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British Standard **Sewerage**

Part 1. Guide to new sewerage construction

Evacuation des eaux usées
Partie 1. Guide des égouts neufs

Entwässerung
Teil 1. Leitfaden für neue Abwasserleitungen

Foreword

This British Standard has been prepared under the direction of the Civil Engineering and Building Structures Standards 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 BS 8005 supersedes and enhances CP 2005 : 1968, which is withdrawn, although some of the material incorporated is a restatement of the earlier text.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 : Part 0 directs the reader to sources of more detailed information, particularly on important and specialized fields such as health and safety. It should be regarded as supplying essential background information for the other Parts of BS 8005.

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

- Part 0. Introduction and guide to data sources and documentation
- Part 1. Guide to new sewerage construction
- Part 2. Guide to pumping stations and pumping mains
- Part 3*. Guide to sewers in tunnel
- Part 4. Guide to design and construction of outfalls
- Part 5*. Guide to 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codes and guides take a long time to revise and if they are reviewed at infrequent intervals, they tend to become out of date quickly, especially in a field where technological development is rapid.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 CSB/5 at 2 Park Street, London W1A 2BS.

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

* In preparation.

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Section one. General

1 Scope

This Part of BS 8005 provides guidance on the materials, design, construction, testing, surveying, operation and maintenance and repair of new sewers.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

Other standards publications not referred to in this standard, but dealing with closely associated subjects, are listed in appendix A. References are made to other sources of authoritative information. These will be found throughout the text, indicated by bracketed numbers thus [21] and are listed in appendix B.

2 Definitions

For the purposes of this Part of BS 8005, the definitions given in BS 892, BS 4118, BS 6100 and BS 8005 : Part 0 apply, together with the following.

2.1 catchment area. The area of a watershed discharging to a sewer, or watercourse.

2.2 flow attenuation. The process of reducing the peak flow rate in a sewer system by redistributing the same volume of flow over a longer period of time.

NOTE. This can be achieved by on or off line storage within the sewerage system, or by above ground storage before flows enter the sewer.

2.3 inverted siphon. A pipe or conduit where the soffit drops below the hydraulic gradient and in which the sewage flows under pressure of gravity.

2.4 nominal size (DN). A numerical designation of the size of a pipe, bend or branch fitting, which is a convenient round number approximately equal to a manufactured dimension.

NOTE. 'Nominal bore' is the approximate internal diameter of a unit as declared by the manufacturer. This quantity is quoted with units (mm) whereas nominal size (DN) is quoted without units.

2.5 percentile peakedness. The departure from the mean value of a storm profile, expressed as a percentage.

2.6 rainfall. Natural precipitation of water in any form, such as rain, snow, hail, etc., the rate of which is measured in millimetres of water per hour.

2.7 renovation. Methods by which the performance of a length of sewer is improved by incorporating the original sewer fabric, but excluding maintenance operations such as isolated repairs and/or silt removal.

2.8 roughness value (K_s). A measure of the resistance of the surface of a pipe or channel under turbulent flow which is expressed in millimetres.

NOTE. This value is based on the diameter of uniformly graded sand grains which would give the same resistance to flow.

3 Abbreviations

Throughout this Part of BS 8005, the abbreviations given in BS 5775 and BS 5555 have been used, together with the following.

ABS	Acrylonitrile butadiene styrene
BMR	Bending moment resistance
BOD	Biochemical oxygen demand
BRE	Building Research Establishment
CF	Compaction Fraction
CIRIA	Construction Industry Research and Information Association
COD	Chemical oxygen demand
DN	Nominal size
DoE	Department of the Environment
DWF	Dry weather flow
GRC	Glass reinforced concrete
GRP	Glass reinforced plastics
HDPE	High density polyethylene
MDPE	Medium density polyethylene
NJHSCWS	National Joint Health and Safety Committee for the Water Service
NWC	National Water Council (now defunct and replaced by WAA, but remain listed publishers of some references)
PE	Polyethylene
PIMP	Percentage impervious
PR	Percentage run-off
SOIL	Soil impermeability index
SRPC	Sulphate-resisting Portland cement
TRRL	Transport and Road Research Laboratory
UCWI	Antecedent catchment wetness
WAA	Water Authorities Association
WASSP	Wallingford computer program
WRc	Water Research Centre

4 Planning

4.1 General

The UK is served by a comprehensive sewerage network which has been developed over many years to satisfy the demands of society in a changing environment. In many areas of the country, urban expansion is now limited, regeneration of derelict inner areas requires urgent investment, the population level is stable or declining and the infrastructure is ageing.

Sewerage planning should determine how best to rehabilitate and extend the existing system to serve future needs.

Structure plans and local plans can assist the planning and design of new, improved and extended sewerage systems. The allocation of land use and the policies for development should be determined for each catchment area. This information will influence the assessment to be made of the extent of impervious areas and the consequent calculation of surface water run-off, and will provide assistance to forecast population changes and foul sewage flows.

The planning horizon will inevitably differ from the various potential lifespans of the many sewers and associated structures within the catchment area. Sewerage planning and design should take account of the impact of changing land use and future alternative developments.

4.2 Population and water usage statistics

4.2.1 Population statistics. An accurate assessment of population is essential in determining the probable flows in a sewerage system.

The official statistics of the Registrar General refer to areas defined by local authority boundaries, but are useful as a check on estimates made by other means.

Planning statistics can be of assistance since they frequently give local information on the average occupancy rate of domestic dwellings. When multiplied by the number of residential properties obtained by physical count, these can provide a fairly accurate assessment of population.

In holiday resorts or other areas where there is an occasional or seasonal influx of people, such a means of estimating is not possible. Peak population may be assessed only by sampling typical areas during the holiday or peak season and extending the densities thus estimated to the whole area under consideration. Registers of accommodation maintained by many local authorities, Tourist Boards, etc., together with information that can frequently be obtained from the local planning department, may be of value.

Where provision needs to be made for future population in areas not yet developed or due for redevelopment, information should be available from the local planning authority on areas scheduled for development and on the scale and intensity of development intended. Planning policies are subject to regular review and the designer should consult the local planning authority to assess the likelihood of future changes in policy.

4.2.2 Water usage statistics. The water supply authority can provide a fairly accurate assessment and forecast of the consumption of water in any particular area; this will have a direct relationship to the likely flows for foul sewerage purposes.

Commercial and industrial premises and public buildings such as hospitals and schools, which obtain a supply of water from public sources, are usually metered. After making due allowance for water use in any industrial process, the figures of consumption can provide a useful guide to the anticipated flows of waste likely to arise from such premises.

Some private and commercial undertakings obtain water direct from private abstractions from rivers, canals, wells or boreholes; these should be taken into account in assessing the possible discharge of foul sewage.

4.3 Trade effluents

Most industries require water for processing or other purposes; much of this water, after use, will be discharged either to public sewers or direct to natural waters.

Such discharges, which may contain a wide variety of matter in solution or suspension, are termed trade effluents. They range from essentially clean but warm water, to strong solutions of organic or inorganic chemicals or suspensions of solid matter. They may be coloured and may have strong odours or other offensive characteristics. They may differ markedly from typical domestic sewage and their discharge to sewers often raises special problems, either as a result of their individual constituents, or in combination with other sewage. These problems include:

- (a) the effects which they may produce on the internal condition and hydraulic capacity of sewers, including effects on the fabric of the sewers and ancillary structures;
- (b) the danger to men working in sewers;
- (c) the effects they may have on sewage treatment processes and works or other means of disposal, and
- (d) their effect on receiving waters when inadequately treated.

There is close relationship between all these problems and they all need to be taken into account when planning sewerage.

Quantities and strengths of trade effluents are difficult to predict as trade practices vary as a result of changes in industrial throughput, technological developments and changes in the occupation of premises. In areas of existing industrial development, information can be obtained from records or investigation of existing discharges and consultation with the dischargers. Where industrial sites are undeveloped, planning policies may identify the nature and size of proposed developments which, together with information on trade effluents from similar industries, will enable an assessment to be made of the likely future discharges. (See 4.1.)

The discharge of trade effluents to a sewer is likely to be subject to conditions governing the quality and quantity of the effluent discharged. Compliance with such conditions may require the discharger to undertake pre-treatment of the effluent before discharge.

4.4 System planning

4.4.1 General. System planning within a catchment area or river basin should consider the sewerage network, storm sewage overflows, pumping installations and the receiving sewage treatment works, and the effects of their discharges on receiving water courses. Hydraulic performance of the whole system has to be considered to ensure that additions or modifications to the system do not result in overloading and/or premature operation of overflows. Where sewage is pumped consideration should be given to the effects of the pump discharge rates on the downstream parts of the system.

4.4.2 Sewerage rehabilitation. Where, as in the UK, a very high proportion of the population is served by existing public sewerage systems the objective has to be to optimize the existing system and to determine what adaptations or improvements are necessary to meet future needs.

The philosophy of sewerage rehabilitation contained within the WAA/WRC 'Sewerage rehabilitation manual' [1] has been accepted by the UK Water Industry as the strategy for rehabilitation of the existing sewerage network. (See BS 8005 : Part 5*.)

4.4.3 New developments (see also BS 8005 : Part 0). When consideration is given to the allocation of land for development, the authority responsible for sewerage should be consulted regarding the constraints which may be imposed as to sewerage provision.

Site plans should include areas reserved for future routes for sewers including any necessary pumping stations and treatment plant, allowing sufficient room and access for construction and subsequent operation and maintenance.

Sewers to serve new development should be constructed in the highway, land to be used for highway purposes, or public open space. Guidance on the location of sewers can be obtained from 'Provision of mains and services by public utilities on residential estates' [2].

The owner of the development may wish the sewers to be adopted as public sewers by the appropriate sewerage authority under the terms of the Public Health Act 1936. It is recommended that adoption be by prior agreement under the provisions of Section 18 of the Act and for this purpose 'Sewers for adoption — a design and construction guide' [3] has been published by WAA.

Sewers needed to connect developments with the existing public sewerage system can sometimes be requisitioned from the appropriate water authority in England and Wales using the provisions of Section 16 of the Water Act 1973.

4.5 Public relations

Good public relations are important in the design, construction and operation of sewerage systems. This Part of BS 8005 draws attention to the necessity for close liaison between developers, land users, local authorities, statutory undertakers and others who may be affected by new sewerage schemes. Such liaison and consultation should not be restricted to that required under appropriate legislation. Persons and organizations affected by the

proposals should be consulted as early as possible in the planning stage and such liaison should continue for the duration of the work. Property owners affected should be made aware of the implications of the works proposed and of their own rights under statutory procedures.

Construction of sewers often has a serious effect on the movement of traffic and pedestrians and can cause severe disruption to the activities of a community. Diversions or other activities should be planned with the persons affected, the police and other authorities well in advance of actual construction. Advance information should be posted to the persons concerned and the general public should be made aware by public meetings, public notices, or through the press and radio.

Attention is drawn to legislation and regulations dealing with issues such as traffic signing, health and safety, planning and noise which may apply during construction. A recognized point of contact should be identified for the use of persons affected by the scheme to deal with matters arising during the work.

Attention is also drawn to legislation and regulations which may apply during operation and maintenance activities to minimize any nuisance and inconvenience. Sewerage authorities should make public the address and telephone numbers of persons to be contacted in the event of routine enquiries, complaints or emergencies. Such arrangements should also cover out of office hours.

Owners of private sewerage systems should also ensure that occupiers of the properties they serve, together with the local authority and emergency services are aware of whom to contact in cases of emergency or malfunction.

Whilst a properly designed, operated and maintained system should normally have little effect upon the general public, there will be occasions when as a result of routine operation and maintenance or as a result of emergencies there will be some impact. This impact may be limited to a few individuals but may also affect very large numbers of people. Careful location of chambers can help to minimize the disruption caused by maintenance activities. Those persons responsible for sewerage and associated work should strive to minimize the nuisance and inconvenience caused by their activities by careful pre-planning, consultation and dissemination of information. Appropriate operational procedures and communication arrangements should be planned to ensure rapid action and good public relations.

* Under preparation.

Section two. Materials, components and appliances

5 Materials, components and appliances

5.1 General

This clause deals with materials for which there are current British Standard specifications and with other materials in common usage in sewerage. Users should refer to manufacturers when reference is made to the latter. The use of new materials is to be encouraged provided that sufficient information on long-term performance is available to enable a minimum service life to be defined with confidence.

5.2 Rigid and flexible pipes, joints and fittings

5.2.1 Factors affecting choice of pipe materials. The choice of pipe will be influenced by the hydraulic and structural design and particularly whether it is a gravity sewer or pumping main. The nature of the effluent to be carried and of the ground water will affect the choice of both pipe and joint. The diameter and length of the pipes available, the ease of cutting, the simplicity of the jointing system and the availability of fittings are among the factors to be considered, along with ease of unloading and positioning in the trench without damage to the pipe or any coating.

Flexible joints are generally available and are recommended. They accommodate degrees of straight draw, angular deflection and axial displacement or shear without loss of watertightness. In certain circumstances rigid joints are required; these are made by caulking a compound or working a cement mortar into the joint, or by bolted flanges or by welding the pipes together.

5.2.2 Rigid pipes

5.2.2.1 General. Rigid pipes do not deform appreciably under their design load and the materials show a linear, brittle stress-strain behaviour. The ability of a rigid pipe to support the total load transmitted to it is established by reference to actual crushing tests.

5.2.2.2 Asbestos-cement pipes. For use with gravity flow for sewerage and drainage applications, asbestos-cement pipes and fittings with flexible joints should comply with BS 3656 which specifies the strength classifications for pipe diameters from DN 100 to DN 2500, in pipe lengths of 3 m, 4 m and 5 m. Half and quarter length pipes are available.

For pressure pipelines, asbestos-cement pipes and flexible joints should comply with BS 486, which specifies the hydrostatic classification for pipe diameters from DN 50 to DN 2500 in pipe lengths of 3 m, 4 m and 5 m. Asbestos-cement bends are available for diameters up to DN 225. Cast iron fittings are also available.

5.2.2.3 Clay pipes. Vitrified clay pipes and fittings for use with gravity flow under atmospheric pressure should comply with BS 65. They are available in nominal diameters from DN 75 to DN 1000, and in lengths up to 3.0 m. The following classifications of pipes are available:

- (a) normal, i.e. suitable for all drains and sewers;
- (b) surface water;

(c) perforated, suitable for French drains and land drains;

(d) extra chemically resistant.

Three crushing strength classifications of pipes are given in BS 65, and there are equivalent bending moment resistance (BMR) classifications for preferred sizes up to DN 225. Requirements are set down for fittings and for flexible mechanical joints according to the type of pipe with which they are used.

Perforated pipes and associated non-perforated fittings normally have integral flexible joints; these pipes are available in lengths up to 2.0 m.

5.2.2.4 Concrete pipes*. Precast concrete pipes and fittings of circular cross section for the conveyance of sewage or surface water under gravity, should comply with the appropriate Part of BS 5911.

BS 5911 : Part 1 specifies requirements for flexibly jointed pipes in nominal diameters DN 150 to DN 3000 in standard lengths 0.45 m to 5 m (3 m for pipes DN 600), in three strength classes for sewage or surface water (and for jacking pipes).

BS 5911 : Part 3 specifies requirements for pipes with ogee, rebated joints, in nominal diameters DN 150 to DN 1800, in standard lengths 0.45 mm to 2.5 m, in three strength classes, used principally for land drainage and surface water and for headings.

Precast glass composite concrete pipes, strengthened by continuous alkali-resistant glass fibre rovings, are covered by DD 76 : Part 1 (see note 1). These pipes are available for sewage under gravity flow in diameters from DN 150 to DN 1800, lengths from 0.45 m to 5 m, and in three strength classes. Flexible in-wall rebated joints are used with elastomeric joint rings complying with BS 2494.

NOTE 1. DD 76 : Part 1 has been reviewed and is being converted to a full British Standard as Part of BS 5911.

Precast concrete pipes strengthened by chopped zinc-coated steel fibres are covered by DD 76 : Part 2. The pipes and fittings are suitable for sewage or surface water under gravity, and are available in nominal diameters from DN 375 to DN 1200, in three strength classes, in lengths of 0.45 m to 2.5 m. Joints are generally of the flexible, spigot and socket type, but in-wall design is also catered for.

NOTE 2. DD 76 : Part 2 is being reviewed to see whether it can be converted to a full British Standard as Part of BS 5911.

5.2.2.5 Box culverts. Precast concrete box culverts for foul sewers, storm sewers, storm water retention tanks, manholes and wells for pumping stations at atmospheric pressure, are manufactured in a range of sizes from 1.0 m to 6.0 m spans with various internal heights between 0.5 m and 3.0 m and effective lengths between 1.0 m and 2.0 m to suit weight limitations. Box culverts are designed individually to suit specific loading situations. They are not currently covered by a British Standard and details should be obtained from the manufacturer.

* Where appropriate in this Part of BS 8005, the term concrete pipes can be taken to include concrete box culverts (see 5.2.2.5).

5.2.2.6 Grey iron pipes. Grey iron pipes and fittings should comply with BS 437 and with BS 4622 and are manufactured in the size range DN 50 to DN 225; BS 437 makes provision for centrifugally cast pipes with flexible joints in lengths up to 5.5 m. Flexible joints for these pipes should comply with BS 6087.

Pressure pipes and fittings with flexible or flanged joints should comply with BS 4622. Pipes with flexible joints are available in 5.5 m lengths and those with flanged joints in 4 m lengths.

Fittings complying with BS 437 can be jointed directly to BS 4622 pipes with lead caulked joints in the smaller diameters (DN 100 and DN 150 only).

5.2.3 Flexible pipes

5.2.3.1 General. Flexible pipes deform under load and the extent of this deformation depends upon the stiffness of the pipe and the compaction of the immediate surround fill. The materials for these pipes show ductile stress-strain characteristics.

5.2.3.2 Corrugated metal pipes. Corrugated metal pipes are manufactured in steel in diameters from DN 150 to DN 2600 and in lengths from 6 m to 9 m. They are jointed by corrugated or dimpled coupling bands and various types of bituminous coatings are available. These pipes are not covered by a British Standard and details should be obtained from the manufacturers. Two forms of corrugation are available for the pipe as follows.

(a) Helically corrugated pipes, available in sizes from DN 150 to DN 1500 made from galvanized steel sheet complying with BS 2989, grade Z2, coating type G600. The helical joint is formed by a locked seam.

(b) Annularly corrugated pipes, available in sizes from DN 1000 to DN 2600 made from steel complying with BS 1449 : Part 1, grade 3, condition HR. Longitudinal joints are rivetted and the pipes are galvanized in accordance with BS 729.

5.2.3.3 Ductile iron pipes. Ductile iron pipes and fittings should comply with BS 4772 and are manufactured in a range from DN 80 to DN 1600. Ductile iron pipes with flexible joints are manufactured in nominal lengths of 5.5 m for DN 80 to DN 800 inclusive and nominal lengths of 8 m for DN 900 to DN 1600 inclusive. Ductile iron pipes are suitable for both pressure and non-pressure applications. A class of pipe (class K9) is available for general purposes but other classes can be supplied. Pipes with flanged joints are manufactured in 4 m lengths.

5.2.3.4 Unflanged corrugated liner plates. Unflanged corrugated liner plates are generally used to form culverts, pedestrian tunnels and similar structures which are

subsequently backfilled externally. To promote long life the plates and fittings are supplied galvanized. Plates are supplied with longitudinal corrugations and curved to the required profile.

5.2.3.5 Glass reinforced plastics (GRP) pipes. GRP pipes and fittings should comply with BS 5480 : Parts 1 and 2, in sizes DN 25 to DN 4000. Pipe lengths range from 3.0 m to 12.0 m although the 6.0 m length is the most common. GRP pipes are suitable for sewers working under gravity flow or working under pressure. The pipes have flexible joints and are available in eight pressure and stiffness classes. Fittings for use with GRP pipes are manufactured of GRP, steel, or ductile iron, and are suitable for the same applications as the pipes.

5.2.3.6 High density polyethylene (HDPE) pipes. HDPE pipes should comply with BS 6437 in the range of outside diameters from DN 16 to DN 500 and in a series of pressure ratings from 2.5 bar* to 10 bar. The manufactured lengths of pipes vary from 10 m to 12 m. Joints can be fusion welded or mechanically coupled.

5.2.3.7 Unplasticized PVC pipes. Unplasticized PVC pipes and fittings with flexible mechanical or rigid solvent welded joints for gravity flow pipelines should comply with BS 4660 for nominal sizes DN 110 and DN 160 and with BS 5481 for nominal sizes DN 200 to DN 630. These standards provide for a wall thickness to diameter ratio selected for the buried sewer application. In accordance with international standards, plastics pipes are designated by their outside diameters in recent British Standards.

Unplasticized PVC pipes for pressure applications such as pumping mains should comply with BS 3505 or BS 3506. Pipes complying with these standards are identical except that BS 3505 contains additional clauses relating to water quality. BS 3506 specifies a range of pipes up to nominal size 24 in four pressure classes. Unplasticized PVC pipes used for intermittent sewage pumping mains should be of not less than class C (9 bar) nominal working pressure in accordance with BS 3506.

Unplasticized PVC pipes are normally available in lengths up to 6 m with either push fit mechanical joints or plain ended for use with couplers. Joints and fittings for unplasticized PVC pressure pipes should comply with BS 4346 : Parts 1 and 2.

Reference should be made to BS 5955 : Part 6 and CP 312 : Parts 1 and 2 for further guidance on the use of unplasticized PVC pipes and fittings.

5.2.3.8 Acrylonitrile butadiene styrene (ABS) pipes and polypropylene pipes. ABS pipes should comply with BS 5391 and are manufactured in nominal sizes of 3/8 to 8 and in lengths of 3 m to 9 m. Polypropylene pipes should comply with BS 4991 in lengths of 6 m.

* 1 bar = 10^5 N/m² = 0.1 MPa.

5.2.3.9 Steel pipes. Steel pipes and specials for sewerage should comply with BS 534; this covers welded and seamless pipes, specials and joints in an outside diameter range of 60.3 mm to 2220 mm.

5.3 Manhole sections

5.3.1 Precast concrete sections. Precast concrete circular manhole components are manufactured for assembly into complete manholes; they should comply with BS 5911 : Part 1. Precast concrete box culvert units are also manufactured for construction as manholes complete with step irons.

5.3.2 Plastics. Plastics manhole components include chambers and shafts. A concrete surround may be required in conjunction with these units.

5.4 Manhole covers and frames

Ductile iron and grey iron manhole covers and frames should comply with BS 497 and are in three grades for heavy, medium and light duty (grades A, B and C respectively).

5.5 Materials for bedding and backfill

5.5.1 General. The classification in figures 1 and 2 provides a practical method of specifying pipe bedding materials for the range of pipes commercially available.

5.5.2 Granular materials for pipe bedding. Generally it will be impractical to use two granular materials in the same trench, and possibly within the same contract. The choice of bedding materials is therefore to some extent a compromise. Granular materials should be durable under the influence of ground water.

Materials should be compacted to give maximum load-bearing capacity. As compaction at the sides and over a pipe is difficult to achieve without special apparatus, a single-sized bedding material may be preferred. If good compaction can be achieved, well-graded materials can be compacted to a minimum void ratio to provide a higher load-bearing capacity.

A compaction fraction (CF) test may indicate that alternative granular materials would be acceptable; material with a CF greater than 0.15 requires extra care in compaction. Details of the CF test are set out in appendix D.

In wet soils the migration of fine soil particles with ground water into the voids of granular bedding may be prevented by surrounding the granular material with filter fabric.

Granular materials for pipe beddings should comply with the following.

(a) Nominal single size aggregate complying with table 4 of BS 882 : 1983 as follows:

DN 100	10 mm size
DN 150	10 mm or 14 mm size
DN 200 to DN 300	10 mm, 14 mm or 20 mm size
DN 375 to DN 525	14 mm or 20 mm size
DN 600 and above	14 mm or 20 mm or 40 mm size

(b) Graded aggregate complying with table 4 of BS 882 : 1983 as follows:

DN 100	14 mm to 5 mm
DN 150 to DN 525	20 mm to 5 mm, or 14 mm to 5 mm
DN 600 and above	40 mm to 5 mm, 20 mm to 5 mm, or 14 mm to 5 mm

(c) Granular material having a CF value not greater than 0.3 for pipes less than DN 300 and 0.2 for pipes DN 300 and above when tested in accordance with appendix D. The maximum particle size should be as follows:

Less than DN 600	20 mm
DN 600 and above	40 mm

It should be noted that rounded materials, especially single sized, may not form stable beds for pipes of DN 300 and above. The greater the proportion of fines in the material the greater is the care needed in compaction.

5.5.3 Selected fill. Selected fill should preferably consist of uniform soil, free from stones larger than 40 mm, clay lumps larger than 75 mm, tree roots, rubbish, organic matter and frozen soil.

5.6 Concrete

NOTE. This clause covers in situ concrete. Precast concrete products are covered by various British Standards.

5.6.1 Cement. Cement for use in sewerage work should comply with BS 12, BS 146, BS 1370, BS 4027, BS 4246 or BS 4248.

NOTE. This clause does not apply to cements used for jointing plastics pipes (see 5.9).

The commonly used cements are ordinary and rapid-hardening Portland cement. High alumina cement complying with BS 915 should not be used for structural (load bearing) work.

Where sulphates are present, reference should be made to BS 8110 (see also 5.17).

5.6.2 Aggregates. Aggregates should comply with BS 882 or BS 1047. Where tests are required they should be carried out in accordance with BS 812.

5.6.3 Water. Water should be clean and free from significant amounts of deleterious matter, either in suspension or in solution. Where sampling and testing of water is required this should be carried out in accordance with BS 3148. If the water is suspect, test cubes should be made with the proposed water and their setting times and strength development compared with cubes made with water of approved quality.

5.6.4 Steel reinforcement. Steel reinforcement for concrete should comply with BS 4449, BS 4461, BS 4482 or BS 4483. Steel for prestressed concrete should comply with BS 4486 or BS 5896.

Whenever possible, the bending dimensions and scheduling of bars for reinforcement should comply with BS 4466. The cover of concrete over all steel reinforcements should be as set out in BS 8110 or BS 8007 as appropriate.

5.6.5 Concrete mixes

5.6.5.1 General. Concrete mixes should be specified in accordance with BS 5328. The requirements relating to permitted concentration of chlorides in concrete should be as recommended in BS 8110.

5.6.5.2 Admixtures. Admixtures, if permitted, should comply with BS 5075. Calcium chloride or admixtures based thereon should not be used for concrete containing steel, or where sulphate-resisting Portland cement (SRPC) is to be used.

5.7 Cement mortar

5.7.1 General. A mortar mix of 1:3 cement/sand ratio is suitable for the following purposes:

- brickwork;
- rigid joints for clay or concrete pipes;
- joints for precast concrete manhole sections;
- rendering of inverts and benchings.

5.7.2 Cement. Cement for use in mortar should be as described in 5.6.1.

5.7.3 Aggregates. The fine aggregate for mortar should consist of sand complying with BS 1199 and 1200, or BS 882, grades M or F.

5.8 Cementitious grouts

5.8.1 Cement. Cement for use in cementitious grouts should be as described in 5.6.1.

5.8.2 Pulverized fuel ash. Pulverized fuel ash should comply with BS 3892 : Part 2.

5.8.3 Aggregates. The fine aggregate for cementitious grouts should consist of sand complying with BS 882, grades M or F.

5.9 Solvent cements

Solvent cements for unplasticized PVC pipes and fittings are specified in BS 4346 : Part 1 for pipes and fittings to BS 3505, BS 3506, BS 4346 : Part 2 and BS 5481. Solvent cements for jointing pipes to BS 4660 are specified in BS 6209 but cements complying with BS 4346 : Part 1 are also suitable.

5.10 Bricks and blocks

Bricks should be class B engineering type complying with BS 3921. Concrete bricks or blocks should comply with BS 6073.

5.11 Step irons

Step irons should comply with BS 1247 in malleable cast iron and in spheroidal graphite iron (ductile) and be galvanized. There are four basic patterns, i.e. general purpose, precast concrete manholes, round bar corner and harpoon.

5.12 Ladders

Fixed ladders should meet the dimensional requirements of BS 4211 except that stringers should be not less than 65 mm × 20 mm in section and rungs 25 mm in diameter. When made of low carbon steel they should be protected by hot dip galvanizing in accordance with BS 729.

5.13 Safety chains

Safety chains should be made of low carbon steel or of stainless steel, 10 mm nominal size, short-link, smooth welded chain to BS 4942 : Part 2. When made of low carbon steel they should be protected by hot dip galvanizing in accordance with BS 729.

5.14 Handrails and handholds

Handrails and handholds should be at least 25 mm in diameter. Low carbon steel tube and bar should comply with BS 1387 and BS 4360. They should be protected by hot dip galvanizing in accordance with BS 729.

5.15 Valves

Guidance on valves is given in BS 8005 : Part 2.

5.16 Gullies

Gullies should comply with BS 65, BS 437 or BS 5911 : Part 2 as appropriate.

A gully usually incorporates a trap, or a sump, or both, to retain detritus. The top should be fitted with either a grating or a sealed cover. Connections should be made below the grating or cover. Gullies may be specially designed to suit selected locations and the volume and nature of the flow. They can also incorporate means of access for rodding the branch drain beyond the trap.

5.17 Resistance to chemical attack

5.17.1 General. Pipes and joints in materials referred to in 5.2 are generally suitable for use in sewers and drains conveying surface water, foul sewage and trade effluent which may legally be discharged to public sewers. The soil in which the sewer is to be laid may be corrosive to certain pipe and/or jointing materials and this may affect the choice of materials. Where a sewer or drain is liable to carry untreated and corrosive trade effluents, further consideration should be given to possible protective measures. Liquids at elevated temperatures are likely to be significantly more aggressive than those at ambient UK temperatures. General guidance is given in table 1.

5.17.2 Concrete and materials containing cement. Normal domestic sewage is not aggressive to Portland cement concrete or cement composite. Attack may however exceptionally occur as a result of aggressive ground water (see BRE Digest No. 250 [4] and BS 8110), or from discharges from hospitals or industrial processes from illegal discharges, or from sewage if it becomes septic.

Table 1 is intended to give general information and, in those cases where it is shown that concrete may be attacked, specialist advice should be obtained.

The cement content, the water/cement ratio and the compaction will have considerable effect on the resistance of concrete to chemical attack. A dense, high quality, well compacted concrete is very resistant to attack. Concrete pipes which comply with BS 5911 are normally resistant to attack by sulphates in solution, as the concrete in the pipes has a high cement content (about 400 kg/m³), a very low water/cement ratio (0.30 to 0.35) and is well compacted by the pipe-making process. For additional protection SRPC should be specified.

5.17.3 Protection of ductile iron. Where conditions are particularly aggressive, additional protection should be considered (e.g. the site fitting of polyethylene sleeving complying with BS 6076 or factory application of zinc coating).

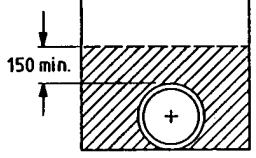
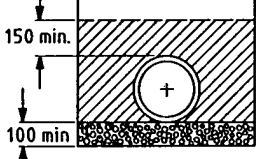
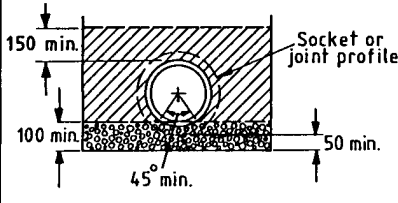
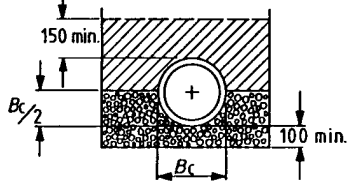
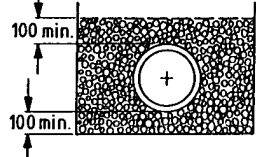
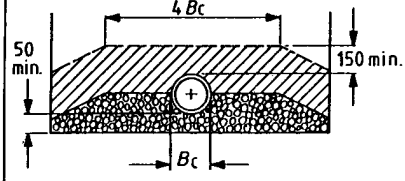
BS 4772 details the standard protection for ductile iron pipes. In sizes DN 80 to DN 800 the pipes are zinc coated externally, prior to bitumen coating internally and externally. For sizes DN 900 to DN 1100 the pipes are cement mortar lined and coated externally with bitumen material. All size pipes and fittings can, if required, be cement mortar lined. The bitumen should comply with BS 3411, type II or BS 4147, type I.

5.17.4 Protection for grey iron pipes. The standard protection for grey iron pipes is as follows:

- (a) cold applied coatings complying with BS 3416; or
- (b) hot applied coatings complying with BS 4147; or
- (c) zinc or epoxy type coatings as described in BS 5493.

NOTE. In some aggressive soils or where aggressive chemicals are being discharged it may be advisable to use additional protective coating systems or combinations of those listed above.

5.17.5 Protection for steel pipes. BS 534 describes internal and external protection systems for steel pipework for sewerage.

Figure	Bedding class		Bedding factor*	Comments
1a	D		1.1	Pipe laid on trimmed trench bottom.
1b	N		1.1	Pipe laid on a flat layer of granular material with CF† not greater than 0.3.
1c	F		1.5	Pipe laid on a flat layer of granular material with CF† not greater than 0.2. Illustrated after settlement.
1d	B		1.9	Pipe laid on granular material to half diameter with CF† not greater than 0.2.
1e	S		2.2	Pipe fully surrounded by granular material with CF† not greater than 0.2.
1f	B (example)		1.9 (example)	Construction as in figures 1b, 1c, 1d and 1e, except that when the trench width exceeds four times the outside diameter of the pipe barrel, the granular material may be sloped down from that width to the trench formation.

All dimensions are in millimetres.

KEY.



Selected fill



Granular material

B_c is the external pipe diameter.

NOTE 1. 5.5.2 gives recommendations for granular material for bedding.

NOTE 2. 5.5.3 gives recommendations for selected material for sidefill and initial backfill.

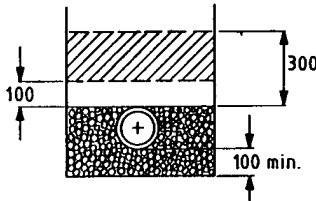
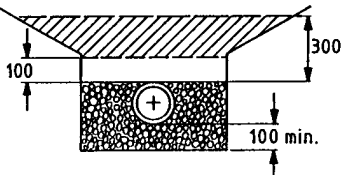
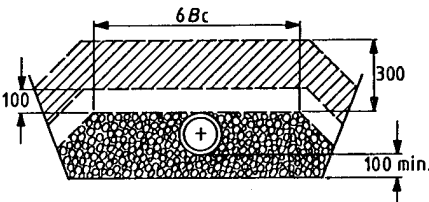
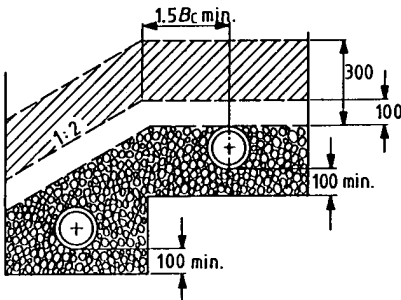
NOTE 3. 12.6.3 to 12.6.6 and 12.9 detail pipelaying procedures for beddings.

NOTE 4. Where there are sockets, these should be not less than 50 mm above the floor of the trench.

* Bedding factor = the ratio of the strength of the pipeline on the specified bedding to the specified crushing strength of the pipe.

† See appendix D.

Figure 1. Beddings for rigid pipes

Figure	Type of trench		Comments
2a	Typical		Pipe surrounded in granular material except above the crown where selected fill may be suitable (see 12.9.2.2).
2b	Vee		A sub-trench should be dug as shown, with construction as in figure 2a.
2c	Wide		Construction as in figure 2a except that when the trench exceeds six times the outside diameter of the pipe barrel, the granular material may be sloped down from that width to the trench formation.
2d	Stepped dual		Construction as in figure 2a for top pipe.

All dimensions are in millimetres.

KEY.

	Selected fill		Granular material		Granular material or selected fill containing no stones larger than 40 mm.
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B_c is the external pipe diameter.

NOTE 1. 5.5.2 gives recommendations for granular material for bedding.

NOTE 2. 5.5.3 gives recommendations for selected material for initial backfill.

NOTE 3. 12.6.3 to 12.6.5 and 12.9 detail pipelaying procedures for beddings.

NOTE 4. Where there are sockets, these should be not less than 50 mm above the floor of the trench.

Figure 2. Beddings for flexible pipes

Table 1. Chemical resistance of materials (for general guidance) (See also relevant information in clause 5)

Group	BS no.	Material and applications	Trade effluent							Soil	
			At normal temperature		Organic solvents	Containing oils and fats		At sustained high temperature*		Soil environment containing	
			Acids and septic sewage	Alkalis		Vegetable	Mineral	Acids	Alkalis	Sulphates	Acids
Ceramic	65 1196 3921	Clayware pipes and fittings	S	S	S	S	S	A	A	S	S
		Bricks and blocks of fired brick-earth, clay or shale	S	S	S	S	S	A	A	S	S
Concrete	5911 6073	Concrete pipes:									
		Concrete masonry units	E	A	A	E	A	E	A	A	E
Asbestos-cement	486 3656	Ordinary Portland cement	A	S	A	A	A	E	A	S	A
		Sulphate-resisting Portland cement									
Metals	534 437 4622 4772	Asbestos-cement pressure pipes and joints	E	A	A	E	A	E	A	A	E
		Asbestos-cement pipes, joints and fittings (gravity) for sewerage and drainage									
Plastics	4660 5481 3505 3506 5480	Steel pipes and fittings	E	A	A	A	A	E	E	E	E
		Grey iron pipes and fittings (gravity)	E	A	A	A	A	E	E	E	E
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	Grey iron pipes and fittings (pressure)	E	A	A	A	A	E	E	E	E
		Ductile iron pipes and fittings									
Plastics	4660 5481 3505 3506 5480	Unplasticized PVC } gravity drain and sewer pressure	S	S	E	A	A	E	E	S	S
		GRP	A	A	E	A	A	E	E	A	A
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	Rubber:	A	A	E	E	E	E	A	A	A
		natural (NR)	S	A	E	A	A	A	A	S	S
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	chloroprene (CR)	S	S	A	A	A	A	A	S	S
		BUTYL (IIR)	A	A	E	E	E	E	A	A	A
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	styrene-butadiene (SBR)	A	A	E	E	E	E	A	A	A
		butadiene/acrylonitrile (NBR)	A	A	E	A	A	E	A	A	A
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	ethylene propylene terpolymer (EPDM)	A	A	E	A	E	A	A	A	A
		ethylene-propylene copolymer (EPM)	A	A	E	A	E	A	A	A	A
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	†Bituminous compositions	A	A	E	E	E	A	A	A	A
		†Polyester resin	S	A	E	A	E	E	E	S	S
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	Polyethylene	A	A	A	S	A	A	A	S	S
		†Polyurethane	S	S	A	S	A	A	A	S	S
Jointing materials (other than Portland cement and iron and steel components (see 5.2))	2494 1972 1973 3284 6437	†Polypropylene	S	S	A	S	A	A	A	S	S
		†Epoxy	A	S	E	E	A	E	S	S	A

KEY

A Normally suitable.
E Need expert advice, each case to be considered on its own merits.
S Specially suitable.

* It is not possible to defined 'high temperature' in respect of this range of materials and manufacturer's advice should be sought.

† There is no suitable British Standard for these jointing materials. The classification given to them in the table assumes that the formulations and methods of curing employed are those appropriate for pipe jointing.

NOTE. It is important to take account of quantities and concentrations of all types of chemical likely to be encountered.

Section three. Design

6 Basic principles

6.1 General

The design of a sewerage system is influenced by the local topography, the extent and character of development, the existing and future flows from adjacent catchments, together with the suitability of the point of discharge of any proposed sewer, and the location and adequacy (both hydraulic and structural) of any existing sewerage system.

6.2 Sewerage systems

6.2.1 The different systems. There are three different systems as follows.

- (a) The separate system (sometimes known as the totally separate system) carries foul sewage (domestic sewage and trade effluents) by an individual system of sewers to a sewage treatment works or outfall point. Surface water from roads, footpaths, roofs and other paved areas is collected in an independent system of surface water sewers and discharged into convenient natural watercourses or soakaways, except in industrial areas where there is a high risk of pollution.
- (b) The partially separate system is one in which foul sewage, together with some surface water, usually but not necessarily from roof or yard drainage, is collected by one sewer and the balance of the surface water is collected in another sewer or discharged direct to a watercourse or soakaway.
- (c) The combined system is a one pipe system which carries all the foul sewage and surface water to a sewage treatment works or outfall point.

6.2.2 Choice of system. The sewerage system to be used depends on both technical and financial considerations, and on the requirement of the water authority. In the UK, the separate system is normally adopted for new development, but if much of the existing sewerage is either combined or partially separate, this may determine the choice of system. The hydraulic design of a combined system is more closely associated with surface water sewerage than with foul sewerage.

During the redevelopment of urban areas, or when sewers are being reconstructed, the opportunity may arise to construct a separate system to replace an existing system of combined or partially separate sewers, and this may be more economical than the provision of additional combined sewerage capacity.

The choice of a sewerage system depends on a number of factors as follows.

- (a) In a separate system, surface water sewerage can sometimes be separated into a number of smaller catchments, each with its own discharge to a watercourse. This will limit the overall pipe size and could show a saving in capital cost, but there will be the additional maintenance costs of the two systems.
- (b) With a separate system of sewers, the foul sewer is normally laid at a lower level to facilitate house connections. The laying of a foul sewer below the

surface water sewer will also minimize the risk of discharge of foul sewage to a watercourse in the event of damage to the surface water sewer, or of any cross connection between the two. Care is needed to avoid incorrect connections when there are two separate sewers.

(c) Combined sewers can provide a means of control of pollution of watercourses as a large part of the surface water run-off will be passed through the sewage treatment works. Additional quality control can be obtained by the installation of oil/petrol traps and grease traps.

(d) A combined sewerage system needs to be large enough to carry storm run-off (see 9.4) but should also work at a self-cleansing velocity during dry weather conditions.

(e) If a part of the surface water run-off can be discharged directly to a local watercourse or to soakaways, the partially separate system should be considered.

(f) With combined or partially separate sewerage systems, storm sewage overflows may be considered to enable flows from storms to be diverted when the design run-off is exceeded (see 7.3).

(g) The amount of surface water in combined or partially separate sewers will increase the hydraulic capacity required at pumping stations and at sewage treatment works. The additional capital investment and operational costs need to be taken into account when comparing alternative proposals.

6.3 Preliminary investigations

6.3.1 General. The scope of site investigations work and the methods employed are covered by BS 5930. Particular attention should be paid to the topography and the nature of the subsoil. Specialist investigations are necessary if there is a possibility of the land being subject to mining subsidence or other ground instability.

6.3.2 Topography. An examination of contour maps enable preliminary lines for sewers and pumping mains to be established so that the general feasibility of the proposals can be determined before details are prepared. It is important to use Geological Survey data in conjunction with contour maps when a choice between deep open cut and tunnel is indicated.

6.3.3 Ground investigations. Ground investigations should be planned in the light and knowledge of site conditions already gained and of the probable disposition and depths of excavation. Where problems are known to exist, appropriate measures to determine their character and magnitude should be allowed for in any contract.

A preliminary ground investigation for a projected sewer or pumping main may be necessary to determine the feasibility of the engineering work involved or to assess the nature and scope of the main site investigation. In the latter case, the preliminary investigation facilitates the preparation of bills of quantities. The preliminary investigation should, in conjunction with information

gained from other sources, reveal any parts of the site which require particular attention in the main site investigation.

In determining whether to arrange for a preliminary site investigation in advance of a main ground investigation, the designer should take into account the cost implications and the disturbance and inconvenience, to land owners and others, of having two separate investigations.

Trial pits (hand or machine dug) should be opened up as a matter of course on a site investigation, unless conditions make it impractical, to gain information about the uniformity or otherwise of soil in the mass. Such detailed information cannot be ascertained from boreholes.

6.3.4 Existing services. The positions of all existing services should be ascertained as accurately as possible. The records of the relevant public and private bodies should be examined and consideration given to their possible inaccuracy. Exploratory holes should be excavated where necessary. The details of proposed roadworks and other development on the route of the new sewers should also be examined.

6.3.5 Existing surface water drainage. The lines and levels of all existing drains, ditches and watercourses should be ascertained. When these are to be drained into a new surface water sewerage system, their drainage areas should be determined and surveyed. The relevant drainage authority should be consulted.

6.3.6 Infiltration. In cases which involve the connection of an old system of sewers (which is not to be reconstructed) to a new system, the infiltration of groundwater to the old system may be of significance and should be estimated by observation of the night flow. This should preferably be done when the ground water table is high.

It may be possible to control infiltration by maintenance, renovation or elimination of wrong connections. This could alleviate the need for, or reduce the capacity of, additional sewers. However it is necessary to show that there is a reasonable probability of abatement and that the necessary works are cost-effective. Infiltration abatement schemes on public sewers have on certain occasions caused a rise in the water table which simply transferred the infiltration source to the private drains.

Notwithstanding the advances in pipe materials and jointing systems, some allowance for infiltration into completely new systems should be made where pipelines are laid below the ground water table. There is always some risk of infiltration through building drainage connections, where the small scale and the piecemeal nature of the work render quality control particularly difficult.

6.3.7 Soil samples. Sampling and testing of soil should be undertaken in accordance with the recommendations of BS 5930, with the extent and nature of tests being related to the nature of the ground and the form of construction under consideration. A site investigation can only cover a relatively small part of the lengths of sewers under consideration and may not identify all variations in ground conditions. Similarly samples and tests may not always be representative of all materials on site. On investigation, if the ground conditions are found to be variable or of a dubious nature, the advice of an expert should be sought.

6.3.8 Ground water. The existence of ground water will be of particular importance and steps should be taken to identify ground water levels, including seasonal variations. Sampling and testing should be carried out to identify conditions which may be corrosive to materials used.

6.4 Financial and engineering assessment

6.4.1 General. The financial and economic aspects of the various options open to the designer should be considered alongside the technical, operational, manpower, social, energy conservation and other factors before reaching a decision as to the preferred solution.

Both capital investment and operational costs should be evaluated on the basis of the best information available and options should be compared using cash flow discounting or other techniques as may be appropriate. Due consideration should be given to the accuracy of the various assumptions made in developing the scheme and the sensitivity of the appraisal to errors in these or to changes arising in the future, including the effects of possible differential inflation.

6.4.2 Staging of schemes. Due to the practical difficulties in duplicating deep sewers in urban areas and the considerable economies of scale in sewer costs, it is often necessary to provide capacity to deal with any possible future flows arising from development of the drainage area. In rural areas, where development is uncertain, or where space is available or can be reserved, development of sewers can be planned in stages according to the relative costings of alternative schemes. Staged construction should be considered particularly when sewers can be laid at minimum depth or where lengths of pumping main are needed.

6.5 Layout of sewerage systems

6.5.1 Economy in the design of sewers and sewer connections. While sewers should generally be kept as short as possible, and unproductive lengths avoided, care should be taken not to restrict potential development. The route and depth of a new sewer should always take account of land where there is the possibility of future development. Where main sewers are laid at considerable depths or under main highways having expensive foundations and surfaces, it may be cheaper or more convenient to lay shallow rider sewers to receive the local house connections, and to connect the riders at a small number of convenient points into the main sewer.

6.5.2 Depths of sewers. Sewers should be laid at depths which will accommodate not only all existing properties but also any future properties likely to be erected within the area which the sewers are designed to serve; in certain cases, the depth of basements may need to be borne in mind.

The depth of a sewer will have a significant effect on the cost of its construction. The depth, in conjunction with other factors such as the nature of the ground, presence of groundwater and the proximity of foundations, services, etc., may influence the form and method of construction enough to justify the adoption of alternative layouts. Longer lengths of sewer where practicable.

6.5.3 Gradients of sewers. The most economical design of sewers is obtained when they follow the natural falls of the ground. Sewers should, however, be laid at such gradients as will produce velocities sufficiently high to prevent the deposition of solid matter in the invert. For surface water sewers this can usually be achieved by ensuring that gradients are sufficient to give full bore velocities of at least 0.75 m/s. For foul and combined sewers this minimum velocity should be exceeded daily, which can be achieved by laying the sewers to a gradient which will give a velocity of 1.0 m/s at full bore flow.

6.5.4 Pumping stations. Circumstances which may make the pumping of foul or surface water sewage either necessary or advisable include the following:

- (a) avoidance of excessive depths of sewer;
- (b) the drainage of low lying parts of an area;
- (c) the development of areas not capable of gravitational discharge to an adjoining sewerage system, a sewage treatment works or an outfall;
- (d) overcoming an obstacle, e.g. a ridge, a watercourse, a railway, or for avoiding an inverted siphon;
- (e) the correction of difficulties in a sewerage system resulting from mining subsidence;
- (f) the provision of sufficient head for operation at a treatment works;
- (g) the centralization of sewage treatment;
- (h) raising sewage to storage tanks.

These points should be considered alongside the long-term energy commitments and the capital cost.

The output from a pumping station is normally irregular, particularly during the early life of the station when the flow in the sewers may be substantially below the design flow. The effects of this irregular flow should be taken into account in relation to the flow in downstream sewers and at any treatment works, the premature operation of overflows and the possibility of septicity of the sewage in pumping mains. The discharge from a pumping station may, however, provide a beneficial flushing effect in the sewers.

Site selection should take account of the possibility of flooding, limiting nuisance or damage caused by overflow in the event of mechanical or power failure and the effect on the general amenity of an area from noise or smell.

Pumping operations may be concentrated at one point or occur at a number of strategic points on a drainage system. Alternatives should be considered and cost comparisons made with due regard given to the capital investment and operational costs which pumping will entail.

NOTE. The design of sewage pumping stations and pumping mains is considered in detail in BS 8005 : Part 2.

6.5.5 Vacuum sewerage. In a vacuum sewerage system a vacuum is induced and maintained in the pipe system by means of central vacuum pumps and a reservoir. The vacuum pulls sewage through the system to a central collection chamber where it is disposed of using gravity or conventional pumping.

This type of system is not really new insofar as installations can be traced back to 1868 in Holland. But these older installations were very complex, requiring two pipe systems

and special vacuum traps at all connections. It is only in recent years that a reliable pneumatically operated vacuum interface valve has been developed which allows the use of single pipe systems drawing the sewage from strategically placed collection sumps to which conventional gravity house drains and sanitary fittings can be connected. This has simplified the pipework, and means that operation and maintenance is a little more complicated than conventional systems and that the cost of installation and operation is competitive with other more normal systems.

Vacuum mains are relatively independent of gradient and the depth of cover can usually be the minimum 1 m to 1.5 m needed for protection. They are a viable alternative to gravity and conventional pumped systems, particularly the former in situations where the terrain is flat, there is a high groundwater level, unstable soils, rock, a requirement for a narrow trench and underground obstructions, although it should be remembered that continuous vacuum pumping will be required.

The vacuum sewerage system has been installed in a number of locations in East Anglia and is being considered in other locations. Pipes are of plastics and can vary in size from 75 mm to 200 mm in diameter, although larger diameters are under consideration.

NOTE. The installation of vacuum sewerage in the UK is described in the paper entitled 'Vacuum sewerage' by Stanley and Mills [5], presented at the International Conference on the Planning, Construction, Maintenance and Operation of Sewerage Systems on 12-14 September 1984.

6.5.6 Location of sewers. To allow for adequate access to a sewer for maintenance and to keep maintenance costs to a minimum, the following factors should be considered:

- (a) the position of other existing or proposed services;
- (b) the proximity of existing buildings and their foundations and the nature of the road construction, in relation to the depth and size of the proposed sewer;
- (c) the impact of the construction of the sewer and subsequent maintenance activities upon road users.

Where practicable, if the majority of development is along one side of a road, the sewers should be laid along that side. The duplication of sewers and the cost of laying these in the verge on each side of a main road should be compared with the cost of a single sewer with individual property connections from either side laid under the carriageway.

Where sewers are located under the carriageway, this will leave verges and footpaths available for services which are more likely to require repairs. However, if the sewer is at sufficient depth, it can be constructed in heading or tunnel to pass under existing services and its position will then only be affected by the requirements to locate manholes to avoid those services. In the case of new development, where the routing of sewers along roads may be difficult or produce an uneconomic layout, it may be possible to lay them under public footpaths or pedestrian areas linking different parts of the development.

When areas are being improved or redeveloped and the existing sewerage system is combined or partially separate, the possibility of changing the system should be considered, together with the possible replacement of old sewers, or their relocation under new or improved roads.

6.5.7 Septicity. Septicity caused by the prolonged retention of sewage under anaerobic conditions should be avoided by limiting the time of retention in rising mains and siphons and by the provision of self-cleaning velocities in all sewers.

Septicity of sewage leads to offensive smells and difficulties in treatment. It is mainly caused by the retention of organic solids for long periods in an environment where there is a shortage of free oxygen. It may occur in lengthy sewerage systems, and in siphons and pumping mains where sewage may be retained for many hours particularly during the night.

Septic sewage may produce gases such as methane and hydrogen sulphide. When mixed with air in certain proportions methane is highly explosive. Hydrogen sulphide is toxic in high concentrations and in part-full pipes may be converted by micro-organisms on the damp crown of the pipe into sulphuric acid. This acid can cause serious corrosion of work constructed with Portland cement.

Hydrogen sulphide is formed under anaerobic conditions at low velocity of flow and warm temperatures. The rate of release is increased at points of high turbulence such as backdrops and the outlets of inverted siphons and rising mains. Corrosion can occur to susceptible materials at these points and downstream of them.

6.5.8 Obstacles to sewer lines. Other services, railways, waterways, major roads and similar structures frequently constitute serious obstacles in the layout of sewerage. Sewers are normally routed beneath such obstacles but, in certain cases, the relative levels may be such as to enable the sewer to be carried above the obstacle. If the sewer is of small diameter, permission may be obtained to sling it alongside an existing bridge structure. To carry a large diameter sewer, however, it will usually be necessary to construct a special pipe bridge. When constraints resulting from the span, headroom and access preclude this it will be necessary to drop the sewer below the obstacle.

The routing of sewers under obstacles can result in considerable wastage of available fall as well as excessive depth beyond the obstacle. This wastage of fall may be reduced by the introduction of an inverted siphon (see 8.9). It may however be possible to effect an economy by choosing a route for the sewer which crosses the obstacle at a more favourable place, even if this entails an increase in its length.

7 Surface water sewerage

7.1 General

Surface water sewers are designed to collect and convey run-off generated within an urban area during rainfall, for safe discharge into a receiving watercourse. The magnitude of peak flows that have to be accommodated will depend primarily on the intensity of rainfall and the size and configuration of the paved areas. The topography, soil type and its permeability have also to be considered when estimating the flows emanating from unpaved areas,

but these are generally small relative to the run-off from paved areas, particularly under UK conditions.

In the past, the most commonly used design methods have been the Rational (Lloyd Davies) Method and the TRRL Hydrograph Method [6]. Since 1981 these techniques have been updated by the methods in the Wallingford Procedure [7], developed by Hydraulics Research Station, with the assistance of the Institute of Hydrology and the Meteorological Office, under the supervision of the DoE/NWC Working Party.

With the older methods a design storm was selected and pipe sizes calculated to carry the resulting flows without surcharge. It was assumed that an adequate protection from surface flooding was thus provided. With the newer methods, the same approach is taken for sizing the pipes, but design can then be checked using a simulation program (WASSP—SIM) to establish the performance of the system under storms of longer return period. If an adequate protection against flooding is not found, the design should be adjusted. WASSP—SIM is principally used to check the hydraulic performance of existing systems. (See BS 8005 : Part 5*.)

7.2 Rainfall

7.2.1 Performance criteria. It is normally impracticable to avoid flooding from infrequent storms. A balance therefore has to be drawn between cost and the level of performance provided. Where the client authority has specified the performance criteria for protection against surcharge and flooding, these should be adhered to. For small schemes the criteria in table 2 have been suggested [3] for protection against surcharge and these should be used in the absence of alternative requirements.

Table 2. Storm return periods for design

Location	Return period
Sites with average surface gradient greater than 1 %	Years 1
Sites with average surface gradient of 1 % or less	2
Sites where consequences of flooding are severe, e.g. existing basement properties adjacent to new developments	5

For larger schemes, following design, checks should be made using WASSP—SIM to ensure that an adequate level of protection against flooding will be present. These checks are particularly important on undulating or steeply sloping catchments. The client authority's requirements should again be followed, but in their absence a 30 year flood protection level should be assumed against surface flooding.

* In preparation.

7.2.2 Design storms. The Modified Rational Method (Wallingford Procedure) and its predecessor the Lloyd Davies Method assume mean rates of rainfall during the storm. The Hydrograph methods use a curve or storm profile which describes the distribution of rainfall intensities during the duration of the storm. Mean rainfall rates and storm profiles for the older methods are tabulated [6] together with adjustment factors for different geographical locations within the UK. For the Wallingford Procedure methods, profiles for typical summer storms are built into the programs. Geographical rainfall variations are taken into account. Alternative storm profiles may be appropriate as, for example, when the combined effects of sewer and river flooding are being studied and both winter and summer storms have to be considered. Guidance on storm profile construction should be sought from the Wallingford Procedure [7] and the 'Flood studies report' [8] or from the Meteorological Office.

7.3 Hydraulic design methods

7.3.1 TRRL Hydrograph method. The TRRL method was published in 1963. Subsequently modifications were made and incorporated in the second edition of Road Note No. 35 [6], and the techniques described there were the preferred method prior to the publication of the Wallingford Procedure.

Rainfall is entered in the form of a variable intensity hyetograph, which can be either an observed storm or a synthesized storm. The volume of run-off is determined by assuming 100 % run-off from drained impermeable areas, i.e. paved and roof areas, and zero contribution from all pervious areas (parks, gardens, etc.).

Surface run-off is represented by a time-area diagram with base equal to time of entry. The recommended value for time of entry is 2 min for normal urban areas, increasing to 4 min for areas which are large and/or have shallow gradients.

Time of flow down individual pipe lengths is calculated from pipe full velocities obtained using the Colebrook-White formula. To allow for temporary storage in the pipe, the input hydrograph is modified by routing it through the reservoir formed by the pipe of the current design length. It is thus possible to obtain a discharge hydrograph for each pipe length in the system, from which both peak flow rates and volumes can be assessed.

The principal limitation of the TRRL method is its inability to model directly flow in surcharged pipes and therefore its unsuitability for modelling existing overloaded systems. Also the assumptions of 100 % and zero run-off are not considered to be a sufficiently accurate representation of actual percentage run-off rates.

7.3.2 Modified Rational Method (Wallingford Procedure). The Wallingford Procedure includes the following programs.

- (a) WASSP—RAT: a modification of the Rational Method for design of sewer networks with catchments of less than 150 ha.
- (b) WASSP—OPT: for optimum design of a new sewer network.

(c) WASSP—HYD: a hydrograph method for design and analysis of non-surcharged sewer systems.

(d) WASSP—SIM: a simulation model for existing and newly designed sewer networks, to check performance under severe storms.

WASSP—RAT is closely allied to the traditional Rational Method in that peak discharge is given by the equation:

$$Q_P = 2.78 CiA$$

where

Q_P is the peak discharge (in L/s);

C is the coefficient (see note);

i is the average rainfall intensity (in mm/h);

A is the contributing catchment area (in ha).

NOTE. The coefficient C is the product of two other coefficients C_V and C_R . C_V is the proportion of rain falling on the catchment which appears as surface run-off, and is used in place of the previous assumption of 100 % run-off from paved areas. The routing coefficient, C_R , is a simple means of allowing for surface routing effects.

For the more sophisticated methods within the package the percentage run-off (PR) is estimated using a regression equation of the form:

$$PR = 0.829 PIMP + 25.0 SOIL + 0.078 UCWI - 20.7$$

where

PIMP is the percentage of the catchment covered by impervious surfaces draining to sewer inlets;

SOIL is a soil impermeability index determined from maps provided in the Wallingford Procedure, Volume 3 [7];

UCWI is a measure of antecedent catchment wetness (in mm). It is calculated from soil moisture deficit and rainfall depth during the 5 days prior to the storm event.

Erroneous results are possible at low values of percentage run-off. A limiting condition is specified such that PR cannot be less than 0.4 PIMP.

Above-ground flow is routed through a non-linear reservoir of the form:

$$S = KQ^{\frac{2}{3}}$$

and which obeys the continuity equation:

$$\frac{dS}{dt} = I - Q$$

where

S is the storage on the ground surface (in m^3);

I is the input to the reservoir (net rainfall) (in mm/h);

Q is the outflow (in mm/h);

K is the storage-routing constant.

In practice, to simplify the procedure the program compares the characteristics of each subcatchment to a matrix of nine standard run-off hydrographs and equates each subcatchment run-off to the most appropriate of the standard profiles.

Pipe flows are calculated on the basis of the Colebrook-White formula and the Muskingum-Cunge method is

employed to evaluate storage-routine effects within the sewer system. WASSP—SIM also includes methods of assessing pipe flow behaviour under surcharged conditions.

7.3.3 Choice of design method. The Modified Rational Method has the advantage that it does not require access to a computer. To facilitate hand computation, a guide has been published as Volume 4 of the Wallingford Procedure [7]. The method can be used for straightforward design on developments up to 150 ha where time of concentration is up to 30 min and pipe size up to DN 1000. The data requirements for the Modified Rational and Hydrograph Methods are similar, so if there is access to a computer and the WASSP programs are available, the more accurate Hydrograph Method should be used for all but the simplest design. The Hydrograph Method should be used wherever WASSP—SIM is to be used, to check the level of flood protection available.

7.4 Balancing

7.4.1 General. The development of agricultural land for residential or industrial use will result in an increased rate of rainfall run-off. Unless this is controlled, it will increase the rate of flow in any surface water sewer or watercourse downstream of the development. If the increased run-off will overload the sewer or result in flooding, it is usual to provide some form of balancing on the surface water system of the new development to reduce the rate of discharge. It will generally be convenient to provide balancing on the new sewerage system, but in some circumstances, balancing of a watercourse could be more convenient.

Retention tanks or balancing reservoirs are used on surface water sewers and occasionally on combined sewer systems to accommodate temporarily that part of the peak flow which cannot be accommodated in the sewers downstream, and where increased overflow to receiving waters is unacceptable. The requirement to provide balancing may be set by the authority responsible for control of rivers, who will wish to consider the implications and approve all designs.

A proposal to provide balancing facilities should be based on a careful economic appraisal of the circumstances. The cost of a balancing reservoir (including the cost of land and the subsequent maintenance costs) should be compared with the costs of any improvements which would otherwise be required to existing sewers or watercourses.

7.4.2 Design criteria. The design should take account of the following:

- (a) the maximum rate of outflow acceptable to the pollution control authority;
- (b) the design storm (a balancing reservoir should be designed to deal with the run-off from a storm with a return period as required by the pollution control authority);
- (c) the dimensions of the proposed balancing facility (there may be limitations in the area available or on the maximum depth of storage as required by the land drainage authority).

7.4.3 Types of balancing. Balancing of flows within the sewerage system can be provided by building in additional

storage in the form of on-line or off-line tanks. For on-line storage an over-sized length of sewer can be installed.

Within the watercourse balancing can take one of two forms. An existing lake or pond can be used; balancing storage will then be obtained by arranging for an increase in water level during periods of storm. Alternatively, an area of land can be set aside to be flooded during time of storm; at other times this land can be used for recreational or similar use.

Careful consideration should be given to existing ground and water levels and to the effects of any excavation or banking. In particular, the safety of any existing or proposed properties should be considered. The Reservoirs Act 1975 will apply when the amount of water to be stored exceeds the minimum laid down in the Act.

7.4.4 Storage capacity. The required storage capacity of storage ponds on watercourses can be obtained by plotting the inflow hydrograph based on an appropriate design storm, together with an outflow hydrograph. The volume to be stored can then be calculated from the excess of inflow over outflow. Detailed advice is given in CIRIA Technical Note No. 100 [9].

The optimum size of retention tanks in sewerage systems can be derived using WASSP—SIM. An appropriate outlet throttle is assumed which gives the required carry-on flow. Various tank sizes can then be tested under a range of design storms. The critical storm duration will be found to be between two and four times the time of concentration of the upstream system. Storage tanks are installed more frequently to upgrade the performance of existing systems than as part of new systems, so for more detailed advice see the Sewerage rehabilitation manual [1].

7.5 Soakaways

A soakaway is a pit to provide soakage and storage capacity for run-off; its base and sides are open-jointed to facilitate the percolation of water into the surrounding subsoil. The pit can be filled with rubble, or a roof slab can be provided. If rubble is used, extra capacity should be provided to allow for this.

When the subsoil conditions are satisfactory, soakaways can be used to take the run-off from new development. Individual soakaways can be provided at each gully, downpipe, etc., or a number of drainage points can be connected to one soakaway. Prior approval from the authority responsible for groundwater protection is required before soakaways are installed and this may be withheld in Aquifer Protection Zones. Particular attention should be paid to the provision of oil spillage interception, in order to safeguard groundwater quality and also to protect the performance of the soakaway.

In ground with low permeability, it is necessary to provide storage capacity to retain the flows during prolonged or heavy rainfall. A capacity equal to 12 mm of rainfall over the area drained should be adopted. Its effective depth is measured below the invert of the lowest incoming drain. This can be achieved by the provision of one soakaway or a number linked at overflow level by piped seepage trenches. Similar trenches can be used to provide means of overflow from a soakaway.