmosphere.

f) Methane when relatively pure 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. Methane 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.

g) The mixture of methane and carbon dioxide can have a range of densities depending on the proportion of carbon dioxide present. The monitoring and ventilation regime should cater for the presence of methane in the crown or invert. Variable density layers can form at the base of excavations and migrate down inclines.

h) 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 layer or source in the tunnel by means of local air movement devices.

For deep tunnels with high in-situ stresses, the risk of outbursts of methane from coal measures should be considered.

12.3 Explosion characteristics

*COMMENTARY ON **12.3***

Methane 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 explosive limits change with pressure, increasing pressure increases both limits however the changes over the pressure range encountered in compressed air tunnelling are minimal.

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**). Limestone or other inert mineral dust should be spread to mix with the coal dust to keep the percentage of combustible (coal) dust below 20%.

12.4 Detection and monitoring

Where the presence of methane is foreseeable, the air in the tunnel should be monitored. The detection system should be coupled to an alarm system in the tunnel to indicate when predetermined alarm levels are exceeded. The alarm should be differentiable from the fire alarm. All persons within the tunnel should be in a position to know that an alarm has been activated and know what measures should be taken. 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 other 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 in accordance with manufacturer's instructions. It should be borne in mind that such equipment only measures the gas concentration at or near the sampling head. Hand held instruments should be functionally tested daily with a standard gas mixture and replaced if the readings are not within the manufacturer's limits.

Monitoring should normally be carried out using fixed monitoring equipment supplemented by portable equipment:

a) in the pit bottom;

b) on excavation machinery at the tunnel face;

c) in extraction ventilation ducts;

d) in the general body of the air within the tunnel;

e) at low-level points such as sumps and pits;

f) where methane layering is suspected;

g) in voids above crown level;

h) upwind of tunnel machinery, electrical switchgear and transformers;

i) areas out of the general ventilation flow such as cross-passages;

j) in slurry treatment plants;

k) EPB screw discharge.

Measurements should be made at the start of each shift prior to the commencement of work. 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 and added to the health and safety file at the end of the project:

1) calibration of the equipment;
2) the results of routine monitoring;
3) abnormally high concentrations of methane;
4) atmospheric pressure;
5) position of sampling;
6) time of day;
7) date; and
8) 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. Many instruments are intended for use in the range 0%–100% LEL only (0%–4.4% methane by volume) and can fail at higher concentrations. Where the concentration of methane is thought to exceed 100% LEL, then an instrument measuring 0% to 100% by volume should be used. Some instruments can measure both percentage LEL and percentage gas by volume. Where necessary, instruments should be fitted with a probe for remote sampling.

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12.5 Action levels

Where there is a risk of methane occurring, the methane concentration in the atmosphere should be continuously monitored and maintained below 5% LEL (0.22% by volume) in the general body of the air, normally through the use of forced ventilation (see Table 4).

12.6 Re-entry procedures

There should be a re-entry procedure to be undertaken following a failure of the ventilation

Table 4 – Action level summary table

Classification	LEL (%)	Methane by volume (%)	Action
	Below 5%	Less than 0.22%	No specific action. Continue atmospheric monitoring.
Action level 1	5% to 10%	0.22 to 0.44%	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. Investigate methane source and reduce where possible.
Action level 2	10% to 25%	0.44 to 1.1%	No explosives, cutting and welding equipment or abrasive disc cutters. Non-explosion-protected mechanical and electrical equipment should be shut down or disconnected.
Action level 3	25% to 40%	1.1% to 1.76%	Non-essential personnel should be evacuated from all parts of tunnel. All non-essential mechanical and electrical explosion proof equipment should be disconnected until concentrations fall below 20% LEL (0.88% by volume).
Action level 4	Over 40%	Over 1.76%	All persons should be withdrawn from all parts of the tunnel and electrical power isolated by means of switchgear at the surface except to BS EN 60079-11 compliant atmospheric monitoring equipment which should remain in operation.

systems, an evacuation or an alarm.

Where there is a risk that flammable mixtures have been present around any equipment enclosure it should be opened and vented once the gas has cleared and prior to the restoration of power.

12.7 Sources of ignition

All electrical and mechanical sources of ignition should be considered including:

- any naked flame;
- any spark or electric arc;
- hot spots generated by friction in machinery (including braking);
- overloaded or inadequately cooled electric cables or lamps;
- faulty earthing and current leakage to earth;
- welding, burning, metal cutting and grinding;
- smoking materials including electronic devices; and

- battery-powered communication equipment, watches or hearing aids.

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 materials should be completely excluded from use in a tunnel where the presence of methane is foreseeable (see BS EN 60079-14:2014, Clause **18**) unless used in equipment specifically designed to operate in these conditions.

NOTE 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).

12.8 Explosion protection (see also 12.5)

Explosion-protected equipment should be used when operating in any atmosphere known to contain methane at a concentration above action level 1 in Table 4.

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 1 Attention is drawn to The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 [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.

NOTE 3 Where Group I Category M1[2] equipment is not available, Group II Category 2[1] 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 can be found in in S180 of the Mines and Quarries Act 1954 [29].

NOTE 5 BS EN 1889-1 specifies requirements for rubber-tyred vehicles and locomotives.

Anti-static ventilation ducting should be used when there is any risk of methane occurring (Ref ITA Report 8 “Guidance on the safe use of temporary ventilation ducting in tunnels”).

Where an extraction ventilation system is used and there is a foreseeable risk of methane occurrence, the design and construction of the system should take into account the hazard of methane passing through fans and fan motors.

*NOTE As part of any risk assessment the ventilation system will require zoning in accordance with the requirements of DSEAR 2002 [30] (see **12.1**).*

The ventilation system should remain operable at all concentrations up to 10% LEL in the duct. As a minimum, fans should meet the requirements for zone 2. The extraction airflow should be continuously monitored for methane content and an alarm should sound at action level 1 (see **12.5**).

When methane occurs in a tunnel and no provision for zoning or explosion protection has been made, the action limits in **12.5** should be followed.

Where it is foreseeable that underground fans would be required to operate (for escape or methane purging purposes) at methane levels above action level 1, the fans should be explosion protected accordingly.

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

Ignition prevention systems such as sprays on machines should also conform to the requirements of BS EN 13463, and hence DSEAR 2002 [30].

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[2] As defined in The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 [28].

When explosives are being used where the presence of methane is possible, specialist advice should be obtained; see BS 5607.

12.9 Work in potentially explosive atmospheres

NOTE 1 The Dangerous Substances and Explosive Atmospheres Regulations 2002 [30] specify requirements for 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" as defined in DSEAR 2002 [30] is not present. Consequently, the recommendations in Clause **12** should be strictly adhered to.

*NOTE 4 Tunnelling which complies with the recommendations on potentially explosive atmospheres in Clause **12** is regarded by HSE as likely to achieve conformity with the relevant parts of The Dangerous Substances and Explosive Atmospheres Regulations 2002 [30].*

The use of refuge chambers in atmospheres where methane or other flammable gas could occur should be undertaken in accordance with the International Tunnelling Association Report 14 Rev 1 2016, *Guidelines For The Provision of Refuge Chambers In Tunnels Under Construction* [31].

12.10 Other explosive gases

As many hazardous organic contaminants found in former industrial sites have lower explosive limits (LEL) which are significantly lower than that of methane e.g. for benzene, toluene etc, the LEL is around 1% gas in air by volume, the action levels in **12.5** should be applied but based on the appropriate LEL for the contaminant encountered.

12.11 Methane occurrence on TBMs

Where methane-bearing ground is anticipated, the use of a slurry TBM should be considered. The accumulation of methane from the ground within the slurry circuit and the pressure bubble should be considered. Any location on a TBM where air from the cutterhead or an air release valve can be vented should be monitored continuously and ventilated as necessary.

In the event that an EPB machine encounters methane in the ground, the area around the screw discharge should be similarly monitored and ventilated. The ventilation system might need to be enhanced to ensure sufficient dilution. Inerting the excavation chamber with nitrogen should be considered for high inflows of methane.

In both situations, the capability to monitor for methane in the pressurized excavation chamber should be provided, together with monitoring where any gas is discharged.

12.12 Methane occurrence in slurry plant

The occurrence of methane in the slurry circuit results in the release of methane in the slurry treatment plant. Hence it, and any building around it, should have atmospheric monitoring and should be zoned appropriately. Persons working in the treatment plant should be trained to work safely in a potentially explosive atmosphere.

12.13 Flammable dust

The explosive potential of flammable dust should not be overlooked however such dust is rarely encountered in tunnelling except when tunnelling through coal measures. Dust suppression at source should be used to control dust emissions. When flammable dust is encountered, extraction ventilation with wet dedusting should be used to remove the dust from the tunnel atmosphere. Total dust levels should be maintained below 10 mg/m^3 throughout the tunnel. Dust should not be allowed to accumulate on tunnel surfaces. A procedure for regular testing of the flammable content of dust on surfaces around the tunnel should be undertaken. The flammable content of dust should not exceed 20%. Specialist advice should be sought.

13 Fire and smoke

13.1 Sources of fuel and ignition

13.1.1 General requirements

In the confined space of a tunnel, all sources of fuel and ignition should be eliminated or controlled. The amount of combustible material should be kept to a minimum.

In mechanized tunnelling there is little need for flammable materials in the tunnel during excavation. In conventional tunnelling there can be a greater use of timber for support or for falsework/formwork purposes.

Any flammable materials not required imminently (generally those not needed during the working shift) should be removed to a surface storage area.

NOTE 1 Items required for emergencies in open faced shields or in hand excavation such as face timbers and, in some cases, straw, are exempt from this requirement. Timber is kept wet or treated with an appropriate fire retardant. Straw is kept in an enclosed metal container.

Activities which can foreseeably produce sparks or heat should be controlled. Mechanical and electrical plant and equipment should be designed, constructed and operated to minimize the likelihood of fire (see **13.1.8**).

Electrical equipment in welfare facilities (e.g. fridges, microwaves, toasters) should also be considered as sources of fuel and ignition and should be protected accordingly.

NOTE 2 The FPA publication, "Fire Prevention on Construction Sites" [32], gives further useful information on the prevention of fire.

13.1.2 Smoking

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

These prohibitions should be applied to electronic smoking devices also.

NOTE Smoking in any enclosed workplace including tunnels is prohibited by law.

13.1.3 Combustible materials

Amongst the main combustible materials which should be expected in tunnelling are vehicle cab furnishings and tyres, paper, plastic and other flammable waste and debris (see **13.1.7**).

NOTE Timber and straw were once common but with the elimination of most hand excavation and the greater use of closed face TBMs, they are now much less common. Timber is still used extensively in shuttering for breakouts, openings, secondary lining etc and is particularly common in underground station construction.

Offcuts and sawdust should be removed to the surface on a daily basis. Substitutes for straw such as rockwool are preferred and should be used wherever possible. However, if straw 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.

Combustible materials stored in a tunnel should have suitable fire-fighting equipment conspicuously located nearby (see Table 5 and Table 6). 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, e.g. in formwork. Tunnel Lining formwork with hydraulically operated sections should use HFDU fluids.

Particular care should be taken to minimize the risk of fire from exposed sheet membrane. Only membranes meeting the requirements of BS EN 11925 or BS EN 13501-1 should be used.

The characteristics of some spray membrane materials, if set on fire, are particularly hazardous and the manufacturer's instructions for fire-fighting should be adhered to (see **11.7.3**).

Table 5 – 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 including locomotives			F		F
Battery plant including locomotives (lithium)				F	F
Battery plant including locomotives (lead acid)				P	P
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 6 – Portable fire extinguishing equipment

Class of materials involved	Extinguishing medium
Fires involving solid material 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.

13.1.4 Flammable liquids

The range of flammable liquids which should be expected underground includes diesel, hydraulic oils, greases, mould oil, adhesives, sealants, chemical solvents and primers. Non-flammable or reduced flammability substitutes should be used where possible.

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. Flammable liquids should be stored apart from other combustible materials and at safe distances from access and escape routes, refuge chambers, areas of high activity and electrical installations. 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.

Details of the precise location of flammable liquids stored underground along with an inventory of materials, the quantity stored, and relevant safety data sheets should be available in the “grab bag” on the surface to the emergency services (see **4.2**).

Care should be taken to remove flammable liquids from tunnel machinery (e.g. TBM) before it is dismantled underground.

13.1.5 Compressed gas cylinders

Compressed gas cylinders should be controlled and only permitted underground in accordance with a permit to work scheme (see **13.2.1**).

Below ground, cylinders containing oxygen should be segregated from cylinders of fuel gas (e.g. propane and butane), except when in use. All 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.

Oxygen cylinders should not be allowed to come into contact with any form of grease. All compressed gas cylinders should be kept away from flammable liquids and combustible materials.

All cylinders should be fitted with valve guards and caps to BS EN ISO 11117. 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.

As gas cylinders are liable to damage from mechanical impact, they should be protected against any risk of impact by falling or being struck by other plant or equipment by the use of suitable frames or containers during handling, storage and use underground. Cylinder valve keys and a fire extinguisher should be immediately available.

NOTE HSE publication HSG 139 [33] gives information on the safe use of compressed gases.

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**). Cold LED lighting should be preferred for such applications.

13.1.7 Accumulation of refuse

All combustible refuse should be removed from a tunnel as frequently as practicable, at least once per day, to prevent the build-up of fuel for a fire. Such material should preferably be removed in the normal process of working.

Combustible refuse should not be deposited close to any other combustible materials.

Combustible refuse should be stored in metal bins with close-fitting lids, and away from sources of ignition and other fire hazards. These refuse storage areas should have suitable fire-fighting equipment nearby (see **13.4**). Bins should be located adjacent to work stations in the tunnel or on the TBM. In underground station complexes and similar, bins should be located at intervals throughout the workings.

13.1.8 Plant and equipment

All plant and equipment used underground constitutes a major source of both fuel and ignition and should be fitted with fire suppression systems (see **13.4**). There are three main categories of

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mechanical plant and equipment used underground which should be considered. This applies to battery and dual powered (diesel/electric) plant and equipment along with bespoke electrically powered plant and equipment used in tunnelling, such as electrically powered 360° hydraulic excavators. The categories are:

- TBMs – all TBMs should be in accordance with BS EN 16191.
- specialized tunnel plant – this includes bespoke plant primarily intended for use underground such as locomotives, roadheaders conforming to BS EN 12111, shotcrete robots, concrete mixer trucks, access platforms, tunnel excavators and dump trucks.

  NOTE 1 Plant in this category might already have had a fixed on-board fire suppression system before arriving on site.

- surface construction plant – this includes mobile plant intended for use on the surface but taken underground such as earthmoving plant, excavators, dumpers, MEWPs, and road going vehicles along with static plant such as concrete/grout pumps, generators, compressors.

  NOTE 2 It is unlikely such plant and equipment has been fitted with fixed fire suppression prior to coming to site. Road legal vehicles are included in mobile plant.

Low flammability hydraulic fluids such as those classed as HFDU in BS EN ISO 12922:2012 should 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 and on the compatibility of pumps, seals, etc.

Fuel or hydraulic tanks should not be drained underground.

Materials for the cab should be of low flammability.

13.1.9 Resins, waterproofing materials and other chemicals

NOTE A variety of chemical substances are used in tunnelling such as resins, sealants and waterproofing compounds. Some of these compounds contain isocyanates.

Fires affecting isocyanate material should only be extinguished using non-aqueous extinguishants such as carbon dioxide or dry powder. Breathing apparatus should be used to prevent inhalation of toxic fume which is likely to contain hydrogen cyanide.

The storage location underground should be clearly marked with the relevant chemical hazard warning signs.

As part of the emergency plan for the site, details of the storage locations for such materials, the inventory of materials stored along with all relevant safety data sheets should be held in the “grab bag” in the site offices to be made available to the emergency services (see **4.2**) in the event of an incident underground along with the appropriate emergency response.

Particular care should also be taken to minimize inhalation and skin contact with isocyanates which are known irritants or respiratory sensitizers, can be toxic on inhalation, and can have carcinogenic potential.

13.1.10 Explosives

Explosives should not normally be stored underground. Only sufficient explosive material for individual blasts should be taken underground at a time (see BS 5607).

13.1.11 Other fuel sources

In addition to the above, there are other sources of fuel or ignition in tunnelling which should be controlled including:

a) conveyor belting (fire resistant to BS EN ISO 340, BS EN ISO 22721 or BS EN 14973);

b) cables and wiring (LSF cables);

c) ventilation ducting (ITA Report No 8); and

d) hydraulic hoses.

Less hazardous, fire retardant, low flammability or low smoke and fume variants of all the above are available and should be used. Consideration should be given to replacing flexible ducting with rigid ducting where it passes close to high fire risk static plant.

Where a tunnel passes through carboniferous strata, precautions should be taken to prevent accumulations of potentially explosive dust or gas. Anti-static materials should also be considered for use in potentially hazardous atmospheres. Similarly, the risk of spontaneous combustion of any coal seam exposed should be assessed and mitigated.

Where a vertical conveyor is used in a shaft for materials transport, the impact of that conveyor catching fire should be assessed for escape and rescue plans and mitigated as appropriate.

It should be noted that flame retardant materials can still produce toxic smoke.

13.2 Welding and cutting (burning)

13.2.1 General

There is a high risk of fire associated with welding and cutting (including disc cutters) with the consequences from underground fires being more serious than for similar fires on the surface. Whenever possible, welding and cutting should be undertaken at the surface or cold processes should be adopted underground (see also **13.1.5**).

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, the fire precautions required and the impact of the hot work on the safety of others in the vicinity. 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.

In tunnels where explosive gases are likely to be present, atmospheric monitoring should be carried out adjacent to the site of the hot work before any hot work commences and continuously throughout the period hot work is being undertaken (see **12.4** and **12.5**). In the event of a build up of flammable gas in excess of 5% of its LEL being detected, all hot work should cease immediately.

On completion of the hot work 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. The fire watcher should have a set of cylinder valve keys.

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 therefore good ventilation should be provided (see Clause **15**). Local exhaust ventilation and air movers should be employed in order to disperse local concentrations of fumes. When hot cut, galvanized steel produces toxic fumes that should not be inhaled.

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

Appropriate personal protective equipment (flame resistant) should be used by those undertaking the hot work. Fire resistant clothing to BS EN ISO 11611 should be used. In confined space situations clothing made from aramid polymer fabric should be considered.

13.2.2 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.

NOTE HSE produces guidance on burning and welding using acetylene – see "safe Working with acetylene" INDG 327 Rev 1 [34].

13.2.3 Electric arc welding and cutting

Petrol-driven generator sets should never be used underground.

Electrically-powered transformers or rotary converter sets should preferably be used as the power source for the generation of electric arcs. If diesel sets are used, adequate ventilation should be provided (see **15.7**). Diesel generator sets should be considered to be within the scope of static plant and equipment listed in **13.1.8**. Arrangements should be made for the storage and handling of fuel (see **24.8**).

NOTE 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 Fire precautions

13.3.1 General

NOTE Fire safety is regulated by the Regulatory Reform (Fire Safety) Order 2005 [6].

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. Whilst the priority is fire-fighting to save life only, account should be taken of the consequences of fire damage to the tunnel structure and the hazards associated with any consequential remedial work required.

Care should be taken not to discharge contaminated firewater into surface watercourses.

13.3.2 Fire mains and hose connections

A temporary fire main providing water for firefighting should be made available throughout the tunnel. The temporary fire main should be provided with twin outlets (suitable for fire and rescue service standard instantaneous couplings) at intervals not exceeding 50 m. Such outlets should be clearly marked and 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, if necessary. Equipment should be located strategically in accordance with the progress of the tunnel and should be regularly tested and properly maintained.

NOTE Guidance on the compatibility of the temporary fire main with Fire and Rescue Service equipment can be found in BS 9990.

13.3.3 Fire suppression and smoke control systems

All mechanical plant and equipment identified in **13.1.8** should have fixed fire suppression systems covering the fire-risk areas of the machine. These should include the engine compartment and fuel storage, hydraulic pumps, motors and oil storage tanks, the cab, tyres, etc. Where the tyres cannot be covered by a fixed suppression system, an additional portable extinguisher of an appropriate size and type should be carried on the vehicle. The fixed fire suppression system should utilize appropriate extinguishants for the types of fire foreseeable on the machine. The need for cooling and quenching to prevent reignition should be considered.

NOTE 1 Fire suppression is a specific requirement of PUWER in Reg 12(3) and Reg 28 [N4].

In addition, 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 5 and Table 6 indicate 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 above.

13.3.4 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.

13.4 Fires involving electrical equipment

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

Electrical equipment should be capable of carrying the requisite loads, with a margin for overload, and should be properly installed, used and maintained. If so, 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 with water commences.

Static electrical installations, including transformers, air compressors, etc, should be fitted with fixed in-enclosure fire suppression systems (see **13.1.8**). Mobile electrically powered equipment, including battery powered plant, should conform with **13.3.3**.

Recommendations for cabling and wiring and for equipment are given in Clause **25** however the hazardous nature of fumes and smoke from burning PVC or similar cables should be taken into account when selecting cabling or wiring.

Due to the restricted space in tunnels and the typically 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 routing of cables should be carefully planned to ensure that essential fire-fighting resources, including pumps, lighting and ventilation, are not cut off in the process of isolating overheated equipment, and that signals and communications are maintained.

Electrical fittings in areas where gas cylinders are stored should be low voltage cold fittings such as LEDs, or they should be Zone 1 explosion-protected so that they do not present a possible ignition source.

13.5 Water spray curtain

All TBMs should be fitted with a water spray curtain at their outbye end to control smoke to aid escape of persons. The curtain should cover the full cross-section of the tunnel, particularly in the crown. The cooling effect on the smoke of the barrier should be recognised.

14 Response to emergencies

NOTE Whilst this British Standard applies to all types of tunnel construction, additional recommendations in respect of fire safety for rail tunnels are contained within BS 9992, when published.

14.1 Escape routes

All escape routes underground should be clearly signed. Blind headings should be marked as such. Whenever possible, escape should be to a place of safety on the surface however it is not always possible to escape to the surface quickly in which case places of relative safety (refuge chambers) should be provided where appropriate, such as in short but complex tunnel layouts e.g. underground stations or long tunnels (see **14.13**).

14.2 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 emergency response including fire-fighting and rescue as well as for contacting the emergency services.

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 taking into account all relevant scenarios.

Reference should be made to the current version of the London Emergency Services Incident Panel (LESLP) "Major Incident Procedure Manual" [35] for information on how the emergency services handle major incidents. Site emergency planning should, where possible, follow the principles in the LESLP manual.

NOTE 1 What might be a major incident on site is not necessarily classed as such by the emergency services.

A desktop exercise of the plan should be carried out as part of the planning stage and for longer duration projects should be repeated annually for new staff and emerging risks.

NOTE 2 Due to 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 required.

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 and/or a bridgehead location(s) 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. hydrants, water mains, fire suppression systems, fire-fighting hose.

f) Portable fire-fighting equipment.

g) Provision of extended-duration breathing apparatus.

h) Location and capacity of refuge chambers.

i) Training and site familiarization for fire service personnel.

NOTE 3 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.

14.3 Emergency control facilities

14.3.1 Control rooms

On larger sites, or where requested by the emergency services, an emergency control room should be provided, from which emergency services personnel 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, refuge chambers, location of fire-fighting and other emergency equipment along with storage areas for hazardous substances should be displayed at these locations. It should also give details of where and how to notify the emergency services.

There should be access to the tunnel control systems and data network.

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.

Leaky feeder antenna systems should be tested by voice transmissions regularly to ensure they remain operational and effective.

NOTE The signals can become affected as construction and fit out stages progress introducing more steel and concrete into the structure. Also, it is not uncommon for the feeder system to be accidentally switched off or become disconnected.

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 or other responsible persons. There should be access to the readout from the fixed tunnel atmospheric monitoring system. A suitably qualified member of the contractor’s staff should also be made available to the fire service to operate the ventilation system, if 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 along with details of all flammable or otherwise hazardous materials stored underground.

14.3.2 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. The bridgehead should be located in an area kept smoke free by ventilation.

14.4 Raising the alarm

For guidance on fire precautions on the surface reference should be made to the Crossrail Best Practice Guide – Construction Site Fire Safety.

Arrangements should be made for raising the alarm and calling the emergency services in the event of an incident 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 2 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; or

e) flashing of the main lighting circuits.

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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 6387:2013, 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.

14.5 Alarm procedures

14.5.1 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**.) Emergency services recommend the information should follow the ETHANE protocol and cover exact location, type of incident, hazards, access, number of casualties, and emergency services required.

14.5.2 Action at point of discovery of an incident

All personnel should be given the following set of instructions to immediately follow 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 any fire only if it is safe to do so;

b) report the incident, stating the following:

   1) exact location of the incident;

   2) type of incident, e.g. fire, injury, illness, collapse, atmospheric contamination;

   3) hazards present;

   4) access to incident location;

   5) number of casualties;

   6) emergency services required;

   7) whether evacuation is in progress; and

   8) any other relevant information, e.g. surface evacuation required or evacuation to a refuge chamber.

14.5.3 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; and

c) activate the site emergency plan.

14.6 Site training

All site personnel should be made familiar with the site emergency procedures prescribed. All personnel should be trained in the care and use of fire-fighting equipment.

All underground personnel should have had practical training including refresher training, in the use of self-rescuers including practice in donning self rescuers in nil-visibility. All personnel underground should have had practical training in the operation of the refuge chambers (see ITA Report No 14 “Guidelines for the provision of refuge chambers in tunnels under construction”) [31].

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

Emergency drills including evacuation and use of refuge chambers should be held at regular intervals to maintain familiarity of all personnel with the practical working of the systems.

14.7 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 including any fire main breeching inlets 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 zero visibility.

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

14.8 Lighting

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

14.9 Smoke control

*COMMENTARY ON **14.9***

Smoke is a major danger in fire, as it can cause asphyxiation. It can interfere with visibility, resulting in disorientation and possibly panic. In most tunnels under construction the hazard can be reduced by using the ventilation system t.

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 assist in controlling the spread of smoke from a fire on the machine or adjacent to it.

14.10 Rescue facilities

First aid equipment, including stretchers, should be available as described in **6.8**.

Rescue equipment, including full breathing apparatus for the site rescue team, 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.

Consideration should be given to storing emergency and rescue equipment in shaft bottoms and at intervals in the tunnel to speed up access to it in an emergency.

In long tunnels consideration should be given to the provision of self-propelled refuge chambers or refuge chambers as part of the transport system.

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14.11 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 30 min nominal duration while walking. Where such oxygen supplies are likely to be needed for longer periods, stockpiles of additional rescuers, possibly including longer duration and consequently heavier sets, should be provided at intervals, e.g. in long tunnels.

Self-rescuer changeover should take place in a dedicated ‘change-over station’ incorporating long duration breathing supply (effectively to refuge chamber standard).

When planning for emergencies, a realistic assessment of likely speeds of escape is essential and should be made.

There are limitations to how long a wearer can endure wearing a self-rescuer in escape conditions and this should be factored into emergency planning.

Everyone working underground should be trained in the use of self-rescuers (see **14.5**).

NOTE 1 As self-rescuers are likely to be of less than 30 min duration, they can be supplemented by stockpiles of conventional self-rescuers as necessary.

NOTE 2 Oxygen self-rescuers are designed to be used in normobaric conditions only but may 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 is significantly reduced.

*NOTE 3 For guidance on the use of self-rescuers in compressed air, see **11.5.3**.*

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.

14.12 Accounting for personnel

There should be a system for accounting for site personnel in an emergency. The more complex the tunnel, the more sophisticated the system should be taking advantage of currently available technology. The system should accurately indicate the number and location of persons underground at all times.

When an evacuation has taken place, each refuge chamber should be regularly contacted to ascertain if or how many persons have entered it. Likewise as soon as a refuge chamber is put into use, those in it should contact the surface and report who and where they are taking refuge.

If it is a single bore tunnel with only one entrance/exit, a simple tally board should be adequate.

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

Electronic tally systems should have battery back-up so they can be interrogated in the event of total power failure.

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

NOTE The accounting system can incorporate security access control if necessary.

14.13 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 safety.

For mechanized tunnels the provision of refuge chambers on the TBM is covered by BS EN 16191. Other refuge chambers should be provided in the tunnel as necessitated by the contractor's emergency procedures.

For conventional tunnels one or more refuge chambers should be provided in each drive unless shown not to be necessary by the contractor's risk assessment and emergency procedures. Underground stations often consist of multiple short, conventional tunnel drives. During construction, as long as the possibility of entrapment underground exists, refuge chambers should be provided adjacent to the working faces. As not all tunnels are large enough to accommodate a chamber, the location of the chamber(s) should be determined by an assessment of the respective risks involved.

There is extensive guidance on the equipping and operation of refuge chambers in ITA Report No 14 "Guidelines for the provision of refuge chambers in tunnels under construction" [31] and this should be strictly adhered to in all respects.

For mechanized tunnels, the provision of refuge chambers on the TBM is covered by BS EN 16191. Other refuge chambers should be provided in the tunnel as necessitated by the contractor's emergency procedures and limitations on the escape distance which can be achieved using self rescuers.

14.14 Escape and rescue in small tunnels

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.

14.15 Response to inundation risk

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

NOTE 1 In addition to inundation from groundwater, possible sources of floodwater include river floods, high tides, burst water mains or sewers overtopping or undermining any protective works.

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 can accumulate there.

Consideration should be given to siting walkways at a level to optimize escape routes in the event of inundation. This should be balanced against the risk of smoke inhalation in the event of a fire.

Electrical supplies to the pumping equipment should be located above a floodable level so that the pumps can be operated to recover the tunnel when they are required. If this cannot be achieved, then the electrics should be protected to at least IPx7.

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

NOTE 3 This is obvious when making sewer connections but is less obvious when tunnelling in proximity to water mains and sewers which can fail without warning due to ground movement.

Shafts and tunnel workings should be provided with a communication system to make flood warnings effective. Immediate action to be taken 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;

g) informing third parties whose apparatus/structures may cause harm to the general public if damaged; and

h) assessing the risk that contaminants could have been brought into the structure under construction.

14.16 Recovery of the situation following inundation

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

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

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

15 Ventilation

15.1 General

The principal objective of the ventilation system should be the provision of a healthy and safe working environment for all in the tunnel without the need for recourse to respiratory protective equipment on a routine basis. A balanced ventilation system to provide fresh air and to mitigate the risk from atmospheric contaminants including heat, should be designed in advance, with the capacity and flexibility to allow growth and adaptation as excavation progresses.

NOTE 1 Experience shows the quantity of fresh air required is usually determined not by life support requirements but by the need to counter atmospheric contaminants and to provide cooling.

*NOTE 2 Attention is drawn to The Construction (Design and Management) Regulations 2015 [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 **15.2**). Additionally, there are requirements that any equipment used to conform with the requirement to provide a safe environment is equipped with audible or visual warning of any failure of the plant.*

The design and installation of the ventilation should be overseen by a ventilation specialist. The following factors should be taken into account when determining ventilation requirements:

- the tunnelling technique to be adopted, mechanized or conventional;
- the nature and quantity of toxic, asphyxiant or radioactive gases foreseeably likely to be present;
- the quantity of flammable gas foreseeably likely to be present and any zoning as required by the Dangerous Substances and Explosive Atmosphere Regulations 2002 (DSEAR) [30];
- the nature and quantity of dust foreseeably likely to be present. SCL works will require a decision on extraction or forced main ventilation;
- the likely need to deal with heat and/or humidity;

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- the number of persons working underground and their locations;
- plant and equipment in the tunnel and whether it is diesel or electrically powered;
- the physical layout of the tunnel or tunnel complex, how it will change as construction proceeds and how the demands and constraints these changes might impose on the ventilation;
- the prevention of secondary exposure by directly ducting contaminants from the tunnel; and
- background levels of contaminants likely to enter the tunnel in the ventilation system.

As construction proceeds the effectiveness of the ventilation system should be reviewed at regular intervals and all necessary steps taken to ensure its continuing fitness for purpose.

NOTE 3 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.

As the mechanical efficiency of a ventilation system can be seriously impaired by poor duct design installation and maintenance, all necessary steps should be taken to prevent unwanted reductions in airflow. This should be done by means such as using proper joints in duct lines, using rigid bends at major changes in duct alignment, rigid fittings at bifurcations, etc.

Discharge or intake points should be moved at regular intervals to maintain system efficiency and to reflect the advancing tunnel faces.

Regular inspection and maintenance of the ventilation system should be undertaken with any leaks, damage, restrictions to airflow, etc., being expeditiously repaired.

Procedures should be set out for regularly testing the operation and efficiency of each ventilation system particularly in long tunnels. The tests should also be used to determine whether the system continues to meet operational requirements, taking account of changes in tunnel length or configuration since the previous check. Appropriate 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. In general, any unintended interruption in the ventilation should result in the cessation of works and the withdrawal of personnel until the ventilation is restored. For the control of dust by extraction ventilation, a minimum average velocity of at least 0.3 m/s should be maintained in the air-body along the tunnel to prevent the movement of dust against the direction of air flow. This should be increased to at least 0.5 m/s for the flow of dust laden air to maintain dust capture and prevent precipitation of dust. Because of the very limited zone of influence of an extraction duct, multiple intakes should be considered to ensure adequate dust capture across the working face. To avoid the need to enter under unsupported ground, mechanical handling or extension of the ducts should be considered.

For the control of dust by forced ventilation, an overlap system should be employed at the face with local extraction into de-dusters as necessary. De-dusting should be sufficiently effective that respiratory protective equipment is not required outbye the de-duster units. Adjacent to the face, the objective should be to maintain an average flow towards the face of at least 0.3 m/s and transversely across the face of 0.5 m/s towards the de-duster intakes.

A nominal velocity of 2.0 m/s should be considered to prevent layering of methane where it occurs (see **12.2**).

The blockage effect of plant and machinery should be taken into account when trying to achieve these velocities and local air movers or brattices should be provided to ensure these velocities are achieved.

It should be recognized that within the first few diameters of any drive, there are difficulties in containing dust due to the effects of general turbulence in the air body and local arrangements might be necessary.

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15.2 Guidelines for fresh air supply quantities

A minimum fresh air supply of 0.3 m^3/min per person should typically be sufficient to maintain a respirable atmosphere. Additional ventilation should be provided to take account of the construction plant or equipment used, and to mitigate the effects of exhaust emissions and/or heat generated. Only fresh air should be used for ventilation to improve the quality of air in the tunnel and oxygen should never be discharged to counteract low oxygen levels.

For ventilation to control exposure to diesel engine exhaust emissions, the requirements should be based on actual emissions, number and type of machines and operating patterns.

*NOTE Previously, a minimum supply of at least 3.0 m^3/min per working kilowatt was recommended for diesel powered machines with stringent emission controls (see **24.8.1**), however even this flow rate can be insufficient to control nitrogen oxide levels. Furthermore, the likely future reduction in exposure limits (see **15.4.3**) will further increase fresh air requirements. Methods for calculating flow rates required to dilute nitrogen oxides are set out in the Br Tunnelling Society publication "Occupational exposure to nitrogen monoxide in a tunnel environment - Best Practice Guide" (April 2008) [N1].*

The ventilation supply should be designed to maintain atmospheric contaminants within acceptable levels and depends 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.

For mechanized tunnels information on the heat output from the TBM should be provided by the manufacturer. Consideration should be given to providing local draw off points or the use of air movers to allow the adequate ventilation of all workplaces on the TBM; particularly to counteract heat generated by the machine.

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

Recommended minimum air velocities, averaged across the tunnel section, should be 0.3 m/s to prevent backflow of dust, 0.5 m/s to transport dust where it is produced, or a nominal velocity of 2.0 m/s to prevent layering of methane where it occurs (see **12.2**). The blockage effect of plant and machinery should be taken into account when trying to achieve these velocities and local air movers or brattices should be provided to ensure these velocities are achieved.

15.3 Quality of air

NOTE 1 Fresh air contains approximately 20.9% oxygen, 79.0% nitrogen and 0.04% 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 which should be taken into account 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 it takes 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 lower temperature can contribute greatly to comfort and efficiency.

If strenuous physical effort, e.g. hand excavation, is required in conditions of high temperature, humidity or low air velocity, the risk of heat strain should be assessed and medical advice sought on appropriate mitigation measures.

Air with a reduced oxygen concentration or deoxygenated air should be treated as a potentially hazardous contaminant. Its likely occurrence should be calculated particularly when tunnelling in carbonaceous strata, the Lambeth group or similar strata with high sulfide content. The likelihood of its occurrence can vary with changes in barometric pressure; falling barometric pressure in particular should be considered to give an increased risk of its occurrence. Deoxygenation of air

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should also be considered foreseeable when tunnelling in other ground types such as permeable organic deposits (see **11.5.4**).

NOTE 3 Previously deoxygenation was considered to be due to oxidation of glauconitic minerals in the Thanet Sands. Whilst this source of deoxygenation has not been conclusively disproved, research has shown that deoxygenation of air in the Upnor formation by so called “green rust” can also occur (Journal reference: Newman, T. G., Ghail, R. C., and Skipper, J. A., 'Deoxygenated gas occurrences in the Lambeth Group of central London, UK' Quarterly Journal of Engineering Geology and Hydrogeology May 2013).

Precautions should be taken where these strata are encountered in partially saturated conditions, as fluctuations in tunnel pressure either in 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.

Another source of deoxygenated air which can affect those on the TBM and for which ventilation should be provided is the gas release from the air bubble of slurry TBMs.

*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 [36], which require levels of airborne contaminants (as defined in Guidance Note EH40 [37]) 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 [37] (see **15.6**.)*

15.4 Atmospheric monitoring

15.4.1 Monitoring equipment

Continuous atmospheric monitoring should be undertaken for oxygen concentration along with monitoring for the presence and concentration of all foreseeable atmospheric contaminants either from the ground or from the tunnelling process. Monitoring should be undertaken in real-time typically by means of fixed monitoring stations. The system should have multi-level alarm and data logging capability. Monitoring stations should be connected to the tunnel data and communications network. Monitoring stations should normally incorporate an alarm sounder.

In mechanized tunnelling, there should be monitoring stations on the TBM whilst in conventional tunnelling there should be a monitoring station close to the face. Additional monitoring stations should be provided in all tunnels as necessary. Real time concentrations should be displayed locally at the monitoring station, to the TBM operator, at the access control point to the tunnels and in the site offices. Data from the monitoring system should be stored for the duration of the contract.

Portable monitoring instruments should be used to supplement the fixed monitoring network and may be used for routine monitoring purposes in small-diameter, short life-span tunnels and headings.

All personnel should be within the range of audible and visual alarms protecting their work area.

Monitoring should be undertaken using instruments conforming to BS EN 50104, and for flammable gases to BS EN 60079-29-1. Routine calibration and functional checks on monitoring equipment should be undertaken in accordance with the manufacturer's recommendations.

15.4.2 Alarm settings for atmospheric monitoring equipment

NOTE Guidance on exposure limits is given in publications such as the HSE’s EH40 [37].

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 the multi-level alarm capability so that an investigation can be carried out and corrective action taken before evacuation becomes unnecessary.

The alarm settings and responses in Table 7 should be adhered to. 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[A)]	10% LEL[A)]
Toxic gas	50% STEL	100% STEL*
Interpretation of alarm and response	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.

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

A) In the general body of air and until explosion protected equipment has been installed (see **12.5** action level 1).

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

Where flammable or potentially explosive gases such as those listed in **15.4.2** (other than methane), or gas mixtures, occur, and no specific guidance is given in **15.4.2** or any other standard reference material, the recommendations in Clause **12** should be followed. In particular, the recommendations given in **12.5** relating to specific concentrations of the gas, in terms of percentage of LEL, should be followed.

15.5 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. Persons entering should be in possession of atmospheric monitoring and personal protective equipment (self rescuers), having first established that a ventilation system is working and that the return airflow has been tested and is safe.

For operational tunnels, the natural ventilation flow should be monitored.

For tunnels with no ventilation or return flow, a bespoke safe system of work should be devised. Additional personnel should be on call and such operations should be planned on a “permit to work” and “confined spaces entry” basis.

Factors that should be taken into account 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; and

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 and in accordance with normal sewer entry procedures.

15.6 Hazardous gases

15.6.1 General

The hazardous nature of gaseous contaminants in the tunnel atmosphere should be taken into account, as some are toxic, flammable/potentially explosive, radioactive or asphyxiant. It should be recognized that some contaminants display a combination of toxic and potentially explosive properties. It should also be recognized that 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 [37] deals comprehensively with the toxicity of airborne contaminants and should be consulted for information on maximum exposure limits and workplace exposure limits for a wide range of contaminants at atmospheric pressure.

NOTE It includes a full explanation of the terms "maximum exposure limit" and "workplace exposure limit". The potential for explosion is not dealt with in EH40 [37] but information on flammability limits can be found in publications such as the "Gas Encyclopaedia" published by Air Liquide (http://encyclopedia.airliquide.com/encyclopedia.asp).

Expert occupational health advice should be sought in assessing the effects of complex mixtures such as fuel residues, not dealt with in Guidance Note EH40 [37].

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

Although immediate incapacitation as a result of exposure to the workplace exposure limit concentrations is considered unlikely, the occupational ill-health which can arise from such exposure should not be overlooked. Concentrations of all atmospheric contaminants should be kept as low as is reasonably practicable (see **15.3**).

15.6.2 Simple asphyxiant

*COMMENTARY ON **15.6.2***

Certain gases and vapours, when present in air in sufficient quantities, act as simple asphyxiant. 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 (see **15.3** and **15.4.1**), 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 Apart from physical displacement of oxygen by carbon dioxide, methane, etc., chemical depletion of oxygen in a confined space can occur due to combustion or corrosion leaving an asphyxiant atmosphere.

Nitrogen gas vented from ground freezing operations is hazardous and should not be allowed to accumulate as that can lead locally to an asphyxiant atmosphere being formed.

15.6.3 Atmospheric contaminants commonly encountered in tunnelling

*COMMENTARY ON **15.6.3***

The workplace exposure limit quoted in this subclause are those specified in Guidance Note EH40 [37].

Relevant information on these gases is summarized in Table 8.

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THIS DRAFT IS NOT CURRENT BEYOND **25 APRIL 2019**.

15.6.3.1 Carbon monoxide (CO)

*COMMENTARY ON **15.6.3.1***

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 also appear in a tunnel environment owing to slow combustion of coal and timber or from spontaneous combustion.

The most common sources of carbon monoxide which should be considered in tunnelling are internal combustion engine emissions and blasting fume. Petrol engines should not normally be used in tunnels under construction, as their exhaust emissions can contain up to 10% carbon monoxide (see **24.8.2**).

NOTE 1 Carbon monoxide is potentially explosive in concentrations of between 12.5% and 74.2%.

*NOTE 2 Diesel engine exhaust emissions usually have a much lower concentration of carbon monoxide, the amount depending upon the size of the engine, its state of maintenance and its mode of operation. Diesel engines can be used underground (see **24.8.1**).*

To minimize the quantity of carbon monoxide generated by blasting, care should be exercised in the choice of explosive and in the use of appropriate stemming and means of detonation.

The current long-term (8 h time-weighted average) workplace exposure limit is 30 ppm,[3)] but short-term (15 min) exposures of up to 200 ppm are permissible.

NOTE 3 From 2023, these limits will be reduced to 20 ppm and 100 ppm respectively (see Table 8).

15.6.3.2 Carbon dioxide (CO_2)

Naturally occurring sources of carbon dioxide which should be considered in tunnelling include carboniferous strata, particularly where acid groundwater acts on limestone or other calcareous rock.

NOTE 1 The presence of pyrites in the rock can exacerbate the effects of acid groundwater.

Other sources which should be considered include the exhaust from internal combustion engines, 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. The concentration of carbon dioxide should always be measured directly and never inferred from the oxygen concentration.

*NOTE 2 Carbon dioxide often acts as a simple asphyxiant (see **15.6.2**). 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.*

15.6.3.3 Nitrogen oxides

*COMMENTARY ON **15.6.3.3***

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

3) 1 ppm = a volumetric fraction of 1×10^{-6}

Table 8 – Summary of most commonly encountered atmospheric contaminants

Contaminant		Relative density (with respect to air)	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 20 ppm **	200 ppm 100 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 monoxide	NO	1.04	Toxic	3 ppm* 2 ppm **	15 ppm*	—	—	Explosives, engines
Nitrogen dioxide	NO_2	2.62	Extremely toxic	0.5 ppm **	1 ppm **	—	—	Explosives, engines and welding
Methane	CH_4	0.55	Explosive and asphyxiant	—	—	4.4	17	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 Ethane		1.55 2.05 0.91 1.05	Explosive and asphyxiant	— 600 ppm — ---	— 750 ppm — --	2.2 1.5 1.5 3.0	9.5 8.5 100 12.4	Leakages and firedamp inflow
Ammonia	NH_3	0.59	Toxic	25 ppm	35 ppm	15.0	28.0	Organic material
Volatile organic compounds	various	—	Toxic and explosive	—	—	approx. 1.0 D)	—	Contaminated land
Organic solvents	various	—	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 [37] for further information).

B) 8 h, time-weighted average.

C) 15 min.

D) Dependent on constituents.

* Limit agreed between HSE and Br Tunnelling Society

** From August 2023

*** Seek specialist guidance as permitted exposure is governed by The Ionising Radiations Regulations 2017 [39] which come into effect where radon is present above the defined level of 400 Bq/m^3. Employers are required to take action to restrict resulting exposures. This level is unlikely to be reached where ventilation is satisfactory.

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Sources of nitrogen oxides which should be considered include blasting fume, welding and diesel engine exhaust fumes.

NOTE 1 Although both oxides are toxic, nitrogen dioxide is the more toxic of the two. It attacks the lung tissue insidiously without major preliminary symptoms, and can cause collapse shortly afterwards, with symptoms of acute broncho-pneumonia.

Nitrogen monoxide (NO) exposure should be controlled with a target long-term average exposure of 3 ppm but not exceeding 5 ppm. Short-term exposure should not exceed 15 ppm. The Br Tunnelling Society publication, *Occupational exposure to nitrogen monoxide in a tunnel environment Best Practice Guide* [N1], should be adhered to.

NOTE 2 However, the 4th Indicative Occupational Exposure Limit Value Directive (IOELV) requires that from 2023, exposure should be limited to 2 ppm.

NOTE 3 Nitrogen dioxide (NO_2), 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. The 4th Indicative Occupational Exposure Limit Value Directive (IOELV) requires that as from 2023, exposure is controlled to 0.5 ppm

NOTE 4 Nitrogen monoxide converts to nitrogen dioxide, slowly but spontaneously, in air and sunlight. In tunnels this conversion is much slower and these changes are unlikely to be significant in normally ventilated tunnels. In general, the emissions from diesel engines are dominated by nitrogen monoxide.

15.6.3.4 Methane (CH_4) and other hydrocarbon gases

*COMMENTARY ON **15.6.3.4***

Methane is a potentially explosive gas which occurs naturally. When in mixtures with other naturally occurring potentially explosive gases, particularly hydrocarbons, it is also known as "firedamp", particularly in mining.

The main sources of methane which should be considered in tunnelling include:

- coal seams and other carboniferous strata;
- methane from geological sources dissolved in groundwater;
- biological decomposition of organic waste, e.g. domestic refuse in landfill;
- methane, released into the ground from fractured "domestic gas" mains;
- porous reservoir rocks; and
- ground containing organic material such as river silts.

Although the primary hazards are of fire and explosion and methane is not toxic, care should still be taken as it can become an asphyxiant by diluting the oxygen concentration of the air.

NOTE 1 Methane when chemically pure has a specific gravity of 0.6 relative to air and has a tendency to layer in the tunnel crown.

NOTE 2 Methane from geological sources tends to be chemically pure whereas methane from biological sources such as landfill decomposition can be mixed with carbon dioxide and can have a specific gravity of around 1 relative to air.

*NOTE 3 The primary hazards of fire and explosion are 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.*

15.6.3.5 Hydrogen sulfide (H_2S)

*COMMENTARY ON **15.6.3.5***

Hydrogen sulfide is highly toxic with a characteristic smell (rotten eggs) but it is flammable and at concentrations of between 4.3% and 46.0% is potentially explosive, although these concentrations are unlikely under normal tunnelling conditions.

It should be noted that exposure to concentrations of the gas as low as 20 ppm can reduce the sensitivity of the olfactory nerves, hence detection of hydrogen sulfide by smell is dangerously unreliable.

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 5 ppm and the short-term standard is 10 ppm.*

15.6.3.6 Sulfur dioxide (SO_2)

*COMMENTARY ON **15.6.3.6***

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. It occurs naturally in volcanic areas. In industrial areas, sulfur 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 0.5 ppm should be adhered to in order to prevent respiratory tract irritation in most persons exposed.

15.6.3.7 Cutting and welding gases

*COMMENTARY ON **15.6.3.7***

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

The principal hazardous property of propane, butane and acetylene is their ability to form potentially explosive mixtures in air. As a secondary effect they are also mildly toxic in high concentrations. Care should therefore be taken, since cylinders containing them can burst if subjected to heat or impact. A particular risk is that propane and butane are denser than air hence leakage can accumulate at low spots in tunnels (see **13.2**).

It should also be noted that acetylene is a potentially unstable substance and can decompose spontaneously and exothermally if subject to heat or impact when hot.

NOTE 1 The use of acetylene is regulated by the Acetylene Safety (England and Wales and Scotland) Regulations, SI 1639/2014 [27].

The guidance is that the cylinder should be cooled with water for at least one hour along with the imposition of an exclusion zone around the cylinder of at least 200 m (Dept Communities and Local Government “Fire and Rescue Service, Operational Guidance incidents involving hazardous materials” 2012 ISBN 9780117541092 [38]).

*NOTE 2 Guidance on the prohibition of acetylene in compressed air can be found in **11.7.1**, Note.*

15.6.3.8 Petrol and diesel in tunnels

Petrol should not be taken underground during tunnel construction.

Where practicable, refuelling should take place above ground. 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 as diesel vapours present both toxic and fire and explosion hazards. Such areas should form part of any zoning assessment under Dangerous Substances and Explosive Atmospheres Regulations, SI 2776/2002.

NOTE Petrol or diesel can occasionally be found in the ground, typically around the top layer of groundwater, as the result of recent leakage or spillage of fuel from filling stations, storage tanks, etc. and as a consequence enter the tunnel thus presenting both a fire and explosion risk and a health risk.

15.6.3.9 Ammonia

It should be noted that 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 a chemical reaction between cementitious grouts and the soil.

15.6.3.10 Volatile organic compounds (VOCs)

*COMMENTARY ON **15.6.3.10***

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 as VOCs are hazardous to health, with 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 obtained.

15.6.3.11 Other toxic gases

NOTE 1 Leakage from sewers into tunnels is a relatively common occurrence which results in a range of hazardous materials including organic solvents entering the tunnel.

Information on likely contaminants should be obtained as part of the initial desk studies and prior to construction should be confirmed with the local sewerage provider. The atmospheric monitoring regime should be capable of detecting foreseeable contaminants.

NOTE 2 Whilst other toxic gases (e.g. hydrogen chloride, hydrogen cyanide and isocyanates) are evolved during the combustion process, especially when burning plastics materials, the risk of their occurrence is low with adequate fire precautions.

NOTE 3 For further information on these gases, see Guidance Note EH40 [37].

15.6.4 Radon

Radon, an inert radioactive gas, is one of the naturally occurring products of uranium, hence any rock or material containing uranium should be treated as a source of radon. Radon activity is not confined to any particular area of the UK, although some areas are more radon-active than others. The absence of recorded radon activity in an area should not be taken as an indication that radon is not present.

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.

NOTE 2 Exposure to radon comes within the scope of The Ionising Radiations Regulations 2017 [39], and the associated guidance document L121 [40].

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 (including coal) 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.

WARNING. THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND **25 APRIL 2019**.

15.7 Ventilation systems and plant

15.7.1 General

The design of the ventilation system should cater for the construction activities and sequences to be undertaken, including interim layouts of the works and fit out. The designs of ventilation systems should be checked however it is sufficient to do so as a category 0 or 1 check as atmospheric monitoring should be used to confirm its efficacy.

The methods of ventilation adopted should reflect the need to provide fresh air and to mitigate the risk from atmospheric contaminants, including dust, in order to provide a healthy and safe working environment without recourse to respiratory protective equipment. Factors that should be considered are given elsewhere in this clause, but it should be recognized that each tunnel presents unique demands on the ventilation system. The normal hierarchy of controls on exposure to hazardous substances should be applied when determining the ventilation requirements.

In a soft ground tunnel advancing as a single face, a direct fresh air supply to the face should be sufficient but in a complex tunnel system, as in underground transport projects or in hydroelectric schemes, there can be many areas of work, consequently 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 should be expected to vary.

The contamination resulting from the discharge of dust-laden air from shafts should be considered. With acoustic enclosures, or confined urban sites, dust should not be discharged into the enclosure or to the atmosphere on a confined site, to prevent secondary exposure or a risk of exposure by the public around the site.

15.7.2 Characteristics of ventilation systems

One or more of the conventional forcing, exhausting or overlap systems are employed in most tunnels, however ultimately it is the tunnelling techniques, machinery and environmental conditions which should influence the appropriate solution.

Ventilation systems should include one or more of the following:

- a forced supply of fresh air to the face, 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;
- reversal of flow;
- more complex systems combining supply and exhaust, such as overlap systems, which can include filters/dedusters;
- controlled recirculation; and
- air movers to assist locally and to eliminate stagnant pockets. If air movers are used locally any recirculation should not be sufficient to vitiate the air.

15.7.3 Supply or forced ventilation

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

NOTE 1 Additional advantages of forced systems include the ability to use flexible ducting and the scouring effect of the discharged air plume which can be effective for a considerable distance from the discharge point. As the air passes back along the tunnel it becomes progressively more contaminated.

NOTE 2 The effective plume length can be as long as 30 x duct diameter and is a function of duct diameter and discharge velocity.

The ventilation system should be designed to be moved forward or extended with the progress of tunnelling. After breakthrough or junctioning, the layout of the ventilation system should be reassessed.

Where additional local airflow is required, such as at diverse local workplaces or to mix or dilute contaminants, e.g. potentially explosive gas at roof level, local air movement devices such as hydraulically powered fans should be used.

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

15.7.4 Extraction ventilation

Ducted extraction ventilation from the working face should be used to remove contaminants such as dust or blast fume directly from the tunnel face without spreading the contamination back along the tunnel and thus prevent secondary exposure, e.g. by reducing the dust build-up on internal surfaces in the tunnel. This is the preferred system for most tunnels where SCL lining is being undertaken.

The main disadvantage of an extraction system is its aerodynamic inefficiency making it difficult to maintain a sufficiently high forward air velocity across the tunnel width to prevent dust moving back over those present. Aerodynamically there is only a very small zone of influence around the intake, hence it is extremely important that the intake should always be kept close to the source of contamination.

NOTE 1 Another disadvantage is the need to use rigid or spirally reinforced ducting on sections under negative pressure.

NOTE 2 The effective zone of influence can be as short as 3 x duct diameter.

If required to overcome the negative pressure restriction, a fan should be sited close to the face so that downstream of the fan the duct is at positive pressure and effectively becomes a forced ventilation duct, however this set-up requires the fan to be advanced with the face and can form an obstruction in the tunnel.

NOTE 3 Extraction ventilation draws in fresh air along the tunnel, but this air accumulates contaminants, including dust and heat, and increases in humidity during its passage.

An extract system, by virtue of exerting a negative pressure, can draw increased quantities of contaminants, including methane from the sources (such as unventilated areas) and, when methane is foreseeable, the air in the duct should be monitored to ensure that a potentially explosive gas mixture does not form.

Where dust is a major problem, the system should be designed to control it; incorporating filters as necessary to clean the dusty air before readmission to the general body of airflow.

The ventilation system should be considered as an adjunct to the other dust control measures, such as suppression at source by the use of water at the cutter head and/or by a machine-mounted dust collector.

Where mechanical plant is being used in dusty conditions, any 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 should be resolved by wetting or cleaning the invert running surfaces and the use of the appropriate ventilation systems such as an overlap ventilation.

15.7.5 Overlap systems

An overlap or recirculatory system of combined supply and extraction ventilation is sometimes necessary, e.g. where dust and diesel engine exhaust emissions both occur, and should normally include dedusters or filters to remove dust within the extraction airflow. The airflows in each arm of the overlap system should allow for the overlap region to be fully ventilated.

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

15.7.6 Methane in the extraction airflow

Where an extraction ventilation system is proposed and there is a foreseeable risk of methane occurrence, the design and construction of the system should take into account the hazard of methane passing through fans and fan motors. As part of any risk assessment the ventilation system should be zoned in accordance with the requirements of DSEAR 2002 [30] (see **12.8**). The ventilation system should remain operable at concentrations up to 25% LEL in the duct, at which point all tunnelling activity should cease and all personnel should be withdrawn. As a minimum, fans should meet the requirements for zone 2 or be Group 1 M1 ATEX certified.

NOTE However, a risk assessment done under the requirements of DSEAR 2002 [30] could indicate a need for a higher level of protection.

The extraction airflow should be continuously monitored for methane content. An alarm should sound at an appropriate level (see **12.5**) to allow the evacuation of the area affected by gas before the ventilation equipment is isolated at 25% LEL. Re-entry to the area should only be undertaken using a purpose-designed ventilation procedure to ensure that any gas leaving the area has been diluted to significantly below 25% LEL.

When the concentration of methane in the duct exceeds 20% LEL, appropriate steps should be taken to increase the ventilation flow to further dilute any methane present before the concentration of 25% LEL is reached.

When methane occurs in a tunnel and no provision for zoning or explosion protection of the extraction ventilation system has been made, the action limits in **12.5** should be followed.

15.7.7 Controlled recirculation techniques

Ventilation systems should be designed to prevent the recirculation of air. However, controlled recirculation may be used where dust or heat and humidity are problems in long tunnels or where there are excessive amounts of dust in mechanized tunnelling but only if dedusters or filters are provided to remove dust from the extract duct. If recirculation is used, the volume of fresh air entering the recirculation zone should be sufficient to control the gaseous contaminants.

15.7.8 Alternating ventilation

Whilst a combined forced and extraction ventilation system can be used (achieved 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), it should be noted that the system is complex and not efficient.

NOTE Reversible fans are available, but involve significant loss of efficiency, due to the compromise fan blade design.

Simply reversing a uni-directional fan is sometimes feasible, with a loss of approximately 30% efficiency, but should only be done by the fan supplier as some fan types can fail spectacularly and possibly dangerously due to fatigue failure of the blades.

15.7.9 Other systems

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

NOTE 1 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 might be necessary to control ventilation flows by means of curtains.

NOTE 2 Where tunnels have connections such as cross passages between one or more tunnels allowing a full ventilation circuit, such locations may be ventilated using jet fans (free-standing axial fans that can be fully reversible). Air to the tunnel face may be taken from the full ventilation circuit by any of the systems described.

15.7.10 Siting of fans

Air intake fans on the surface should be sited away from sources of contamination and air being exhausted from the tunnel.

Air exhaust fans should be sited away from working areas or areas close to the site boundary.

Noise emissions from fans should be subject to reduction at source. Where necessary, additional attenuation of emissions should be provided through the use of noise enclosures; particularly around fans sited close to site offices or to the site boundary in urban areas.

15.7.11 Earthing and static electrical charge

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.

Anti-static ducting should be used along with earth bonding to prevent electrostatic build up (see **12.8** and **15.7.12**).

15.7.12 Material properties of ducts

For guidance on material properties of ducts, International Tunnelling Association Report No 8 “Guidelines on the safe use of temporary ventilation ducting in tunnels” [41] should be consulted.

15.8 Ventilation in drill and blast tunnelling

Where explosives are in use, the forced ventilation flow carries back a plug of dust and heavily polluted air, which although it gradually diffuses into the main body of air should still be considered potentially dangerous. Hence extraction ventilation should be used as the preferred method for removal of blasting fume and dust. Timing of blasts should take advantage of dispersion of fume and dust during times when the tunnel is unoccupied.

In drill and blast tunnels with extraction ventilation, the first length of rigid duct back from the face is subject to frequent damage and hence should be a sacrificial length to be replaced regularly.

In long rock tunnels advanced by blasting, the provision of local blast shelters in the tunnel, furnished with a fresh air supply for use by face workers during a particularly long clearing period, should be considered as an alternative to extraction ventilation.

NOTE Requirements for shelters are contained in BS 5607.

15.9 Cooling through ventilation

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**).

Cooling of the ventilation airflow should be considered where tunnel temperatures cannot routinely be kept below the recommendations of **15.3**.

Cooling should also be considered for near surface tunnels in areas of high ambient above ground temperatures and in tunnels in rock at depth.

NOTE 1 The feeling of warmth is a result of the combination of temperature (including radiant heat from concrete or grout curing or hot surfaces associated with machinery), humidity (usually measured as the wet-bulb temperature) and air velocity. In the UK the comfort index effective temperature (ET) has been used in coal mines and the HSE recommend controls when the ET>30ºC with substantial additional controls when the wet bulb temperature exceeds 32 ºC. (Prevention of heat illness in mines, HSE 07) [42].

NOTE 2 At great depths cooling is important, owing to the high ground temperature. In the UK a typical temperature rise is roughly 3 ºC/100 m of depth, although at 1000 m the rock temperature is between 30 ºC and 40 ºC. In igneous regions rock temperatures might be higher.

15.10 Ventilation of shafts

During shaft construction the shaft might require to be mechanically ventilated to remove contaminants such as diesel engine exhaust emissions and contaminants from the ground. The ventilation principles for tunnels should apply also to shafts. However, practice suggests that for shafts, an average ventilation velocity of 0.1 m/s should be sufficient unless high levels of pollution are present when local circulatory ventilation or higher average upwards airflows should be provided.

16 Dust, particulates and other contaminants

16.1 Importance of dust control

Exposure to dust should be considered as one of the major occupational health hazards of tunnelling as it can lead to life changing consequences and hence control of exposure should be a health and safety priority.

Advancements have been made in real time particulate monitoring technology and characterization of particulates such that these monitors should be used for monitor purposes. This should allow the contractors to respond to rapidly rising levels of dust through an increase in ventilation flow.

16.2 Effects of dust

16.2.1 Control of primary and secondary exposure

Two sources of dust exposure should be considered:

a) Primary exposure which arises from the process of breaking or cutting rock, face excavation in dry ground, breaking out sprayed concrete linings, concrete spraying, grout batching, handling or spillage of fine materials such as cement and additives; and

b) Secondary dust exposure which often affects a much larger group of workers arises from the disturbance of primary dust which has settled on surfaces in the tunnel, as a result of other work activities or by vehicle movements. To minimize exposure and the spread of dust around the tunnel, extraction ventilation or overlap systems with dedusting are the preferred ventilation techniques for dealing with dust.

Primary dust exposure should be controlled at source by means such as:

1) wet drilling or cutting;
2) spraying excavated material with water;
3) the use of sprayed concrete mixes designed to minimize dust release; or
4) control of the spraying technique, etc.

Dust production during cutting should be minimized by the use of sharp tools and low cutting speeds.

It should be recognised that dust control by wetting can be of limited success because of the fineness of the dust particles, hence it should be coupled with effective ventilation and the use of dedusters as appropriate. Control of dust emissions should be sufficiently effective that use of respiratory protective equipment is not required on a routine basis (see **16.6**). An exception might be the nozzleman and supervisory or engineering staff in SCL operations. Machine operators should be protected from dust emissions by a ventilated cab on machines.

The control of primary dust emissions at source coupled with effective ventilation and the use of dedusters should be used to control secondary exposure. Secondary exposure due to dust being raised by traffic and other activities should also be controlled. The level of control should be sufficiently high that respiratory protective equipment to protect against secondary exposure throughout the tunnels should not be required on a routine basis.

A powerful torch or handlamp should be used to identify sources of dust, particularly around conveyor transfer points, grout batching plants, shotcrete machinery, etc., so that effective dust capture can be undertaken.

16.2.2 Occupational health outcomes from mineral dust exposure

Three categories of dust should be controlled in tunnelling:

a) inhalable dust;

b) respirable dust; and

c) respirable crystalline silica.

The main occupational ill-health conditions which should be of concern from dust inhalation include chronic obstructive pulmonary disease and silicosis whilst respirable crystalline silica has now been formally classified as a human carcinogen.

NOTE 1 Life style factors such as smoking are now considered to exacerbate the effects of occupational dust exposure.

NOTE 2 Inhalable and respirable dust are defined in HSE publication MDHS14/3 "General methods for sampling and gravimetric analysis of respirable and inhalable dust".

Exposure to other naturally occurring mineral dusts can occasionally occur in tunnelling, e.g. coal dust or asbestos dust, and should be addressed as it arises.

16.2.3 Silica as a carcinogen

NOTE 1 EU Directive 2004/37/EC [45] on controlling exposure to carcinogens in the workplace was amended by Directive 2017/2398 (http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/614670/EPRS_BRI(2018)614670_EN.pdf) to include respirable crystalline silica in the list of group 1 carcinogens. The current exposure limit for an inhalable dust without a WEL is 10mg/m^3. For respirable dusts without a WEL the exposure limit is 4 mg/m^3. The limit for respirable crystalline silica dust is 0.1 mg/m^3.

NOTE 2 Attention is drawn to Regulation 7(5) of the Control of Substances Hazardous to Health Regulations 2002 [36] which sets out additional requirements to those in Regulation 7(3), specifically for the control of exposure to carcinogens.

As respirable crystalline silica (RCS) is now classified as carcinogenic to humans more stringent exposure control measures should be taken to control exposure, including secondary exposure than for exposure to non-carcinogenic hazardous substances.

This should be achieved by reduced emissions at source, e.g. in shotcrete spraying, along with the use of ventilation to control movement of RCS in the tunnel atmosphere. Effective extraction ventilation should be the preferred option as it both removes the contaminant and reduces the amount of secondary exposure. In rock tunnelling, dust suppression and/or capture at source should be provided. Dedusting as part of the extraction system should be used as necessary, depending on the amount of airborne dust and the airflows required. Where there is a pilot tunnel, it should be used as an extraction duct to remove dust from the face area. Eating or drinking should be prohibited in contaminated areas. The contaminated area should be demarcated by appropriate warning signs.

It is normal practice in tunnelling to control exposure to gaseous atmospheric contaminants to below workplace exposure limits by ventilation thus removing the need for respiratory protective equipment and a similar principle should be adopted for exposure to dust and RCS in particular. For SCL tunnelling the indicator of adequate emission control should be that no one in the tunnel apart from the nozzleman should require RPE to control exposure. In rock tunnelling sufficient ventilation should be provided to totally avoid the need for RPE. Where the emission of RCS arises from the operation of an excavator, roadheader or other machine the operator of that machine should be protected by a cab with a filtered air supply and not by the use of RPE.

Continuous real time monitoring should be undertaken (see **16.2.1**).

16.2.4 Effects of mineral dust exposure on safety

The safety implications of mineral dust in the tunnel and tunnel atmosphere which should be considered include reduced visibility, which increases the risk of accidents related to moving machinery and equipment, and increased wear and tear on plant and equipment.

Coal dust, whilst uncommon in tunnelling, creates a special hazard as it forms a potentially explosive mixture when mixed with air and appropriate steps should be taken to reduce coal dust generation at source as well as to prevent the build-up of dust deposits in the tunnel.

Where coal dust is generated, stone dust barriers should be installed in tunnels in accordance with mining practice. Any electrical equipment present should be selected in accordance with and conform to BS EN 61241 (all parts).

16.3 Exposure limits for dust

NOTE Attention is drawn to the Control of Substances Hazardous to Health Regulations 2002 [36] and to Guidance Note EH40 [37] which require that the exposure of any person to airborne dusts does not exceed the appropriate occupational exposure limit.

The currently accepted exposure limit for any inhalable mineral dust should be taken as 10 mg/m^3 and for respirable dust should be 4 mg/m^3. The limit for respirable crystalline silica dust should be 0.1 mg/m^3.

However, cognisance should be taken of guidance published by the British Occupational Hygiene Society, *Information for members on application of COSHH to dusts not assigned Workplace Exposure Limits or hazard classifications*, which recommends a limit of 5 mg/m^3 for inhalable dust and 1 mg/m^3 for respirable dust.

Tunnelling is a cyclic process during which dust levels can fluctuate widely. The current practice of selecting respiratory protection based on an 8-hour average exposure should be considered inappropriate for the widely fluctuating tunnel exposure patterns particularly when concrete spraying is being undertaken. In these situations, it is the peak dust levels during the spraying operation and based on a 15 min average value on which the selection of respiratory protective equipment should be based.

16.4 Sampling

NOTE Real-time dust monitoring instruments are available which give instantaneous and short-term exposure measurements for inhalable and respirable dust exposure and these instruments can be used for area monitoring purposes on a continuous basis.

Sampling should be undertaken at locations where persons can be exposed to dust.

Real-time dust monitoring instruments should be the preferred means of front-line monitoring of dust exposure but should be backed up with traditional personal sampler data.

In conventional tunnelling, dust monitoring should be undertaken as a continuous routine operation on a similar basis to atmospheric monitoring for gaseous contaminants.

16.5 Control and removal of dust

16.5.1 Control by water

High-pressure water jets at the point of rock or concrete fracture should be used to suppress dust. A spray density of around 4l/sec/m^2 has been found to be effective in coal measures. In drilling, hollow bits with continuous water feed should be used as they can substantially reduce dust.

If required, cutter heads in tunnelling machines should be wetted with high-pressure jets of water to reduce dust generation.

NOTE 1 A solid cone spray can sometimes be preferable to a jet and the addition of emulsifying and wetting agents to the water can enhance its effectiveness.

NOTE 2 Water curtains have been used in severe conditions but their effectiveness is unproven.

Water sprays should be used while handling spoil to suppress dust by preventing it from becoming airborne as once dust has become airborne, it cannot easily be controlled by water sprays.

16.5.2 Control by ventilation

In dusty conditions, extraction ventilation or overlap systems coupled with the use of dedusters, as appropriate, should be the preferred option. Extraction intakes should be kept close to the face and should be moved forward as frequently as is necessary to maintain effective control. For drill and blast tunnelling, the use of extraction ventilation for a period following the blast should be used for controlling fume and dust concentrations in the tunnel.

As dusty air is likely to be erosive, fans and ducts should be designed accordingly and be properly maintained.

Dust hoods, in the form of enclosures with extraction, should be fitted to known dust sources, such as at conveyor transfer points, grout pans and shotcrete batching plant.

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.

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

16.6 Respiratory protective equipment (RPE)

NOTE Attention is drawn to The Control of Substances Hazardous to Health Regulations 2002 [36] and The Personal Protective Equipment at Work Regulations 2002 [43] which set out requirements for respiratory protective equipment.

Respiratory protective equipment should not be used for routine protection from respiratory hazards in tunnelling. It should only be used as a last resort where, for short periods, collective control measures such as ventilation cannot effectively control 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 and should be based on short-term peak exposure levels (see **16.3**) rather than long-term exposure levels due to the widely fluctuating nature of tunnel dust levels. Once issued, the equipment should be used in accordance with the manufacturer's instructions.

The contractor should put in place and maintain a robust RPE management scheme for the selection, issue, fit, proper storage, maintenance, cleaning of the RPE along with a training programme for users.

16.7 Asbestos

NOTE 1 Attention is drawn to The Control of Asbestos Regulations 2012 [44] which prohibit the use of asbestos or materials containing asbestos.

NOTE 2 Exposure to naturally occurring asbestos during rock tunnelling is unlikely in the UK, however many segmentally lined tunnels built prior to the 1990s could have been caulked with materials containing asbestos.

An asbestos survey should be undertaken before any such materials are disturbed. When materials containing asbestos are encountered in the course of the work, e.g. during maintenance or repair, they should be encapsulated or 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.

16.8 Diesel particulate matter (DPM)

*COMMENTARY ON **16.8***

Diesel particulate matter (DPM) is emitted during the combustion of diesel fuels and in large enough concentrations is visible as a haze in the atmosphere. DPM is a complex mixture of particulate matter, the major constituent of which is elemental carbon; often referred to as soot. The elemental carbon particles have a range of hydrocarbon and other molecules adsorbed on them, depending on the fuel used and engine conditions. These molecules are referred to as organic carbon. The elemental carbon particles make up around 60% –80% of DPM and are typically significantly below 1 micron in size. Apart from being a cause of respiratory irritation and illness, DPM is considered to be carcinogenic. Consideration has been given to amending the Carcinogens and Mutagens at Work Directive (CMD)(2004/37/EC) [45] to enable the inclusion of DPM with a binding occupational exposure limit but discussions are ongoing.

Exposure to diesel engine exhaust emissions should be controlled to prevent exposure to DPM. Primary control should be achieved by reducing emissions at source along with adequate ventilation. Until further guidance is issued by HSE, a limit value of 100 μg/m^3 as a 15 min time-weighted average, and measured as elemental carbon, should not be exceeded.

Additional control should be achieved by adhering to exposure limits for the main gaseous components of diesel engine exhaust emissions such as CO, CO_2 and NOX. An exposure limit of 1 000 ppm for CO_2 should be adhered to.

Real-time monitoring of DPM using light scattering technology should be considered, however appropriate correction factors should be applied to ensure differentiation between DPM and mineral dust along with aerosols in the tunnel environment. Analytical monitoring for DPM should be carried out in accordance with BS EN 14530.

Continuous real time monitoring should be undertaken (see **16.1**).

16.9 Fumes from cutting and welding

Fumes from cutting and welding are toxic with the composition and quantity of toxic particulates depending on the metal or alloy being welded and the welding process undertaken. Gaseous contaminants found in association with welding fume include oxides of nitrogen, ozone, argon, carbon dioxide, carbon monoxide, 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. Care should also be exercised to ensure that the local exhaust ventilation system does not reduce the airflow in an overlap zone, allowing contaminant concentrations to increase there.

The requirements of HSE Health and Safety Bulletin STSU1 – 2019, *Enforcement Expectations for Mild Steel Welding Fume*, should be implemented.

*NOTE Unprotected persons might have to be temporarily withdrawn (see **15.1**).*

16.10 Spray-applied membranes

Spray-applied waterproof membranes exist in both powder and liquid forms and chemically they can contain a range of toxic or carcinogenic materials. Consequently, they present multiple risks in the workplace which should be controlled, in order of preference, through the selection of less hazardous materials by designers, reduction of emissions at source, remote spraying techniques and ventilation. Apart from the person directly controlling the spray nozzle, the level of control should be sufficient that RPE is not routinely required by others in the vicinity of the spray operation.

16.11 Other ground contaminants

16.11.1 General

If tunnelling at shallow depth under brownfield sites, the possible presence of a range of chemical contaminants associated with heavy industrial legacy industries including gas production, steel smelting, metal processing and chemical industries should be considered. Although unlikely to have a major impact on large deep tunnels, the effect of contamination on shallow utility tunnels and shaft sinking should be taken into account.

Contaminants to be considered should include hydrocarbon fuel residues, tar and its residues, polychlorinated biphenyls, volatile organic compounds and heavy metals and organic solvents. Whilst contamination can be found both in the ground and in groundwater, plumes of contaminated groundwater should also be expected to extend some distance from the source of the contamination.

When such contaminants are encountered, specialist occupational hygiene advice should be obtained.

NOTE 1 The odour threshold and odour tolerance of many hydrocarbon and organic contaminants is very low and therefore persons exposed to the odour from relatively low levels of contamination can experience nausea or other symptoms.

NOTE 2 Excavated contaminated material along with associated groundwater and runoff can present problems for storage and disposal.

16.11.2 Desk studies and ground investigation

A comprehensive desk study to identify contamination sources from previous uses of the site and surrounding area should be undertaken.

The ground investigation should be designed to identify the nature, concentration and extent of the contamination. Care should be taken to ensure the sampling and testing undertaken as part of the ground investigation is aimed at quantifying occupational exposure and not just environmental exposure.

Information on health and safety issues should be made available.

16.11.3 Total petroleum hydrocarbon residues

Old hydrocarbon fuel residues, including petrol and diesel residues, should be expected in the ground in the vicinity of former fuel handling or storage facilities in the vicinity of the tunnelling work. Whilst such residues are relatively non-volatile, they contain complex mixtures of total petroleum hydrocarbons (TPH) including benzene, ethylbenzene, toluene, xylene (BTEX) for which EH 40 should be consulted for exposure limits.

NOTE *Most of these compounds are carcinogenic and have relatively low explosive limits.*

16.11.4 Polycyclic aromatic hydrocarbons (PAH)

*COMMENTARY ON **16.11.14***

Hydrocarbon fuel residues contain polycyclic aromatic hydrocarbons (PAH) which are a group of 16 defined compounds including pyrenes, anthenes, anthracenes and naphthalene, all of which are carcinogenic.

Exposure risk to PAH should be based on “Slope factor”, i.e. the cancer potential relative to Benzo(A)pyrene, weighted by mixture proportions to give total risk from the mixture for the given exposure period. The cancer risk from exposure should be < 1×10^6.

16.11.5 Polychlorinated biphenols (PCBs)

*COMMENTARY ON **16.11.5***

Polychlorinated biphenols (PCBs) are a group of around 200 related chemicals which were used as electrical insulating fluids in transformers up to the 1990s when their use including use underground was banned.

PCBs are carcinogenic and are amongst the most persistent environmental contaminants known. The workplace exposure limit should be taken as 0.1 mg/m^3 and contact with PCBs should be avoided as skin absorption also occurs.

NOTE *Occurrence is from deliberate or accidental spillage. Disposal of contaminated soil is very challenging and expensive.*

16.11.6 Volatile organic compounds

*COMMENTARY ON **16.11.6***

Volatile organic compounds are solvents and chemicals from industrial degreasing and cleaning processes and include tetrachloroethylene, acetone, methylene chloride, benzene, formaldehyde. Their hazardous properties include being carcinogenic along with causing skin irritation, neurological disturbance and kidney damage.

16.11.7 Heavy metals

When heavy metal contamination, typically containing compounds of lead, arsenic, cadmium, chromium, nickel is likely to be present, soil and water analysis should be undertaken to quantify the contamination. These compounds are often neurotoxic and/or carcinogenic and if they occur in the tunnel should be categorized as contaminated dust, and therefore exposure should be controlled by reducing exposure to dust at source by water spray, ventilation or other dust control measures. EH40 [37] should be consulted for exposure limits.

16.11.8 Respiratory protection equipment

It should be noted that because of the hazardous nature of many of the above contaminants and the difficulty of avoiding contact in the confined space of a tunnel, the provision of protective clothing and full face RPE might have to be considered.

16.12 Heat strain

Heat should be considered as a contaminant in the tunnel atmosphere, however there is an enhanced risk of heat strain when chemical protective clothing or full face RPE is being worn. An even greater risk of heat strain should be anticipated if the tunnelling in contaminated land is being undertaken under compressed air.

17 Quality of illumination

17.1 General

NOTE 1 Attention is drawn to The Construction (Design and Management) Regulations 2015, 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 personnel or obstructions on walkways and tracks can easily be seen. Higher lighting levels should be provided locally, particularly on TBMs, at the face and other working areas. The use of LED lighting should be considered in preference to other types because of its low power demand and low operating temperature.

NOTE 2 Floodlighting might be more appropriate for access and task lighting, especially when large areas need to be lit.

NOTE 3 For illumination of access routes, moulded rubber fittings with tungsten lamps operating on reduced low voltage or below can 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.

Depending on the size and final use of the tunnel, general lighting can be desirable as a permanent installation, particularly on pedestrian access routes. The design and installation of lighting should be carried out in accordance with **17.2**, **17.3**, **17.4**, **17.5** and **17.6**, and the recommendations for electrical matters associated with lighting in **25.11**.

Fixed lighting should normally be installed but, 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 and emergency lighting installation should be explosion protected to at least Zone 2 requirements so that in the event of an evacuation of the tunnel due to the presence of a potentially explosive atmosphere, the evacuation can be undertaken with the main tunnel lighting system operational (see **17.5**).

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. Mobile phone “apps” are now available to give approximate light levels.

Lighting levels can be measured with a light meter and should be as high as is reasonably practicable, taking into account the work to be undertaken in the area. The recommended mean lighting levels should be as set out in Table 9.

Table 9 – 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, areas with lifting operations	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 9.

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 and shadow. The type of luminaire should be selected to minimize fire risk through the use of LED lights where reasonably practicable.

Where colour recognition is an important factor, the type of light source should be carefully assessed. Light sources which replicate daylight should be selected to reduce health risks particularly for those underground on nightshift.

Protective covers over lamps should be maintained, especially over 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 **17.7**). 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. Emergency lighting should be provided for the safety of vehicle operators in the event of vehicle breakdown.

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. Emergency lighting should also be provided.

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 **25.12.3**) 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.

Uniformity of illumination and prevention of 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 fixed obstructions or plant and vehicles.

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

17.5 Emergency lighting

Because tunnelling is wholly dependent on artificial light, lighting systems and their power supplies should be made as secure as possible. Either there should be battery back-up or uninterruptible power supplies, or alternative mains supplies or standby generation should be used to power the emergency lighting.

NOTE 1 Such power supplies are sometimes needed to maintain other essential services in the event of mains failure.

Separate emergency lighting should be provided if the lighting system does not incorporate an adequate emergency power supply. A proportion of these lights should be battery supplied in case the alternative emergency power supply fails.

NOTE 2 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 available along the tunnels at 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;
- adjacent to refuge chambers;
- escape routes and staircases;
- emergency exits;
- tunnel access points;
- crossings, points, switches, etc., on the track;
- electrical substations;
- control and communication points; and
- locations where particular hazards, e.g. stairs, ladders, hop-ups, in-tunnel construction works, exist.

The condition of the emergency luminaires should be regularly checked and any faults immediately rectified. The emergency lighting system should be functionally tested at intervals not exceeding three months.

Allowance should be made for the fact that batteries require a certain time to recharge following restoration of the supply after a prolonged power cut.

17.6 Fire hardening of wiring

Where shown necessary by the tunnel risk assessment, the wiring for the main and/or emergency lighting systems should be protected from heat and flame. Protection should conform to BS 6387:2013, 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)0. It should also be protected against mechanical damage (see **25.7.6**).

17.7 Hand lamps and cap lamps

Where torches, hand lamps or cap lamps are used, management procedures should be put in place and facilities should be provided for their proper storage, charging, distribution, use and maintenance. Where the presence of methane is foreseeable, hand and cap lamps should be explosion-protected to at least Zone 1 level.

17.8 High visibility clothing

Personnel working underground should be required to wear high-visibility (hi-viz) clothing to make them more easily seen.

NOTE Hi-viz clothing which differentiates between front and back is available.

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 control of locomotives or moving plant, the transportation of persons, materials and plant and in the management of emergencies.

A voice 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.

On more sophisticated tunnelling projects, electronic digital data transmission systems should be used for transmitting control, monitoring and alarm information between a central control room and various tunnel locations. Such a system should include safety-related matters such as machine condition monitoring, instrumentation monitoring, atmospheric monitoring and fire detection and alarms.

There should be a back-up communications system for use in the event of failure of the main system.

18.2 Communication systems

18.2.1 General

NOTE Attention is drawn to BTS Guide [24] for guidance on communication that applies to working in compressed air.

The person in charge of a workplace should have the facility to communicate requirements for materials and equipment, give warning of unexpected hazards and receive instructions. Voice communications systems should be considered the norm. 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.

All communications systems, including CCTV, should be subject to regular maintenance.

18.2.2 Communications with locomotive and other vehicle drivers

All drivers of free-steered vehicles underground should have voice communication links to a central control point. Communication can either be by a device personal to the driver or by a device fitted to the vehicle.

All locomotive drivers should be in radio contact with the train control point as part of the train control system.

18.2.3 Requirements for communications systems

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. Voice and audibility 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 sound-proofed enclosures should be provided as necessary. The base station and fixed stations in the tunnel should be powered by an uninterruptable power supply and installed so that failure of one unit does not interrupt the use of the other units in the system. Where shown to be necessary by the risk assessment, 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 **25.8.5**. Those needed to transmit warnings in an emergency should have increased integrity under fire conditions by conforming to BS 6387:2013, 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 or similar wireless communication systems should be used in conjunction with a suitable system for propagating the signals in the tunnels. There should be coverage throughout the tunnel system. Underground communications systems should link into the surface communications system as well as to the site emergency system. The contractor should discuss with the emergency services the potential for compatibility with their requirement (see **14.2**). The contractor should also discuss and aim for system compatibility with other contractors with whom there is an interface.

Where multiple hard-wired communications systems are installed, the cables should be routed separately to minimize a single event interrupting all communications.

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

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

18.2.4 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 signal 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.

18.2.5 Use of mobile phones underground

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

It should be noted that mobile phones are radio devices which emit increasingly strong signals when unable to find a base station to connect to.

Mobile phones should normally be prohibited unless checks have been made to confirm there are no compatibility issues between mobile phones and wireless control or communications systems such as those used for remote control of lifting plant or equipment as part of the segment handling and erection equipment underground.

18.3 Signals

18.3.1 General

NOTE Attention is drawn to The Health and Safety (Safety Signs and Signals) Regulations 1996 [46], 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.

A system of signalling, preferably by coloured lights (to reduce noise pollution underground and be visible to those in the vicinity of the train), should still be considered appropriate for routine communications, such as controlling train movements at the TBM or requesting that lining segments or other materials be sent forward.

The signal code should be communicated to all affected by the operations being controlled.

18.3.2 Audible signals

All lifting operations in a shaft or winch operations on an incline should normally be controlled by slingers/signallers using radio or other voice communication systems for contact with the crane or hoist operator. Audible signals by bell, whistle, air horn or other device should be considered for emergency control of 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 signal code should be communicated to all affected by the operations being controlled. The codes for both audible and visual signals should be displayed at strategic locations for the slingers/signallers and operators.

18.3.3 Visual signals

Signals to machine operators should normally be given only by slingers/signallers 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 slinger/signaller giving the signal, the signal code detailed in CP 3010, BS 7121- and BS 7121-5 should be employed. However, it should be noted that as shafts can present special difficulties (see Clause **20** for further information) control of lifting operations by visual signals is unlikely to be the appropriate option.

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, e.g. TBM segment magazine area.

Other uses of CCTV in tunnelling which should be considered are on TBMs, on locomotives, and in the pit bottom.

Particularly on locomotives, CCTV systems for improving driver visibility should have the capability to operate in both colour and infrared modes.

18.5 Emergency response

The provision of adequate communications should be considered a fundamental part of the site emergency response procedures. There should be sufficient in-built redundancy to cope with foreseeable disruptions to service including those from adverse weather. Consideration should be given to the provision of dedicated phone lines to the emergency control which are not accessible by outside parties.

All site communications networks should be accessible to those in charge of the emergency response. The emergency services should be consulted on their specific communications requirements and be made aware of the site communications infrastructure which they can use.

All communications systems for emergency use should have an uninterruptible power supply.

Regular functional testing of all emergency communications systems should be undertaken.

The emergency communications system should extend to include the means of contacting personnel required as part of site emergency procedures.

Consideration should be given to mimicking the communications structure set out by LESLP [35].

On large contracts emergency communications procedures should extend to contact with the media along with means of controlling the media on site in the event of an emergency occurring.

19 Noise and vibration

19.1 General

NOTE 1 Attention is drawn to The Control of Noise at Work Regulations 2005 [7], 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 [47], 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 account 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) impairment of both communication and the perception of warning alarms and signals; and

d) distraction of 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 5228-1 and 5228-2 give guidance on the control of noise and vibration on construction sites.

19.2 Noise emission and exposure

19.2.1 General

A noise assessment should be carried out to 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.

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 to below that associated with the second action level (SAL).

Noise health surveillance should be undertaken where there is a foreseeable risk of hearing damage.

NOTE Guidance on the selection and care of hearing protection is given in BTS Guide [24], 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 of noise 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.

The need to use silenced tools, such as the use of acoustically damped moil points or spades, should be determined.

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 peak action level (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. However, persons should be withdrawn prior to blasting for safety reasons which also reduces their exposure to noise.

The sources of noise from tunnelling machines should be addressed, taking account of the following.

a) On TBMs (**7.6.2**), 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 as a requirement of BS EN 16191.
b) On hard-rock TBMs (**7.6.2.4**), ground-breaking produces significant levels of noise which should be addressed through either the use of 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 specified in BS EN 16191 and in BS EN 12111 for part face machines. 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 have 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.

The need for communications head-set/hearing protection combinations, which allow conversation in noisy areas without having to remove hearing protection, should be determined.

The effectiveness of audible alarms and warning signals should be assessed in accordance with 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. Reduction at source should be used as the most effective method of controlling exposure.

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.

NOTE 2 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 3 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 known as hand–arm vibration syndrome (HAVS), or vibration induced carpal tunnel injury. HAVS and carpal tunnel syndrome are reportable under The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 [13].

NOTE The Control of Vibration at Work Regulations 2005 [7] and the HSE website http://www.hse.gov.uk/health-surveillance/index.htm [5] give information for assessing vibration exposure and designing a system of health surveillance.

Guidance on the control of hand-arm vibration exposure in tunnelling is given in the BTS publication, *The Management of hand-arm vibration in tunnelling - a Guide to Good Practice* [48].

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

- job rotation;

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

20 Shafts, pits and piles

20.1 General

NOTE 1 In this clause, "shafts" include rectangular pits and hand excavated piles.

NOTE 2 Shafts have increased in depth, cross-sectional area and complexity in recent years. The range of construction methods has broadened also.

Shaft construction and construction operations undertaken from within completed shafts should be treated as a safety-critical aspect of tunnelling because:

- they can have a relatively small cross-section compared to their depth;
- of the lack of space to provide effective protection from falling objects;
- 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 in the shaft;
- 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;
- the risk from unexploded ordnance (UXO) is greater nearer the surface; and
- atmospheric risks from natural ground gases, contamination, e.g. hydrocarbons in the soil, cold gas from ground freezing, carbon dioxide plant exhaust fumes and any gas heavier than air, e.g. leaks from propane cylinders.

NOTE 3 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 pipe jacking 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; and

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).

*The same categories apply for vertical or inclined shafts (see also **20.11** on escalator shafts).*

20.2 Design

The design of shafts should take into account the factors listed in **20.1** and the irregular shape of the shafts, i.e. non-circular or non-rectangular making analysis more difficult.

Shafts can be permanent or temporary, vertical or inclined. The requirements of **6.4** apply equally to shafts as to the tunnels leading from them. When being design checked all foreseeable 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 should be included.

The temporary loading conditions can be greater than the permanent loading conditions, in which case the shaft should be designed for the temporary loading condition. Temporary works in shafts should be managed in accordance with **6.4**.

The designers should include construction sequence details within the design including an assessment of the working space required for the type of plant likely to be needed to excavate the shaft, taking account of the ground conditions. Shafts of 6 m diameter or less (or of similar cross-sectional area) present particular difficulties in respect of working space, use of mechanical excavation plant and protection against falling objects. For this reason, shafts of 6 m or less should, preferably, be constructed as caissons (see **20.5.2**). If the shaft bottom is to be plugged with concrete, reinforced if necessary, full account should be taken of any possible hydraulic uplift, flotation, heave of the formation, or materials which could swell when in contact with water. An appropriate factor of safety should be applied in the design.

Clause **9** should be referred to for guidance on the construction of sumps.

NOTE Guidance on shaft design and thrust loads on shaft linings can be found in the PJA design guide [20], C760 (https://www.ciria.org/ProductExcerpts/c760) [49] and in the BTS "Tunnel Lining Design Guide" [50].

20.3 Locating shafts

When determining shaft locations, particularly in urban areas the need for working space and space for storage and handling of materials at the shaft location should be determined. Similarly, the environmental impact of shaft construction on the surrounding area should be considered, as should the presence of underground and above ground services. Some form of early contractor involvement in determining shaft location should be taken into account as they will have the expertise to determine the space and type of plant likely to be required.

20.4 Safety considerations relating to shaft construction

20.4.1 Working and storage space

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.

As shaft sinking in urban areas can be characterized by the confined nature of the site and the lack of working space on the surface, particular care should be taken in designing and locating shafts to maximize the working space available, but also to minimize disturbance outside the site. Both safety and environmental factors should be taken into account. Particular attention should be paid to the arrangements for storing and loading excavated material, especially if it is either hazardous or waterlogged.

Observational methods may be used in shaft construction to eliminate some of the temporary propping and thus give a larger clear working space. The guidance in CIRIA report R185, *Observational method in ground engineering: principles and applications* [51], should be strictly adhered to.

If temporary propping is used, it should be designed and positioned to minimize the risk of impact from either the mechanical plant working within the shaft or from hoisting operations within the shaft. The temporary support in a shaft should be sufficiently robust to withstand impact from loads being hoisted without being displaced.

20.4.2 Mechanical excavation of shafts

Shafts should normally be excavated using mechanical means of excavation. The use of excavators with telescopic dipper arms or other equipment specifically designed for shaft excavation, such as crane-mounted clamshell grabs, should be used.

Appropriate measures should be taken to ensure the safety of all personnel working in and around the shaft.

20.4.3 Shafts as confined spaces

Most shafts have the potential to be confined spaces. However, all shafts with a depth greater than twice their diameter (or minimum and maximum horizontal dimension if non-circular) should be formally risk assessed as confined spaces. Where necessary, ventilation should be provided where the air quality cannot otherwise be assured.

20.4.4 Ground stabilization techniques

Dewatering, grouting, compressed air or ground freezing can be used as ground stabilization techniques in shaft sinking. The cost, speed of application and ability to extend the treated area should all be considered when selecting the technique to be used. When considering the use of compressed air, the linear increase of water pressure with depth should be considered a limiting factor in its use unless high-pressure techniques can be used. Ground freezing should be considered to offer greater flexibility in the range of depths over which it can be used as it is affected less by water pressure.

20.4.5 Deep shafts

Conventional hoisting by jib or gantry cranes can be limited by the amount of rope which can be accommodated on the winch drums. In addition, consideration should be given to preventing excessive sway of the load during the lift. Hence, for shafts in excess of 100 m depth, consideration should be given to the use of a hoist or a cage suspended from a winding engine. Where necessary, the use of CCTV cameras linking the shaft base to the crane operator's cab as a visibility aid should be used.

20.4.6 Minimum shaft diameter

Shafts of less than 6 m diameter and which are too deep to be excavated mechanically from the surface 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 implemented. For shafts less than 6 m in diameter, a caisson is preferred in suitable ground.

20.5 Shaft construction techniques and operation

20.5.1 Underpinning

*COMMENTARY ON **20.5.1***

Underpinning is a well-proven technique in firm dry self-supporting soils or rock. Excavation takes place around the base of the shaft, followed by the installation of ground support. Compressed air can be used to maintain dry conditions within the structure during construction. The remainder of the ground within the shaft is excavated later.

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

NOTE There is a trend towards shaft units of 1.0 m or 1.5 m in depth which leave a greater amount of ground unsupported prior to grouting and increase the risk of sidewall failure. Support can be in the form of segments or sprayed concrete.

Grouting should be carried out as required by the ground conditions but as a minimum at the end of every shift. Measures should be adopted to allow trapped air to be released through the grout hole in the ring above; so called "pricking up".

If wet conditions are encountered, pre-installed dewatering, ground treatment or the application of compressed air should be used to control water inflow and allow underpinning to continue. The effect of the use of these measures should also be taken into account in planning for the efficient and environmentally beneficial disposal of wet material.

20.5.2 Caisson construction

*COMMENTARY ON **20.5.2***

Caisson construction is a well-proven technique in non-self-supporting ground or in ground below the water table.

In its common form, excavation takes place within the caisson and as the structure sinks, additional lining is added to the top of the structure. Caissons normally utilize precast concrete ground support elements.

In suitable ground conditions and where size permits, caissons should be excavated by grab to avoid the need for persons to be present within the shaft during construction. In particular, this method of shaft construction should be considered for shafts of 6 m diameter or less (see **20.2**).

NOTE 1 Alternative mechanised excavation techniques are becoming available.

There should be a concrete collar and slab at ground level around the caisson to provide ground stability and counteract any local loss of ground around the caisson extrados. The collar should be designed to meet the particular parameters of the shaft under construction and may be permanently incorporated into the shaft, once sunk, to counteract flotation.

A cutting edge should be installed around the leading edge of the caisson which can, in the case of smaller shafts, be supplied as part of the precast segmental lining. It should provide an overcut to the nominal shaft external diameter to minimize friction and to create an annulus for introducing a thixotropic lubricant to support the ground. For larger shafts, and also where ground conditions are onerous, a steel cutting edge should be used to facilitate sinking.

The water level within the caisson should be equalized with that outside to maintain a hydrostatic balance in water-bearing ground to minimize the risk of ground movement around the shaft.

Externally-bolted segments should be used where necessary for extending the lining of the caisson to remove the need for persons to work over water or at height. In small-diameter shafts one-piece lining rings should be used. Exceptionally where internally bolted segments are used, purpose-made building cages or stages within the shafts should be provided to allow safe access to joints. Such cages or stages should meet all the requirements for man-access.

Unless the primary lining is sufficiently heavy to sink under its own weight, additional load to maintain penetration of the cutting edge should be provided by the use of jacks, as they provide a more controlled method of applying load and ensuring correct alignment. Alternatively, the use of kentledge weights stacked on steel frames can provide additional load for sinking, in which case the risks to persons from placing or removing these weights should be addressed. If the caisson “hangs up” and becomes impossible to sink under the load available, compressed air working and manual intervention to identify and remove the obstruction should be considered.

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 such that they cannot fall into the shaft in the event of jacks becoming slack.

Typically a thixotropic fluid such as a bentonite suspension should be used in the annulus 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 and made watertight before underpinning commences. Work under cutting edges should not take place unless the shaft lining has been secured. In some cases, it might be possible and economical to remove the cutting edge if a steel unit has been used.

The application of compressed air should be considered as an option to control water ingress and facilitate sinking.

NOTE 2 There is an alternative form of caisson sinking in which the entire caisson is constructed as a monolithic structure before sinking under compressed air begins. The base of the caisson forms the air deck with a downstand and cutting edge around the perimeter to form the working chamber. Material is excavated hydraulically from around the cutting edge and from within the working chamber and discharged by slurry pumps through the air deck. Large structures can be sunk into position by this method.

20.5.3 Piled shafts

NOTE Lining types include contiguous piles, secant piles or sheet piles. Sheet piles can also be used for temporary shafts.

Pile installation equipment should conform to BS EN 16228 (all parts). Ground support by propping, ring beams or ground anchors should be placed as excavation proceeds and as required by the design.

In principle, the piles should form a watertight shaft lining hence care should be taken during pile driving to ensure the required alignment is maintained. A tolerance on verticality of better than 1 in 100 should be adopted to ensure sufficient overlap between piles.

Loose material should be cleared from the internal surface of the lining as excavation proceeds to avoid it drying out, becoming dislodged and falling on persons working below.

The design should provide for adequate toe-in to ensure stability of the base of the excavation. The design of the propping regime should include an allowance for impact loads on props. It should also include sufficient redundancy to allow for the failure or dislodgement of a single prop due to impact from plant or equipment.

The propping layout should be designed to minimize its impact on shaft excavation and other operations in the shaft. To this end the application of observational methods can reduce the obstructive effects of propping but any observational methods should be undertaken strictly in accordance with the CIRIA report, *Observational method in geotechnical engineering* [52].

The recommendations of Clause **3** of BS 6031:2009 should be met.

20.5.4 Diaphragm walls

A tolerance on verticality of better than 1 in 100 should be adopted to ensure sufficient overlap between panels ends.

NOTE Diaphragm wall (D-wall) techniques have become popular for irregularly shaped and/or deep shafts.

D-walls should be excavated by purpose-made grab or by hydrofraise which for deep walls or where verticality is critical should incorporate steering capability. Grabs should be hung from a cable excavator conforming to BS EN 474-13 and not from a crane. Hydrofraise devices should conform to BS EN 16228-5.

The design should provide for adequate toe-in to ensure stability of the base of the excavation. The design of the propping regime should include an allowance for impact loads on props. It should also include sufficient redundancy to allow for the failure or dislodgement of a single prop due to impact from plant or equipment.

The propping layout should be designed to minimize its impact on shaft excavation and other operations in the shaft. To this end, the application of observational methods can reduce the obstructive effects of propping but any use of observational methods should be undertaken strictly in accordance with the CIRIA Report 185, "*Observational method in geotechnical engineering"* [51].

The recommendations of Clause **3** of BS 6031:2009 should be followed. Reinforcement cages should incorporate a purpose-made lifting structure and not depend on the tying wire joints between bars for strength during lifting.

During shaft excavation, soil adhering to the intrados should be regularly removed to prevent it drying out and becoming loose.

Provision should be made for preventing persons falling into the slurry-filled trench. Adequate washing and skin care facilities should be provided where the slurry or any additives in it are skin irritants.

20.5.5 Drill-and-blast shafts

Drill-and-blast techniques are normally only used in rock and the environmental problems presented by such methodology in urban areas should be considered. The risk of flying debris and vibration should be addressed in relation to both structural damage and personal injury, for example by the use of blast mats.

*NOTE Underground services can be at greater risk of damage (see **7.8**).*

BS 5607:2017, Clause **11** should be referred to for guidance on the safe use of explosives and for guidance on the different types of detonators and explosives available for use in shaft sinking. These should be chosen 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. Where necessary, operations using explosives should be monitored by a vibration monitoring system.

20.5.6 Raise bored shafts

Raise bored shafts should only be considered for competent rock. A different construction method should be used where the ground investigation identifies a need for a lining.

The area around the base of the raise bore should be designated an exclusion zone and be barriered off during boring to exclude personnel.

Care should be taken to prevent the raise bore head becoming jammed in the bore as freeing it could put persons at risk.

20.5.7 Mechanized shaft sinking

Shaft sinking machines are now being developed which mechanize the shaft sinking process.

NOTE Such machines are not yet within the scope of BS EN 16191 however the safety requirements of BS EN 16191 are generally applicable to such machines.

The system for the suspension of the machine in the shaft should be adequate for the loads acting on it.

20.5.8 Small diameter shafts as piles

Only where machine access is not possible should small diameter man-entry shaft construction techniques be used to form end-bearing or under-reamed piles. The minimum internal shaft diameter should be not less than 1.8 m. Underpinning techniques should be used for lining the shaft. Normally a precast segmental concrete lining should be used.

Sprayed concrete lining should only be attempted in shaft diameters of 3.5 m and over, and robotic application is to be preferred. Where spray concrete lining is used, only essential personnel should be in the shaft during spraying. They should all wear airline fed full face masks during spraying. Personnel should then be withdrawn until the levels of respirable and inhalable dust in the shaft atmosphere have been shown to be below the limits in Clause **16**.

Where hand excavation techniques are used, the normal occupational health hazards associated with hand tunnelling, of manual handling, noise, vibration and heat strain foreseeably occur and the should be controlled as in hand tunnelling. Under-reams can be formed using timber lining techniques.

All persons in the shaft should wear a full body harness with extension rescue strap conforming with BS EN 361. If lone working is being undertaken in the shaft, a second person on the surface should observe the miner in the shaft at all times. Sufficient lifelines should be provided such that lone workers are always attached to a lifeline. There should be an airline fed mask at the base of the shaft for each person normally working there. There should be a means of communication between the shaft bottom and ground level which should be continuously monitored on the surface.

There should be a dedicated crane or hoist suitable for man-riding and capable of lifting at least two persons at a time. There should also be a similar crane or hoist on standby.

There should be rescue capability on site at all time persons are working in the shaft. A minimum of two rescuers should be immediately available on site at all times when persons are working in the shaft. An airline fed mask should be available for use by each of the rescuers. Access to the shaft base should be available at all times.

20.6 Lifting in shafts

The planning for shaft works should include the positioning of services and access ways such that the size of the available lifting window is maximized.

The number of persons in the shaft bottom area should be kept to a minimum at all times while lifting operations are in progress. Procedures should be implemented to prevent 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 up or down. A warning should be sounded by the slinger/signaller before a suspended load is moving over or inside the shaft.

All skips used in shafts should have means of suspension such 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.

When handling a load 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;

d) there is sufficient rope on the crane drum to allow for operation in the full depth of the shaft (see **21.2.2**); and

e) appropriate lifting equipment is used for all loads, and that pallets are not lifted using strops but are only lifted using a purpose made pallet lifting device with full netting enclosure.

NOTE Attention is drawn to HSE publication PM 15 Pallet Safety.

All plant regularly transferred down the shaft should be designed for hoisting with purpose built lifting points and should be regularly tested and certificated for such a purpose. The normal operating weight of the item of plant should be clearly marked on it.

As a standard procedure in lifting, the load should be lifted a short distance then stopped, steadied and inspected and, if necessary cleaned, before hoisting continues.

As excavation proceeds, the shaft should be fitted with skip guides or partitioning to protect personnel and shaft services, e.g. an enclosed ladder bay or protection to pipe ranges.

20.7 Protective structures in shafts

Whilst consideration should be given to the provision of a structure to give protection against falling objects in a shaft during construction, in small diameter shafts such a structure, particularly if freestanding, can obstruct the movement or operation of plant and can give rise to impact risk to those in the shaft bottom.

20.8 Pit bottom safety

The pit bottom should be treated as one of the more hazardous areas on site not least because of the amount of activity in a relatively restricted space. Hazardous activities which should be considered include transport movements, including the shunting and marshalling of trains, materials handling, personnel movement, and lifting operations. Robust management, supervisory and organizational controls should be put in place to ensure the risks from these activities are adequately controlled.

No one should exit the tunnel into the shaft without first checking that it is safe to do so.

20.9 Plant safety

All electrical and mechanical plant and equipment in shafts should meet the recommendations on fire safety applicable to similar plant and equipment operating in a tunnel. The recommendations for control of diesel engine exhaust emissions in tunnels (see Clause **15** and **24.8.1**) apply equally in shafts. Given the confined nature of many shafts, consideration should be given to the use of electrically powered plant to reduce exhaust emissions.

20.10 Services in shafts

All services in shafts should be supported in racks or frames attached to the shaft wall and should be designed to provide minimal interference with lifting operations. Means of protection to the service should be included in the design. Provision should be made for the regular inspection of the fixings and anchorages.

20.11 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 the transport of material and to preventing unintentional movement of plant and equipment on the sloping invert.

The design of the face support system should be given particular care to ensure that the correct transfer of face loads takes place. Detailed method statements, and thorough personnel training, should be provided before shaft sinking begins. Uphill drives should only be used in competent ground. They 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 keep pace with the moving face as the shaft is constructed. The risk to persons from material rolling down the slope should be appropriately managed.

Personnel access should be by stairs or walkways with gripper battens, designed for the specific application.

20.12 Transport systems for inclined shafts

20.12.1 General

Particular care should be taken in SCL tunnels where the invert backfill comprises excavated material and hence the gradient of the incline can be variable if the area is heavily trafficked. The area should be well maintained and any deterioration of the plant running surface rectified immediately.

20.12.2 Monorail

*COMMENTARY ON **20.12.2***

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 visual and/or audible warning system should be installed to warn face workers when the monorail system is in use. The monorail should be securely anchored in the shaft crown and restrained against horizontal or vertical movement. A proportion of the anchors should be tested before being loaded for the first time. A fail-safe system should be put in place to prevent or limit runaway. Any machine on the monorail should have a spring-applied mechanical parking brake capable of holding the full weight of the machine on the incline. There should be a means of emergency escape from the vehicle operable at any position over the length of the monorail.

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.

20.12.3 Invert rail-mounted system

*NOTE 1 In an invert rail-mounted system, unpowered wagons are winched from fail-safe winch units at the head of the shaft located in a level marshalling area. Rail systems in inclined shafts are covered in Clause **23**.*

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 to the winch. The means of coupling of the wagon to the rope should be secure to prevent uncoupling, and only rope fixings manufactured specifically for this purpose should be used.

*NOTE 2 See Clause **23** for guidance on maximum permissible gradients.*

Safety gates should be fitted at the crest and on the incline, and interlocked consecutive gates should be installed, one of which should always be closed.

NOTE 3 As the shaft progresses, more gates might 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 tested for competence before being put to work.

All plant and safety mechanisms on transport systems should be examined and serviced regularly, and records should be kept.

20.12.4 Rubber-tyred or tracked vehicles

Vehicles should be attached to fail-safe winch units at the head of the shaft located in a level marshalling area. Vehicles should be capable of climbing the incline fully loaded without winch assistance. The braking systems of all vehicles should be capable of braking the fully loaded vehicle on the incline and should be subject to regular inspection and maintenance reflecting the hazardous nature of the operation. All plant and safety mechanisms on transport systems should be examined and serviced regularly. Records should be kept of all inspections and maintenance.

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 rope 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. Rope guides should be included in the winching system to avoid excessive wear on the rope as necessary.

Safety gates should be fitted at the crest. Consideration should be given to installing additional gates on the incline depending on the length. Interlocked consecutive gates should be considered for long shafts. In large diameter shafts gravel drags in lieu of gates should be considered for use on the incline.

NOTE As the shaft progresses, more gates might 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.

Both vehicle and hoist operators should be trained and tested for competence before being put to work.

20.13 Disused shafts

20.13.1 Permanently disused

When a shaft is to be permanently disused it should be capped on completion of its use. The cap used should be specifically designed for that purpose and should be capable of withstanding all foreseeable loads which could be imposed upon it given its location. An assessment should be made of whether the cap should be ventilated. A decision should be taken as to whether the shaft is backfilled to eliminate the need for future maintenance.

Where a shaft it is not backfilled, access should be provided for asset management and maintenance purposes. Traceable records should be kept within the health and safety file of all disused shafts giving details of the shaft, the tunnel below and the method of capping or filling.

20.13.2 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 capable of being opened from below in an emergency, should be maintained in the cover to enable escape or to allow access for inspection purposes. The cover should be vented.

20.14 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. A soft eye and of glass fibre reinforcement in the shaft lining should be used where necessary to facilitate the breakout from the shaft. Before breakout the groundwater 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 breaking out operation should be carried out in a planned and managed way, and only once it has been established that the exposed ground and groundwater can be adequately controlled. The requirements for ground support should be taken into account.

Where TBMs are entered through the tunnel eye (EPBMs or slurry shields), the tunnel eye should be fitted with an appropriate seal where necessary to prevent ground or slurry loss. A sealing system should also be used to contain lubricant or annular grout for use with pipe jacking systems. A similar system should be used where necessary at the reception chamber.

In (bad) unstable ground the first ring of lining or the first setting of a heading should be fixed and built within the shaft.

NOTE Where other methods are not practical, 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. In unstable ground, it can be necessary to undertake ground stabilization immediately behind the shaft before the break out operation begins.

20.15 Removal of temporary rings and panels of d-walls

Where an opening is to be formed in a D-wall by a TBM, glass fibre reinforcement should be used in lieu of steel reinforcement over the area of the opening.

In conventional tunnelling, where an opening is to be formed in a D-wall using diamond drilling techniques, the drilling equipment should be guarded appropriately. Initially, probe holes should be drilled through the base of the wall to relieve water pressure. Means of support and/or lifting points should be attached to sections of the D-wall before they are separated from the main wall structure.

Where temporary lining rings have previously been installed to facilitate later removal, care should be taken to ensure stability of the remaining lining before their removal.

20.16 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. Comprehensive planning of the layout around the shaft should be undertaken, and early contractor input should be obtained before construction begins.

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 9).

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. As mobile plant poses a particular hazard, barriers should be erected that are robust enough to prevent the equipment from falling into the shaft.

Facilities should be provided for the shaft top slinger/signaller 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 **10.10**).

20.17 Personnel access

Personnel access in shafts under construction should be planned as part of a safe system of work. Means of access which should be considered include man-riding crane or the incremental installation of steel ladder with planned extensions to the working level using timber ladders.

Personnel access in completed 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.

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, 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 should include stairways, scaffold ladder towers, ladderways or vertical ladders with protective hoops and designed in accordance with BS 4211.

Stairways or ladder towers should be used whenever possible, 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 another 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 handrails, 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.

20.18 Communication

A means of voice communication should be provided between persons at the shaft top, and those working in the shaft, which allows for background noise, obstructed vision, etc. There should be a backup system of visual signalling. The use of two-way radios should be considered for providing clear and effective means of communication.

*NOTE See also Clause **18**, Clause **19** and Clause **21**.*

21 Lifting equipment and operations

21.1 Lift plan

NOTE Attention is drawn to The Lifting Operations and Lifting Equipment Regulations 1998 [52] 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.

All lifting operations should be planned. The appointed person should determine what is required in terms of a generic or specific plan for each lift.

The lift plan should be briefed to the lifting supervisors, machine operators and signaller/banksmen. The lift plan should contain, as a minimum, information on the lifting equipment and accessories to be used, description of the load and the lifting arrangement and the maximum working radius when lifting the load, including the weight of the lifting accessories.

21.2 Cranes

21.2.1 General

NOTE 1 Attention is drawn to The Lifting Operations and Lifting Equipment Regulations 1998 [52] 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 can involve testing of lifting equipment and accessories for lifting.

NOTE The term slinger/signaller includes banksmen.

All lifting operations should be planned. The appointed person should determine what is required in terms of a generic or specific plan for each lift. The hazards of heavy lifts along with repetitive lifting and lowering to considerable depths below ground level should be factored into the planning of lifting operations in tunnelling.

The lift plan should be briefed to the lifting supervisors, machine operators and slinger/signaller. The lift plan should contain, as a minimum, information on the lifting equipment and accessories to be used, description of the load and the lifting arrangement and the maximum working radius when lifting the load, including the weight of the lifting accessories. All cranes and crane operations should be carried out in accordance with the relevant parts of BS 7121.

Any examination scheme prepared under the Regulations should take into account the environmental conditions that can occur in below-ground works.

21.2.2 Cranes at shafts

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, crawler, mobile or gantry cranes should not be used for shafts deeper than approximately 100 m.

In circumstances where an extensive reach is required at the pit top with a deep shaft, tower cranes should be considered. Their height should be minimized. The wind loading on the jib along with the maximum operating wind speed should be taken into account in the selection of the crane. The guidance on derating in BS ISO 12482 and on “high intensity operations” in Construction Plant Association Tower Crane Interest Group Technical Information Note 42 [53] should be taken into account.

Crane selection should take into account the nature of the work, which could require frequent high-speed hoisting and lowering, potentially with heavy loads. The crane supplier should be made aware of the exact duty cycles so that they can supply plant which is not regularly working at or near the design limits for prolonged periods, which could affect crane reliability.

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 any restrictions imposed on 24-hour working should be considered where appropriate.

Where appropriate physical restrictions on slewing should be applied

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 loading on tunnels or lateral thrust from the ground against the shaft lining or other structures.

With mobile cranes that are not restricted to predetermined locations, loadings imposed upon the ground should be kept within safe limits considering the variability of the ground.

Rope lengths should be checked to confirm that at least three full turns of rope remain on the hoist drum when the hook is at full depth in the shaft bottom, including any sumps. The hoist drum should be fitted with a “last wrap” roller which cuts out the lowering when it is tripped, but allows the operator to hoist back up the shaft.

The weight of the rope should be taken into account when determining the safe working load at full depth.

21.2.3 Clearances

Adequate personnel clearance should be provided around a crane. When this cannot be provided, access to areas of restricted clearance should be prevented while the crane is operating.

21.2.4 Long loads or complex lifting operations

NOTE Long loads might need to be slung vertically because of restricted space.

Complex lifting operations involving multiple cranes, lifting of people or heavy loads, such as lowering a TBM or parts of the backup into a shaft, should be specifically planned and supervised.

NOTE Where such lifting operations involve tandem lifting or the use of cranes of significantly greater capacity than the crane normally servicing the shaft, it can be appropriate to involve heavy lift specialists in addition to the contractor’s own plant specialists.

For long loads or complex lifting operations, the slinging arrangements should be devised to ensure the stability and security of the load. This should include the provision of properly designed lifting points where possible. 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 those essential to the lifting operation while the lift is in progress. These persons should be safely positioned.

21.2.5 Lifting accessories

NOTE Lifting equipment and lifting operations are regulated by the Lifting Equipment and Lifting Operations Regulations.

Copies of current reports of thorough examination for all lifting equipment, including accessories, should be held on site.

Suitable lifting accessories should be provided for all loads. Appropriate lifting equipment or accessories should be used for handling segments, pipes, rails, etc., with no risk of load displacement. This may include the use of bespoke lifting equipment such as frames for lifting segments.

21.3 Winches

NOTE Winches are used in tunnelling operations, e.g. in hand tunnelling operations.

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

Remotely-operated materials hoists should be enclosed with guards or barriers throughout their length of travel where persons could have access to or be struck by moving parts of the installation or by falling materials. Interlocked gates which can only be opened when the hoist is adjacent to them should be provided at all landings. 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 Slinger/signallers or visibility aids can be required. This can also involve the use of pendant controls.

21.5 Communication

Effective communication between the crane operator and the working level should be maintained both for control of all hoisting and lowering operations and for the exchange of information on loads being handled.

Slinger/signaller should be designated having first undergone specific training. The movement of loads by lifting equipment should be, at any stage, under the control of one person.

*NOTE 1 See also Clause **18**, Clause **19** and Clause **20**.*

Where possible, the plant operator should have an uninterrupted view of the load while it is within the shaft.

Where full visibility is not possible there should be visibility aids and 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:

- *radios;*
- *slinger/signallers;*
- *CCTV;*
- *signal lights;*
- *audible signals; and*
- *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/signaller might not be required for that part of the operation.

When more than one slinger/signaller is responsible for directing the lifting operation, the transfer of responsibility should be clearly defined.

Where one or more slinger/signallers are required to control the lifting operation a voice communications system should be the preferred means of communication between the crane driver and the slinger/signallers. Alternatively, the visual system of crane signals given in BS 7121-1 should be used. The visual system should only be used where the signaller is viewed from a position where crane signals could not be misinterpreted.

To enhance safety, CCTV should be used where appropriate to link the crane operator at the surface with the shaft bottom. 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 to replace normal visual checks of shaft operations by the slinger/signaller.

Hands-free radio sets (headsets with fixed microphones) provide an effective means of communication with the plant operator and should be considered for use in busy locations. Where radio communication is relied on, loads should be talked down and lifting should be stopped if contact is lost.

Verbal instructions should be given at normal voice level to allow the slinger/signaller to simultaneously guide and signal a load into position.

21.6 Lifting of persons

21.6.1 General

A mast-climbing elevator should be used for transporting personnel in shafts in preference to manriding on a crane. Manriding on a crane should still be the norm during shaft sinking and works from the shaft which are of such duration as to not warrant provision of an elevator.

Mobile elevating work platforms (MEWPs) should be considered for work at height underground particularly in caverns, station enlargements and similar large structures.

*NOTE Attention is drawn to **21.1**.*

21.6.2 Construction hoists

Construction hoists should be used in accordance with BS 7212:2016.

There should be an emergency plan for rescuing persons from the hoist in the event of breakdown or power failure.

21.6.3 MEWPs

The use of MEWPs should be undertaken in accordance with BS 8460.

*NOTE Further recommendations on MEWPs for use underground are given in **24.15**.*

21.6.4 Personnel riding cage

Where a cage is used for the carriage of persons, it should conform to BS EN 14502-1. The sling legs should be < 45° to the vertical. Use of the cage should also conform with BS EN 14502-1. Chains/bonds should be captive to the load, inspected daily (recorded) and not used for purposes other than man riding.

The safe working load (SWL) and maximum number of occupants should be clearly marked and visible to the personnel in the cage.

Although not a requirement of BS EN 14502, for applications in tunnelling, the cage should be constructed to enclose the passengers fully, with a roof and an inward opening gate.

Dual-purpose cages may be used, where the duty can be for riding, or for working out of the cage. Where cages are designed to be used with upper side panels removed for access (thus not fully enclosed), sufficient and suitable attachment points for safety harnesses should be provided for all occupants and the cage structure designed to take the load of a person falling in a harness. Whenever a cage is not fully enclosed, all occupants should wear safety harnesses, and be “clipped on” to the strong points.

Purpose-built open-topped personnel carrying baskets may be used in shafts, typically for extending the lining of shafts sunk as caissons (see Clause **20** for alternative methods). These should generally be limited to working in the upper part of the shaft due to the lack of overhead protection, and susceptibility to “catching” projecting shaft furniture while being raised up the shaft. Baskets should be constructed to the same standards as the man-rider cages, with sufficient harness attachment points

21.6.5 Alternative personnel egress

A secondary means of egress from the underground works should be provided in case the primary method becomes unavailable, e.g. a ladder, a second crane or a purpose-built emergency egress device such as a winch and davit system. Any crane or winch should be used in accordance with the applicable part of BS 7121.

21.6.6 Injured persons

A suitable means should be provided for hoisting injured persons from the shaft.

21.6.7 Other lifting plant – forklift or telehandler

Man-riding using a telehandler should only be undertaken using an integrated working platform.

NOTE The terms “non-integrated working platform” and “integrated working platform” are defined in HSE PM28, Working platforms (non-integrated) on forklift trucks Guidance Note PM28 (Fourth edition) 2013 [54].

21.7 Arch and mesh installation

Steel arches for roof support should be lifted using a purpose-built clamp or similar attachment, mounted on a roadheader or other machine with lifting capability.

21.8 Lifting with excavators

Excavators should only be used for lifting in tunnels or on the surface on where:

a) they have been designed for that purpose and the surrounding conditions are considered safe;

b) the manufacturer's instructions and recommendations are followed; and

c) their designated lifting points are used.

21.9 Visual and/or audible alarms

Visual and audible alarms should be activated in the pit bottom area when lifting down or up the shaft to warn the operatives that lifting operations are taking place. The same alarms should also be activated if a load is slewed over the shaft (**21.2.2**).

22 Access

*NOTE See also **12.6**.*

22.1 Walkways

Every tunnel should have a safe pedestrian route from the face to the surface, with escape routes properly signed. Pedestrian access should be provided by walkways in the tunnel. Where reasonably practicable, the 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.

NOTE 1 In a TBM-driven tunnel in which man-riders are used for routine personnel transport the clear width of the pedestrian route can be reduced to 600 mm.

Access routes and walkways which do not lead to the surface should be clearly signed as such.

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. When determining clearances, allowance should be made 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 the 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:

- recesses constructed outside the general line of excavation; or
- robust barriers between the safe position and the haulage route; or
- stages raised clear of any foreseeable 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 2 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. Handrails 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. Spillages of oil or chemicals should be removed promptly using appropriate equipment and absorbent materials. Any accidental spillage of muck or other material on a walkway should be cleared away promptly.

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.

*NOTE 3 Recommended illumination levels are given in Clause **17**.*

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 winch haulage is in operation, unless there is adequate protection to the walkway.

NOTE 4 Attention is drawn to The Construction (Design and Management) Regulations 2015 [1] and The Work at Height Regulations 2005 (as amended) [55].

22.2 Stair and ladder towers

Stair or ladder towers should be provided as a means of non-mechanical access in shafts. Stair towers should be preferred over ladder towers. Landings should be provided at not more than 6 m vertical intervals. Guard rails and toe boards should be provided on all stairs and landings.

Stair towers should be netted or otherwise enclosed to reduce the risk of articles being dropped from the stair tower into the shaft.

Ladders should be secured and extend at least 1.1 m above landings. Ladder positions in the tower should be staggered. The tower should be securely tied to the shaft lining. Appropriate protection should be provided against impact from loads being hoisted in the shaft.

22.3 Access for maintenance

Access should always be provided for track inspection and maintenance, as well as for other tunnel inspection and maintenance activities. Access in tunnels can also be required to carry construction equipment through the tunnel.

The safe system of work for access should address as a minimum:

- minimum dimensions for access, in accordance with the BTS/PJA/HSE Table [20] (see also **22.1**);
- adequate ventilation;
- gas detection equipment;
- rescue procedures with due allowance made for the reduced number of personnel on site, and obstructions in the tunnel;
- necessary rescue equipment with due allowance made for self-rescue sets, the type of breathing apparatus and stretcher availability;
- avoidance of lone working; and
- communication equipment.

For major maintenance, a decision should be taken as to whether to remove machinery to the surface, construct a dedicated maintenance shaft or excavate a maintenance chamber underground.

22.4 Gradients

A slope of approximately 15° should be considered the limit for a pedestrian ramp and a slope of approximately 45° should be considered the limit for pedestrian access, which can be achieved using a properly constructed stairway.

22.5 Temporary tunnels

All relevant requirements for permanent tunnels apply to temporary tunnels, including temporary tunnels which are specially built for access purposes.

22.6 Working at height in tunnels and shaft

22.6.1 General

Control measures which apply to work at height on the surface should be applied equally to work at height underground. Where work at height is required in tunnels and shafts, the system used should be fit for purpose and should be selected in accordance with normal work at height protocols.

Provisions for access and work at height on TBMs should be in accordance with BS EN 16191.

For work such as charging the face, the installation of bolts in conventional tunnel linings or mesh in sprayed concrete linings, mechanical access equipment should be used. A Level 1 falling object protect system (FOPS protection) should be provided for those working at height.

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. intermediate conveyor drive stations.

NOTE 1 In small tunnels, use of MEWPS is unrealistic. If a company wants to ban ladders, it is free to do so. Towers can get easily damaged.

Rope access techniques, if utilized for work in shafts, should be undertaken in accordance with recognized safe working procedures, such as those recommended by the Industrial Rope Access Trade Association (https://irata.org).

NOTE 2 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, as they are insufficiently robust to withstand the rigours of the tunnel environment.

Site emergency procedures should include all work at height operations foreseeable on the tunnel or shaft works.

22.6.2 MEWPs

MEWPs can be used to facilitate work at height underground and their use should be undertaken in accordance with BS 8460 and **24.15**.

23 Materials handling systems

23.1 Rail haulage

23.1.1 General

*NOTE 1 Recommendations covering free steered vehicles are set out in Clause **24**.*

A risk assessment should be carried out for rail haulage operations.

Railway systems used in tunnel construction should be operated in accordance with this clause.

Self-propelled vehicles should be classed as locomotives.

The use of rail-borne plant should be planned, and safe operating procedures developed. All railway operations should be undertaken in accordance with the procedures. The procedures should reflect the complexity of the railway system.

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The operating procedures should cover as a minimum:

a) practical train control procedures;

b) communications and signalling;

c) train speeds and temporary speed restrictions;

d) gradients;

e) length of main haul;

f) rate of muck removal;

g) clearances;

h) walkways and crossing points;

i) other tunnel activities;

j) total mass of trains;

k) whether passing points are required, either fixed or moveable (Californian type);

l) size and availability of haulage system;

m) carriage of persons and/or materials;

n) abnormal loads;

o) driver competence and authorization;

p) rolling stock maintenance;

q) track inspection and maintenance; and

r) passing of instructions to operating staff.

NOTE 2 Attention is drawn to The Crossrail Best Practice Guide “Construction Railways Operations” [56].

NOTE 3 Attention is drawn to The Construction (Design and Management) Regulations 2015 [1], which give statutory requirements for transport during the construction process.

In the case of operational railways, the advice of The Office of Rail and Road should be sought when necessary.

23.1.2 Track

23.1.2.1 General

The track system selected should suit the production system intended, including the hauling of muck from the face. The safe system of work should include measures to prevent the track itself becoming a hazard potentially resulting in derailments and injuries. This should be the responsibility of an experienced and competent engineer. Design factors should include the tunnel diameter and alignment, the tunnel lining, temporary invert conditions, track support system, the intended locomotives and rolling stock, train weight, and availability of the track itself.

The track and its support should be designed as a system to take account of:

- spacing of fixings of the track to the tunnel structure to prevent movement and overturning and track going out of alignment; and
- compatibility of track to sleeper spacing taking account of maximum load to limit rail twisting and lifting and deflection of the rail.

Rails should be heavy enough to avoid twisting and lifting in use, and the track should be stable and secure in use to minimize maintenance problems. Used and worn rail should be inspected before use and rejected if unacceptable wear and defects, such as kinks, bends, and damaged ends are found.

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NOTE 1 As a general rule, rails with less than a 3 mm running face top radius cause wheel wear, and possible derailment, and high running surface wear leads to knife-edge wheel contact, and rough joints.

Advice should be sought from the rolling stock supplier to ensure the wheel profile and rail head profile are correctly matched.

Track should be properly supported and secured against displacement in the tunnel. 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. If burrs are created during drilling, they should be removed to reduce the risk of stress fractures around drill holes.

NOTE 2 Due to the composition of the rail steel, any cutting or welding of rail can cause minute shrinkage cracks which spread if stressed, eventually leading to fracture.

Cold sawing, drilling and clamp-type connections should be used. Hot cutting and welding should be avoided where possible but if either is necessary it should be carried out in accordance with guidance from the rail manufacturer.

In an unlined tunnel with an uneven invert, the track can suffer from sinking and rolling hence a regulating layer of concrete or granular material should be laid to provide a suitable base to allow safe laying and maintenance of the track.

To avoid derailments, turnouts and crossings should be laid on a sound base to accurate gauge and be maintained with adequate guide rails and close-fitting switch blades. The radii should be able to accommodate the longest wheelbase vehicle and be suitable for all wheel flange depths and thicknesses.

NOTE 3 Poor selection can lead to jamming and jumping.

Sidings for the storage of unbraked skips and trailers should be constructed on the level wherever possible. Scotches should be used to prevent accidental movement; chains should not be used as they can be run over or slid along.

A derailing mechanism, such as catch points should be installed at the exit from the sidings if there is a downhill gradient away from the sidings.

23.1.2.2 Crossings, passing bays and work platforms

The design of crossings, passing bays and work platforms (referred to in this clause as “crossings, etc.”) should take into account both maximum and eccentric or out of balance loads. Any requirements necessary for securing the deck or platform to the segmental lining to prevent displacement or rotation should be clearly stated on the working drawings.

It should be clearly stated if moveable or towed crossings etc., can be moved when loaded particularly when loaded eccentrically.

If the stability of a moveable or towed crossings, etc., relies on restraint provided by the tunnel rails then the fixing requirements for the tunnel rails should be specified.

When a crossing is propelled along the tunnel by a locomotive or rubber-tyred vehicle then either the vehicle and the connection to it, should be capable of restraining the crossing to prevent the crossing running away on a gradient or the towing vehicle should be positioned on the downhill side of the crossing, to prevent a runaway.

If a moveable crossing is moved along the tunnel by a winch then either the winch should be attached to the uphill side of the crossing or a means of braking the crossing should be provided.

The layout of tracks on a crossing should allow sufficient clear space for the passage of personnel in the tunnel when both tracks are occupied.

When both tracks are occupied, there should still be sufficient space for persons to be able to escape from one or other train or locomotive in an emergency.

The radius of curved track should be sufficiently large to prevent excessive wheel wear. The inclination of ramps leading up to a crossing, etc. should be sufficiently flat to maintain adequate wheel adhesion and to prevent the unintentional uncoupling of rolling stock passing over it.

23.1.2.3 Track inspection and maintenance

A designated person should be responsible for the inspection and maintenance of the track.

A track inspection programme and track maintenance regime should be implemented. This should include a schematic of the track identifying the various sections of the track including, curves/canted, straight, crossings, etc, speeds, gradients. A record of track inspections and maintenance undertaken should be kept.

In addition to the programmed track inspections, additional track inspections should be undertaken following any reported rough ride, derailment or track defect including observations by the locomotive drivers who should be required to record the condition of the track after every shift.

The track inspection programme should ensure that every section of track is inspected at least once every two weeks. Track inspections should be undertaken on foot under adequate lighting conditions. Where two or more lines exist on a stretch of track, each line should be walked separately. Spoil and water should not be allowed to accumulate above top of sleeper level.

The track inspection programme should identify any components (such as California Crossings) which require specialized inspections other than a visual check.

The initial inspection should take place while the track is being laid to ensure proper track installation, including the correct assembly and tightening of fishplates, and the spacing and securing of the track and the sleepers.

Track inspection and maintenance should not normally be attempted during train operations. In exceptional circumstances, when maintenance 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 and operate with caution in and around affected areas.

*NOTE Further recommendations for illumination are given in Clause **17**, and for communications in Clause **18**.*

23.2 Operational considerations

23.2.1 General

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 minimum 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 can safely brake when travelling down that gradient, without recourse to engine braking. Air-braked rolling stock should be used to enhance downgrade braking performance of the whole train.

The braking system should allow a train to stop within the range of its driver's vision under the worst conditions and within not more than 60 m in any case.

The correct locomotive for any application should be selected by careful calculation, for which established formulae are available from manufacturers. Manufacturers or plant hire companies should be consulted for advice. Preference should be given to rolling stock with full or partial air brakes, which is inherently safer than rolling stock that relies on braking by the locomotive only.

In particular, the conditions for starting uphill and for braking should be analysed. Attention should be given to the potential for contamination being transferred along tracks by trains travelling from outside to inside. The adhesion between rail and steel wheel can vary from 25% in good dry conditions to 15% or worse in bad conditions caused by muck spillage, ice, snow, water or oil. Rubber-tyred locomotives can be used to improve adhesion up to 50% in dry conditions or 30% in slippery conditions.

Additional measures should be implemented to prevent accidents on steep or long gradients. Where vehicles 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 braking 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 shown to be necessary by risk assessment, speed-limiting devices should be fitted to trains.

Regular brake tests should be undertaken as part of routine maintenance to confirm the braking efficiency of trains remains above minimum requirements, taking account of maximum payloads and gradients. Details of the tests should be recorded.

A functional test of the brakes should be carried out prior to commencing work on each shift.

The maximum gradient for steel-tyred locomotives should be 6.67% (1:15), and for rubber-tyred locomotives should be 10% (1:10).

23.2.2 Rack and pinion systems

For gradients steeper than the maximum recommended in **23.2.1**, rack and pinion locomotives should be used.

There should be a Manchester gate or similar device to prevent runaways at the top of each track.

23.2.3 Roles for personnel

The practical operating procedures should include appointing personnel to be responsible for the following:

- the selection, training and authorization of drivers;
- the selection and training of vehicle and track maintenance personnel;
- the enforcement of railway operating procedures;
- the recording of track inspections, logging and resolving faults, derailments or incidents and their investigation;
- the regular auditing of maintenance procedures for both track and rolling stock, and keeping maintenance records; and
- specifying and checking the haulage system relative to loads, distances and gradients.

After their training and testing, locomotive drivers and other safety critical personnel should be appointed to their roles in writing by the site management. Each should be issued with a written statement of their duties and responsibilities.

23.2.4 Pedestrian separation

Methods of working should be adopted that prevent persons accessing 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. Except in small-diameter tunnels where lack of space prevents total separation of pedestrians from the train path, pedestrian access via the track should not be permitted.

In tunnels where tunnelling work (e.g. cross passage construction) is being undertaken adjacent to live tracks, there should be a robust physical barrier around the tunnelling worksite. Flashing warning lights should be placed at either end of the worksite.

23.2.5 Driver containment

Locomotives should be provided with driver-containment cabs to mitigate the risk of impact injury to the operators. The cab design should allow reasonable freedom of movement and visibility for the driver. There should be an emergency door or exit hatch on a face of the cab other than that on which the main access door is located. It should be possible for the driver to be able to leave the locomotive when in a section of tunnel where one side is adjacent to the wall and the other blocked by a second stationary train.

NOTE 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 sized to allow clearance for personnel and room to manoeuvre a stretcher past an immobilized locomotive.

23.2.6 Propelling

Propelling (or breasting) of trains should be avoided where possible. A 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**). The driver should not have to lean out of the cab to meet visibility requirements (see **24.1.7**). Visibility aids should be provided to ensure the driver can see the track ahead of the train for a distance at least as great as the train's stopping distance. In addition to headlights on the train, appropriate visibility aids for the driver include CCTV which can be enhanced by infrared capability or other sensing technologies for poor light conditions if necessary.

Where propelling is necessary the additional risks including those to persons, due to poor driver visibility, should be considered and appropriate steps taken to mitigate these risks. Steps should include additional driving positions such as from a man-rider at the rear of the train or driving the train under the control of a signaller who is in a safe position.

In addition to the locomotive lights, the train should be equipped with a flashing amber warning light on the lead vehicle.

Trains being propelled into the backup equipment on a TBM should be under a controlled signalling system. Preference should be given to light signals, particularly those including strings of lights along the length of the backup. The convention of red = stop, green = move inbye and blue = move outbye should be followed. Persons should be kept off the tracks when the train is moving. The default colour should be red with green/blue selected by hold-to-run control.

The driver should move off only after checking that all persons are clear, or safely aboard.

Where locomotives or driving positions are located to both ends of a train, the operating system should ensure that the train is controlled from the lead position only.

23.2.7 Locomotives

23.2.7.1 General

Any self-propelled rail-borne vehicle should be classed as a locomotive. All locomotives should conform to BS EN 1889-2.

The locomotive should not be used if the driver or other person identifies a fault that compromises safe operation.

Locomotives should be inspected and serviced, including brake testing, in accordance with the manufacturer's service schedules, taking due account of any site-specific requirements for more frequent testing. A record of all inspections and servicing should be maintained. A functional brake check should be carried out and the results recorded, by locomotive drivers at the beginning of each shift.

In addition to conforming 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. White lights should be powerful enough to illuminate objects at the full stopping distance of the train.

23.2.7.2 Diesel locomotives – emissions

For emissions purposes, diesel locomotives should be classed as non-road mobile machinery. New build locomotives with engines larger than 56 kW should be Stage V exhaust emission compliant. If older locomotives are used with non-compliant engines, then the tunnel ventilation should be increased to maintain exhaust emissions levels below the limits in Clause **15** and Clause **16**.

NOTE 1 Revised emission standards will be introduced under EU Regulation 1628/2016 [57] for all new non-road mobile machinery including railway locomotives between 1st January 2019 and 1st January 2021.

Old diesel locomotives surplus to requirements on surface railways should not be used in tunnels due to the very high levels of emissions which they normally produce.

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.

*NOTE 2 The storage and handling of diesel fuel can give rise to fire hazards (see **13.1.3**, **13.4** and **15.6.3.8**).*

The fuel system should be robust, and pipework kept clear of hot components as far as possible. Unauthorized repairs or modifications to the system should be prohibited, and vigilant maintenance applied to this area. The engine compartment and fuel tank should be protected by a fire suppression system. There should be a warning on the driver's control panel if the engine compartment exceeds a predetermined safe temperature.

23.2.7.3 Diesel locomotives – fuelling

Fuelling operations should, wherever possible, be undertaken outside the tunnel. Where underground fuelling points are unavoidable, particular attention should be paid to the prevention of overfilling of fuel tanks, fuel spills and leakage from the fuelling system. It should be possible to lock off the fuel supply at both the tank and the nozzle. Where appropriate, refuelling rigs that automatically shut off when the vehicle tank is full should be used.

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. 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.

Local drainage should be passed through oil interceptors to trap fuel spillages. Fire extinguishers appropriate for the type of fuel being used should be located in the vicinity of the fuelling point.

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.

In addition to any automatic fire suppression system required by BS EN 1889-2, a hand-held fire extinguisher containing at least 2 kg of dry powder or CO_2 extinguishant should be fitted in the cab.

23.2.7.4 Battery powered vehicles

*NOTE 1 Safety issues associated with batteries are covered in **24.9.***

Where battery-powered vehicles use lead-acid cells, measures should be implemented to prevent the build-up of hydrogen gas which is highly flammable (see **24.9.1**).

Lead-acid battery powered vehicles such as 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 vehicle. All battery-powered vehicles should be fitted with a switch fuse isolator (lockable), so the fuse will blow in the event of a short circuit.

NOTE 2 There are various emerging battery technologies giving higher power densities such as those based on nickel metal hydride or lithium/lithium ion components which are gaining acceptance for underground use as a means of reducing diesel exhaust emissions.

23.2.7.5 Electric locomotives with external current collection

Electric locomotives with external current collection should only be used during maintenance works in existing railway tunnels.

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The railway operator's rule book and procedures on working in tunnels with live rails or catenaries should be followed. This should include compliance with the railway operator's requirements for staff training and certification when working on the live railway. The railway operator should have oversight of the contractor's operating procedures and should agree to them.

Special precautions should be taken when using locomotives with external current collection from catenary wire, third or fourth 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.

23.2.7.6 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 requirements for the use of equipment in explosive atmospheres are specified in BS EN 60079-10-1 and BS EN 60079-14.

Where the occurrence of methane is foreseeable but predicted concentrations are low, monitors detecting low levels of methane should be fitted to locomotives and should stop locomotive operations when 5% of the LEL of the gas is reached (see **12.5**).

23.2.8 Rolling stock

23.2.8.1 General

All narrow-gauge rail-borne plant used in tunnel construction, including muck cars, material transport (for solid and liquid materials needed for the tunnel build), personnel transport (man-riders) and maintenance vehicles should be operated in accordance with **23.2.8.2** to **23.2.8.8**.

Standard gauge vehicles used in rail tunnels for final construction fit-out, or repairs and maintenance should be operated in accordance with national railway procedures.

23.2.8.2 Muck cars and skips

*COMMENTARY ON **23.2.8.2***

Muck cars are open top boxes usually filled by belt conveyor at the tunnel construction point. In the smallest tunnel, open-ended boxes are used for loading by shovel. Two basic muck discharge systems are generally used, either hoisting the entire skip, sometimes including the wheels, and side discharge at the rail head (outbye end).

Where muck cars or skips are hoisted, they should be designed and used as lifted equipment (see Clause **21**). Periodic examination (and re-testing or after repairs or modification) should take place as for lifting tackle. All muck cars or skips hoisted for discharge should be equipped with sufficient lifting points to allow the load to be lifted in a safe, stable and secure manner.

Muck cars which discharge material at the outbye end (side tippers), should be constructed and maintained so that accidental discharge cannot occur, even with wear or muck build-up.

Purpose-built skips, materials bogies and flat cars should incorporate restraint of the intended load to prevent, for example, a box or stack of segments from sliding off and fouling walkways. Where necessary, ratchet-type load binders should be used to ensure that the load does not vibrate across to an unsafe position.

23.2.8.3 Shuttle cars

*COMMENTARY ON **23.2.8.3***

Shuttle cars with a chain conveyor floor (e.g. Hagglund) are sometimes used for handling drill and blast rock spoil.

Shuttle cars are long wheelbase bogie vehicles, which require a specifically designed track system to accommodate the substantial end throw implicit in the design, hence the track layout should be compatible with the cars. The shuttle car supplier should be consulted before track is acquired.

23.2.8.4 Materials transport

All cars (or bogies) used to transport segments, grout, track, pipes, cables and other production items should be capable of being safely marshalled together, with compatible brakes and couplings. All loads should be secured during travelling to prevent falling off or fouling of walkways or other tunnel fixtures. In most applications ratchet-type load binders should be used to ensure the load does not move. The cars should be inherently stable in transit, and not top heavy. All vehicles should be sufficiently robust to tolerate rough handling at times and have sufficient deadweight to take account of poor track and rough handling, and to resist derailing on turnouts.

Abnormal loads should be checked for side and overhead clearance before entering the tunnel. Abnormal loads overhanging the platform of flat cars should be checked for stability before moving off. Road-going truck mixer drums should be used on flat cars for concrete only after the dynamic stability of the load has been confirmed.

23.2.8.5 Personnel carriers (man-riders)

Personnel should only be transported by rail in purpose designed man-riding cars. These should normally be attached as near as possible to the locomotive, with a safety chain in addition to the main coupling (unless air brakes are fitted). However, on some projects the man-rider is fitted with a secondary locomotive control panel in which case, the man-rider should be attached at the rear of the train for reason of driver visibility.

Man-riders should be fitted with comfortable seats, with containment adequate to prevent personnel coming into contact with objects in the tunnel (typically fully enclosed with sliding doors), and where feasible, a tell-tale device to indicate that the containment is closed. They should be constructed to withstand derailment with minimum injury to passengers. For smooth running and minimum noise, the wheel diameter should be as large as possible. Suspension systems on man-riders should be capable of preventing discomfort, but stable against sway and bounce. The cars should also be ballasted sufficiently to avoid derailment on crossings.

Consideration should be given to fitting an emergency manual air-brake valve or providing a loud audible alarm (such as a portable air horn), in case the occupants need to stop the train.

The noise level in the cars at full speed should not exceed the lower exposure action value of 80 dBA and preferably be significantly below it.

23.2.8.6 Rolling stock–brakes and brake systems

Brakes on rolling stock should be held on by springs or air pressure, and only released by application of power (manual, pneumatic, or hydraulic).

NOTE These are normally termed as failsafe brakes.

Such brakes should be fitted to rolling stock to prevent unintended movements of wagons during marshalling, and runaways downgrade.

Unbraked rolling stock should only be used where a risk assessment shows such vehicles to be safe in an environment.

The possibility of vehicle runaways, particularly during marshalling, and when parked, should be recognised, examined and risk assessed, and suitable control measured designed and implemented.

Hand-propelled vehicles should be fitted with mechanical braking systems using spring-applied brakes which are simple and effective, and suitable for hand tramming, where the operator holds the brake off as part of the pushing action.

Braked rolling stock should have a minimum service braking effort of 12% of unladen weight.

Hydraulic braking systems should be used in conjunction with accumulators or spring packs, where braking energy is stored mechanically.

23.2.8.7 Rolling stock – air brakes

Apart from locomotives and rolling stock fitted with UIC compliant braking systems (usually on permanent operational railways), the following recommendations should be followed.

a) The locomotive should be able to sustain three consecutive full brake applications with the maximum train formation. This will require sufficient air reservoir and air compressor capacity to avoid an unacceptable loss of air pressure. The locomotive manufacturer should state the reservoir capacity and pressure in the operating manual to allow the permissible train weight to be calculated.

b) The service brake (train line) pressure should be 0 bar-6 bar, where 0 bar is brakes fully on, (i.e. failsafe), and 6 bar is brakes fully released.

c) The emergency brake (main reservoir) should be set at 8 bar minimum.

d) The differential pressure between the service brake line and the emergency brake line should be at least 1 bar.

e) The minimum brake pipe size should be 12 mm (1/2”) dia. nominal bore.

f) With two-line air-braked stock, the reservoir pressure on each wagon should be sufficient to hold the brakes on while uncoupled.

23.2.8.8 Maintenance and inspection

All rolling stock should be subject to an ongoing maintenance regime, initially based on the manufacturer's recommendations, but possibly modified during use to reflect site conditions and experience. Where the working environment is particularly harsh, such as wet tunnels, salt water ingress, abrasive muck, etc., maintenance should be increased to suit, and to ensure continued safe operation.

Apart from locomotives and rolling stock fitted with UIC-compliant braking systems, where air braking systems are fitted the following standards should apply, in accordance with international practice.

23.2.9 Couplings and buffers

The use of traditional “loose-link” or rigid bar (with slotted or circular holes) couplings should be restricted to the simplest railway systems in small diameter tunnels. It should be noted that the slack inherent in loose link couplings, and bar type with slotted holes, can give rise to difficulties in train marshalling, moving cars into the TBM back up system, and particularly when loading muck cars from a conveyor belt. Otherwise proprietary self-latching couplers which largely eliminate these issues should be used.

Latching couplings can uncouple in service if damaged or contaminated with dirt. A visual indicator should be incorporated to allow marshalling staff to verify the security of each coupling as it is made.

All coupling types used should allow for free-running while breasting (propelling) the train, with the couplings in compression, without jamming, catching, or uncoupling while running through ramps with sudden change of gradient, and crossings with abrupt swings**.**

NOTE 1 This might necessitate the use of slotted coupling bars.

All loose vertical coupling pins should be designed to avoid the possibility of the pin riding up and disengaging, e.g. by adequate weight and length. Pins and coupling bars should be capable of prolonged use without excessive wear.

NOTE 2 Correct sizing of the components, and selection of hard wearing material is important.

Renewable wear bushes should be considered. Tunnel bolts and jigger points should not be used as coupling pins.

The matching of different types of rolling stock, such as muck car, man-rider, grout car, segment carrier, should ensure compatible “end throw” (offset on curves), to prevent derailments on crossings and ramps.

NOTE 3 Some vehicles require semi-permanently attached bar type couplings to allow this.

Couplings and safety chains should be rated to suit the maximum train tractive effort (i.e. the most powerful locomotive) plus a 50% “snatch” factor.

Secondary couplings or safety chains should always be used with unbraked vehicles.

Measures should be implemented to ensure that coupling and uncoupling activities are carried out as safely as possible, wherever practicable avoiding the need for operatives to be placed between vehicles. Safe systems of work should be produced which give clear guidance on the precautions to be taken to prevent hand crush injuries or striking personnel.

All couplings should be subject to an inspection and maintenance regime to detect excessive wear, bending, or overloading. Damaged couplings should be replaced as soon as they have been identified.

The layout of the track system, including minimum radii on turnouts and in marshalling areas, ramp vertical curve transitions, and type and quality of rail, should be compatible with the rolling stock system and coupling arrangements used. The rolling stock suppliers should be involved in specifying the track for compatibility with the train systems intended.

Buffers should be sized to prevent adjacent items of rolling stock becoming locked on turnouts crossings, curves, etc.

23.3 Conveyors

23.3.1 Belt conveyors

A belt conveyor can significantly reduce the size and/or frequency of traffic movements in a tunnel, but precautions should be taken when used in the confined space of the tunnel, to address hazards to persons working alongside it or undertaking maintenance at height. Belt conveyors including the main in-tunnel conveyors should be guarded in accordance with normal conveyor guarding practice unless the conveyor is "safe by position" in which case guarding is not required.

All moving parts, including return idlers which are accessible from any walkway below the gantry on small TBMs, chains, sprockets, gears, tensioners, belts and in-running nips and pinch points between the conveyor belt and the drum, should be guarded. Where the conveyor is accessible from a walkway, workstation or similar, emergency stop pull cords should be provided or other measures necessary taken to minimize the risk to persons working within the vicinity of the conveyor. Guarding and other protective measures should conform to BS EN 618 and BS EN 620 which specify requirements for conveyor safety.

When maintenance is being undertaken on a section of the conveyor, it should be possible to lock off all power to that conveyor.

It should be possible at all intermediate drive stations to lock off all power to the conveyor while maintenance is undertaken.

Emergency stops and pull cords should be inspected and tested regularly and maintained in serviceable condition. A record of the inspection and tests should be kept.

Starting of the conveyor should only be possible from a single position. The operator should ensure it is safe to start the conveyor. An audible signal should be given automatically, and a safe interval allowed to elapse before start-up.

NOTE BS EN 16191 specifies requirements for audible signals.

Fire-resistant belting conforming to BS EN ISO 340, Class A should be used wherever conveyors are used underground.

All motors on conveyors should include protection against muck/dust accumulation leading to over-heating. Fire prevention measures should be implemented (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.

The conveyor should be sized to carry the maximum rate of spoil removal required for compatibility with the output of the TBM. Belts should have sufficiently high sides to prevent spoil spillage on straights or bends. Oversize material should be prevented from travelling up conveyors by means of a gating device.

The conveyor manufacturer should advise on the starting and stopping of fully loaded conveyors on inclines. Steeply inclined conveyors, other than short lengths, should be fitted with anti-runback devices to prevent the belt running backwards in the event of a belt or power failure.

Man-riding should not be permitted on a conveyor. Use of a stationary conveyor for access, such as to the TBM cutter head, should only be undertaken under full lock out access procedures in accordance with the TBM manufacturer's instructions.

When dry spoil is being handled and dust presents a problem, effective dust control measures should be implemented (see Clause **16**).

To ensure safe use, a thorough inspection of the conveyor should be undertaken at least once each working shift. Maintenance, including replacement of worn or damaged parts, should be undertaken expeditiously.

The build-up of spoil on belts and rollers should be controlled as this is likely to result in spillage and motor overloading. Maintenance, including 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.

A risk assessment should be undertaken to confirm the number of fire extinguishers required to be located at intervals along the length of the conveyor.

The area on the TBM where the conveyor support equipment is installed, and where work is undertaken between the belts, presents a range of guarding difficulties which should be addressed (see BS EN 16191).

The audible pre-start warning should be audible for the full length of the conveyor where it is not safe by position, as required by PUWER.

23.3.2 Conveyor support structures

As a minimum the support structure should remain functional with any two adjacent anchorages inoperative. The conveyor should be designed to carry the maximum design output of the TBM with a suitable margin for overload and any foreseeable surcharge that could occur from a blockage.

All conveyor support structures should be subject to a periodic inspection programme. The designer of the conveyor support system should specify the testing required and the frequency of testing necessary to ensure that the anchorage system supporting the conveyor has sufficient capacity to support a fully loaded conveyor.

Where a conveyor passes over live roads, railways or other publicly accessible locations, the support structure should be subject to a category 3 design check.

An integral maintenance and inspection walkway as part of the support structure to facilitate maintenance should be provided where necessary.

A structure enclosing the conveyor to reduce dust and noise emission should be provided as necessary.

23.3.3 Belt weighers

NOTE The use of conveyors for removal of spoil from TBM tunnels provides no physical evidence that over-excavation has occurred. Over excavation can lead to excess settlement or collapse.

Calibrated belt weighers should be fitted to the TBM conveyor prior to discharge onto the main tunnel conveyor to inform the reconciliation of the amount of spoil removed, the volumetric advance and the amount of grout injected to identify the risk of voids being left in the ground.

The accuracy required of the belt weighers should be determined by the user of the TBM, taking account of the degree of control on face loss required.

Calibration, maintenance and cleaning of the belt weighers should be carried out in accordance with the manufacturer's instructions. Any guards around the belt weighers should be designed to facilitate their operation.

Additional spoil/advance reconciliation methods should also be implemented where ground settlement could be safety critical.

23.3.4 Vertical and sub-vertical conveyors

When spoil is transported out of the tunnel by conveyor, consideration should be given to the use of a vertical or sub-vertical conveyor for spoil handling in the pit bottom or shaft, thus reducing the number of lifting operations required.

Conveyors should be designed and constructed to contain the material on them and not allow material being transported to fall into the shaft. Advice should be sought from the conveyer supplier about cleaning and maintenance requirements in shafts, and provision should be made for safe access and maintenance compatible with a safe system of work.

23.4 Slurry transport systems

23.4.1 System components

COMMENTARY ON ***23.4.1***

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 ***7.5****). The fluid can be water, or a water-based slurry with additives to improve its performance as a spoil transport medium.*

Slurry transport systems should be used where appropriate to reduce the frequency of traffic movements in tunnels and the train size. The technique is particularly suited to use in small non-man entry tunnels and pipe jacks.

The slurry system should comprise as a minimum:

a) a mixer which will mix the components of the slurry;

b) an injection device to inject the slurry into the tunnelling machine;

c) a discharge pump to pump the slurry from the machine;

d) pipework to deliver the slurry to the point of discharge; and

e) a separation plant to separate the spoil from the slurry, sized to be compatible with TBM advance rates.

All power supplies to mixing and slurry plant should be subject to the recommendations of Clause **25** for remotely operated mechanical plant.

NOTE Attention is drawn to The Control of Substances Hazardous to Health Regulations 2002 [36] when handling bentonite and other hazardous chemical additives

23.4.2 Operating procedures

NOTE 1 High slurry 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 high pressure on the face of the TBM could present a hazard to those engaged in lining erection 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.

Good housekeeping procedures should be implemented to contain and remove slurry spillage, to prevent slipping accidents and facilities becoming untidy and contaminated.

23.4.3 Mixing and separation plant

Mechanical mixing systems should be established in order to avoid any manual contact with moving parts.

The mixing and separation plant consists of a range of storage tanks, holding tanks and settling tanks, along with cyclones, filters and presses, all of which should be considered an integral part of the tunnelling process, and which are hazardous in some way. Health and safety should be as much a part of the design, construction and operation of the plant as of the TBM or pipe jacking operation. Whilst separation plants for pipe jacking operations can be compact and containerized, the separation plants for major tunnel projects are substantial fluid treatment installations which by their nature require relatively complex control systems for their safe operation. There should be appropriate control system integration along with communication between those controlling the slurry plant and those operating the TBM.

All mechanical plant should be guarded to prevent impact and crushing injuries. Procedures should be in place for the safe maintenance of the plant. All maintenance and adjustments should be carried out in accordance with the manufacturer’s instructions.

Tanks and the walkways around them should be guarded to prevent falls into the tanks or the tanks covered by gratings. Lifebelts and throwing lines should be available around the tank and an emergency plan should be in place for rescuing persons from the tank. Where lagoons are employed, they should be adequate fenced to prevent access with warning signs identifying the depth of the lagoon and the nature of the contents.

Tank covers should be provided where necessary to minimize splashing. Any spillage should be cleaned up to avoid contaminating working areas. Appropriate spill kits should be available near to any area where there is the potential for a spillage. First-aid kits including eye wash equipment should be provided on the plant.

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.

Vibrating screens should have mountings which prevent the transmission of vibration to other parts of the plant.

23.4.4 Chemical storage

The chemicals used in slurry plants, particularly in bulk concentrated form, can be hazardous and safe systems of work should be developed to handle them from initial delivery on site to storage and their use in the mixing plant.

Plans, equipment and materials for dealing with foreseeable chemical emergencies should be immediately available.

23.4.5 Slurry pumping system

The design of slurry systems should allow for high pumping pressures and surges, along with movement in connections between pipework and pumps.

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 can be generated in use and whether this is likely to require special attention.

In the tunnel, pumps should not normally be located in confined spaces or in spaces where entry of personnel is forbidden. Exceptionally, if they are, special procedures should be in place 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 and depressurize/empty the line before maintenance work commences.

Where power cables to the pump have to be regularly connected and disconnected for the purpose of pipe installation, such as in pipe jacking, the recommendations of **25.5** should be followed.

23.4.6 The piping network

The slurry pipework, whether flexible or rigid, should be able to withstand the maximum pressure in the system, including foreseeable transient pressure surges. Advice on maximum pressure should be sought from the TBM supplier. All slurry pipework should be inspected prior to use to confirm its suitability for use.

The pipe wall thickness, particularly at bends, should be sufficient to allow for abrasive wear from the spoil transported, taking into account the abrasivity of the spoil and the project duration. An inspection and maintenance regime should be set up to monitor pipe wall thickness, especially at bends. Spare bends should be carried in stock where necessary. Straight sections of pipe should be rotated by 120° or 180° as wear occurs.

Shouldered pipes should be quality controlled to ensure that the welding of the pipe end rings is adequate to resist surge loading which could cause the ring to blow off. Grooved pipe ends for couplings should not be used as they can fail prematurely through wear.

All flexible hoses on the TBM and at the pit bottom on pipe jacking systems, should be subject to an inspection and maintenance regime to identify any age deterioration, internal and external wear, kinking, and other mechanical damage. Pre-used hoses should in addition be water pressure tested before being used on a project. Hoses should be positioned and restrained not to cause injury if they burst.

Valves should be provided at regular intervals to allow the line to be shut off in the event of a spill, etc. Valves should be positioned so as not to create obstructions to access. The valves should be readily accessible, clearly marked and show whether they are open or closed. In non-man-entry small diameter tunnels and pipe jacks, in-line valves in the pipestring should not be used and alternative means of controlling flow should be used.

Valves within the system, whether manually or power-operated, should be selected to close at a sufficiently slow rate to avoid pressure surges (hydraulic hammer) which could lead to pipe or coupling failure. Advice should be sought from the suppliers of the TBM and separation plant about the number and type of valves required.

Where telescopic slurry pipes are used, they should be capable of withstanding the maximum anticipated surge loads. Telescoping pipes should be restrained against excessive movement.

Anchorages should be provided to resist normal thrust forces at bends, etc., as well as surge loading when valves are opened and closed and not cause detriment to the permanent works.

Pipe support systems in the tunnel should be sufficiently robust to allow for misalignment in some brackets or anchors not carrying the load, through misplacing, or rolled tunnel linings. Pipe support brackets should be designed to carry at least twice their theoretical load. A representative sample of supports should be load tested.

The support systems for pipes and pipe clusters (by-passes typically) in tunnel shafts should be robust, and periodically inspected to ensure continued security in use.

Where slurry booster pumps operate in series in the system, there should be a pressure sensing and relief system linked to the pump controls to avoid excessive pressure build up within the system in the event of a blockage.

Where pipes are extended behind a TBM, there should be an effective slurry drain-down procedure which is fast enough to avoid production delays, thus avoiding the incentive to rush the work. The spill system should be able to cope with the maximum planned volume of slurry to be dumped without being overwhelmed. In addition, procedures should be put in place to ensure that before

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pipes are uncoupled, it is possible to verify that all pumps have been isolated, valves have been closed as required, and that the relevant section of pipe has been depressurized.

23.4.7 Intervention procedures – slurry TBMs

A TBM with man-entry facilities to a normally flooded slurry chamber should have extensively documented procedures for safe interventions in the slurry chamber. Compressed air should normally be used to maintain face stability (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 and any appreciable change in air loss investigated as this could indicate incipient failure.

d) If conditions appear unfavourable, the crew should be withdrawn and the chamber reflooded.

e) Whilst fall prevention and access to and around the slurry chamber is primarily covered in BS EN 16191, 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.

g) Monitoring of the slurry chamber should be undertaken.

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.

23.5 Personal protective equipment

Personal protective equipment should include masks, goggles and gloves and, where necessary, protective overalls.

NOTE More severe consequences can arise from contact with the concentrated chemicals rather than with the slurry.

Any site on which slurry is being used should have facilities that incorporate, as a minimum, eyewash facilities, and fluids for cleaning both skin and eyes if contaminated with slurry. These facilities should be located at the mixing plant and on the TBM as a minimum.

23.6 Other haulage methods

23.6.1 Vehicle haulage

Where spoil is removed by rubber-tyred or tracked vehicles, a safe system of work such as that recommended in in **24.1.1** should be implemented. This should address traffic movement and control, loading, reversing of vehicles, turning of vehicles, lighting, signage and pedestrian separation. Only vehicles specifically intended for use underground and conforming to BS EN ISO 19296 and recommended in Clause **24** should be used.

Unless the natural invert material is stable under traffic, imported granular material should be used to form a safe running invert surface. Regular maintenance of the invert, including grading and compaction, should be undertaken. On gradients and in wet conditions a concrete invert slab should be placed as tunnel excavation proceeds.

Poor invert conditions place additional demands on vehicle suspension, braking and steering systems which should be factored into planned maintenance schedules.

23.6.2 Winch haulage

Where winch haulage is undertaken, such as on steep gradients or in small diameter hand excavated tunnels, precautions should be taken to ensure the design and construction of the anchorage for the winches is sufficient as are means to control the ropes and the system for checking the brake operation of the winch.

*NOTE See **21.3** for further recommendations for winches.*

23.6.3 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 be checked regularly to prevent uneven wear or misaligned wheels causing a trolley or skip to ride up the side of the pipe and overturn. Defective components should be replaced as soon as they are identified.

Personnel should be prevented from entering an area while tyred skips or trolleys are being moved by winch.

23.7 Adits and inclines

The recommendations in **8.5.2, 20.11** and **20.12** should be followed.

23.8 Storage and disposal of excavated material

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 to ensure tip stability in the siting and formation of the tip, 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 adequate traction and stability of haulage and tipping vehicles. Safe tipping practices such as the use of “stops” to prevent overrun of haulage vehicles or earthmoving machinery to move tipped material should be adopted.

Dust control measures (see Clause **16**) should be put in place during the tipping or 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

*COMMENTARY ON CLAUSE **24***

*This clause covers the use of plant other than rail plant, conveyors or slurry systems which are covered in Clause **23**.*

24.1 General

24.1.1 Safe system of work

A safe system of work should be prepared which should include the layout of traffic routes, pedestrian separation, control of vehicle and material movements, vehicle maintenance, operator competence and clear signage and notices underground.

When several vehicles are in use, the control of movements should be the duty of supervisory personnel underground, each of whom should be in charge of a defined section of the works.

24.1.2 Fire suppression

Mobile plant, such as excavators, shotcrete robots or dumpers, and any major static plant underground, such as compressors or generators, should be fitted with fixed fire suppression systems as set out in **13.3.3**.

24.1.3 Static plant

Static plant used underground should be electrically-powered whenever possible. If diesel-powered, it should normally be located down wind of any operatives.

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.

24.1.4 Underground use

NOTE 1 Due to the confined space in a tunnel, when a plant-related hazard occurs, the severity of outcome is likely to be greater.

NOTE 2 Due to hazards specific to work in the underground environment, plant and equipment intended for use in surface construction might be unsuitable in the confines of a tunnel or other enclosed space without modification.

All plant and equipment intended for surface use should be assessed and, if required, modified appropriately before being taken underground. Hazards which should be addressed include fire, impact with tunnel walls, atmospheric contamination, restricted visibility, exhaust emissions, electric power supply and lifting of the plant.

NOTE 3 Typical machinery to which this applies includes earthmoving machinery, multi-service vehicles, load haul dumpers, drill jumbos, face charging vehicles, continuous rock loaders, MEWPs, concrete truck mixers, shotcrete robots, dumpers, compressors, and generators.

NOTE 4 Whilst BS EN 1889-1:2011 and BS EN 474-1:2006+A5:2018, Annex D contain generic requirements for mitigating a number of the hazards of operating machinery in the underground environment, both standards are likely to be superseded during the lifetime of this standard by BS EN ISO 19296 and other standards.

In the absence of machine specific standards for underground use the requirements of BS EN ISO 19296 should be applied to plant and equipment used underground as far as is reasonably practicable.

24.1.5 Hired plant

Particular attention should be paid to ensuring that hired plant meets the recommendations in **24.1**.

Tunnelling contractors should ensure that staff who negotiate plant hire contracts or hire individual items of plant have knowledge of the many safety recommendations for the safety of machinery and plant to be used underground in of this standard. Only machinery and plant meeting these requirements should be hired.

24.1.6 Operator competence

Operators/drivers should have site-specific training, carry a valid certificate authorizing them to drive specific vehicle(s) and should be certified medically fit.

24.1.7 Visibility aids

NOTE Requirements for operator visibility are normally set out in the CEN standards for individual types of machine. Collision avoidance systems are currently being considered by ISO/TC127.

Active camera systems, which provide a warning when an object resembling a person is detected in the field of view, and obstruction identification systems should be used as visibility aids in preference to passive systems to reduce the risk of vehicle impact events. Systems should cover the rear of vehicles and along the blind side.

The protected area should be checked before use of the vehicle to ensure there are no “blind spots”.

Reflective plates or tape should be applied to vehicles to make them more visible when parked underground.

24.1.8 Cabs

NOTE Cabs on underground plant provide a means of reducing exposure to physical hazards of the tunnel environment including impact, dust, noise and adverse temperatures without the use of PPE. Cab seats are designed to protect against whole body vibration. Cabs also offer falling object, rollover and tip-over protection (FOPS/ROPS/TOPS).

Appropriately designed, constructed and maintained cabs should be provided on plant where necessary to mitigate risk from impact, dust, noise, adverse temperature and vibration without the need for PPE.

24.1.9 Driver restraint

NOTE The need for driver restraint is normally set out in the relevant machinery safety standards. On some machines an audible alarm sounds when the operator is seated and the belt not fastened. To counter this, operators sometimes fasten the belt behind the seat.

The primary means of preventing a machine operator from falling out the cab of a machine when in motion should be a cab door. An alarm should sound if the machine is moving without the door being shut.

24.1.10 Isolation of power

Before attempting any work on powered machinery, the power source should 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.

Where equipment is isolated at its place of use (rather than in a repair workshop), it should be clearly marked/tagged to inform all personnel that it cannot be used.

NOTE Isolation devices can include lock-out padlocks, locking bars, or removal of vital components. Plant manuals should prominently highlight isolation procedures.

24.2 Separation of vehicles and pedestrians

Measures should be put in place to segregate and protect pedestrians from vehicular traffic.

Clearances from people and objects should take account of steering tolerances and spragging capability.

Planning of operations should include consultation with the suppliers. Vehicles should not be employed on gradients steeper than 12.5% unless they have been specifically designed as suitable for that purpose. Where fitted, the parking brake should be capable of holding a vehicle, plus a possible coupled load, on a 12.5% gradient.

Level loading areas should be provided and discharging should be on level ground, with kerbs to locate the wheels and a stop barrier provided where a drop occurs.

Traffic signing underground should be similar to that used on the surface

Aids such as convex mirrors should be provided to improve visibility at tunnel intersections.

24.3 Rubber-tyred free-steered vehicles

Rubber-tyred vehicles including road going vehicles and surface construction vehicles should be safe for use underground (see **24.1**).

Vehicles should not be operated underground without confirmation that they are capable of operating in the prevailing ground conditions and on the tunnel gradients, taking account of the loads to be transported.

Each vehicle should be provided with the following equipment, functional at all times:

- a horn or similar audible warning device;
- two white front headlights visible at 60 m;
- two red rear lights visible at 60 m;
- braking system conforming to the machine-specific EN machinery standard;
- sprays or jets for cleaning windscreens if fitted;
- vehicles should be fitted with visual and/or audible reversing warning systems;

- measures to prevent persons coming into contact with vehicle wheels; and
- the white/red lights on vehicles which routinely travel forwards and backwards such as dumpers should change colour automatically to indicate direction of travel.

24.4 Crawler tracked plant

Crawler-tracked vehicles should be used for excavation and loading operations where rubber-tyred vehicles are unsuitable, such as on rocky inverts or if the invert conditions are soft and where there could be stability risks for rubber-tyred vehicles.

The same general recommendations as for rubber-tyred vehicles (see **24.1** and **24.3**) should be applied to the construction, use and control of crawler-tracked vehicles.

The ability of a crawler vehicle to “sprag”, i.e. lock one track to turn the machine on the spot, should be taken into account when controlling pedestrian access, as standing next to a working crawler poses the risk of being knocked or trapped as the tracks skid sideways. As a general rule, protection measures should be used to segregate personnel from works areas where crawler vehicles are in use.

24.5 Pneumatically-powered plant and equipment

NOTE 1 Pneumatically-powered plant includes vacuum plant.

NOTE 2 Air supply hoses and couplings are a hazard if they disconnect while in use, due to the whiplash effect caused by escaping air.

Hose restraint bonds should be fitted at every coupling point for all hoses 19 mm or greater. Hoses should be routed clear of possible impact or crushing damage, and workshops where portable air tools are in use should be kept clear of debris and obstructions. Regular safety inspections should be made of the hoses, and damaged hoses should be withdrawn. The correct matching of hose, hose tail and clamps should be made to ensure that hose does not blow off or leak in use.

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 do 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 close to the plant, to minimize exhaust mist and avoid freezing up of the exhaust. In cold weather it might be necessary to use an antifreeze agent in the lubricator bottle to avoid total freezing up.

Vacuum lifting plant used for handling segments should conform to BS EN 16191.

24.6 Hydraulically operated plant or equipment

NOTE This includes the parts of machinery operated by hydraulic power.

The following precautions should all be taken as far as practicable.

- Hoses should conform to BS EN ISO 8030.
- Fire resistant (BS EN ISO 6743-4 classification HFDU) bio-degradable fluids should be used in hydraulic systems. If exemption is sought for plant due to incompatibility of seals for instance, it should only be permitted after stringent analysis of the increased fire risk, and might only be permitted for short term use of small plant coupled with the application of stringent fire suppression requirements.
- Effective oil coolers should be incorporated to maintain oil temperatures below 70 °C. Temperature switches should automatically shut down overheated circuits.
- 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 with components of the same specification.

24.7 Electrically-powered plant and equipment

The use of electrically-powered plant and equipment should be used where appropriate as a means of eliminating exhaust emissions.

NOTE The major disadvantage of electrically-powered machinery is the need to provide a power supply through a trailing cable to the machine, the impact on mobility and the safety risk associated with trailing cables. Dual-powered machines with a diesel engine for travelling and electric motors for working have long been used to overcome this problem.

Mobile electrically-powered machinery should conform to BS EN 12111:2014**, 5.82** and **5.8.5.2**. Trailing cables should conform to **25.8** and **25.10**.

Care should be taken to prevent electrically-powered machinery from running over their own supply cable, as the sharp track edges can easily cut through cable insulation. Self-reeling cable drums should be employed wherever possible.

However, with advances in battery performance, battery power for travelling or even for working should be considered. Batteries and battery charging should comply with **24.9**.

24.8 Internal combustion engines

24.8.1 Diesel engines

NOTE Revised emission standards will be introduced under EU Regulation 1628/2016 [57] for all new non-road mobile machinery including railway locomotives between 1st January 2019 and 1st January 2021.

The guidance in **23.2.8.2** for emissions, fuel systems and fuelling procedures should be applied to diesel-engined mobile plant and equipment.

Ultra-low emission specialist fuels are now becoming available and should be used where appropriate for diesel engines, to reduce emissions at source and lower demand for ventilation air flow, with savings in energy costs. Suitable particulate filters should be fitted to older engines and engines should be well-maintained.

24.8.2 Petrol engines

Petrol engines should not be used underground except in an emergency when no alternative is practicable, due to the high fire risk with low flashpoint fuel, and the high concentration of carbon monoxide in the exhaust.

Emergency services should be made aware of these issues when planning emergency procedures and should have their own protocols for mitigating these risks.

24.9 Battery power

24.9.1 Lead acid batteries

An area should be designated for the safe charging of batteries that is well ventilated to disperse any hydrogen given off during charging. There should be a supply of clean water along with an eye wash kit to wash off spilt electrolyte.

Either the lids on battery boxes should be vented, or if unvented, the lids should be lifted during charging to prevent the accumulation of hydrogen within the box.

Naked flames and hot work should not be permitted within 10 m of the charging point.

All lighting should be suitably zone rated and suitable for hydrogen.

The correct type of charger should be used for each battery to prevent heating and possible explosion of cells. Defective chargers should be repaired by an electrician as soon as a fault is identified.

Reference should be made to BS EN IEC 62485-1 and HSE publication INDG139 [58] for guidance on battery charging installations.

Appropriate firefighting equipment should be provided close to the charging point.

24.9.2 Lithium batteries

NOTE 1 Battery technology and in particular lithium battery technology is rapidly developing. The term "lithium-ion batteries (LIBs)" covers a number of high energy density cell types based on the combination of lithium compounds with other compounds. The cathode can comprise a variety of metal oxides, such as nickel, cobalt, aluminium, manganese, iron oxide or titanate. The electrolyte is a mixture of lithium salt and organic solvents in liquid or gel form.

High energy density batteries should be used where the energy storage capacity is critical, taking into account that LIBs can overheat either from an external heat source, or high current events in use, in both charging and discharging mode, and individual cell overheat temperatures can cause thermal runaway, where adjacent cells progressively fail. It should particularly be noted that any of these faults can ultimately lead to explosion and very intense fire, with the release of toxic smoke.

Consequently, LIBs should only be used underground where a battery management system (BMS) controls the battery operation. The BMS should monitor individual cells and should be able to shut down the battery in the event of overheating or other malfunction with a cooling system provided if required. LIBs should be contained within strong enclosures to minimize the possibility of mechanical damage and help to contain possible fire and explosion.

Appropriate firefighting equipment covering the battery pack should be fitted to any vehicle powered by LIBs.

An appropriate hazard symbol ADR, class 9a should be affixed to any vehicles with a LIB power source.

NOTE 2 See the Global Mining Standards and Guidelines Group publication for Battery Electric Vehicles in Underground Mining, http://www.globalminingstandards.org,) for further information.

24.10 Concreting plant

24.10.1 Concrete pumping

Pumping should be carried out in accordance with BS 8467. Concrete delivery pipes should be installed and maintained to the pump manufacturers' guidelines.

The pipeline when 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. Pipes can move with the pump strokes, so account should be taken of reaction forces which are generated at every bend. Fixed delivery lines should be restrained against movement due to pressure surges.

Pump lines should be cleaned by pumping water through them. Compressed air should only be used where there is no practical alternative (see **24.10.3**). The cleaning ball or sponge should be caught in a suitable 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. Metric and imperial pipes and fittings, as well as pipes and fittings from different manufacturers, can appear similar but are not interchangeable hence should be kept separate. Over centre lever type couplings should be locked with clips or pins.

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.

24.10.2 Shotcreting

*COMMENTARY ON **24.10.2***

Shotcreting systems generally comprise:

- *surface mixing and batching plant (possibly off site);*
- *a means of delivery of material from the surface to the underground worksite which can be by pumping or by vehicular transport;*
- *delivery pump at the work site; and*

- *hose and application nozzle – either hand held for small works, or more generally mounted on a manipulator arm with remote operator control. Larger machines have the pump and manipulator arm combined on one chassis.*

NOTE 1 BS EN 12001 does not currently apply to shotcrete robots underground though this is expected to change with the revision of that standard which is currently underway.

Wet delivery systems should be used wherever practical.

Ventilation of shotcreting worksites should remove the airborne dust. Provision should be made during ventilation planning for dust extraction (see also Clause **15** for ventilation).

All operations in the production cycle, from mixing and handling to pumping and application, should be covered by thorough operator training especially as the material is caustic, and high pressures are often involved. Thorough plant cleaning out and washing through delivery lines are essential to keep the plant safe and reliable, and wash-out areas or containers should be provided.

The pressure rating of pipework, hoses, couplings, etc., should be compatible with the maximum pump output pressure. Regular inspection of all components on the delivery side of the pump (including the pump itself) should be undertaken to monitor wear and damage.

NOTE 2 Steel bends, and flexible hoses are particularly vulnerable to wear and damage, and some aggregate mixes are highly abrasive and cause rapid wear.

*NOTE 3 For guidance on safe practice in using the pump and pipework, covering preparation, pre-lubrication of the pipes, through to final water wash-outs, reference see BS 8467 and **24.10.1**.*

Individual manufacturers procedures should also be followed.

Shotcrete pumps should be fitted with an auto shut-down device to detect excessive pressure when a blockage occurs. Reverse pumping should still be possible to relieve the pressure before dismantling the system.

The flow of accelerator additive to the nozzle should be as constant as possible and should be monitored to prevent the application of an un-accelerated mix, with possible serious consequences. The flow monitor should be linked to a shutdown device to stop work immediately.

Load-holding valves should be fitted to critical nozzle manipulator cylinders to prevent personnel injury in the event of hose failure.

Emergency stop systems should be linked to ensure that pump and nozzle manipulator (robot) are stopped together. The pump hopper lid shutdown interlock should be functional at all times.

The site management system should monitor and record the correct maintenance of all shotcreting plant.

Care should be taken when moving mobile plant to avoid overturning. Movements on inclines or very uneven ground should be planned, and suppliers consulted if in doubt.

Portable plant should incorporate fork slots and/or lifting eyes for safe relocation as the work progresses.

Where stabilizers are fitted to robots they should always be used.

24.10.3 Cleaning pumping lines

NOTE A number of major injury incidents have occurred in tunnelling from the explosive release of pressure during clean out operations on concrete and shotcrete lines using compressed air.

Cleaning pump lines should be carried out in accordance with **24.10.1**.

24.11 Water drainage pumps

Reliability of the drainage system, and adequacy of pumps and their power supply, should be considered critical for the safety of personnel where flooding could occur.

Duplicate pumps and pipework should be used where necessary, along with an independent back-up power supply and 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.

24.12 Drilling and piling rigs

24.12.1 General

Drilling and piling rigs used in any operation associated with tunnel construction should conform to BS EN 16228 or ISO 18758-2 as appropriate.

NOTE Typical drilling equipment in tunnels includes:

- *"jumbo" for blast hole drilling or rock bolting;*
- *drill mounted on TBM for probing or bolting;*
- *geotechnical drilling rigs taken into to the tunnel;*
- *drill mast attachments on 360° excavators;*
- *hand-held drilling equipment for blast hole drilling bolting, etc.; and*
- *spiling/face bolting rigs.*

24.12.2 Operation

The operation of drilling or piling rigs and their ancillary equipment should be carried out in accordance with established safe working practices, including as appropriate the following:

- *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 manufacturer's handbook.

24.12.3 Specific recommendations for drill rigs

The rig and in-hole equipment selected for a specific operation should be suitable for its intended use and the working environment.

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, vibration and dust emissions should be a factor in selecting the drilling equipment.

24.13 Grouting equipment

Fixed grout mixing plant should be set up with ventilation in place to deal with dust. Where manual bag splitting is required, extraction ventilation should be installed where necessary to protect personnel from dust inhalation together with suitable PPE. Skin contact with caustic cementitious products should be avoided by the use of correct PPE.

Grout mixing machines should be guarded so that rotating parts are not exposed. Interlocks should be incorporated to isolate the power source before guards are removed for cleaning.

Grout pumps should be selected to be appropriate for the duty intended. The pressure performance should be matched to the delivery requirement, particularly taking account of the

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location of the delivered grout. Tunnel and shaft linings, and structures such as headwalls, should have a design maximum permissible grout pressure. Grout pressure should be monitored as close as practicable to the injection point. The operative at the injection point should be able to stop injection when the safe limit is reached. Secondary grouting, and one-off grouting operations should have adequate control measures and be set up using the most appropriate type of pump.

NOTE The potential pressure of some piston pumps is very high (100 bars).

All hoses, pipe fittings and injection nozzles (grout guns) should be matched to the maximum pressure rating of the pump. All grouting equipment should be regularly inspected and maintained with any grout build-up regularly removed. Care should be taken as high-pressure grout blow-outs can cause serious injuries. Where the operator of the grout pump cannot see the point of delivery in the works, an effective means of communication should be in place between the operator and the point of delivery.

Whip restraint wire loops should be provided for both the feed air and the grout transfer hoses.

Potential hazards arising from the use of grouting equipment such as the following should be addressed:

- bursting of the grout feed hose through damage, inadequate maintenance or improper connection, or solidification of the grout, with care taken in grout mix design to avoid segregation which could lead to blockages. 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, with a stop valve installed where necessary to retain the grout until it has set; and
- damage to lining or to surface installations due to excessive pressure.

24.14 Earthmoving plant

Earth moving plant used underground should conform to the EN 474 series standards and BS EN ISO 19296. Requirements in BS EN ISO 19296 should take precedence.

NOTE BS EN ISO 19296 supersedes the requirements of BS EN 494-1, Annex F.

24.15 MEWPs

MEWPs used underground should be suitable for use in the underground environment envisaged. Purpose built MEWPs for use in the underground environment, including those complying with ISO 19296, should be used if available.

MEWPs intended for surface use should be checked for suitability before being brought underground. In particular, their stability when operating on rough or uneven surfaces such as tunnel inverts should be confirmed, along with their ability to resist impact with tunnel walls etc.

MEWPs used underground should have secondary guarding fitted to the platform to protect those on the platform from impact with the tunnel crown. The guarding should conform with IPAF guidance UK T3 [59] to a height of at least 1.6 m above the platform.

Where MEWPs could foreseeably work under unsupported or poorly supported ground such as fresh shotcrete or in rock tunnels, a FOPS conforming to BS EN ISO 3449, Level 1 should be fitted and the capability of the MEWP to remain stable and to withstand impact loading on the FOPS should be confirmed.

All MEWPs should have lifting points to facilitate lowering in shafts. Details of weight and location of centre of gravity should be marked on the MEWP.

An exclusion zone should always be put in place on the ground below the MEWP platform.

25 Electrical

25.1 Company and site management hierarchy

Appointments of the Electrical Duty Holders for any site along with the person in overall charge of implementing the ESRs should be made or endorsed by the company senior electrical engineer in the principal contractor's organization in accordance with the site Electrical Safety Rules and should be presented on a clear organogram. The guidance in the IET Code of Practice for Electrical Safety Management for electrical safety which includes definitions for the following roles should be followed:

- Authorizing Officer AO
- Authorizing Engineer AE
- Senior Authorized Persons SAP
- Authorized Persons AP
- Competent Persons CP

NOTE 1 For smaller companies and site establishments, the role of EDH/AE may be delegated to outside consultants or companies; however, all employers retain their legal responsibilities to comply with the Electricity at Work Regulations [#].

NOTE 2 Employees also have responsibility for electrical safety Electricity at Work Regulations.

25.2 Planning, management and control of the electrical system

*COMMENTARY ON **25.2***

In tunnelling operations, where environmental conditions can be very severe and where high-voltage (HV) power distribution frequently has to be used, this is critically important.

With regard to the appointing of electrical personnel, the development of electrical safety rules and management of site electrical systems, attention is drawn to the following standards, guidance notes, and codes of practice:

- *The Electricity at Work Regulations 1989 [N7];*
- *HSE publication HSR 25 [60];*
- *BS 7375:2011;*
- *HSE HSG 230 – Keeping Electrical Switchgear Safe [61];*
- *BS 6626;*
- *IET Code of Practice for Electrical Safety Management [62];*
- *BS 7671;*
- *IET Guidance Notes 18th edition on conforming to BS 7671 [63];*
- *BS EN 50110; and*
- *BS 7430:2011.*

Persons competent to work on low-voltage (LV) systems are not, without the necessary additional knowledge, training, experience and authorization competent to do so on high-voltage (HV) systems.

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.

Persons should only be permitted to work on systems and equipment including HV switchgear/devices for which they have had training and familiarization, and for which they have the correct level of competence and are authorized to work on.

A formal system should be established for the management and control of an electrical distribution system meeting the requirements of BS EN 50110 and BS 7671.

NOTE When correctly implemented, a management system can help address the safety issues identified with the operation, use, and maintenance of HV switchgear. The management system need not be complex but be proportionate to the complexity of the electrical system.

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The management 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.

25.3 The management system

Electrical duty holders and site management should clearly understand the Electrical Safety Rules (ESRs) under which any site operates.

25.4 Training and competence

NOTE 1 This covers the training of staff to specific levels of competence, with titles to suit, such as Competent Person (CP), Appointed Person (AP), and Senior Appointed Person (SAP)

There should be an authorization system for staff based on competence, interview and assessment.

NOTE 2 The EDH/AE is responsible for the rigorous vetting of potential staff appointments.

Periodic ongoing capability assessments should be considered.

25.5 Safe system of work

A Safe System of Work should be in place addressing the following:

- preparation of operational safety documents;
- arc flash risk assessment;
- implementation of manufacturers operational restrictions;
- switching schedule – HV specific;
- permit to work procedures;
- preparation and distribution of isolation and earthing diagrams;
- sanction for test;
- limitation of access for non-electrical work;
- regular review and update as required of network diagram;
- upkeep of maintenance systems and asset register;
- upkeep of maintenance records, which should be subject to periodic audit; and
- dealing with emergencies.

NOTE 1 Specific challenges occur when designing and installing the tunnelling distribution network where various other standards and conditions apply.

NOTE 2 BS 7375 gives further guidance and recommendations of specific relevance to electrical installations on construction sites.

25.6 Mains supply connection

Care should be taken as the safety of persons and works can be dependent on the continuity of power supplies to safety critical equipment including:

- lighting;
- pumping;
- atmospheric monitoring equipment and ventilation;
- compressed-air working;
- signalling and communications, including the emergency channel 5 system;
- alarms and shutdown systems;
- firefighting;
- refuge chamber; and

- electrically powered lifting equipment.

The importance of each of these, and the time for which interruption of supply can be tolerated, should be determined according to 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.

*NOTE See **17.6** for guidance on the fire hardening of cables.*

Distribution of electricity on site should be in accordance with BS 7375.

25.7 Site installations

25.7.1 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.

For tunnelling installations, additional safeguards should be put in place where necessary for any of the following reasons:

- HV systems are frequently required for economic power distribution;
- 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;
- wet conditions and high atmospheric humidity can frequently be encountered;
- hazards from smoke and fumes are intensified in the event of fire;
- potentially explosive atmospheres can be present;
- power supply cables to the working face have to be continuously extended;
- there is high risk of mechanical damage to equipment; and/or
- oxygen-rich atmospheres can be encountered.

25.7.2 Voltage

NOTE See BS EN 60204-1.

25.7.2.1 High voltage

NOTE HV supplies, i.e. those above 1 000 V AC, 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 control of the installation, operation and maintenance of HV systems by persons who are competent to work at these voltages (see **25.4**).

While voltages should be kept as low as reasonably practicable for the system in question, nominal voltages for HV systems are likely to be 11 kV or higher, 3-phase 50 Hz.

25.7.2.2 Low voltage

NOTE LV supplies are those between 50 V AC and 1 000 V AC.

The nominal voltages for LV systems should be 690 V or 400 V, 3-phase 50 Hz.

Low voltage should generally be used to supply the majority of electrically powered tunnel plant.

230 V single-phase supplies should not be used except to supply fixed equipment through armoured cables.

25.7.2.3 Reduced low voltage

NOTE 1 Reduced low voltage supplies are those at 110 V, 50 Hz derived from centre tap earthed (CTE), single-phase or three-phase neutral earthed (NE) transformers.

Three-phase 110 V NE supplies should be used to give good load sharing across the phases. Overcurrent protection suitable for the circumstances should be installed in each pole of the outgoing supplies.

They should normally be used for lighting or hand-held portable tools.

NOTE 2 Reduced low-voltage systems, particularly when equipped with residual current devices (RCDs) for additional earth leakage protection, are likely to be safe in all but the most hazardous conditions, if correctly maintained.

Where portable lighting or tools are being used in wet or confined or conductive conditions (such as inside a metal pipe), an extra low voltage system (**25.7.2.4**) should be used.

NOTE 3 Battery-operated tools might be a safer alternative in adverse environments.

25.7.2.4 Extra low voltage

NOTE Extra low voltage supplies are those not exceeding 50 V (AC or DC), between conductors or conductor and earth.

Extra low voltage supplies should normally be used for:

a) portable tools and lighting in damp or confined locations. In these circumstances the supply should be limited to 25 V and derived from a CTE transformer; and

b) control circuits for electrical plant. These supplies for control circuits should 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.

25.7.3 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. Where possible, actual fault levels should 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;*
- *kV, 50 MVA;*
- *400 V, 30 MVA.*

25.7.4 Earthing

25.7.4.1 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.

Earthing should be in accordance with 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 BS 7671:2018, Section 604, details requirements for earthing and electrical protection. However, they are more relevant to commercial situations than to industrial ones.

25.7.4.2 System earthing

LV systems should be solidly bonded to earth unless special circumstances preclude it. HV systems may be connected either solidly to earth, or via a suitable limiting device that can be installed to limit the prospective earth fault current. HV supplies used in a tunnel should always incorporate an earth fault limiting device – usually a Neutral Earth Resistor (NER). Where this device is used, the operational integrity should be regularly monitored using inspection and testing techniques, or with a suitable monitoring device incorporating an alarm and indication function.

NOTE Failure of the limiting device could result in an unsafe condition continuing unnoticed.

25.7.4.3 Circuit protective conductors

NOTE It is normal practice to utilize the armouring of power cables as the circuit protective conductor.

On longer tunnels, additional separate single core copper earthing conductors should be installed where 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 used where necessary, especially for HV to LV distribution within the tunnel where protective multiple earthing (PME) or TN-C-S earthing (defined in BS 7671) 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.

25.7.4.4 Lightning and static electricity protection

To avoid dangerous touch voltages arising as a result of a lightning strike, extraneous metalwork such as rails, walkways 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.

Protection against lightning and static electricity should be in accordance with BS 5958-1 and BS EN 62305 (all parts) respectively.

25.7.4.5 Protection of circuits against electrical shock, short circuit and overcurrent

The main protection against electrical shock short circuit 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; and
- equipment capable of withstanding the aggressive tunnel environment.

Additional protection against electric shock should be provided by the use of residual current devices (RCDs) (see **25.7.5**).

25.7.5 Residual current devices (RCDs)

25.7.5.1 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.

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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. 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 61008-1 and associated standards.

25.7.5.2 RCD sensitivity and discrimination

RCDs should be provided to guard against:

- direct-contact electric shock caused by persons touching a live conductor; and
- 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 voltage circuits carrying less than 32 A supplying portable tools, hand-held lighting and mobile plant.

NOTE 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.

The operating parameters in Table 10 should be taken to represent 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 10 – Earth leakage protection

Circuit voltage	Earth leakage protection	Time delay feature
High (1 000 V AC 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	Residual current device (RCD) with a rated trip current not exceeding:	
(50 V AC to 1 000 V AC)	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 AC)	30 mA for portable lighting and hand tool	No

25.7.6 Waterproofing, dustproofing, vibration, mechanical stress and impact protection

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.

The required degree of protection should be selected in accordance with 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 55 in accordance with BS EN 60529. It is recognized that this might be impracticable to achieve in certain circumstances (e.g. for air-cooled variable speed drives (VFDs) and transformers), in which case alternative external measures should be used to protect the equipment from the conditions.

NOTE IP 67 is often used for cutterhead motors and IP 66 for manlocks.

For protection against vibration, mechanical stress and impact the requirements of BS 7671 should be followed.

25.7.7 Flammable or potentially explosive atmospheres

NOTE 1 Explosion-protected electrical equipment is used to prevent danger when operating in explosive atmospheres. The requirements of the Dangerous Substances and Explosive Atmospheres Regulations 2002 [30] and the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 [28] might apply.

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 has 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 normally 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

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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 that no normally sparking components are used and that other components reduce the risk of causing a fault that could 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 **12.8**).

If non-explosion-protected electrical equipment is used, the following conditions should be fulfilled.

- Ventilation, coupled with atmospheric monitoring, should be 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 should be 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 should automatically lead to disconnection of the equipment.
- All items of electrical equipment deemed essential for safety, including emergency lighting, atmospheric monitoring equipment, fire suppression equipment necessary for escape, and telephones, 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 HSG278 [64].

25.7.8 Explosion-protected equipment in compressed air

NOTE 1 Explosion-protected lighting can be used in manlocks to reduce the risk of hot particles being ejected in the event of failure of the luminaire and resulting in ignition of non-inert materials in the manlock.

NOTE 2 Explosion-protected equipment is not certified for use in compressed-air workings.

If an explosive atmosphere is encountered in compressed air workings, tunnelling should be suspended and an alternative methodology adopted.

25.8 Cables

25.8.1 General

Cables should be selected according to the external influences to which they will be exposed and the uses for which they are required, including the effects of hydraulic fluids, oils, grease and water.

Cables should be of the low smoke-emission and zero halogen types. PVC-sheathed power cables should not be used because of their flammability and the toxic nature of the products of combustion released.

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.

NOTE 1 Various designations are used to indicate low smoke and fume characteristics, especially in the context of halogen compound emissions, 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.

NOTE 2 Aluminium sheathing requires a high degree of protection against corrosion in the humid and possibly saline conditions in a tunnel.

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)].

NOTE 3 For cable selection as part of work in compressed air see the BTS guidance on the Work in Compressed Air Regulations 1996 [24].

25.8.2 Power supply cables

For HV and LV power supplies other than through trailing or flexible cables, the following cable types should be used:

- for voltages above 3.3 kV: Low Smoke Zero Halogen(LS0H), 3-core, screened with single wire armouring and cross-linked polyethylene (XLPE) insulation, conforming to BS 7835;
- for voltages of 3.3 kV and below: Low Smoke Zero Halogen(LS0H), 3-core or 4-core, with single wire armouring and cross-linked polyethylene (XLPE) insulation, conforming to BS 6724.

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.

Pilot cores should not be used for HV tunnel feeder cables where such feeders could be more than 2 km in length. Pilot earth monitoring systems have proved to be unreliable over such distances. Where pilot earth monitoring is omitted the following recommendations should be met.

Tunnel cable joints should be made using bolted or resin type joints. The bolted joint should be a joint chamber, a half coupler, or similar. A plug and socket system should require the use of tools to separate the components.

*NOTE 1 For cable joints in pipe jacking operations see **25.9.3**.*

Where a cable reeling drum is used in the system, the earth path through the reeler should be robust, and assured.

*NOTE 2 See **25.8.9**.*

All flexible trailing (extending) cables used to supply TBMs or other advancing machinery, should be constructed with individual metallic earth screens around the phase conductors.

*NOTE 3 See **25.8.3**.*

25.8.3 Trailing and flexible cables

For trailing and flexible cables the following should be used:

- 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, such as Type 7, 7S, or 7M;
- for mobile plant such as grouting or shotcreting equipment, three power cores, pilot and earth conductors, EPR/CSP insulated, PCP sheathed, with overall metallic screen.

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To tie in with the possible lack of a pilot core in the tunnel power supply cable (**25.7.2**), all machinery connection cables (trailing, reeling, or on mono-rail) should have metallic earth screening around each phase conductor.

NOTE This arrangement ensures that if the cable is crushed or snagged in any way, it always initially produces an earth fault. This is important because it is a requirement to incorporate a neutral earth resistor (NER) in HV tunnel supplies to limit the earth fault current. The difference in energy let through between a phase-phase fault, and a phase-earth fault in a system incorporating an NER, could be as much as 100 times.

Cable types should be carefully chosen 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.

25.8.4 Control systems cables

Control systems cables should conform with BS EN 50525.

25.8.5 Storage of cables

*COMMENTARY on **25.8.5***

Cables are often 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 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, connected between the machine and the end of the existing cable, and the process is repeated as the machine continues its advance.

The method of storage and running out of a cable should not induce twist or mechanical stress in the cable and should be compatible with the flexibility of the cable.

NOTE Cables can be stored on drums, or coiled in a figure of eight if no drum is available.

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.

25.8.6 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.

NOTE Typically this involves installation of tunnel brackets (e.g. J-brackets) as the tunnel advances.

Within the safe system of work, cable handling from the machinery (TBM, roadheader, excavator gantry etc) to the tunnel wall should be taken into account.

Cables should be protected against mechanical damage, fire and water. Consideration should be given to the fire resistance of cable fixings in critical areas where collapsed cables could become an entanglement hazard in the event of a fire. High standards of insulation and mechanical protection along with a high standard of workmanship should be adopted in the installation of HV cables.

Care should be taken to ensure that no longitudinal twists are induced in a cable during installation, as they can result in internal damage which is not visible from external inspection.

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**).

Where cables are run vertically down shafts the cable should be supported. There should be support at the point of access to the shaft (suitable brackets, cable socks, etc). Cable weight should be assessed and additional support added down the shaft if required. The support should be fit for purpose, using cable clamps, trays or ladders.

Cables should not be sited where they might be submerged.

Cables entering a switchgear cabinet or other enclosure should be brought in from below to prevent ingress of water. All non-utilized cable entries into electrical equipment should be sealed to prevent ingress of water, dust or other materials.

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, without a safe system of work being in place to cover the possibility of wet conditions, cable damage, plug and socket damage, or gland damage. Where the integrity of the cable is in doubt, the power should be removed, and the cable inspected.

25.8.7 Reuse of cables

There should be a procedure for identifying, inspecting and testing cables before they are reused to ensure their safety.

25.8.8 Fire risk associated with cables

NOTE 1 In the event of fire, cable insulation can ignite and spread the fire as well as producing toxic fumes and smoke. Grouped cables in a vertical shaft are particularly vulnerable.

Essential circuits, such as fire alarms and emergency lighting (see **14.3** and **17.5**), 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 Circuit overloading or poor connection can cause heating, with damage to insulation and subsequent breakdown.

NOTE 4 See IEE's Guidance Note 4 [65].

25.8.9 Cable reeling drums

Where reeling drums are used to feed a TBM, roadheader, travelling formwork, or gantries, care should be taken to ensure a reliable earth path through the system. The slip ring assembly should incorporate two independent earth collector rings. Where practicable, each earth collector should be capable of carrying the full earth fault current, thereby giving redundancy. Where this is not possible, a rigorous inspection regime should be implemented for the slip ring assembly, including taking earth loop impedance readings, incorporating the slip rings. For HV reelers this should be done under a sanction to test (HV), after regular cable extensions and before the circuit is re-energized.

Cable reels should only be retro-fitted to mobile machinery where they can be securely mounted without risk of being damaged as the machine manoeuvres in the tunnel. There should be an interlock between the reeler, and the means of propulsion of the machine to prevent over-extension of the cable.

Account should be taken of the consequences of using larger cable sizes due to the necessary de-rating of cables on reels, including the implications of handling the heavier cable.

25.9 Joints and terminations

25.9.1 General

Joints should be both electrically and mechanically suitable for the application in which they are used.

Power supply cables should be extended periodically to match the progress of the tunnelling operations, however 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.

Cable sections should be joined together by either:

- utilizing resin 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.

Barrel type couplers should be used where practicable as they allow 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 by bolting the half couplers of the new and existing cables together.

NOTE Using this method 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 and voltages recorded. 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 the outer metallic shell of the coupler.

Couplers for type 321 and 331 flexible, pliable armoured trailing cables should have an internal earth fitting to terminate the earth screens.

Low voltage cable connections should be in accordance with BS 7375 and BS 7671.

25.9.2 Flammable atmospheres

In potentially explosive or flammable atmospheres, all joints and couplers should be of the flameproof type (see **25.7.7**).

25.9.3 Pipe jacking operations

In pipe jacking operations, cables are frequently connected and disconnected in the thrust pit to allow for additional pipe sections to be installed, and accordingly the cable connectors and the system of work used should allow this to be done safely and easily. Pilot core protected circuits should be used, and only suitably trained and competent staff should carry out work with cables. For cables operating above 1 000 V, the persons responsible for this work should be competent to work on HV systems. A means of switching power on and off should be provided in the thrust pit in an accessible location.

25.9.4 Cable terminations

Terminations should be both electrically and mechanically suitable for the application in which they are used.

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.

Terminations should be torqued or tightened according to the manufacturer's recommendations.

NOTE This especially applies to MCBs and protective devices.

Cable terminations on machinery subject to high frequency vibration (fans, power packs, etc), should be by flexible cable and regularly checked for loosening, which can lead to overheating and phase loss.

The type of glands used should maintain the integrity of the IP rating of the apparatus (see **25.6.6**) 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 to allow for cross-connexion of cores in order to minimize capacitance.

Protection cable cores within power cables should be avoided.

25.9.5 Location of electrical equipment 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 recommendations given in BS 5607 should be followed.

25.10 Transformers and switchgear in tunnels

25.10.1 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 taken into account when selecting transformers.

Transformers should be in accordance with BS EN 60076-1.

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. The liquids should be synthetic organic esters as specified in BS EN 61099 or silicone-based fluids manufactured in accordance with BS EN 60836.

Only synthetic liquids which do not contain PCBs or other toxic or eco-toxic ingredients when in liquid form or in the combustion products in the event of fire should be used.

Mineral-oil-filled transformers should not be used in any underground location.

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 is generally unable to withstand significant 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 used where necessary.

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 used for transformers mounted above ground.

25.10.2 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.

Transformers in temporary installations should be located remote from vehicle routes or adequately protected by vehicle impact barriers.

25.10.3 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:

- fault currents;
- entry of water and dust (the minimum degree of protection as categorized in BS EN 60529:1992 should be IP 55);
- methane or other flammable gas;
- damage from moving plant and vehicles or other mechanical sources;
- 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.

25.11 Electrical plugs and sockets

It should be possible for flexible trailing cables to high-powered mobile plant such as power loaders and roadheaders 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. For operating voltages above 110 V and current ratings above 32 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 **25.7.7**).

25.12 Lighting installations

25.12.1 General

Electrically powered lighting should be used in tunnel construction. The selection and siting of luminaires should be in accordance with Clause **17** and should be such as to minimize the fire load.

The design of tunnel lighting systems should take account of circuit length, extensions to circuit length, overload and short circuit protection along with automatic disconnection times.

25.12.2 Voltages

Lighting circuits should be separate from other sub-circuits and should be designed in accordance with the recommendations in **25.7**. The preferred operating voltage for tunnel lighting should be reduced low-voltage 110 V single phase (see **25.7.2.3**) or lower.

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.

25.12.3 Luminaires

Luminaires should have a protective enclosure that conforms to a rating of IP 55 in accordance with BS EN 60529:1992 where practicable. Where required, waterproofing and dustproofing of luminaries should be in accordance with **25.7.6**.

Where methane might foreseeably occur, explosion protected luminaries, typically rated Ex “e” or Ex “d”, should be used for underground locations.

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.

Each lamp should be protected by a suitable mechanical guard or cover or placed out of reach.

25.12.4 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 should be continuous and effectively earthed.

25.12.5 Emergency lighting

Emergency lighting should be provided in accordance with **17.5**.

25.13 Electric motors

25.13.1 Types

Totally enclosed fan-cooled or liquid cooled motors in accordance with BS EN 60034-5 should be used. Open ventilated motors should not be used.

25.13.2 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 **25.7.2.4**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.

25.13.3 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.

25.14 Laser products

25.14.1 General

*COMMENTARY ON **25.14.1***

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 impractical, therefore, to regard lasers as a single group to which common standards can apply.

The manufacturer’s instructions and classification should be followed 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 These are Class 2M and Class 3R in the revised international standard IEC 60825-1+A2:2001.

Laser should not normally be sited at head height to avoid exposure to laser radiation. If siting a laser at head height cannot be avoided, an easily moveable device to obstruct the laser when not required, should be placed in the line of the beam.

25.14.2 Class 2 laser products

*COMMENTARY ON **25.14.2***

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.

25.14.3 Class 3A laser products

*COMMENTARY ON **25.14.3***

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 five 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 be in place to ensure that this is avoided.

25.14.4 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 Laser Safety Officer should be appointed whenever lasers above Class 2 are in use.
- Suitable and appropriately trained persons should be assigned to install, adjust and operate the laser equipment.
- 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.
- Wherever reasonably practicable, mechanical or electronic means should be used to assist in the alignment of the laser.
- 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.
- 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.
- The position of any laser beam path should, where reasonably practicable, be either well above or well below eye level.
- Precautions should be taken to avoid the laser beam being directed intentionally at reflecting surfaces such as mirrors and lenses. Any such reflecting surfaces should be stopped from being accidentally introduced into the beam path.
- When not in use, the laser should be stored securely, so that unauthorized persons cannot gain access to the equipment.

25.15 Generators

25.15.1 General

There should be an interlock to stop parallel operation between the generator and the mains supply in accordance with BS 7430.

There should be a robust system for ensuring that all consumables, including fuel, are always available.

25.15.2 Standby generators

There should be a robust system for regularly maintaining and testing the generator. The generator should be ready to go on load immediately on start-up.

25.15.3 Earthing

Earthing of generators should be in accordance with BS 7430:2011, **7.2**.

25.15.4 Bunding of tanks

All generators should have double skin fuel tanks or be set within suitably bunded locations.

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26 Maintenance, renovation and repair

26.1 General

The recommendations in Clause **4** to Clause **25** should, where applicable, be met when undertaking maintenance, renovation and repair of 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. Except for the simplest and shortest of tunnels for which a paper-based asset management system is expected to suffice, a digital asset management system should be used.

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 of the tunnel.

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. However 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.

NOTE 2 Points which are likely to require attention include:

- *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; and*
- *chemical and thermal effects.*

In tunnels where the presence of gases poses a danger, a scheme should be drawn up for the continuous assessment of the gases (see **15.5** and **15.6**).

NOTE 3 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 4 In addition to normal inspection procedures, specialized techniques are available, including:

- *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 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 Attention is drawn to The Construction (Design and Management) Regulations 2015 [1]. General recommendations on the control of risk are given in 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 these are 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 should be determined.

NOTE 1 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.

NOTE 2 Available procedures include 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.

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.; and
- 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**.

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" [66].

26.4.4 Fire precautions

The recommendations for fire precautions including requirements for fire suppression on plant and equipment used underground given in Clause **13** and Clause **14** should be met when undertaking maintenance, renovation and repair activities.

26.5 Work in shafts

26.5.1 General

The recommendations for work in shafts given in Clause **20** should be met when undertaking maintenance, renovation and repair activities.

26.5.2 Lifting operations

Cranes may be used for raising or lowering personnel riding cages (see **21.6.4**) 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 [52].

26.5.3 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 determine whether it is still safe.

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 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.

26.5.4 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" [67] provides information.

26.5.5 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

The recommendations for temporary works given in **6.4** should be met when undertaking maintenance, renovation and repair activities.

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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