

BS 6164:2019



BSI Standards Publication

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

bsi.

AVA Documents
Document Sharing Hub

Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

© The British Standards Institution 2019

Published by BSI Standards Limited 2019

ISBN 978 0 580 94022 4

ICS 93.060

The following BSI references relate to the work on this document:

Committee reference B/513

Draft for comment 19/30340390 DC

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

Contents

	Page
Foreword	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	6
4 The control of risk	6
4.1 From hazard identification to safe systems of work	6
4.2 Planning for contingencies and emergencies (see Clause 14)	7
4.3 Types of accidents	8
4.4 Occupational health and welfare	8
<i>Table 1 — Accidents – Indicative examples of cause and prevention (not in order of priority)</i>	10
<i>Table 2 — Principal occupational health hazards</i>	13
5 Investigation and information gathering	17
5.1 General	17
5.2 Preliminary studies	17
5.3 Project-specific studies	19
5.4 Ground investigation during construction	23
6 Detailed planning for health and safety	24
6.1 Integral nature of design and construction	24
6.2 Pre-construction stage organization	24
6.3 Construction stage	24
6.4 Safety of permanent and temporary works	25
6.5 Recruitment of project personnel	30
6.6 Competence	30
6.7 Personal protective equipment	32
6.8 First aid provision and procedures	33
7 Excavation and control of ground movement	35
7.1 Management of risk in the tunnel construction process	35
7.2 Basic principles	35
7.3 Ground movement control	36
7.4 Ground characteristics	37
7.5 Tunnel excavation	40
7.6 Tunnelling machines	40
7.7 Control of ground movement when tunnelling in soft ground without a segmental lining	43
7.8 Tunnelling in rock	45
7.9 Hand excavation, headings and small tunnels	47
7.10 Pipe and box jacking	49
7.11 Soil conditioners	50
<i>Table 3 — Soil conditioners</i>	50
8 Permanent support	51
8.1 General	51
8.2 In-situ linings	51
8.3 Prefabricated linings	52
8.4 Construction of openings	54
8.5 Monitoring of loads and deformation	55
9 Management of groundwater	56
9.1 Control of groundwater	56
9.2 Geotechnical processes for water management and ground improvement	59
9.3 Compressed air	61



9.4	Drilling through the tunnel lining for dewatering, ground treatment or freezing	61
9.5	Risk from groundwater on entry to cutterhead	61
9.6	Handling of groundwater	62
10	Inundation	63
10.1	General	63
10.2	Reliance on geological information	63
10.3	Other potential sources of flooding	63
10.4	Precautions for probe drilling	64
10.5	Inundation during shaft and portal construction	64
10.6	Inundation of a tunnel constructed with open faces (including backshunts and foreshunts)	64
10.7	Inundation during Tunnel Boring Machine (TBM) launch	65
10.8	Inundation via the TBM during operation	65
10.9	Inundation during face inspections of closed face TBMs	65
10.10	Dealing with inundation	65
11	Compressed-air working	65
11.1	Physical effects of compressed air	66
11.2	Structural considerations	68
11.3	Shaft construction under compressed air (see also Clause 20)	70
11.4	TBMs and compressed air	71
11.5	Air supply	72
11.6	Bulkheads, airlocks and associated compressed-air equipment	73
11.7	Fires and rescue in compressed air	74
11.8	Inundation	77
11.9	High pressure compressed air	77
12	Explosive atmospheres	77
12.1	General	77
12.2	Occurrence	78
12.3	Explosion characteristics	79
12.4	Detection and monitoring	79
12.5	Action levels	81
12.6	Re-entry procedures	81
	<i>Table 4 — Action level summary table</i>	81
12.7	Sources of ignition	81
12.8	Explosion protection (see also 12.5)	82
12.9	Work in potentially explosive atmospheres	83
12.10	Other explosive gases	83
12.11	Methane occurrence on TBMs	83
12.12	Methane occurrence in slurry plant	83
12.13	Flammable dust	84
13	Fire and smoke	84
13.1	Sources of fuel and ignition	84
	<i>Table 5 — Provision of fire extinguishing equipment</i>	85
	<i>Table 6 — Portable fire extinguishing equipment</i>	86
13.2	Welding and cutting (burning)	88
13.3	Fire precautions	90
13.4	Fires involving electrical equipment	91
13.5	Water spray curtain	91
14	Response to emergencies	91
14.1	Escape routes	91
14.2	Emergency services and operational capacity	91

14.3	Emergency control facilities	92
14.4	Raising the alarm	93
14.5	Alarm procedures	94
14.6	Site training	95
14.7	Access	95
14.8	Lighting	95
14.9	Smoke control	95
14.10	Rescue facilities	95
14.11	Self-rescuers	96
14.12	Accounting for personnel	96
14.13	Refuge chamber	97
14.14	Escape and rescue in small tunnels	97
14.15	Response to inundation risk	97
14.16	Recovery of the situation following inundation	98
15	Ventilation	98
15.1	General	98
15.2	Guidelines for fresh air supply quantities	100
15.3	Quality of air	101
15.4	Atmospheric monitoring	101
	<i>Table 7 — Alarm settings and responses</i>	102
15.5	Unoccupied tunnels and stagnant areas	103
15.6	Hazardous gases	103
	<i>Table 8 — Summary of most commonly encountered atmospheric contaminants</i>	106
15.7	Ventilation systems and plant	111
15.8	Ventilation in drill and blast tunnelling	114
15.9	Cooling through ventilation	115
15.10	Ventilation of shafts	115
16	Dust, particulates and other contaminants	115
16.1	Importance of dust control	115
16.2	Effects of dust	115
16.3	Exposure limits for dust	117
16.4	Sampling	118
16.5	Control and removal of dust	118
16.6	Respiratory protective equipment (RPE)	119
16.7	Asbestos	119
16.8	Diesel particulate matter (DPM)	119
16.9	Fumes from cutting and welding	120
16.10	Spray-applied membranes	120
16.11	Other ground contaminants	120
16.12	Heat strain	122
17	Quality of illumination	122
17.1	General	122
17.2	Level of lighting	122
	<i>Table 9 — Mean lighting levels</i>	123
17.3	Type of lighting	123
17.4	Siting of luminaires	124
17.5	Emergency lighting	124
17.6	Fire hardening of wiring	125
17.7	Hand lamps and cap lamps	125
17.8	High visibility clothing	125

18	Operating communications	125
18.1	General	125
18.2	Communication systems	126
18.3	Signals	127
18.4	Closed-circuit television (CCTV)	128
18.5	Emergency response	128
19	Noise and vibration	129
19.1	General	129
19.2	Noise emission and exposure	129
19.3	Vibration	131
20	Shafts, pits and piles	132
20.1	General	132
20.2	Design	133
20.3	Locating shafts	133
20.4	Safety considerations relating to shaft construction	133
20.5	Shaft construction techniques and operation	135
20.6	Lifting in shafts	138
20.7	Protective structures in shafts	139
20.8	Pit bottom safety	139
20.9	Plant safety	139
20.10	Services in shafts	140
20.11	Inclined shafts and escalator shafts	140
20.12	Transport systems for inclined shafts	140
20.13	Disused shafts	141
20.14	Tunnel eye	142
20.15	Removal of temporary rings and panels of d-walls	142
20.16	Shaft top layout	142
20.17	Personnel access	143
20.18	Communication	144
21	Lifting equipment and operations	144
21.1	Lift plan	144
21.2	Cranes	144
21.3	Winches	146
21.4	Materials hoists	146
21.5	Communication	146
21.6	Lifting of persons	147
21.7	Arch and mesh installation	148
21.8	Lifting with excavators	149
21.9	Visual and/or audible alarms	149
22	Access	149
22.1	Walkways	149
22.2	Stair and ladder towers	150
22.3	Access for maintenance	150
22.4	Gradients	151
22.5	Temporary tunnels	151
22.6	Working at height in tunnels and shaft	151
23	Materials handling systems	151
23.1	Rail haulage	151
23.2	Operational considerations	154
23.3	Conveyors	162

23.4	Slurry transport systems	164
23.5	Personal protective equipment	167
23.6	Other haulage methods	168
23.7	Adits and inclines	168
23.8	Storage and disposal of excavated material	168
24	Tunnel plant	169
24.1	General	169
24.2	Separation of vehicles and pedestrians	171
24.3	Rubber-tyred free-steered vehicles	171
24.4	Crawler tracked plant	172
24.5	Pneumatically-powered plant and equipment	172
24.6	Hydraulically operated plant or equipment	172
24.7	Electrically-powered plant and equipment	173
24.8	Internal combustion engines	173
24.9	Battery power	173
24.10	Concreting plant	174
24.11	Water drainage pumps	176
24.12	Drilling and piling rigs	176
24.13	Grouting equipment	177
24.14	Earthmoving plant	178
24.15	MEWPs	178
25	Electrical	178
25.1	Company and site management hierarchy	178
25.2	Planning, management and control of the electrical system	179
25.3	The management system	179
25.4	Training and competence	179
25.5	Safe system of work	180
25.6	Mains supply connection	180
25.7	Site installations	181
	<i>Table 10 — Earth leakage protection</i>	185
25.8	Cables	187
25.9	Joints and terminations	190
25.10	Transformers and switchgear in tunnels	191
25.11	Electrical plugs and sockets	193
25.12	Lighting installations	193
25.13	Electric motors	194
25.14	Laser products	195
25.15	Generators	197
26	Maintenance, renovation and repair	197
26.1	General	197
26.2	Asset management	197
26.3	Preparation for renovation or repair	198
26.4	On-site procedures for renovation and repair	200
26.5	Work in shafts	200
26.6	Temporary works	201
26.7	Record of work	201
	Bibliography	202

Summary of pages

This document comprises a front cover, and inside front cover, pages i to viii, pages 1 to 205, an inside back cover and a back cover.

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 = $10^5 \text{ N/m}^2 = 10^5 \text{ Pa}$.

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.

Presentation 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.

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*

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

[BS 5306-10](#), *Fire extinguishing installations and equipment on premises – Part 10: Colour coding to indicate the extinguishing medium contained in 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 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*
- [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 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 14973:2015, *Conveyor belts for use in underground installations – Electrical and flammability 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*
- BS EN 50110-1, *Operation of electrical installations – General requirements*
- BS EN 50110-2, *Operation of electrical installations – National Annexes*
- 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 62305 (all parts), *Protection against lightning*
- 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*

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 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.

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 endeavour to 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.

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.

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

Table 1 (*continued*)

Accident category	Examples	Precautions and/or principal references	Other references
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	

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 [68] and the Working Time Regulations 1998 (as amended) [69].

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 [68] and BTS Guide on HAVS [9].

Table 2 — *Principal occupational health hazards*

Hazard	Occurrence	Possible symptoms and/or consequences	Clause reference
Physical			
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

Table 2 (continued)

Hazard	Occurrence	Possible symptoms and/or consequences	Clause reference
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

4.4.6.5 Heat stress and exhaustion

Mechanization, ventilation, air chillers, cool breaks and job rotation should be considered 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 recognized 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 to be considered 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 be considered 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 3 See the Working Time Regulations 1998 (as amended) [69], 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 ordnance

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 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, consideration should be given to carrying out pumping tests in boreholes sunk specifically for the purpose.

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.

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.

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.

Consideration should be given on complex projects to setting up a peer review group 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.

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, 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 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 considered 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 7.3.3.

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

NOTE 1 Settlement control of TBM driven tunnels is driven by the confinement pressure in slurry TBMs and earth pressure balance in EPB machines.

Operating pressures should be derived from calculations which consider the prevailing ground conditions.

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 2 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 3 Reference ought to be made to the BTS report on closed-face working [18].

NOTE 4 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 considered 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.

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 7.5.2

“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