

Code of practice for

Safety in tunnelling in the construction industry

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- Association of Consulting Engineers
- British Tunnelling Society
- Chief and Assistant Chief Fire Officers Association
- Construction Health and Safety Group
- Department of the Environment (Building Research Establishment)
- Department of the Environment (Water Directorate)
- Federation of Civil Engineering Contractors
- Health and Safety Executive
- Institution of Civil Engineers
- Institution of Mining Engineers
- Institution of Mining and Metallurgy
- Institution of Public Health Engineers
- Institution of Structural Engineers
- Institution of Water & Environmental Management (IWEM)
- London Regional Transport
- Pipe Jacking Association

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Foreword

This British Standard has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee. It supersedes the 1982 edition which is withdrawn.

The code aims to define good practice in the construction of tunnels and in their maintenance, renovation and repair with the principal objectives of improving safety and harmonizing the precautions to be adopted. To help achieve this the code has been substantially rearranged and a new section added about the maintenance, renovation and repair of existing tunnels.

The recommendations have been prepared primarily for the guidance of those responsible for tunnel construction, renovation and repair on site but also to assist engineers designing and maintaining tunnels so that provision can be made in specifications for the elimination of unnecessary hazards. It has been assumed in the drafting of this code of practice that the execution of its provisions is entrusted to suitably qualified and experienced people for whose guidance it has been prepared.

Emphasis throughout the code has been placed on safety, particularly the safety of those engaged in tunnelling operations and the safety of others who may be in the vicinity of the work. Particular acknowledgement is made to the Inspectors of the Health and Safety Executive for their assistance in drafting this code.

Tunnels driven through the coal measures will often be affected by the hazards more commonly associated with mineral workings (see note) and although the code makes reference to such matters as precautions against fire and explosion these references should be regarded as indicative only. In such conditions tunnelling should not be started until a safety routine has been established under the control of an experienced engineer.

NOTE Workings for minerals may not be started without the approval of HM Principal District Inspector of Mines and Quarries.

The code lists the current legislative requirements appropriate to tunnelling and makes reference to Construction Industry Research and Information Association (CIRIA) Report 44 "Medical code of practice for work in compressed air". These should be studied and carefully followed.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

This code of practice represents a standard of good practice and takes the form of recommendations. Compliance with it does not of itself confer immunity from relevant legal obligations.

Summary of pages

This standard comprises a front cover, an inside front cover, pages i to vi, pages 1 to 92, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This code of practice makes recommendations and gives guidance for safe practices in man-entry tunnelling and in the maintenance, renovation and repair of tunnels.

The code does not include recommendations for cut and cover tunnelling or immersed tube tunnels, nor does it apply to the construction of tunnels for the purposes of the winning of minerals.

NOTE 1 The design, manufacture and use of plant and machinery are referred to only where safety considerations are affected.

NOTE 2 The titles of the publications referred to in this code are listed on page 92.

2 Definitions

NOTE There are no definitions used in this code that are particular to the code itself. The terms are those in common use in tunnelling operations.

For the purposes of this British Standard the definitions for building and civil engineering terms given in BS 6100, together with those for electrotechnical and related terms given in BS 4727, apply.

3 Legislation

The principal legislation, current at the date of publication of this code, affecting safety in tunnelling or relating to operations associated with it, is contained in the following:

- the Health and Safety at Work etc. Act, 1974;
- the Health and Safety at Work (Northern Ireland) Order, 1978;
- the Factories Act, 1961;
- the Factories (Northern Ireland) Act, 1965;
- the Public Health Acts, 1961 and 1969;
- the Public Health (Scotland) Act, 1987;
- the Consumer Protection Act, 1987;
- the Control of Pollution Act, 1974;
- the Employment Medical Advisory Service Act, 1973.

Regulations made under these Acts, with any amendments, include:

- the Work in Compressed Air Special Regulations, 1958;
- the Construction (General Provisions) Regulations, 1961;
- the Construction (Lifting Operations) Regulations, 1961;
- the Construction (Working Places) Regulations, 1966;
- the Construction (Health and Welfare) Regulations, 1966;
- the Protection of Eyes Regulations, 1974;
- the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations, 1972;
- the Health and Safety (First Aid) Regulations, 1981;
- the Control of Asbestos at Work Regulations, 1987;
- the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, 1985;
- the Electricity (Factories Act) Special Regulations, 1908 and 1944.

In Northern Ireland and Scotland relevant equivalent legislation should be referred to.

If, on any particular site or part of a site, the regulations are not directly applicable to tunnel work their requirements should nevertheless be complied with to the greatest practicable extent.

NOTE Copies of Government Acts and Regulations may be obtained from Her Majesty's Stationery Office.

Section 2. Planning and organization

4 Organization and administration

4.1 General

While this code is primarily directed to safety in the execution of tunnel construction, maintenance, renovation and repair of tunnels at site, all preparatory planning and design is directly relevant.

The parties normally concerned are as follows:

- a) the client;
- b) the engineer, responsible for the design and supervision of the work and for ensuring compliance with specifications, represented on site by the resident engineer;
- c) the contractor, responsible for the execution of the work and for providing the labour and physical means for construction, represented on site by the agent;
- d) public authorities applying statutory and administrative regulations.

4.2 Precontract organization

Before a contract can be let the client and engineer will plan the project. If special hazards or abnormal conditions are expected which come within the responsibilities of statutory authorities they should be fully consulted.

When tenders are invited any special responsibility of the contractor for safety aspects of planning or design should be made clear.

Clients and engineers need to appreciate that safety involves expenditure and that contracts should be so drafted as to ensure that contractors are obliged to make full and proper provision for those costs. In particular, it should be policy to ensure that, as far as is practicable, the extent and adequacy of the safety measures are not the subject of competition in tendering and that the contractor's complete responsibility for the safety of the work and men remains clear and unambiguous and is in no way abrogated (see clause 6).

The safety staff required and the organization and provision of medical and other facilities may with advantage be specified in detail in the contract document, with appropriate items to be priced in each tender.

As part of the tender, contractors should be instructed to submit particulars of qualifications and experience of key staff who will be employed on site, since appropriate, skills and experience are essential prerequisites of safety. Details of the contractor's training programmes for new employees should also be requested. Similar high standards of skill and experience, together with appropriate qualifications, are also necessary where a client employs direct labour.

4.3 Contract site organization

4.3.1 *Contract site management*

The Construction (General Provisions)

Regulations, 1961 require the appointment of a safety supervisor by contractors working on sites. Such a supervisor should have an adequate knowledge and experience of tunnelling operations, including the plant to be used. The supervisor should advise the contractor or employer about the observance of the requirements for the safety or protection of the persons employed and for promoting the safe conduct of the work generally.

On safety matters, it is essential that the person appointed be given adequate authority, with support from the site manager and the resident engineer.

On a well-run site, there should be no conflict between production targets and safety, providing that preplanning takes account of both and that basic safety standards are regularly observed. Senior management should insist on both these aspects and take an active interest in ensuring that their site staff are adequate to cope with both production and safety.

The contractor should be responsible for the recruitment of sufficient suitably experienced labour for the safe execution of the work and for proper supervision at all levels and in all capacities.

The site should be surveyed to anticipate likely hazards as early as is practicable by the contractor, with any necessary investigations and tests carried out, and contingency plans drawn up (see clause 6). At frequent intervals thereafter, the hazards should be monitored and the prevention of accidents reviewed in detail (see 4.4.1).

It is important that a chain of authority and of communication be defined and established from the beginning so that all relevant information is given quickly to those responsible for assessing it and acting on it. This is particularly important in respect of information concerning safety at the tunnel face.

4.3.2 Temporary works

Temporary works of a substantial character are almost invariably necessary in the construction of tunnels and in their maintenance, renovation and repair. They may constitute an essential phase of the permanent construction, as in the case of a pilot tunnel, a working shaft, or framing to form an opening, or they may be structurally independent incidental works, such as working gantries, access stairways, access roads, thrust pits and walls. It is essential that all these works are properly designed and that appropriate drawings, calculations and specifications are prepared in advance, subjected to an independent check, and worked to. Changes should be made only after consultation with the designer. The main contractor should appoint an engineer from his site staff as coordinator of temporary works to ensure proper design and checking and compliance with safety requirements. This is particularly relevant to larger contracts where several subcontractors may be employed whose temporary works may not otherwise receive proper scrutiny and attention.

In tunnelling, one aspect of special relevance is that the adequacy of temporary support may be critical to the loading and stresses in the permanent structure.

Procedures for face timbering, for break-ups and for the construction of openings should therefore be properly designed and subjected to the same supervision as the permanent construction and to the same standard of workmanship.

4.3.3 Supervision and inspection

While the contractor should be fully responsible for the safety of the work under his control, independent experienced site supervision and inspection by the engineer's and/or client's staff can contribute much in establishing safe working.

Judgement of varying ground conditions is necessary at every stage in the construction of tunnels and in their maintenance, renovation and repair and it can be vital to safety to anticipate hazards and to decide on the appropriate action without delay.

Inspection of the tunnel by a competent person is a statutory requirement and of great value in ensuring that safety aspects are not overlooked. It is particularly important that daily inspections by reliable men employed by the contractor should be made when work is not continuous, namely at weekends, holidays or other interruptions. In all cases, the precautions indicated in 15.4 should be observed.

The person responsible for the design should be adequately represented on site. Any modifications in agreed procedures necessitated by changes in ground behaviour should be notified as quickly as possible to the responsible engineers.

4.3.4 Statutory controls

Statutory control of works of engineering construction is exercised under the Health and Safety at Work etc. Act, 1974 and the Factories Act, 1961, in particular Section 127. Administration is by the Health and Safety Commission through the Health and Safety Executive (HSE). The Factory Inspectorate should be consulted regarding relevant notices, registers, forms and other notifications. In the case of work on operational railways the Department of Transport Railway Inspectorate is responsible for the enforcement of the Act.

Unless the work is to be completed within 6 weeks, the undertaker of the work is obliged to notify the Principal Inspector of the Construction Industry Group of the local area office of the Health and Safety Executive.

Over and above the minimum requirements the inspector should be given wherever practicable 7 days advance notice of the intention to start:

- a) tunnelling;
- b) shaft sinking for tunnelling;
- c) compressed air working.

Statutory Regulations require certificates, reports and other documents to be made available to the Factory Inspectorate.

There are, of course, other statutory obligations not specific to engineering construction.

4.4 Accidents and dangerous occurrences

4.4.1 Accidents

All accidents, whether or not they result in personal injury, are to be reported to the contractor's site management by the individual involved or his immediate superior. Accident records are to be kept and accidents reported in accordance with HSE regulations. These records should be studied and analysed by the contractor and the safety committee at frequent intervals to highlight the frequency and cause of accidents so that steps can be taken to prevent a recurrence of similar accidents.

It is important that visitors report to the contractor on arrival and that they have his agreement to the site visit. They should also check whether the contractor's insurance covers them in case of accidents.

The principal causes of personal accidents are categorized in Table 1, together with particular examples illustrating their relevance to tunnelling. The major hazards are dealt with more fully elsewhere in the code, but it should be emphasized that minor hazards can be just as serious for the individual.

4.4.2 Protective wear

Personal protection equipment should be worn by any person exposed to foreseeable risk on the following basis.

- a) *Head protection.* All persons should wear suitable protective headwear at all times. A bump-cap is not adequate if there is a danger of material falling from a height. This effectively limits its use to tunnels with a working space less than 3 m high.
- b) *Foot protection.* Strong boots, preferably with steel sole plates and toe guards, should be worn at all times; in wet tunnels, heavy rubber knee boots may be appropriate.
- c) *Hand protection.* Suitable gloves should be worn where a man is particularly exposed to cuts, burns, electric shock or corrosive or irritant substances. Elbow length gloves should be worn when grouting. Barrier creams should be available.
- d) *Eye protection.* Attention is drawn to the Protection of Eyes Regulations, 1974 (SI 1974 No. 1681). Safety goggles, face shields, and fixed shields are to be provided, as appropriate, for protection against flying particles, hazardous substances or injurious light rays.
Eye protectors should always be worn by operators when sandblasting, shotblasting, air and water cleaning, spraying concrete, grinding or chipping metal, cutting and welding, grout mixing and placing. Where there is a foreseeable risk of injury they should always be worn by operators breaking, cutting or drilling concrete or stone or similar material, and by operators injecting liquids under pressure.
- e) *Body protection.* Protective clothing should be waterproof where appropriate. Special clothing may be necessary for those handling injurious substances.
- f) *Ear protection.* See clause 19.
- g) *Lung protection.* Suitable respiratory equipment should be used where there is unavoidable excessive exposure to harmful fumes or dust. Elimination of the hazard should be the primary aim, then ventilation to transfer it elsewhere and dilute it, and lastly the use of suitable respiratory equipment.

4.4.3 First aid organization

There is a requirement under the Health and Safety (First Aid) Regulations, 1981 for the employer to make appropriate arrangements for treating persons injured at work. Direct reference should be made to the Health and Safety series booklets HS(R) 11 First Aid at Work. Potential hazards in tunnelling make availability of trained personnel essential on each shift during working hours. Such persons should hold a current certificate issued by an organization approved by the Health and Safety Executive to carry out training for first aid at work. They should also have undergone specific training to deal with the circumstances described in 21.2.5. Employees should be informed of the first aid arrangements.

Both contractor and engineer should consider sending a proportion of their senior personnel, including foremen and inspectors, on first aid training courses.

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

4.4.4 First aid boxes

A sufficient number of first aid boxes should be provided. First aid boxes should be made of suitable material and designed to protect the contents as far as possible from damp and dust. They should be clearly identified, the recommended marking being a white cross on a green background. They should be adequately equipped as set out in the Guidance Notes for Health and Safety (First Aid) Regulations, 1981. Boxes should be readily accessible to working areas and should be in the charge of a designated first-aider on each shift.

4.4.5 Stretchers

Stretchers (complete with blankets) suitable for hoisting on a crane or winch hook 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, a stretcher should, where practicable, be stored at tunnel level. Means of safely transporting an injured man to the surface should be ensured (see 21.2.5).

In the event of serious injury, a patient should not be moved until qualified medical personnel can reach the area, unless there is an immediate chance of further injury.

4.4.6 Ambulances

The local ambulance service should be notified of the location of the site and the nature of the work to be carried out. First-aiders should be aware of the procedure for calling an ambulance and permitted to do so when required. Notices should be affixed on site naming these first-aiders and giving instructions on the making of emergency calls.

Where such arrangements are not practicable, a vehicle suitable for stretcher cases should be provided on site. A notice giving the address of the hospital dealing with emergencies should be prominently displayed.

On a tunnel site these requirements should apply even if fewer than 25 persons are employed. In particular, care should be taken to ensure ready vehicle access to the top of any working shaft or adit in the event of an emergency.

Table 1 — Principal causes of accidents

Accident category	Detailed examples	Prevention and principal references	Other references
1. Falling from a height	Fall down shaft Fall from staging at face	Proper barriers Secure decking. Barriers where practicable	20.6
2. Falling on the level	Tripping or slipping on walkway	Handrails, even non-slip surface, cleaning of surface, good lighting	17, 23.3
3. Materials falling from a height	Tools and small items dropped or kicked off staging or from of shaft	Toe boards, Proper stacking and storage. Hand tools provided with thongs	20.6
	Slung loads dropped	Proper slinging and loading. Loading area kept clear. See CP 3010 and BS 4898	20.6, 21.2
4. Materials falling from stacks or vehicles	Collapse of stacks, e.g. timber, segments, cement bags	Proper foundation for stacks. Systematic building of and maintenance of stacks	
	Loads falling from vehicles	Loads properly stacked and secured. Level road or track well maintained	
5. Burial by fall of material	Collapse of face	See clauses 7 and 9	
	Rock falls	Barring down loose rock. Immediate support	7.8
	Collapse of stacks or stockpiles	See item 4	
6. Flooding or inrush of water	Broken sewer or pipeline, ground water, etc.	See clause 11	
7. Lifting machinery	Cranes and hoists	See clause 21	
	Hoisting and placing of segments at face	Appropriate equipment properly maintained. Safe procedures enforced	9.3.3
8. Other machinery	Excavating machines	Exclusion of men from digging zone. Safe procedures defined and enforced. See clause 7	
	Grouting operations	Robust equipment properly maintained. Operation by trained men (see 9.3.4)	
	Conveyors	See 23.2.2	
9. Vehicles	Locomotives and rolling stock	See 23.1	
	Road vehicles	See 23.2.4	
10. Electrical installation		See clause 24	13.3
11. Fire and explosion		See clauses 12, 13, 14	10.3, clause 24

Table 1 — Principal causes of accidents

Accident category	Detailed examples	Prevention and principal references	Other references
12. Atmospheric pollution		See clauses 12, 15	10.4
13. Handling materials	Lining segments. Pipes	Concrete Pipe Association Technical Bulletin No. 6 ^a	
^a The Concrete Pipe Association, 60 Charles Street, Leicester LE1 1FB.			

4.4.7 First aid rooms

A properly constructed and equipped first aid room should be provided, to be used for treatment and rest only. It should be in the charge of a person trained in first aid and should be available during working hours.

4.4.8 First aid training

A person carrying out first aid should have successfully undergone a course of training and be in possession of a current certificate issued by an organization approved by the Health and Safety Executive under the Health and Safety (First Aid) Regulations, 1981. Details of such organizations are available from the local office of the Employment Medical Advisory Service.

4.4.9 Duplication of provisions

Where employees of more than one employer are involved and the employers concerned wish to avoid duplication of provisions they may make an agreement in writing, a copy being kept by each employer. Each employer should inform its own employees of the arrangement made for them.

4.5 Labour: recruitment and training

4.5.1 Recruitment

In the recruitment of labour for tunnelling work it is essential that a high standard of physical fitness is ensured. The provisions of the Employment Medical Advisory Service Act, 1973 also apply.

In respect of persons under 18 years of age it is advisable that they produce a medical certificate of fitness.

For certain operations such as crane drivers and signallers there is a statutory requirement to employ persons over 18 years of age. In general, it is desirable that all operatives below ground are more than 18 years old.

The principles to be applied to all tunnelling operations include regular inspection by competent and experienced persons, execution of work under the direction and supervision of competent and experienced persons, and execution of work by competent persons possessing adequate experience. It is accordingly of the utmost importance that suitable persons are given responsibility for the functions of:

- a) inspection;
- b) supervision;
- c) direction.

Experience in the work to be done should be considered essential for a substantial proportion of the persons recruited. Should the recruitment of experienced and competent persons be difficult, a training course should be set up, with particular emphasis placed on training shift supervisors who are the key persons in the day to day safety programme.

4.5.2 Training

There is a legal requirement for training to be given to all employees. Laws that are drawn up for specific industries also lay down requirements for training. Under this heading come first-aiders, plant operatives, and, in tunnelling, compressed air attendants and lock keepers. For hand mining it has been traditional to train on the job with the miners' labourers being under training to the miner. Training courses are available through the Construction Industry Training Board (CITB)¹⁾.

Widely recognized grading and training schemes are available to assist in recruiting electricians, fitters, and plant operators. However for tunnelling work the operatives' personal records are the only reliable source of information.

The most vital contribution to safety in any tunnel is a trained and disciplined workforce.

Clients and engineers should encourage contractors to institute training programmes by requiring details in the tender documents (see 4.2) so that contractors can price accordingly.

¹⁾ Construction Industry Training Board, Bircham Newton Training Centre, Kings Lynn, Norfolk PE31 6RH.

It is highly desirable that operators of specialized tunnelling plant such as mechanical excavators, lining erectors (including winches), grout pans, drilling equipment and pipe jacking pressure systems be experienced in general procedures in tunnelling. Whenever possible, staff employed for the maintenance of mechanical plant should have served an appropriate apprenticeship or similar training; however, a reasonable proportion of this staff may well be trainees. Reference should be made to the operative's registration grading, under the industry registration scheme, for the appropriate level of competence that has been obtained.

Staff employed for the installation, operation and maintenance of electrical circuits and equipment should be graded in accordance with the current industrial agreement of the Joint Industry Board for the electrical contracting industry and should be suitably trained and competent for the work.

4.6 Records and reports

The keeping of proper and adequate records of the physical aspects of the work in tunnel construction and repair is of the utmost importance. This is not only for safety during construction but for future safety in any necessary later maintenance and repair work, and also in any future tunnelling or other works in the vicinity.

The preservation of records for future reference and use should be the responsibility of the client, subject to delegation of that responsibility in the event of the establishment of any regional or central registry for the purpose. Any construction contract should provide for such records to be prepared and handed over by the contractor.

The minimum record to be preserved should be a longitudinal section based on day-to-day records of the strata encountered, correlated with any available borehole records and with any abnormal ground water levels, tidal and river levels and rainfall. Settlements and movements of the tunnel supports and the ground above the tunnel are particularly important and should be recorded.

Progress in excavation and lining, with a note of the type of lining used, should be noted at least on a weekly basis, together with areas of overbreak or special difficulty.

Any continuously monitored or frequently measured data, such as surface settlements, dry and wet bulb temperatures, dust conditions and atmospheric monitoring, should be recorded as fully as practicable.

5 Information and investigation

5.1 General

All reasonably accessible information relevant to the construction of a tunnel and to any maintenance, renovation and repair of it should be obtained before the work starts. Special site studies are essential before tunnel construction can proceed, and are a continuing activity during construction.

Safety of the works can depend critically on adequate pre-contract ground investigation and proper interpretation of the information obtained. There should be the fullest practicable disclosure of all relevant information, or gaps in information, to those responsible for construction.

The recommendations set out in 5.2 and 5.3 should be treated as a check list and in no sense as a comprehensive specification. BS 5930 deals with site investigations in much greater detail. Further guidance may be obtained from TRRL Reports LR 403, LR 625 and LR 740²⁾ to which reference should be made.

5.2 Preliminary studies

5.2.1 Topography

Ordnance Survey maps and plans normally provide sufficient detail for the preliminary studies and for the siting of the works. Up-to-date information not yet embodied in published maps can be obtained from the regional offices of the Ordnance Survey and the local authority, to whom enquiries should be directed. Rights of way in England and Wales are shown on recent editions of the 1:63 360 (one inch) and 1:50 000 maps but further information is recorded in the Maps Library of the Department of the Environment. Old editions of maps may be important where they record workings and structures, and watercourses now abandoned and concealed. Aerial photographs of many areas are held by the Ordnance Survey, local authorities and air survey organizations.

In tidal waters and coastal areas Admiralty charts show the topography of the bottom and its nature.

5.2.2 Geology

The published maps, both solid and drift editions, of the Geological Survey, supplemented by much extra information accessible in the published and unpublished records of the British Geological Survey provide the essential background to tunnel siting and construction.

²⁾ Transport and Road Research Laboratory Reports LR 403 "Preliminary sources of information for site investigation in Britain"; LR 625 "Guidance on planning, directing and reporting site investigations"; LR 740 "A guide to site investigation procedures in tunnels". Copies obtainable from TRRL, Old Wokingham Road, Crowthorne, Berks RG11 6AU.

Other material which may be of use includes soil maps and memoirs of the Soil Survey of Great Britain and land utilization maps.

5.2.3 Hydrology

Record of surface water levels and flooding are usually obtainable from the appropriate regional Water Authority or Scottish Regional Council. In tidal waters Admiralty charts and other Admiralty publications provide essential information, which may be supplemented by the records of local harbour authorities. Tidal predictions, embodied in Admiralty tide tables, are of great importance for work at or near sea level. Discharge rates for rivers are published by HMSO in "Surface water year book for Great Britain". All appropriate records and predictions should be fully examined in the case of exposed areas.

5.2.4 Existing structures and services, and old workings

Knowledge of structures and earthworks should be sought within any possible zone of influence of the tunnel excavation. Plans of buildings and other structures in possession of the owners or deposited with the local authority should be examined both from the point of view of ground support required within the tunnel and of danger to the existing structure from settlement.

Industrial works and waste disposal sites, in operation or defunct, can constitute a special hazard to tunnelling particularly if noxious substances have seeped into the strata to be tunnelled. Ground anchors, whether permanent anchors providing support to existing structures or temporary anchors abandoned after temporary use for construction purposes, should be fully investigated as being both a hazard to tunnelling and liable to be detrimentally affected by tunnelling operations. Similar considerations will apply to piles and piling records should be consulted where available.

Enquiries should be made for records of wells and boreholes in the area to minimize the danger of breaking into old wells, and also to provide information on water table levels. Records of previous tunnel construction may provide valuable information. Learned societies and libraries may also give evidence of previous land use.

In mining areas, the fullest information on existing and abandoned coal mines kept by the British Coal Corporation should be consulted, but this may be incomplete in respect of older workings. Enquiries should be made as to whether there are any records of methane gas. Records of other mines and quarries are kept by the Mining Records Officer, HM Inspectorate of Mines and Quarries³⁾. Local knowledge of pits, adits and workings may be available, and may be supplemented by aerial survey photographs.

The fullest practicable information on services should be obtained from British Telecom, electricity, gas, water and drainage authorities and any other bodies having underground services. It should be noted that trunk mains and services may be the separate responsibility of national rather than local or area authorities.

5.2.5 Weather

The influence of local weather conditions on tunnel construction should be taken into account, e.g. predictions of rainfall and barometric pressure changes.

5.3 Special site studies

5.3.1 Boreholes

Boreholes, vertical, horizontal and inclined, should be sited to provide information specific to the tunnel under construction and possibly for tunnels to be renovated or repaired. This is to supplement the geological and hydrological information obtained from maps and records. They should be located close to the tunnel but not so close as to intersect it, unless for some special reason. A borehole too close to or intersecting the tunnel constitutes a serious hazard if water is present and particularly when compressed air is in use. In any case all boreholes need to be properly refilled, including the use of an adequate concrete plug. The siting of a borehole where a shaft is to be sunk makes possible the correlation between the borehole data and the actual ground experienced.

The number of boreholes to be provided depends on the length of tunnel and on the character and variability of the ground. There will normally be a need for the original pattern of boreholes to be supplemented by additional boreholes to check areas of doubt and to resolve special problems appearing at the construction stage. It is never safe to assume continuity of strata between boreholes or to join up apparently similar horizons.

³⁾ HM Inspector of Mines and Quarries, Health and Safety Executive, St Peter's House, Stanley Precinct, Bootle, L20 3LZ.

For tunnelling, it is important that some boreholes are taken to a depth well below the anticipated tunnel invert and adequately sampled and recorded. Automatic data recording techniques should be considered. Samples of subsoil and ground water should be properly identified, labelled and photographed where necessary, and stored for further examination if required. Expert supervision of boring operations and of sampling is essential if their full usefulness is to be ensured.

Where practicable, valuable additional information can be obtained from large diameter auger borings in which the strata can be examined in situ, or from test pits or shafts. Precautions against loose ground, water, gases and other hazards are necessary when boreholes and pits are inspected.

5.3.2 Probing ahead

Horizontal probing ahead of the tunnel face can provide valuable additional information. For large or difficult tunnels a pilot tunnel may be the appropriate method, providing both information on the nature and behaviour of the ground in advance of the main tunnel and the need for any special construction, ground support and ground treatment measures.

Probing from the face as it is advanced should be made possible in all tunnels. The extent to which it is actually utilized depends on the hazards in question and on minimizing interruptions to progress. The hazards which may call for such investigation include faults and fissures, cavities, ground water, loss of safe overhead cover and methane gas. In extremely bad conditions probing ahead in all directions may be necessary, combined with ground treatment, but care should be taken when drilling to ascertain cover to avoid penetrating aquifers above and below the tunnel (see 8.1.2 and 8.2).

5.3.3 Geophysical investigation

Geophysical methods most readily applicable to tunnel conditions are seismic and electrical ground resistivity surveys. Their usefulness is limited but they can supplement borehole information, principally in tracing well defined underground strata when boundaries between them have been clearly identified in boreholes.

The use of geophysical methods in combination with horizontal probes may be valuable. In urban areas, geophysical methods are not usually applicable, except to a very limited extent, because of interference by existing services and structures.

For a subaqueous tunnel, a marine seismic survey, e.g. sparker survey, may be of assistance in charting the river bed, determining bedrock surface, discovering buried channels. The survey may assist in deciding locations for site investigation boreholes.

5.3.4 Topography and surface survey

It is essential that an accurate site survey be made for the purposes of setting out and tunnel construction, and this is normally a contract requirement. This survey should define accurately the relationship of the tunnel to all existing structures and other features that might be affected.

An aerial survey can provide valuable additional information particularly for a major scheme.

Reference points, which are related to Ordnance Survey reference points, for the coordinate grid system of the survey should be established and preserved, as should adequate benchmarks for levelling.

Among the existing features that should be identified and recorded are manholes and valve covers, which help in locating existing sewers and buried services.

5.3.5 Underground survey

In addition to the surface topography, any underground structures should be accurately related to the proposed tunnel. A detailed survey to a stated order of accuracy may be a contract requirement prior to tunnel construction.

Among the structures to be surveyed are existing basements and foundations (owner's plans should, if possible, be verified by actual survey), existing headings, tunnels and underground workings, main sewers, and underground services generally. Any ground anchor cables which can be located should be accurately surveyed.

If any existing structure or service intersects or is very close to the exposed tunnel, possible special hazards which might result should be carefully examined and appropriate precautions taken.

5.3.6 Structural survey

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

5.3.7 Ground water tests

Where water levels in the area are variable or may be affected by the tunnelling operations, observation wells to observe and record any variation of levels are desirable and may be required preliminary to or during construction. Water levels in boreholes should be recorded, and any perched water tables or artesian supplies should be identified if possible.

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

Where tidal variations can be critical, as in compressed air working, tide gauges should be provided.

In special circumstances, other water tests can be made for salinity, acidity or pollution, and/or the presence of chemicals of natural or artificial origin.

5.3.8 Gas

Ground conditions should be considered very carefully to ascertain the probability of gas being present or entering the ground to be opened. According to this probability, tests should be carried out to ascertain the mode of its occurrence and the hazards it may present in the ground to be excavated during both the construction and the use of the works. This applies particularly to work in the coal measures, landfill sites and refuse tips.

5.3.9 Ground investigation during construction

It may be necessary to continue ground investigation during construction and this can be part of the probing operation (see 5.3.2).

6 Contingency planning

6.1 Assessment of hazards

Possible hazards should be considered and plans made for either their elimination or the reduction of the severity of their effect.

At an early stage, the contractor should prepare a tunnel hazard analysis considering the following questions.

- a) What hazards are there?
- b) How probable is each hazard?
- c) If the hazard should occur, what is the danger to life?
- d) What is the extent of possible damage to the tunnel?
- e) What damage could result outside the tunnel to other interests?
- f) What are the appropriate precautions and when should they be taken?

The use of formal mathematical or logical techniques to assess the level of risk from a tunnelling operation or item of tunnelling plant may be appropriate. The sophistication of the analysis used should be in keeping with the complexity of the project. Determination of the relative probability of the various hazardous events occurring may facilitate emergency planning by identifying the priorities. Each emergency should be considered and should be the subject of contingency planning so that all concerned are prepared and know how to take the appropriate action.

This analysis should be considered by the employers of persons on site with regard to their responsibilities under the Health and Safety at Work etc. Act, 1974, and by a site safety committee where formed.

6.2 Need for review of methods of working

Hazards should be considered in terms of their likely duration and recurrence and contingency planning should prepare staff for unexpected conditions. Along with immediate action to deal with the hazard complete review of the methods of tunnelling and of the plant used may be necessary. For example, replacement of, or modifications to, electrical equipment in particular may have to be considered. The alternative use of compressed-air-driven equipment would overcome problems of methane and very wet conditions.

6.3 Types of emergency

Emergencies for which contingency plans should be prepared are not only those arising primarily from natural hazards but also those arising from accidents, and from plant and power failures and stoppages; for example:

- a) ground collapse at the face which may be accompanied by an inflow of water (see clause 7);
- b) failure of temporary or permanent support some distance behind the face, which may be accompanied by an inflow of water (see clause 7);
- c) flooding of the tunnel from the face, from burst water pipes, from pump failure or by inundation at a shaft (see clause 11);
- d) gas and explosion most commonly arising from methane in strata of organic origin, or in strata near the surface due to leakage from a piped public supply, especially following any subsidence in adjacent workings (see clause 12);
- e) oxygen deficiency (see 10.4.2);
- f) fires in stored materials, timber supports, electrical installations, mineral oil, fuel or gas (see clauses 13 and 14);

g) accidents from moving plant which may, in the confined space of a tunnel, give rise to disproportionate consequences affecting the safety of all persons in the tunnel or the structural safety of the tunnel (see clause 23);

h) plant and power failures, particularly when the tunnel is dependent on a compressed air supply, pumping capacity or ventilation, when standby facilities should be installed (see 10.4.3 and 15.2);

i) stoppages, for whatever reason, that can constitute an emergency because of the need for increased support (see 7.3).

6.4 Chain of authority

Irrespective of the size or scope of the tunnel work involved on any site there should be a clearly defined chain of authority for emergency action.

There is a duty on all persons to report any abnormal circumstances thought likely to give rise to an emergency. Notices giving details of emergency procedures should be prominently displayed in all locations where concentrations of work are expected to occur, e.g. shaft tops, shaft bottoms, faces, airlocks, control rooms. Such notices should give the names of the responsible persons, the reporting procedure, a list of emergency telephone numbers and details of the nearest exit.

The primary responsibility for assessing and taking any immediate action necessary on such reports should be placed on one designated person, usually the senior site shift foreman, and this should be made clear to all concerned. This person should always have a nominated deputy.

The ultimate authority for implementing contingency planning and for action in an emergency should rest with the site manager or other nominated senior person. The senior site shift foreman should report fully to this person as early as possible. The resident engineer or other person responsible for supervision and inspection should be kept fully informed and should be consulted to the greatest practicable extent.

6.5 Priorities

In contingency planning for emergencies, the first consideration should be to minimize risk to persons working in the tunnel, and only then to reducing possible damage to the works and to ensuring that means are available to recover the face and restore damaged structures.

It is important that the number of people in any particular part of the tunnel should be known. The planning should therefore place on someone the responsibility of keeping a record of everyone entering or leaving that part of the tunnel.

In an emergency causing risk to the workforce evacuation of the tunnel may become advisable. The plan should allow for progressive steps of evacuation according to the nature and magnitude of the hazard, so that only persons vital to the safety of the works remain.

Power supply priorities should be clearly defined, circuits being designed, labelled and isolated accordingly for such services as emergency lighting, pumping, compressed air supply, ventilation, signalling and communications.

6.6 Emergency access

Access in all possible emergencies should be considered in advance. It is not always possible to ensure alternative access routes, but means of access such as ladders and walkways, independent of hoists or other mechanical equipment, should be provided in all cases.

Safe and well planned routes for access and escape can contribute greatly to the safety of persons and of the tunnel, as emergency work at the point of hazard can then be continued for a much longer period. Routes of escape should be planned to accommodate injured on stretchers.

In an emergency, teams unfamiliar with the tunnel works may require access for rescue, fire fighting or other reasons. A clear, durable, up-to-date diagram of the underground workings accessible from each shaft should be located at the shaft top.

Escape routes should be marked by signs, and other access routes also indicated. A senior designated person, often the senior site shift foreman should be responsible for ensuring that such signing is kept up to date.

Where a fire brigade, ambulance team or other outside organization may be called on to enter the tunnel, arrangements should be made for those concerned to visit the site and familiarize themselves in advance with access routes and any special procedures. During such visits, and in an emergency, any such team should be met and accompanied by a responsible person from the site fully familiar with the site conditions. Plans of major works should be made available to such teams for the use of their emergency controllers.

A particular problem arises with compressed air working; unless the outside organization concerned accepts a duty to enter, and prepares its team accordingly, it is the responsibility of the contractor to train and maintain emergency teams for fire fighting and other foreseeable emergencies.

6.7 Standby provisions

It is a normal part of construction planning to provide reserve capacity in plant, to consider standby power supplies (see 24.2) and to ensure the availability of spare parts and equipment for minor emergencies and breakdowns. For tunnelling, a particularly high standard has to be observed; in some cases full duplication of maximum requirements.

Additionally, contingency planning should ensure that essential equipment for major emergencies can be obtained when required. It may be necessary for critical items to be kept on site, but sometimes availability from another site or from a plant yard may be satisfactory; where such an arrangement is made, appropriate up-to-date records of stock should be available to all parties contributing to the arrangements.

6.8 Emergency exercises

To ensure that emergency procedures are adequate and are known to all personnel working underground, it is recommended that emergency exercises are carried out at frequent intervals. Involvement of the emergency services should be considered. Exercises are of little value if personnel are forewarned. To obtain maximum benefit from an exercise, observers should be posted at critical areas and key personnel should be debriefed after the exercise. Emergency procedures should be assessed and revised as necessary after each exercise. Where shift working is in operation emergency exercises should be applied to each shift.

7 Excavation and initial support

7.1 General

As the ground support and excavation are often one operation, appropriate cross-references are made. Some detailed methods of ground support are given in Appendix A, Appendix B and Appendix C.

7.2 Basic principles

The essence of safe excavation is to open up only so much ground as is self-supporting until temporary or permanent support can be provided. This varies over a very wide range from a small hand hole requiring immediate support in soft clay or running sand to the whole area of a tunnel in sound hard rock which may safely remain unlined for many weeks or indeed permanently. A safe system of work should be instituted and maintained at all times.

Time is of the essence in tunnelling. The safe time intervals between excavation, immediate support and final lining are critical to the whole construction procedure and its cost. As soon as a volume of ground is excavated, the stresses carried by it are relaxed and the load is immediately transferred to another section of the ground. The new loadings then initiate movement in the ground, which may cease quickly in sound rock, or may continue to develop slowly in firm and stiff clays, or rapidly in soft to very soft clays, sand or gravel. If the effects are to be localized, immediate support has to be provided to prevent progressive deterioration.

As safe times of exposure range from seconds to days or weeks, and the loadings range from mere containment to full overburden, the temporary support requirements vary enormously in strength and character.

The size of a tunnel is a major factor when determining the loads to be taken in the ground support system. In a ground where a small face may be safe to leave almost indefinitely, extensive and continuous support may be required when the face is large. In soft ground and sometimes in shattered rock, large faces present a hazard which is usually best reduced by construction of one or more pilot tunnels driven ahead of the main face. Pilot tunnels are preferably lined with a structurally continuous lining such as bolted cast iron (see 7.13.2 and 7.14.1). Alternatively it may be necessary to introduce an earth balanced or bentonite shield (see 7.16.3).

Experience and sound judgement are essential in deciding how much ground can safely be opened and for how long. It is not possible to specify any tests of general validity.

In all cases, where sudden changes are encountered immediate temporary support and containment may be vital. In loose ground where silt or sand may start to run, stuffing quickly with bags, straw, puddled clay, treated timber packing or other available material can be effective in maintaining the safety of the face. This "first aid" action has to be followed with more orthodox timbering to a high standard, and when the face is re-opened very great care is necessary.

Use of the Incremental Support and Observation Method (often called the New Austrian Tunnelling Method) can be made in certain limited conditions of ground such as the well cemented sands and clays, soft rocks (e.g. poorly formed slates) and similar types.

The basis of the method is constant observation of the ground and measurement of ground deformations as excavation proceeds. A range of support systems is kept readily available and used to accord with the ground conditions and deformations recorded. The range of systems typically includes arches, both rolled steel and lattice steel, benk bars or mesh, sprayed concrete, rock bolts and dowels. Various combinations are used according to conditions to provide the most economic support needed at the face. The theoretical basis of the method is to accommodate extra loads in a stress ring of strata around the opening assisted by a hoop tunnel lining.

7.3 Ground characteristics

7.3.1 Granular soil

Failure in granular soil may occur as:

- a) slow or fast ravelling, when material begins to dry out due to loosening or overstress or;
- b) running, in dry granular materials lacking cohesion or;
- c) flowing as a viscous mixture when a wet granular material becomes waterborne and can fill a long length of tunnel.

7.3.2 Sand and gravel

In sand and gravel there is no plasticity and little yielding under stress, but a small fall of loose material may quickly destroy the arching action which is carrying the load and result in progressive collapse. Accordingly, it is vital to provide support immediately 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, may be necessary. Careful boxing up and grouting of all voids is necessary when progress is interrupted.

7.3.3 Cohesive soil

In soils having some degree of cohesion and plasticity, ranging from silts to clays, failure may occur as:

- a) ravelling, where the ground is overstressed but fractures rather than flows or;
- b) squeezing, e.g. where a clay is overstressed and slowly extrudes without visible fractures or;
- c) flowing, by vibration or liquefaction in moist or saturated silts and by vibration in clays or;
- d) swelling, of a clay absorbing water possibly from the atmosphere and increasing in volume.

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

7.3.4 Clay

In soft clays, and in stiff clays where the presence of slickensides or backs causes weakness, it may be necessary to provide, as soon as practicable, support that restrains movement. Such support timbering should fit closely against the excavated ground and should be tightly wedged into position with a proper system of struts accurately cut to length and shaped at the ends. "Buttering" of poling boards with cement mortar or puddled clay can be helpful, as can cement grouting behind the boards in a close poled face. The plastic characteristics of clays produce a gradual development of disturbance. Immediate support keeps disturbance to a minimum. Changes of moisture content in clays due to exposure of the surface and load changes may, over a long period, result in swelling or shrinkage, with consequent need for improved support.

In a tunnel in clay, or any yielding ground, where a satisfactory cycle of operations is interrupted for any reason, the need for additional temporary support of a high standard should be recognized as should the possible need for sealing the clay surface against changes in moisture content. Boxing up and grouting all voids should be standard practice where there is an interruption such as at weekends and holiday periods.

7.3.5 Silt

Silt is particularly dangerous because cohesion can be suddenly lost in the presence of water, or when dried out. Close timbering of all faces becomes essential, unless the time of exposure is brief, the exposed area is small, or cohesion can be ensured. When a tunnel in silt is below the watertable, the use of compressed air, freezing, or other stabilization measures is essential.

7.3.6 Chalk

The Upper Chalk is usually well fissured and waterbearing and should be regarded as weak rock although North of East Anglia it may be stronger. Middle Chalk contains more marl and is usually more competent. Lower Chalk is really a marl and can be regarded as a very stiff clay.

7.3.7 Rock

After excavation or blasting in rock, there is normally an arching action across the tunnel in the newly exposed roof with some support from the undisturbed rock ahead of the face. The value of this support depends greatly on the direction and slope of the planes of weakness in the immediate vicinity; therefore the dip and strike of the bedding planes, the spacing and pattern of joints, and the presence of faults and any consequent fracturing and crushing all need to be taken into consideration.

The immediate arching action is followed by redistribution of stresses and movement of blocks of rock with possible penetration of water acting as a lubricant. Progressive disturbance may result in roof falls and repetition of the process at higher levels. In weak rock with frequent horizontal joints, this may lead to a void forming above the tunnel in the shape of a cone several metres in height. Near horizontal slabs of rock present in the crown can fail in bending if they are relatively thin with perhaps a damp layer of soft material above. Rock tunnels that break with a square crown should always be treated with the utmost caution. At all times the hazard of breaking into water-filled faults, fissures or cavities should be recognized. At faults, changes in the strata may be encountered and there will possibly be zones of extensive fracture, often with slickensides and fissures filled with gouge. Advance exploration followed by grouting or other special precautions may be required, particularly in subaqueous tunnelling.

In fault and shear zones rock may be altered so much as to have the characteristics of a soil. The combination of this alteration, the presence of groundwater and high cover or in situ stresses causes some of the most difficult tunnelling conditions found. In such fault zones full face excavation is often impossible even with pre-drainage, pre-grouting, forepoling, etc.

7.4 Methods of initial ground support

Table 2 sets out the main types of tunnelling and ground support systems. The initial support may be the first stage in the ground support system or, as in some uses of sprayed concrete, may be the only functional lining of the completed tunnel.

7.5 Methods of excavation and loading

7.5.1 Hand excavation

Excavation in many types and sizes of tunnel is carried out by hand using either conventional picks and shovels or airpowered picks, breakers and clay spades. The main hazard of this type of work is from falls of men and materials. It is important that proper working platforms be provided, as detailed in 7.6.2.2, 7.6.3.1, 7.7.2 and 7.9.3. Broken or badly maintained tools are a hazard not only because they may fail in use but also because of the need for excessive force on the part of the operator.

Small elevating conveyors are often used in conjunction with hand excavation and the safety precautions for these are described in 23.2.2.

7.5.2 Mechanical excavators and loaders

There is a variety of mechanical excavation and loading equipment used in tunnels. The full face tunnelling machines (see 7.16.2, 7.16.3 and 7.16.4) have their own excavation and loading equipment. Cutter booms (see 7.16.1) may not. Hand excavation and drill and blast tunnelling require separate equipment for loading away the spoil. Where these are mobile they pose additional dangers. Special care is required in the installation and use of conveyors (see 23.2.2). Only experienced or fully trained personnel should be permitted to operate such equipment. The designated machine operator is responsible for the safe operation of the equipment and should ensure that all personnel keep clear of moving parts. Before any part of the machinery is set in motion

an audible warning device should be sounded. Power is often routed to excavation and loading equipment by means of either hoses or electric cables. Arrangements should be made to ensure that there are no large tension forces on the hose or cable. Safety chains should be fitted to hoses and cables at the point of entry to the machine and retention devices should be provided at hose and cable connections.

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

7.6 Tunnelling and pipe jacking shields

7.6.1 General

Tunnelling shields are stiffened steel cylinders used to provide initial support and protection during excavation and lining erection or pipe installation in all types of ground except sound rock. Figure 1(a) and Figure 1(b) show a 4 m outside diameter tunnelling shield (see Appendix C) and Figure 2 shows a general arrangement of pipe jacking equipment. Shields are normally used in conjunction with concrete or cast iron segmental rings and jacking pipes. Common features include a cutting edge which can, in suitable ground, be used for trimming the periphery of the excavation. In most conditions it is useful to extend forward the cutting edge in the crown to form a hood. The stiffened body of the shield contains rearward acting rams which jack the shield forward off the completed segmental lining or pipes.

Table 2 — Methods of initial ground support

Type of tunnelling		Approximate size range	Typical ground	Usual initial support
1	Open shield a) with face support	1.0 m to 5.0 m diameter	Very soft clay to soft or shattered rock	Segmental lining
	b) with cutter boom or back hoe	1.2 m to 6.0 m diameter	Dense sand or gravel with binder. Stiff or firm clay	Segmental lining
			Soft rock without discontinuities	Steel arches and lagging. Rock bolts
2	Compartmental shield with face support	4.0 m to 10.0 m diameter	Very soft clay to soft or shattered rock	Segmental lining
3	Hand driven without shield with face support	1.2 m to 10.0 m diameter	Very soft clay to soft or shattered rock	Segmental lining
4	Rock tunnelling	Up to 12.0 m span	Other than in decomposed rock	Steel arches and packing
		Over 2.5 m		Sprayed concrete
		All sizes		Rock bolting
5	Small heading	1.0 m × 1.3 m to 2.5 m × 2.5 m	All types except sound rock	Timber
6	Small tunnels	Up to 2.0 m diameter	All types	Segmental lining
7	Pipe jacking	900 mm and larger	All types	Concrete and steel pipe. Box culverts
8	Soft ground tunnel boring machine	900 mm and larger	Stiff or firm clay	Segmental lining
9	Bentonite, slurry shields and earth balanced shields	Over 900 mm diameter	Granular soils below watertable	Segmental lining. Concrete pipes
10	Hard ground tunnelling machine	1.2 m to 12.0 m diameter approx.	Generally sound rock	Nil
			Weak rock	As for 4
11	Compressed air	All sizes	Soft ground	Segmental lining. Concrete pipes
12	Geotechnical processes a) ground freezing	All sizes	Waterbearing granular soils	
	b) chemical ground treatment	All sizes	Granular soils	
	c) ground dewatering	All sizes	Waterbearing sands and gravels	

Before “shoving” the shield, excavation should be complete to the stage where excessive ram pressures are not required. Unless an expanded lining is to be used, a tail skin is fitted behind the shield. This provides protection within which the bolted segmental lining can be erected or a lead pipe fitted. After erection of a ring of such lining and further excavation the tunnelling shield is jacked forward and a radial gap of the thickness of the tail skin plus clearances is left between ground and lining. This gap tends to fill by ground movement which should be minimized by grouting as soon as possible. The pipe jack shield is designed to produce a small overbreak to the external diameter of the pipeline. Normally a lubricant such as bentonite is introduced into this overbreak to reduce friction and minimize ground movement. All shields should have provisions for face support, which may be required continuously as tunnelling proceeds or kept for emergency use only. The frequent or continuous use of face support on a shield drive normally means a handmucking operation. When the shield is being jacked off the segmental rings, i.e. “shoved”, it is essential that the person designated as shield operator ensures that nobody can be caught between the rams and the lining.

The operation of clay pocketing is a safety procedure whereby a shield is used in conjunction with compressed air in sands or gravel; this technique is described in C.2 and Figure 1(b).

7.6.2 Open shield

7.6.2.1 General

Open shields used in conjunction with manual excavation and ground support methods can be employed in a variety of ground conditions. When face support is required it is normally held by hydraulic face jacks which maintain pressure on the face timbering by retracting as the shield is jacked forward. Alternatively, if the requirement for face support is likely to be infrequent the support can be strutted back through the shield to the completed segmental lining or jacking pipes. This also allows the shield to be jacked forward without affecting the timbering.

In some shattered rock conditions or where there is a mixed face, e.g. of rock and soft ground, the rock will need to be excavated clear of the cutting edge. It may then be necessary to provide crown and shoulder support in the form of headboards which span between the shield cutting edge and the face timbering. This is often one of the most hazardous tunnelling situations.

7.6.2.2 Specific

The work of providing ground support should be carried out from properly designed and installed working platforms. In the 2.5 m to 5.0 m diameter range platforms should span across the shield, giving access to the face whilst allowing muck to fall into a clear invert.

Scaffolding or similar is not suitable for this purpose as the uprights are liable to be knocked away by falling debris. If there is a hood on the shield it will be necessary to provide working platforms with a sliding facility in order to get the platforms close to the face. Working platforms are frequently temporary, being installed only for the initial support and mucking part of the tunnelling cycle and then removed. Responsibility for their correct and safe installation should be given to a designated person, customarily the senior site shift foreman who will generally be a leading miner or shift boss.

The erection of the tunnel lining will normally be carried out by hand, with or without the use of air winches. Air winches, snatch blocks, roller bolts and fixings should be designed and tested after installation. Wire ropes used in erecting lining should be inspected frequently as they are subject to heavy wear and damage.

7.6.3 Compartmental shield

7.6.3.1 General

For larger tunnels in soft ground the cylindrical shield is braced horizontally and vertically to form compartments. These compartments or “boxes” form workplaces for face excavation and timbering.

Face jacks or other arrangements for supporting the face should be incorporated. It should be noted that the face strutting or jacking device should maintain its thrust when the shield as a whole is being jacked forward and yet allow the shield and platform to move independently. Access to the face will be by ladders and gangways which should be protected by handrails and provided with toe boards as for a normal scaffold.

7.6.3.2 Specific

The shield should be designed to give operatives working on it protection from falling muck, and easy egress in an emergency. Segment erection will normally be by erector arm and an audible warning device should be provided and sounded prior to operation of the erector arm. During a shove, only operatives with specific duties relating to the safety of the operation, including the control of the face timbering, should be allowed on the shield.

7.7 Hand driven segmental lined tunnel without shield

7.7.1 General

There are many occasions where cast iron or precast concrete segments are built without the use of a shield. Tunnels built in this way vary greatly in size and ground conditions, and few rules are applicable overall. In the most general terms the procedure for excavation of a full tunnel face in soft ground is to excavate from the top downwards, securing the top and face as soon as exposed. The face is taken out in steps or benches. Appendix B gives a procedure for timbering a 3.5 m diameter face without a shield in soft ground. In better ground it may well be possible to take the face down vertically with little or no timbering and build the ring in a correspondingly shorter time.

7.7.2 Specific

In larger diameter tunnels where the length of drive warrants it, a permanent access stage should be designed and built which will normally run on roller brackets fixed on the completed lining. This access stage should be independent of any face timbering. If the drive does not warrant a fully mechanized segment erection system, the equipment and working procedure for the segment erection method should be predetermined and each member of the team made aware of his duties and the equipment to be used.

7.8 Drill and blast

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

NOTE See BS 5607 for the storage, handling and use of explosives.

With this method of excavation the principal direct hazard at the tunnel face (apart from hazards connected with the use of explosives) is that of rock falls. The degree of risk will depend upon the characteristics of the rock and its structure, and on the techniques adopted for drilling and blasting, which may need to be modified as experience is gained in the particular tunnel.

The hazard of rock falls is most acute in the period after the blast and before temporary support, if required, is completed. Scaling down of loose rock should be done in a systematic manner working towards the face. Apart from checking the area of the ground that has just been fired, areas that have been previously scaled should be rechecked. Scaling down should be carried out by experienced persons and checked by a senior foreman. The persons carrying out the scaling should stand to one side of the area of rock being worked: this means that scaling bars of adequate length need to be used and access provided where necessary. Mechanical scaling should be considered as an alternative to manual scaling.

The handling of air drills and pusher legs requires strength and skill. If several drills are in use at a face it is necessary that they are handled in a systematic manner under experienced supervision.

Flying rock can easily become lodged in disconnected compressed air lines and air mains. These lines and mains should be checked before they are connected to the compressed air system, and then blown out before use, clear of personnel.

7.9 Steel arches and packing

7.9.1 General

In rock tunnels that require support, a common form of immediate support is the steel arch rib. If this, in conjunction with timber or steel poling, can be fixed, wedged or packed up sufficiently quickly after excavation, safety can be greatly enhanced. Arched support varies widely in size and geometry and only the most common type and some typical hazards are dealt with.

The type of arch and spacing should be fully specified. In variable rock conditions there should always be a competent person on site who has the experience and authority to order the use of arched support.

7.9.2 Two-part arches

An inverted U-shaped arch with one bolted joint at the crown is commonly used in tunnels up to 3.5 m high [see Figure 3(a)].

After blasting, mucking and scaling the initial objective is to place the arches in position with some packing in order to give protection as soon as possible. Further packing, wedging or fixing as necessary can then take place.

Care should be taken to ensure that the arch is founded on rock capable of taking the vertical load. Arches should be securely fixed one to the other with ties and struts. It may also be necessary to rock bolt the arches or fix steel dowel pins alongside the arch in order to stop movement during subsequent blasting. The packing between arch and rock should be wedged tight and the arches should be securely packed, particularly at springing level, to stop sideways movement at that point. If it is thought that the vertical leg part of the arch is liable to take sideways load, the leg should be tied back to the rock with rock bolts, or otherwise secured.

Horseshoe-shaped arches should not be used without the foot of the arch being effectively restrained from movement. The bolted joint at the crown should be made correctly with all the bolts tightened through the designed fishplates. Arch rib support adjacent to the face should be checked for movement after each round is fired. During its working life each arch rib support should be checked on a regular basis. Where arches are used to support a top heading they should be secured before lower excavation proceeds.

7.9.3 Large arches

All the criteria for the correct setting of two-part arches apply to large arches, but in addition the following points apply.

The erection procedure for large arches, made from several bolted sections, should be specified. The erection equipment, which can often be mounted on excavating or drilling machinery, should be properly designed for the particular situation. Access to the bolted joints and for packing should be from properly designed platforms and stagings.

7.10 Concrete spraying

The term “concrete spraying” is deemed to cover all pneumatically applied mixes of cement, water, additive and aggregate, including “shotcrete” and “gunite”. In rocks where there is liable to be a progressive loosening, the rock surface should be sprayed with concrete as soon as possible after blasting. The effect of this is to stop deterioration of the rock surface, secure any loose material and reduce changes in the self-supporting stress pattern in the rock surrounding the tunnel (see Figure 3). The precautions to be taken when using concrete spraying equipment are detailed in 9.2.

7.11 Rock bolting

Rock bolting, in which bolts are anchored into holes drilled into the rock, functions primarily as a method of support by preserving the integrity of the rock mass [see Figure 3(b) and Figure 3(c)]. Rock bolting may be either temporary support or an element of the permanent support. There are several systems of rock bolting which can be divided into two types. The first type consists of providing an anchorage, either mechanically or chemically, at the far end of the drill hole and then tensioning the bolt against a face plate at the rock surface. This type of rock bolt can be grouted up after fixing. The second type of rock bolt is anchored along its length using resins or cement mortar in a perforated sleeve. The effect of having a bond along the length of the bolt is to stitch together rock masses which are divided by natural jointing.

While rock bolts may be used merely to tie back loose slabs which would otherwise be liable to fall, their more fundamental use is in maintaining compression across discontinuities such as joints, fissures and bedding planes so that arching action can be sustained by the whole mass of rock.

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

The safe installation and functioning of a rock bolting system depends on proper design to suit rock characteristics and the excavation and lining methods. Further guidance is available in BS 8081.

Among the precautions necessary are the following.

- a) The anchorage should be designed to resist the full pull-out value of the bolt without slipping in the bore or crushing the rock locally. Load tests in situ should be carried out on representative bolts.
- b) The bolting should be completed as quickly as possible after excavation.
- c) If a rock is at all friable, metal mesh should be secured to span between bolts, the surface being gunited if necessary.

Secure anchorage at sufficient depth is vital. Fixing as quickly as possible is important to prevent the initiation of movement. All such systems should be executed in accordance with plans prepared by a person competent in the principles of rock mechanics and familiar with the local geology. The condition of the rock in the roof should be thoroughly examined and when necessary the rock should be scaled down. Personnel should be adequately protected before drilling takes place.

7.12 Compressed air

Compressed air on its own may not always support a tunnel face. Tunnels may require face support in addition to the assistance provided by compressed air. Compressed air may also reduce settlement caused by ground moving to fill the annular space behind the shield before grouting takes place (see clause 10).

7.13 Geotechnical processes

7.13.1 Freezing

Waterbearing ground can be made impermeable and given cohesive strength if it can be frozen and so maintained.

Freezing is normally effected by circulation of brine at subfreezing temperatures in a closed system of pipes. Freezing of the ground water takes place slowly and may be impossible if there is an underground flow of water which brings in heat at too fast a rate. This hazard may not be apparent until excavation is in progress when there arises a risk of very rapid erosion: appropriate tests should be made and precautions taken against the development of such an emergency. Freezing by liquid nitrogen is possible and acts more quickly, but its use presents special problems such as reduction in tunnel oxygen.

Freezing can be a particularly effective technique in silts and in gravels with silty layers which are very difficult to treat by grouting.

Ground heave may result from the expansion of water on freezing and from the build-up of ice layers. This can be a hazard to overlying structures, and water mains within the freezing zone may need to be insulated.

If a heading, such as a pipe heading, is driven through frozen ground there is likely to be a build-up of ice on timber supports. The utmost care needs to be taken in refilling the heading to ensure that ice is not left in to form a void and cause settlement. If the ice cannot be wholly thawed or removed, subsequent pressure grouting may be necessary through pipes left in and leading to the critical areas.

7.13.2 Ground injection

Chemical ground treatment in advance of tunnelling is used to enhance safety in excavation. It does this directly by improving the characteristics of the ground to be excavated and indirectly by sealing off water, or strengthening the overlying or surrounding ground. The design of a suitable grouting system and pattern for particular circumstances is very specialized and expert advice is essential.

If sand or gravel is expected in the tunnel face, particularly if it is waterbearing, its permeability can be greatly reduced by the injection of suitable grout mixtures; cohesive strength can be added and if the tunnel is being driven in compressed air the loss of air can be greatly reduced.

The choice of grout mixture and the spacing and pattern of injection holes will be determined largely by the grain size of each stratum. For example, cement grout will not travel far or prove effective except in very coarse open gravel, and progressively finer grouts of lower viscosity are required in fine sands. Most difficult of all are silts which can normally be treated only by clacquage. Clays can not be treated by traditional methods. However, new techniques of jet grouting have proved successful in many cases and should be considered especially where ground heave is not a problem. The permeability of the ground is rarely consistent and the possibility of meeting untreated pockets should never be ignored. Ground water quality should be taken into account when designing the grout.

If fissured rock is to be treated, it may be difficult to locate and treat all significant fissures, especially if some are filled with gouge or soft clay.

When advance ground treatment by grouting is considered necessary it may be carried out in one of the following ways:

- a) from the surface by driving down grouting tubes to the level requiring treatment;

NOTE If this method is used after compressed air has been used in a tunnel it often results in the grouts being blown aside during injection.

- b) radially from a pilot tunnel to improve conditions for driving the main tunnel;
- c) through a tunnel face during construction.

In all cases the chemical characteristics of the grout used should be ascertained and appropriate precautions taken.

The hazards to be avoided are:

- 1) pollution and damage at the surface from spillage and waste discharge. Arrangements for collection and disposal of waste should be made in advance and should be approved by all relevant authorities, including those for water supply and sewerage;
- 2) pollution of underground water by transfer from the stratum treated;
- 3) risks to men handling the materials during and after mixing, including risks from burst pipes and hoses;
- 4) toxicity of some special grouts which enhances the risks in handling makes more stringent precautions necessary, including the provision of protective clothing and full washing facilities;

- 5) grouting from inside the tunnel, particularly in a small pilot tunnel where the enclosed space makes it essential to take all necessary precautions, to adopt high standards of cleanliness and to ensure that the ventilation system provides an ample supply of fresh air;
- 6) interference with adjacent services and property;
- 7) excessive pressures which may cause ground heave and damage to surface structures;
- 8) excavation in ground previously impregnated with toxic grouts or grouts which give off toxic gases or vapours.

7.13.3 Dewatering

For shallow tunnels in waterbearing sands and gravels, it may be possible to stabilize the ground by means of wellpoint dewatering. Expert advice is essential but the basic process consists of lowering the ground water along the line of the tunnel by means of a pattern of filtered well points connected to a header pipe which runs to a vacuum pump. The filters on each well point stop fine particles being drawn into the system. By using deep wells and “down the hole” pumps, ground can be stabilized to greater depths than is possible by wellpointing.

The main hazards of these systems are as follows:

- a) settlement at the surface due to the watertable being lowered;
- b) failure of the dewatering system whilst the tunnel is being driven. This causes the ground to revert to its former unstable condition and rapid massive ground loss can follow. It is imperative that the system is set up with the best available equipment and plant, that items are duplicated where possible and that the surface pipework is protected from accidental damage.

7.14 Small headings and tunnels

7.14.1 General

Small headings are generally temporary in character and are driven to explore the ground ahead of the main tunnel, for operations such as pipelaying, or to provide access between two points. No permanent lining is required because the heading will be either refilled or eaten out by the main tunnel; however, temporary support needs to be adequate to last for as long as the heading remains open and to secure the surrounding ground against settlement and collapse.

It should be emphasized that the risk of collapse or excessive settlement is greater with small timbered headings than with other forms of tunnel construction. Only the highest standards of workmanship in initial timbering and subsequent backfilling will ensure safety.

Various types of timbered headings are described in Appendix A to illustrate general principles.

Tunnels having a face area of less than 2 m² are included under this code to the extent that operatives are employed inside them for excavation and construction. For tunnels under construction the minimum internal size for man-entry should be not less than 900 mm diameter in order to facilitate rescue; tunnels smaller than this should be non-man-entry.

The principles of safety are the same but because of the very restricted space some hazards are intensified. As it is frequently the case that such projects are very limited in space, time and resources, it becomes impracticable to apply systems designed for larger projects. It is therefore essential that those working in such tunnels should be responsible and fully experienced persons familiar with the actual and potential hazards, and that safety procedures for the particular tunnel should be precisely defined before work commences and faithfully observed.

7.14.2 Specific

The size of timber used will depend on the ground type and the size of the heading, but no timber under 38 mm thick should be used for headboards. All timbers should be checked for imperfections that reduce strength. Timber that is to be built in should be pressure creosoted or otherwise treated against decay (see BS 913, BS 5268-5 and BS 5589). All materials required for the heading should be readily available as close as is practicable to the face.

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

The primary responsibility for workmanship and safe practice within the technique of the timbered heading chosen rests with the competent person in the face gang, who should be experienced in the type of timbering employed.

The backfilling of small headings with concrete should be done with the greatest care. The top 600 mm of heading should be pneumatically filled with concrete or hand stuffed with dry concrete. If the prevention of surface settlement is critical, the heading should be backgrouted in sections to ensure that all voids are filled.

In small tunnels, operatives cannot walk upright and can pass one another only with difficulty. It is normal practice for a single operative to excavate the face, although a second should always be present.

Arrangements should be defined for the rescue and escape of the face workers in the event of accident, injury, illness, immobilization of a locomotive, derailment or fire.

Ventilation may be a problem of particular difficulty because there will be little or no natural circulation and because shallow tunnels through variable ground will frequently pass through or near ground with organic content or with other contamination that may pollute the tunnel atmosphere. A supply of fresh air to the face is therefore essential.

7.15 Pipe jacking

The pipe jacking process is a system in which pipes or similar structures are thrust through the ground and the material from the face is removed through the pipeline, having been excavated by hand, or mechanically (see 7.16). The pipes are introduced at the working pit and cumulatively thrust forward by jacks. The leading pipe is preceded by a shield, as above, which enables the pipeline to be kept on line and level by using jacks for steering. (See Figure 2.)

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

The use of bentonite grout or other lubricant injected onto the sliding surfaces may assist in reducing thrusts. If lubricants are injected at high pressures it is recommended that eye protection be provided.

When jacking pipes through loose or waterbearing soils, precautions should be taken against a run of loose material from the face of the shield which could lead to the collapse of the overlying ground. When jacking pipes into firm or stiff clays, the techniques adopted should take into account the displacement of the soil caused by entry of the pipes, and the possibility of heave of the ground surface. Particular care is necessary when jacking pipes beneath the running lines of railway tracks, rivers, canals, other water courses and sensitive structures.

Pipe jacking pipes are installed via a working shaft and jointed using hydraulic jacks. It is essential that all operatives should seek shelter or protection within the part-completed pipeline or elsewhere whilst pipes are lowered.

For small diameter pipe jacks arrangements should be defined for rescue and escape of face workers in the event of accident, injury or illness. Ventilation may be a problem as with small headings and tunnels (see 7.14.2).

7.16 Tunnelling machines

NOTE These machines may also be used for excavation for pipe jacking.

7.16.1 Cutter boom or other mechanical excavator

Part face attack machines, often described as cutter booms, are usually used only in ground where face support is not normally required. Nevertheless a set of sized and cut timbers should be kept available for emergency use. Steel arches described in 7.9 are often used in conjunction. Additionally cutter booms are often installed in shields to increase rate of excavation. The controls described in 7.5.2 apply.

7.16.2 Soft ground boring machine

A soft ground boring machine is generally installed on long tunnel drives through sound clay where there is a low incidence of ground support hazards. As with all full face tunnelling machines, access to the tunnel face may be required from time to time for inspection, maintenance, repair or other purposes.

Strict precautionary rules need to be enforced to ensure that the machine will not be started up while any operatives remain in the face. A locking device should be provided, or a main fuse removed, and a competent person designated to ensure that movement of the machine is prevented until all who have entered have checked out again.

7.16.3 Bentonite, slurry and earth pressure balanced shields

A special type of closed tunnelling machine is the bentonite or slurry shield designed for use in waterbearing ground. Bentonite or other slurry is retained at appropriate pressures ahead of a diaphragm within a cylindrical shield, and a cutter head rotates within the slurry chamber, excavated material being discharged to the rear through a valve system. In normal operation, the face is totally enclosed and permanent prefabricated linings or pipes are erected within a tail so that there is no hazard of falls of ground. The full thrust from slurry pressure against the whole area of the excavation is carried back through the shield structure to the finished lining.

Some equipment uses compressed air in the slurry chamber with access by a lock. Access for rescue should be considered.

Earth pressure balanced shields differ from slurry shields in having mechanical means (e.g. auger or screw conveyor) for removing the spoil from the face. This adds to the danger from moving machinery. Provision should be made to control the flow of water through the conveyor. To cope with an emergency during construction or a repair at the tunnel face, provision should be made for the use of compressed air or any other suitable method.

7.16.4 Hard ground tunnelling machine

Full face tunnelling machines have to meet extremely varied and variable conditions of rock hardness, jointing, water, etc. and there is little standardization of equipment. In general, the face is inaccessible while excavation is in progress so that, provided men are excluded from the moving parts, personal danger at the point of excavation is minimized.

The precautions required for access to the tunnel face are as detailed in **7.16.2** for the soft ground boring machine.

Danger to the tunnel may arise where a sudden change in rock conditions at the face is encountered and where emergency action is difficult because of inaccessibility. The probability of such a contingency should be considered and means to overcome it should be examined before such a machine is put to work and, if necessary, provision should be made for borings and probes ahead of the face to ascertain the presence of fissures, faults and other changes in the ground. Probing routines should be incorporated where necessary in the operating cycle, after a full study of the information likely to be gained and of the risks involved. Where safe cover is shallow and uncertain, probes should be made to a point above and ahead of the crown of the machine and should be plugged immediately after completion.

In some rock conditions, unless continuous support is incorporated immediately behind the cutter head, there is a risk of falls of ground from the roof behind the face and ahead of the completed lining; appropriate screening should be provided to avoid risk to operatives and damage to equipment.

Tunnelling machines may also incorporate lining erection devices behind the face for either immediate support such as ribs, or permanent prefabricated linings. Moving parts for such operations cannot be fenced off and operatives will almost invariably be required to handle the structural element being erected. The special hazards particular to tunnelling machines arise from the confined working space and unavoidable noise, and overlap of the operations of excavation, muck disposal, erection of support or permanent lining and grouting.

Operatives working on and immediately behind a machine should have clearly defined responsibilities and should receive instructions in their duties and on the hazards before commencing work (see also **4.4.2**).

8 Management of water

8.1 Exclusion of ground water

8.1.1 General

The hazards from water are manifold. At the face the pressure of water tends to wash out any fine grained loose material and thereby to loosen the whole face. If there is present any considerable reservoir of water, as in subaqueous tunnels or where underground springs may be encountered, any flow at the face may lead to piping and enlargement of the water passage and ultimately to inundation. In less onerous conditions there may still be serious settlement and loss of stability in the ground ahead.

In rock, fissures may be scoured out resulting in ever increasing inflow. Water following along behind the finished lining can also cause a hazard by scouring out cavities.

Water is probably the greatest single cause of tunnel disasters. In all routine provisions for handling water it is essential that the contingency of inundation be taken into account. Hazards and precautions are further dealt with in clause **11**.

During excavation, water in the ground surrounding the tunnel should be managed by holding it back, by allowing it to flow in under restriction or by draining it off externally. Care should be taken to ensure that the presence of water in the tunnel itself does not create hazardous working conditions.

Methods of excluding water or restricting its inflow are described in **8.1.2** to **8.1.8**.

8.1.2 Use of impermeable cover

Where water overlies an impermeable stratum of uncertain nature through which a tunnel is being driven, the thickness of the stratum ahead of the excavation should be proved by probes diagonally ahead and upwards, which should be plugged securely immediately after augering.

Occasionally, the threat of water comes from below the invert and this calls for great care in probing, to prove safe ground ahead. Suitable equipment, such as glands and packers should be used as a precaution to prevent an unmanageable flow of water developing during construction.

Where clay or other impermeable cover is in a river bed above a subaqueous tunnel, it may be necessary to enhance it or to repair it by depositing a clay blanket from above.

8.1.3 Ground freezing

Sealing of ground water may be effected by freezing; details of this process are given in 7.13.1.

8.1.4 Ground injection

Water in the ground may also be sealed by injection grouting of the waterbearing strata using appropriate mixtures and techniques of treatment. The design of a grout curtain for any particular situation is highly specialized and should be entrusted only to those fully experienced. Details of ground treatment are given in 7.13.

8.1.5 Compressed air

Water may be controlled rather than excluded by use of compressed air; this is dealt with more fully in clause 10 and 7.12.

8.1.6 Bentonite, slurry and earth pressure balanced shields

The bentonite, slurry and earth pressure balanced shields described in 7.16.3 exclude water by sealing off the working face.

8.1.7 Regulation

Where the flow of water is small, it may be better to restrict or regulate it than to seal it off, so avoiding the building up of pressures, before the tunnel is finally lined.

In granular soils close timbering of all exposed ground at the face and the use of puddled clay in the joints and straw or hessian in small voids may eliminate washing out of fines.

The use of a bottom drainage heading or a drainage tunnel ahead of the tunnel and at or below invert level may draw down the level of the water table and dry up the face. In tunnels where the ground will allow, drains bored ahead of the face in the invert may prove effective.

In rock tunnelling in particular, water flows may be accepted and piped through the immediate lining membrane so that pressure is not allowed to build up. Ultimately, such piped flows may be sealed up and backgrouted, or they may be accepted as permanent, according to circumstances.

8.1.8 External drainage

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

8.2 Handling of water in tunnels

8.2.1 Tunnel gradient

Under wet conditions there is normally great advantage in driving a tunnel on an ascending gradient because all water flows back from the face.

Unless the tunnel is dry or drains satisfactorily by gravity back to the portal, a system of sumps and pumps will be required. Subdrains leading to the sumps, or connecting successive sumps, may be helpful.

8.2.2 Sumps

Sumps are often sited in the invert and are liable to be submerged; they therefore constitute a hazard to men walking along the tunnel and should be decked over. The decking should provide secure foothold without substantial gaps and should be so fixed that it cannot float up when submerged. While it needs to be removable for maintenance and pump access, it is desirable that it should be hinged or otherwise located so that it can be seen when it is open and can be replaced correctly.

Submerged sumps, such as cleaning pits at the bottom of main sumps, should be covered by secured gratings. Sumps with access from the tunnel side should have adequate handrailing.

8.2.3 Pumping capacity

In all tunnels capable of being flooded, pumps should provide a wide margin of capacity to meet abnormal conditions and partial failures. All tunnels on a downgrade should be considered liable to flooding and availability of adequate spare pumps for emergency use should be ensured. Pumps sited near the face should be submersible so that access to the face can be recovered after flooding. Float switches operating audible and/or visual alarms should be fitted in sumps to give adequate warning of defective pumps.

8.2.4 Subdrains

Subdrains beneath the tunnel invert may be used to interconnect sumps or assist in lowering ground water. Unless there is good reason to the contrary, they should be grouted up solid when no longer required.

8.2.5 Compressed air

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