

Sewerage —

Part 3: Guide to planning and construction of sewers in tunnel

UDC 628.2 + 628.24:624.196

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Civil Engineering and Building Structures Standards Policy Committee (CSB/-) to Technical Committee CSB/5, upon which the following bodies were represented:

- Association of Consulting Engineers
- Association of County Councils
- Association of District Councils
- British Ceramic Research Ltd.
- British Coal
- British Plastics Federation
- British Precast Concrete Federation Ltd.
- British Tunnelling Society
- Clay Pipe Development Association Limited
- Concrete Pipe Association
- Construction Industry Research and Information Association
- Convention of Scottish Local Authorities
- County Surveyor's Society
- Department of the Environment (Property Services Agency)
- Department of Transport (Highways)
- Federation of Civil Engineering Contractors
- Fibre Cement Manufacturers' Association Limited
- Health and Safety Executive
- Hydraulics Research Station Ltd.
- Institute of Water Pollution Control
- Institution of Civil Engineers
- Institution of Environmental Health Officers
- Institution of Public Health Engineers
- Institution of Structural Engineers
- Institution of Water Engineers and Scientists
- Royal Institute of British Architects
- Scottish Development Department
- Trades Union Congress
- Water Authorities Association
- Water Research Centre

This British Standard, having been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee was published under the authority of the Board of BSI and comes into effect on 30 November 1989

© BSI 03-1999

The following BSI references relate to the work on this standard:
Committee reference CSB/5
Draft for comment 84/11183 DC

ISBN 0 580 17559 6

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
Section 1. General	
1 Scope	1
2 Definitions	1
3 Abbreviations and symbols	1
Section 2. Planning, design, safety and choice of lining	
4 Planning	2
5 Design	4
6 Safety	6
7 Preformed primary tunnel linings	6
8 In situ primary tunnel linings	9
9 Secondary linings	9
Section 3. Construction	
10 Construction techniques	12
11 Permissible deviations	27
Appendix A Bibliography	28
Appendix B Stability number	29
Index	31
Figure 1 — Details and dimensions of typical bolted precast concrete segmental lining	7
Figure 2 — Details and dimensions of typical expanded precast concrete segmental lining	10
Figure 3 — Guidance on the range of possible ground treatments related to D_{10} of soil	15
Figure 4 — Influence of heading geometry on stability number at tunnel collapse	30
Table 1 — Stages of site investigation	3
Table 2 — Range of preformed linings in the UK	22
Table 3 — Recommended permissible deviations for internal faces	27
Publications referred to	Inside back cover

Foreword

This Part of BS 8005 has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee and is directed at general engineering practitioners who may either be embarking on a career in sewerage or be dealing with a particular aspect for the first time. It is not intended to be exhaustive in any field but sets out to present guidance on basic principles and good practice, indicating where a more detailed and comprehensive study may be made. BS 8005 supersedes and enhances CP 2005:1968, which is withdrawn, although some of the material incorporated is a restatement of the earlier text.

BS 8005 gives guidance on the planning, design, construction, operation and maintenance of works to convey sewage, including storm sewage, surface water and trade effluents to a sewage treatment works, tidal waters or other final place of disposal. Recommendations are given for the repair, renovation and replacement of sewers.

Many end users of this British Standard, such as governments, public authorities, sewerage authorities and consultants, issue their own recommendations and specifications for sewerage which BS 8005 is intended to complement rather than replace.

BS 8005 is being published in six separate Parts, as follows.

- *Part 0¹⁾: Introduction and guide to data sources and documentation;*
- *Part 1¹⁾: Guide to new sewerage construction;*
- *Part 2¹⁾: Guide to pumping stations and pumping mains;*
- *Part 3¹⁾: Guide to planning and construction of sewers in tunnel;*
- *Part 4¹⁾: Guide to design and construction of tidal outfalls;*
- *Part 5²⁾: Rehabilitation of sewers.*

It has been noted that substantial one-part codes and guides take a long time to revise and if they are reviewed at infrequent intervals, they tend to become out of date quickly, especially in a field where technological development is rapid. It is intended therefore to keep a constant watch on new developments and to update BS 8005, Part by Part, as soon as the work can be justified.

BS 8301 sets out recommendations for building drainage and, while it relates generally to smaller pipelines, there is some overlap between it and BS 8005. BS 6297 gives recommendations for the design and installation of small sewage treatment works and cesspools.

Apart from Part 0, which is directed more specifically at the UK sewerage field, BS 8005 is for use both in the UK and, in appropriate circumstances, overseas.

Suggestions for the improvement of any Part of BS 8005 will be welcomed by the Secretary of SEB/43 at British Standards Institution, 2 Park Street, London W1A 2BS.

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.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 32, 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.

¹⁾ Published.

²⁾ In preparation.

Section 1. General

1 Scope

This Part of BS 8005 provides guidance on the planning, design and construction of sewers constructed in tunnel. It includes guidance on tunnel linings and ancillary materials and recommends permissible deviations for internal faces.

NOTE 1 For the purposes of this Part of this standard a sewer constructed in tunnel means a pipe, conduit, or culvert constructed entirely below ground level within an excavation which is not open to the surface except at access shafts.

NOTE 2 The titles of the publications referred to in this Part of this standard are listed on the inside back cover. Attention is particularly drawn to BS 6164.

The titles of standards publications not referred to in this Part of BS 8005 but of interest as dealing with closely associated subjects are listed in Appendix A of BS 8005-1:1987.

Other references will be found throughout the text, indicated by bracketed numbers thus [21], and these are listed in the bibliography in Appendix A of this Part.

2 Definitions

For the purposes of this Part of BS 8005, the definitions given in BS 4118 and BS 6100 apply, together with the following, some of which enlarge upon those given in the above standards.

2.1

primary lining

the lining required to support the ground for the life of the structure

2.2

secondary lining

either:

- a) a tunnel lining to provide decorative finish, usually combined with waterproofing, or to improve the flow characteristics of a hydraulic tunnel; or
- b) a second structural tunnel lining.

2.3

preliminary lining

lining provided to facilitate application of the primary lining

2.4

temporary lining

a preliminary lining which is not relied upon to survive once the primary lining is constructed

2.5

competent ground

self-supporting ground which will not deform significantly until the primary lining to the tunnel has been installed

2.6

ground support

any support required to secure the ground until the primary lining is complete

2.7

caulking

the operation of making a joint watertight to withstand pressure usually by packing with a filling material and ramming it home

2.8

shield

a mobile steel structure, usually cylindrical, to protect miners excavating the tunnel and to enable the tunnel to be erected

2.9

de-watering

the temporary lowering of groundwater using deep wells or well points, depending on the circumstances

2.10

heading

an accommodation tunnel built to accept a smaller service

3 Abbreviations and symbols

For the purposes of this Part of BS 8005 the abbreviations and symbols given in Part 1 of this standard apply.

Section 2. Planning, design, safety and choice of lining

4 Planning

4.1 General

The principal reasons for constructing a sewer in tunnel are as follows.

- a) The sewer has to be at such a depth that other methods of construction are impossible or too costly.
- b) Disturbance of the ground surface and/or disruption of the general environment and traffic are to be minimized.
- c) The route of the sewer need not follow the highway or open ground and consequently a more direct route may be followed. While a tunnel may be within or outside the highway, if tunnelling is used to reduce traffic interference the shafts themselves should, if possible, be sited off the highway.

There are indications that tunnelling may on occasions be economic in urban areas at quite shallow depths. It is suggested that clients' interests would be best served by including the alternatives of trenching and tunnelling in sewer contracts in built-up areas.

4.2 Preliminary location of route

The cost of a tunnel can vary widely depending on ground conditions and, in urban areas, on constraints such as the types of structures, foundations and utilities in the vicinity. The principal objective at the outset should be to establish whether a tunnel scheme is a technically and economically feasible solution to the engineering problem in the prevailing ground and other environmental conditions. The correct choice of route is, therefore, of crucial importance. Particular care needs to be exercised near to mining works, made-up ground, derelict urban areas and rubbish dumps.

A number of feasible tunnel routes may arise from a study of existing records, geological maps and Ordnance Survey sheets. A detailed survey and study of each option is required. There may be little choice in the location of the beginning and end of a tunnel sewer or in intermediate connection points. Apart from this, the route plan should follow the best tunnelling ground available, consistent with the hydraulic design requirements and any legal constraints (see BS 8005-0). Directness of route may sometimes be a secondary consideration, e.g. if a relief sewer or flood alleviation tunnel can be built at a lower level and allowed to run full during its occasional use (to be emptied by a small pump later), then the level of the sewer should be constructed in the best ground available. Where it is proposed that the sewer pass under a canal, motorway or railway, the responsible authorities should be consulted.

Sewer tunnels may be constructed to curves but, if small radii curves are proposed, consideration should be given to the cost implications.

4.3 Topographical survey

The topographical survey should extend well beyond the zone likely to be influenced by tunnelling and shaft sinking. The most recent Ordnance Survey sheets should be used for this purpose but details should be checked, and amended as necessary on the ground, as change may have occurred since the last revision.

Sub-surface information can be even more crucial and more difficult to obtain. For tunnel design, details of all other tunnels or subways, with their shafts, and of deep basements and deep piled foundations should be obtained. In addition, boreholes for water supply may exist below premises and, if undetected, could compromise the works. Boreholes can be traced through the abstraction licence records of water supply authorities and companies and the borehole records of the National Geosciences Data Centre at the British Geological Survey, Kegworth.

Settlements due to tunnelling can affect structures and services near to the tunnel (see also 10.2.1). Particular care is needed in the case of gas mains, sewers and water mains because of the dangers of fire, explosion and flooding. Such facilities are often in poor condition and consideration may have to be given to replacing and/or re-routing these services before tunnelling commences.

The topographical survey should also identify possible working shaft sites of suitable size and accessibility.

4.4 Site investigation

4.4.1 Geotechnical uncertainty. Regardless of the thoroughness of the site investigation, there will always remain a degree of uncertainty in the ground conditions for all tunnelling projects. The uncertainty of these geotechnical factors has an influence on the choice of tunnelling technique and also on the construction cost. A detailed knowledge of the ground conditions is of fundamental importance to the minimization of risk, both technically and financially.

Various tunnelling methods carry different risks and may require different degrees of site investigation. For instance, the standard of geotechnical information required for tunnelling machines is much higher than for drill and blast methods and, while full-face tunnel boring machines may perform better than conventional techniques in uniformly good rock conditions, they can be inflexible and cumbersome in faulted ground. There are well documented examples (see Athorne and Barratt [1] Athorne and Snowdon [2]) where, over a complete tunnel drive, potentially slower but more flexible tunnelling methods have achieved a better outcome than sophisticated mechanical techniques.

4.4.2 Objectives. The objectives of the investigation are to provide the following information:

- a) the assessment of the technical and economic merits of alternative schemes;

- b) the selection of the most suitable alternative;
- c) the preparation of an adequate, economic and safe design;

- d) to allow construction costs to be estimated and difficulties and hazards that may arise during construction to be foreseen and provided for.

To allow these objectives to be achieved, the site investigation should establish in three dimensions the geological structure, the succession and character of the strata present on the site, the ground water conditions and the presence of any special hazards. This involves examining existing information, making field investigations, taking samples and carrying out in situ tests, as needed. This includes a programme of laboratory tests to obtain the required information on the properties of the site materials. The investigation should also locate any existing underground works and services.

Table 1 — Stages of site investigation

Stage 1. Preliminary appreciation of site and ground conditions (desk study) Examination of the following readily available information to assess feasibility, to select possible routes, to make preliminary estimates of cost and to plan more detailed investigations. a) Available information including geological and other maps and reports. b) Geological and engineering enquiries. c) Air photographs and surface reconnaissance including examination of local geological features and outcrops. d) Interpretation together with recommendations for the ground investigation.
Stage 2. Ground investigation before construction Ground investigation can be divided into four sub-stages as follows. a) <i>Preliminary ground investigation.</i> An amount of work, where required, sufficient to confirm the feasibility and to establish the approximate cost of the project, to narrow route options and to aid in the planning of the main ground investigation. It may include selected boreholes or open, excavations, perhaps a geophysical investigation and selected tests. b) <i>Main ground investigation.</i> To obtain the information required for the final alignment, design and construction of the tunnel. It will usually include a programme of in situ and laboratory tests. c) <i>Other investigations before construction.</i> For example, trial shafts, trial adits, assessing and, if necessary, recording the condition of structures and services, grouting trials, dewatering trials, rock bolt trials and monitoring of trial sections. d) <i>Interpretation and recommendations.</i> To enable ground investigation during construction to be carried out.
Stage 3. Ground investigation during construction Observation and investigation, where necessary, continued during the construction phase to confirm and supplement the earlier investigations, as follows. a) Observations and records of ground conditions and pressure of water or gases should be made during construction. b) Probing ahead in tunnels. c) Other investigations and records during construction, e.g. of ground water levels, extra boreholes, observation of ground movement and settlement, grouting trials, rock bolt trials, monitoring of vibrations and monitoring of trial sections. d) Review and amendment of plans and sections which is a continuous process throughout the work.

4.4.3 Choice of construction method. The choice of permanent structure and construction method is closely related in tunnelling work. It is, therefore, essential before survey work starts to determine the full range of relevant design and construction parameters for which survey information may be needed. The survey should then establish, as far as is practicable, the nature of the ground in relation to these parameters so that the structure and construction method adopted will be practicable and cost effective. Lack of information leading to the choice of a construction method wrong for the tunnel lining finally selected is a major problem which has to be overcome by the survey work.

4.4.4 Investigation programme. An effective site investigation is best achieved by carrying out the work in three broad stages as shown in Table 1. Each successive step aims to narrow the choice towards the best line and level for the tunnel route as follows:

- a) to indicate the next steps required in the investigation;
- b) to fill the gaps in existing knowledge of the site;
- c) to confirm or correct earlier predictions.

In practice, each stage may not be sharply divided from that which follows it and either more or fewer stages may be involved depending on the circumstances and magnitude of the works. The programme should be flexible so that it can quickly adapt to changes occasioned by variation in ground conditions from those predicted by the preceding steps of the investigation.

4.4.5 Methods of site investigation. The various methods available for carrying out the site investigation are listed in Table 1. As well as boreholes, consideration should be given to the use of trial shafts and adits which can provide more positive information than geophysics but which will be more localized and more expensive. It is important to record the condition of nearby buildings, particularly if blasting is to be involved or if settlement damage is possible during tunnel construction.

Boreholes may be required at every shaft and the method of sinking larger shafts will be governed by the nature of the soil at that point. If additional boreholes are required at intermediate points along the tunnel, they should be sunk sufficiently clear of the proposed tunnel line to avoid later interference with the construction, either through ingress of water or by loss of compressed air. It is important to take boreholes well below the proposed tunnel level because changes in design often result in an increase in the depth of the tunnel. All boreholes should be grouted-up after the necessary information has been obtained.

Stable water levels should be determined in permeable strata, if necessary, by sealing the boreholes to that level. It can be useful to keep representative samples of the various strata encountered. In stiff clay and rock, as large samples as possible should be obtained in order that fissures or jointed structure may be examined. Granular samples should retain their finer components. Continuity of data should be sought by comparing adjoining boreholes, e.g. claystones in London clay often follow a continuous horizon which may be traceable.

Following the main borehole investigation, it may be worthwhile considering using geophysical methods, such as seismic refraction, along all or part of the proposed tunnel line. These techniques may be able to show the form and approximate depth of, for example, soil over bedrock and may serve to locate soil-filled depressions or buried valleys in the rock and help identify areas of difficulty. These can then be investigated by further boreholes.

4.4.6 Use of data. The data obtained from the desk studies, boreholes and geophysics, where appropriate, should be used to produce geological sections along the proposed tunnel route. The cross sections produced should be geologically credible and it is prudent to undertake this work with the help of an engineering geologist.

The guidance given here is generally related to tunnelling for sewers but further details on site investigation in general are given in BS 5930, and for tunnels in particular by West, Carter, Dumbleton and Lake [3].

5 Design

5.1 Selection of tunnelling method

5.1.1 General. Tunnelling consists of the following two basic and interactive processes:

- a) the excavation and removal of the ground; and
- b) the maintenance of ground stability, including the provision of tunnel support.

At its simplest, excavation can be carried out by hand using spades and pneumatic tools in soft ground and drill and blast methods in hard ground. Alternatively, full-face and partial-face tunnel boring machines can be used where the tunnelling works are of sufficient magnitude to justify the use of such plant. Where uniform ground conditions are predicted, it is possible to tailor the construction method to suit thereby achieving rapid advance rates and economic lining design. Considerable economies have been achieved in this manner in proven ground or where very thorough site investigation has been performed. However, the choice of an inflexible tunnelling method may result in delays to the construction programme and an overall increase in expense in the event that adverse unexpected ground conditions are encountered. It is also possible that the safety margin would be diminished.

Many tunnel drives can be expected to pass through a range of ground conditions, often with both hard and soft ground at the tunnel face simultaneously. Tunnelling in such conditions is at least awkward and at worst it can be extremely difficult. There is therefore merit, where possible, in selecting an alignment for the tunnel which either eliminates or minimizes the extent of such mixed face conditions (see 10.2.4 and 10.3).

5.1.2 Ground conditions. (See also BS 5930.) Soils likely to be encountered during tunnelling are as follows.

- a) *Non-cohesive.* Sands, gravels, ballasts and silts. The standard penetration test (see BS 1377) can be used to indicate the relative density of sands and gravels (see 41.2.5 of BS 5930:1981).
- b) *Cohesive.* Clays and marls with up to 20 % gravel and chalk having a saturation moisture content of 20 % or greater. Where the moisture content is less than the plastic limit the soil would be described as stiff; soils wetter than the plastic limit would be described as very soft, soft or firm, depending on their undrained shear strength (see 41.2.5 of BS 5930:1981).
- c) *Mixed.* Sand and clay, sand and silt, non-saturated clays and silts.
- d) *Fills.* Mixed materials of recent deposit such as domestic refuse containing ash, vegetable matter, etc., and materials of varying content and compaction used for embankments for railways, roads, etc.

- e) *Rock.* Hard material of geological origin or other comparable hard inert material such as concrete, brickwork, etc. It also includes chalk with a saturation moisture content of less than 20 %. Both compressive strength and discontinuities are important determinants of rockmass behaviour and their use is described in 44.2.6, 44.2.7 and 44.3.3 of BS 5930:1981.

Comprehensive information on the description and classification of soils and rocks is given in section 8 of BS 5930:1981.

In common tunnelling usage, ground consisting of items a), b), c) and d) would be described as soft ground while rock as described in item e) would constitute hard ground. A mixed face is one where soils and rock each occupy part of the tunnel face.

To assess the method of excavation and lining of a tunnel through the soils described in items a) to e), the following conditions have to be considered.

- 1) *Ground stability.* Stability at and above the tunnel working face is the first consideration in the building of a tunnel during the construction phase when a variety of support either temporary or permanent has to be applied. In the long term, the tunnel lining has to be capable of sustaining the loads applied to it. The ability of the ground to be self-supporting even over quite short periods, i.e. its stand-up time, is therefore important in the choice of tunnelling method. (For cohesive soils see also Appendix B regarding stability number.)
- 2) *Presence of water and level of permanent water table.* Ground and groundwater conditions are a dominant engineering consideration in the choice of tunnelling method. Thus the tunnelling system chosen has to be capable of dealing with the ground conditions identified during the ground investigation. Particular importance should be attached to any information on the conditions experienced in previously constructed tunnels in the vicinity.

5.2 Structural design

The structural design of a sewer in tunnel differs from the design of a loadbearing pipe because allowance should be made for any flexibility in the lining both longitudinally and, transversely, the stresses caused during construction may be more critical than those occurring in the completed sewer.

In all areas where buildings, railways, roads, services and other structures lie adjacent to the line of the sewer, discussion should be held with their owners and the method of construction chosen should be such as to limit the ground movement to an acceptable amount. In the case of railways, roads and services it is usually a statutory requirement that notice be given of the proposed sewer. It is advisable and it may also be a statutory requirement to give notice to owners of private buildings. In extreme cases it may be necessary to underpin buildings overlying the area which may be affected by the tunnel (see Morgan [4]).

The types of tunnel lining available are described in section 3 and advice on their use as tunnel support is given in 10.2, 10.3, 10.4 and 10.5. In the UK it is seldom necessary to deviate from a conventional lining and to have to produce an original lining design from first principles. Nevertheless a check should be carried out to ensure that predicted stresses and deformations lie within acceptable limits.

5.3 Hydraulic design

The general principles of hydraulic design which should be followed for pipe sewers should also be followed for sewers in tunnel. However the economic size for construction purposes may be larger than that necessary for carrying the flow. This may result in low velocities and the deposition of solids. In these circumstances the invert of the sewer should be shaped to create the required velocity at low flow.

6 Safety

Reference should be made to clause 17 of BS 8005-1:1987 which outlines the legislative framework with regard to the health, safety and welfare of persons engaged on the planning, design and construction of sewers in tunnels. Detailed advice on safety in this field is contained in BS 6164. Particular attention is drawn to the fact that the safety of tunnelling works can depend critically on the adequacy of the preliminary ground investigation and the proper interpretation of the results obtained (see 4.4). Ground investigation work should be as comprehensive as possible and there should be the fullest disclosure of all information, or of all gaps in information, both factual and interpretive, to those responsible for the design and for the construction of the tunnel (see also 7.3 of BS 8005-1:1987 and BS 5930).

The constructors of the tunnel should report to the designers the occurrence of any unforeseen ground conditions or the presence of water or gases which could influence the safety of the permanent works. There is a particular need to consider and guard against the possibility of methane gas infiltration from geological or mining sources below or near the proposed line of any sewer tunnel.

Additional safety hazards may arise where a new sewer in tunnel is to be connected with, or constructed near to, an existing sewer system or when there are existing tunnels, basements or other services nearby.

7 Preformed primary tunnel linings

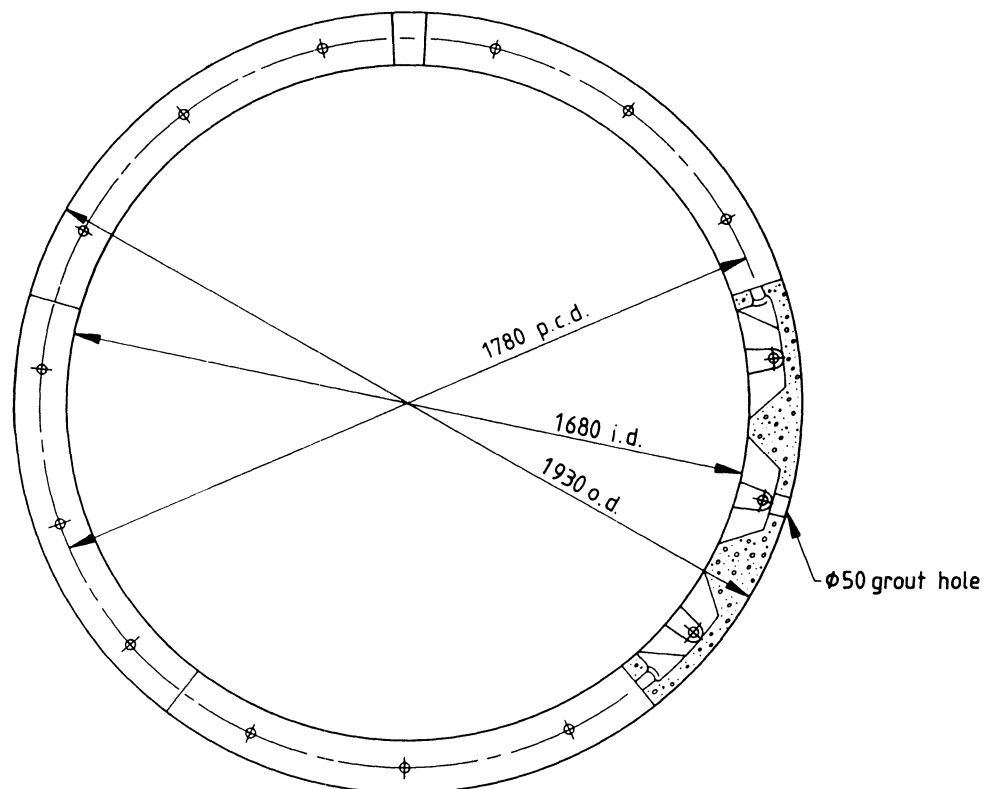
7.1 General

There are at present no British Standards for segmented tunnel lining components. These components are predominantly manufactured in concrete but other materials may be available. For precast concrete tunnel segments reference should be made to the Water Authorities Association's Civil Engineering Specification for the Water Industry [5].

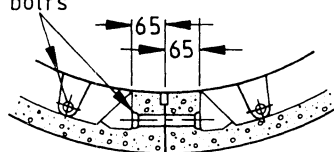
A degree of protection against corrosive attack can be achieved for all precast concrete linings. The concrete cover to reinforcement should be carefully considered and designed, as appropriate to the severity of corrosive attack. The use of sulphate resisting cements in accordance with the recommendations of BRE Digest 250 [6] is satisfactory in most cases (see BS 8110). In severe cases, the use of applied bitumastic or epoxy coatings or the use of integrally cast protective systems will provide improved protection (see 5.17.1 and 5.17.2 of BS 8005-1:1987 and 9.4 of this Part).

7.2 Bolted precast concrete segmental linings (see Figure 1)

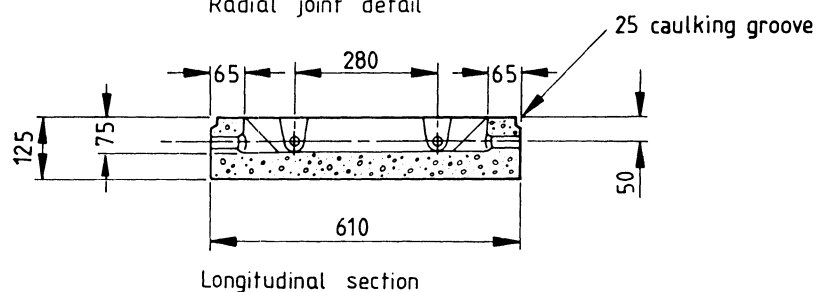
Bolted precast concrete segmental linings are steel reinforced to accommodate temporary construction and permanent loads. They are formed of segments erected and bolted together, forming circular rings, each with a narrow key segment at the soffit. They can be erected with or without a shield, depending upon ground conditions. Once erected they are self-supporting, requiring no temporary supporting framework. In some circumstances rolling of the key may assist in maintaining the shape of the ring. Suitable packing materials can be inserted in the joints, and grumets are placed under the washers at the head and nut of each bolt. The joints between the segments are designed to accommodate caulking materials.



$\phi 27$ bolt holes to accept M20 bolts



Radial joint detail



All dimensions are in millimetres.

NOTE This is a typical arrangement and dimensions are shown only for guidance

Figure 1 — Details and dimensions of typical bolted precast concrete segmental lining

Production diameters range from 1.5 m upwards in increments suited to most common applications. Standard segments are generally capable of withstanding normal loading at depths between 1.5 diameters and 25 m (see 5.2). Linings of greater strength can be obtained and the external loading on the lining should be considered in each case.

Precast concrete blocks can be used to fill the panels between the ribs of bolted precast segments to provide a smooth internal finish when the tunnel is constructed to close tolerances. The precast infill blocks are usually made of lightweight concrete for ease of handling and are fixed in place with specially designed cement mortar. Alternatively, a secondary lining of in situ concrete can be provided giving more protection to the primary lining (see 10.5).

Bolted smoothbore linings are available and can provide a primary structural lining which needs no secondary finish. They are not as vulnerable to uneven ground loading or internal hydraulic surcharge as the unbolted versions. Positive connection is generally achieved across the longitudinal joint only and the circle joint connection is generally confined to dowels. Similar practical limitations may apply to the use of these linings in difficult ground conditions, as apply to non-bolted linings, and expert advice should be obtained in such cases.

7.3 Unbolted smoothbore precast concrete segmental linings

Unbolted smoothbore precast concrete segmental linings provide an economic alternative to bolted linings for use in circumstances where balanced ground loading can be achieved. Depending on ground conditions they may not be suitable for use where significant internal hydraulic surcharge pressures may occur. In order to transmit ground loadings on to the lining it is essential that the annulus between the extrados of the lining and the adjacent ground is filled with grout (see 10.11).

The unbolted lining is suitable for a range of diameters generally between 1 m and 3 m. A number of proprietary designs have been developed, suitable for use with or without a shield, which broadly fall within the following categories:

- a) those requiring temporary steel formers to assist with ring erection and stability prior to grouting;
- b) those having dowels between segments for ease of erection which, being permanent, also give greater rigidity to the permanent works;
- c) those not requiring any temporary support or permanent joint fixing.

Various shaped joints have been developed to enable the location of segment to segment, to allow some degree of flexibility in the structure and to facilitate load transfer. A caulking groove is normally incorporated and in some systems the joint profile is designed to accommodate a bituminous sealing strip.

7.4 Expanded precast concrete segmental linings (see Figure 2)

Expanded linings were developed to be used for tunnels constructed in firm and stiff clays and where the tunnel size and route, length, grade, etc., enable rapid construction to be considered. A number of designs have been used for the construction of sewer tunnels over a range of diameters between 1.2 m and 2.5 m while larger diameters have been used in tunnels constructed for other purposes.

A tunnel shield has to be used for the construction of expanded linings, ensuring that the profile of the excavated ground is a true circle. The shield is designed without a tail so that the rings can be built directly against the ground, which has to be self-supporting to enable this to take place.

The normal method of expanding the lining is by the use of wedge-shaped segments where the actions of the shield rams cause the ring to expand.

The action of expanding the lining against the ground may be facilitated by lubricating the concrete-to-ground interface to reduce friction. As the linings are designed to expand to a nominal diameter, it is necessary to consider the swell of the ground from the time of excavation to the time of the erection of the lining. To allow for variations it is necessary to accept that the jacking space can vary and that the wedge may not always be driven home. Allowable deviations from line and level may need to be greater than those for non-expanded linings.

7.5 Bolted cast iron segmental linings

Bolted cast iron segmental linings have good corrosion resistance and should be considered when severe ground loading or water pressures exceeding 2 bar³⁾ are likely to be encountered. A secondary lining of in situ lining has to be provided.

7.6 Pressed steel liner plates

Pressed steel liner plates can be used to provide initial ground support during construction in soft ground conditions but a primary lining has to be provided.

³⁾ 1 bar = 10^5 N/m^2 = 100 kPa.