

Code of practice for site investigations

ICS 91.200

Committees responsible for this British Standard

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- Association of Geotechnical Experts
- British Geological Survey
- Chartered Institution of Water and Environmental Management
- County Surveyors' Society
- Department of the Environment, Transport and the Regions
- Geological Society
- Institution of Civil Engineers
- Institution of Structural Engineers
- Transport Research Laboratory

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Foreword

This British Standard has been prepared under the direction of the Sector Board for Building and Civil Engineering. BS 5930:1999+A2:2010 supersedes BS 5930:1999+A1:2007, which is withdrawn.

The start and finish of text introduced or altered by Amendments No. 1 and No. 2 is indicated in the text by tags **A1** **A1** and **A2** **A2**. Minor editorial changes are not tagged.

Amendment 1 to this standard (primarily to Section 6) removes text superseded by BS EN ISO 14688-1:2002, BS EN ISO 14688-2:2004 and BS EN ISO 14689-1:2003, and makes reference to the relevant standard for each affected subclause.

Amendment 2 to this standard removes text superseded by BS EN 22475-1:2006, and makes reference to the relevant standard for each affected subclause.

The original code of practice for civil engineers, *Site investigations*, was prepared by a committee convened in 1943 by the Institution of Civil Engineers on behalf of the Codes of Practice Committee for Civil Engineering, Public Works, Building and Construction Work, under the aegis of the former Ministry of Works, for publication in the Civil Engineering and Public Works Series. The code was published in 1950.

In 1949, the responsibility for the preparation and issue of the codes of practice in the Civil Engineering and Public Works Series was handed over to the Institution of Civil Engineers, the Institution of Municipal Engineers, the Institution of Structural Engineers and the Institution of Water Engineers. Arrangements for the preparation and publication of these codes were made by the Civil Engineering Codes of Practice Joint Committee constituted by those four Institutions.

In 1954, agreement was reached between the professional Institutions concerned, the British Standards Institution and the Council for Codes of Practice for Buildings (under the aegis of the former Ministry of Works) to transfer responsibility for the issue of codes of practice to the British Standards Institution. At the request of the British Standards Institution, a committee was convened by the Institution of Civil Engineers to amend the 1950 code. A revised code was published in 1957 by the British Standards Institution, under authority of its Council for Codes of Practice, as CP 2001.

The Institution of Civil Engineers similarly convened a further committee in 1965 to prepare a revised code. In 1976, the convening responsibility was transferred to the British Standards Institution and a revised code was issued in 1981 as BS 5930. With one or two minor exceptions, this was a completely new text.

Under the continuing authority of the British Standards Institution, this revision has been prepared with the following objectives:

- a) **A1** To clarify the scope: in this code, the term “soil” has the meaning ascribed to it by common current usage in UK civil engineering and construction. A number of current British Standards define “soil” in relation to its use in agriculture and horticulture. In order to avoid any possible confusion, the title of BS 5930 has been revised in order to indicate its precise application.
- b) To revise material which is now obsolescent. To this effect, there is new information on geophysical surveying and a new annex on site investigations on contaminated ground, as well as smaller amendments throughout the code.
- c) To maintain compatibility with all the parts of BS 1377:1990, *Methods of test for soils for civil engineering purposes*. Whenever one of these tests is referred to in the revised BS 5930, only a very brief description is given and reference is made to BS 1377:1990 for more detailed information. **A1**
- d) To maintain conformity with European and International codes. In so far as information was available at the time of drafting, the revised BS 5930 is generally in agreement with comparable European and International codes.

NOTE 1 The numbers in square brackets used throughout the text of this code relate to the references in the Bibliography.

A1 NOTE 2 BS 5930 makes every effort to keep up with changes in organization of the UK government departments, but this is not always possible. **A1**

The European Committee for Standardization, CEN, has the responsibility for preparing a series of Eurocodes, which would harmonize practice throughout the European Community and eventually would replace the existing national codes. The British Standards Institution (BSI) represents British interests in CEN.

A1 BS EN 1997, *Geotechnical design* and BS EN 1991, *Basis of design*, are relevant to BS 5930 and give information that could be helpful in planning site investigations. **A1**

A further proposed group of European Standards, *The execution of special geotechnical works* give specifications for standardizing practice throughout the European Community.

As a code of practice, this British Standard takes the form of guidance and recommendations **A1** in contrast to specifications such as BS EN ISO 14688-1:2002, BS EN ISO 14688-2:2004 and BS EN ISO 14689-1:2003, which take the form of requirements **A1**. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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 cannot confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to ix, a blank page, pages 1 to 192, an inside back cover and a back cover.

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1 Scope

This Code of Practice deals with the investigation of sites for the purposes of assessing their suitability for the construction of civil engineering and building works and of acquiring knowledge of the characteristics of a site that affect the design and construction of such work and the security of neighbouring land and property. It has been assumed that in the selection of construction sites due regard has been paid to the wider environmental and economic considerations affecting the community generally. More than one site may require detailed investigation before the final choice is made.

In this code, the expression Site Investigation has been used in its wider sense. It is often used elsewhere in a narrow sense to describe the exploration of the ground, which in this code has been termed Ground Investigation. It is to be noted, however, that although the treatment of ground investigation is detailed, the treatment of other aspects of site investigation is less detailed.

The use of soil and rock as construction materials is treated only briefly; further information is given in BS 6031.

This code of practice consists of the following sections:

- *Section 1: Preliminary considerations;*
- *Section 2: Ground investigations;*
- *Section 3: Field investigations;*
- *Section 4: Field tests;*
- *Section 5: Laboratory tests on samples;*
- *Section 6: Description of soils and rocks;*
- *Section 7: Reports and interpretation.*

Section 1 deals with those matters of a technical, legal or environmental character that have usually to be taken into account in selecting the site (or in determining whether a selected site is suitable) and in preparing the design of the works.

Section 2 discusses general aspects and planning of ground investigations, including the influence of general conditions and ground conditions of the selection of methods of investigation.

Sections 3, 4 and 5 discuss methods of ground investigation, sub-divided as follows: section 3 excavation, boring, sampling, probing and tests in boreholes; section 4: field tests; section 5: tests on samples. The division between sections 3 and 4 is somewhat arbitrary and has been based mainly on convenience in arranging the subject matter.

Section 6 deals with the terminology and systems recommended for use in describing and classifying soil and rock materials and rock masses.

Section 7 deals with the preparation of field reports and final borehole logs, the interpretation of the data obtained from the investigation and the preparation of the final report.

Users of this Code of Practice, particularly those of limited experience, are advised against referring to the methods of ground investigation in sections 3, 4 and 5 without studying the preliminary considerations in sections 1 and 2. It should be appreciated that the description of a method is only to be considered as a guide and should not be taken as mandatory. In this respect, it should be realized that development continues to take place involving changes in some of the methods.

It may be noted that there is an imbalance of treatment between tests; in some cases more comprehensive treatment has been given to tests less frequently used. This is because many of the common tests are described extensively elsewhere (see BS 1377), whereas there is a paucity of reference to other tests.

The code has been drawn up in relation to conditions existing in the United Kingdom, but occasional reference is made to conditions overseas where this has appeared desirable.

2 Definitions

[A₁] For the purposes of this standard, the terms and definitions given in BS 6100 (all parts), BS EN ISO 14688-1:2002, BS EN ISO 14688-2:2004, BS EN ISO 14689-1:2003 and the following apply. **[A₁]**

2.1 soil and rock

[A₂] Soil is defined in BS EN ISO 14688-1:2002, 3.1 and rock is defined in BS EN ISO 14689-1:2003, 3.1. **[A₂]**

2.2 ground

general term covering soils, rocks and made ground

2.3 made ground

covers all deposits which have accumulated through human activity and may consist of natural materials, e.g. clay and/or man made materials, e.g. refuse

2.4 fill

“made ground” in which the material has been selected, placed and compacted in accordance with an engineering specification

2.5 groundwater control

has been adopted in preference to “dewatering”, since the former is considered to convey a better description of the scope of the expedient

3 Normative references

[A] The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 410-1/ISO 3310-1, *Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth.* **[A]**

BS 812-2, *Testing aggregates — Part 2: Methods for determination of density.*

BS 812-103, *Testing aggregates — Part 103: Method for determination of particle size distribution.*

[A] Reference deleted **[A]**

BS 882, *Specification for aggregates from natural sources for concrete.*

BS 1377-1:1990, *Methods of test for soils for civil engineering purposes — Part 1: General requirements and sample preparation.*

BS 1377-2:1990, *Methods of test for soils for civil engineering purposes — Part 2: Classification tests.*

BS 1377-3:1990, *Methods of test for soils for civil engineering purposes — Part 3: Chemical and electro-chemical tests.*

BS 1377-4:1990, *Methods of test for soils for civil engineering purposes — Part 4: Compaction-related tests.*

BS 1377-5:1990, *Methods of test for soils for civil engineering purposes — Part 5: Compressibility, permeability and durability tests.*

BS 1377-7:1990, *Methods of test for soils for civil engineering purposes — Part 7: Shear strength tests (total stress).*

BS 1377-8:1990, *Methods of test for soils for civil engineering purposes — Part 8: Shear strength tests (effective stress).*

BS 1377-9:1990, *Methods of test for soils for civil engineering purposes — Part 9: In-situ tests.*

BS 1881-6, *Testing concrete — Part 124: Methods for analysis of hardened concrete.*

BS 1924-1, *Stabilized materials for civil engineering purposes — Part 1: General requirements, sampling, sample preparation and tests on materials before stabilization.*

BS 4019-3:1993, *Rotary core drilling equipment — Part 3: Specification for System A — Metric units.*

BS 4019-4:1993, *Rotary core drilling equipment — Part 4: Specification for System A — Inch units.*

BS 5493:1977, *Code of practice for protective coating of iron and steel structures against corrosion.*

BS 6031, *Code of practice for earthworks.*

BS 6068-0:1995, *Water quality — Part 0: Introduction.*

BS 6068-2, *Water quality — Part 2: Physical, chemical and biochemical methods.*

BS 6316:1992, *Code of practice for test pumping of water wells.*

BS 7361-1, *Cathodic protection — Part 1: Code of practice for land and marine applications.*

BS 8004-1, *Code of practice for foundations.*

[A] BS 22475-2:2010, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 2: Qualification criteria for enterprises and personnel.* ^{A)}

BS 22475-3:2010, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 3: Conformity assessment of enterprises and personnel by third party.* ^{A)} **[A]**

CP 2012, *Code of practice for foundations for machinery — Part 1: Foundations for reciprocating machines.*

[A] BS EN 933-3, *Tests for geometrical properties of aggregates — Part 3: Determination of particle shape — Flakiness index.*

[A] BS EN 1997-2:2007, *Eurocode 7 — Geotechnical design — Part 2: Ground investigation and testing.* **[A]**

BS EN ISO 14688-1:2002, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description.*

BS EN ISO 14688-2:2004, *Geotechnical investigation and testing — Identification and classification of soil — Part 2: Principles for a classification.*

BS EN ISO 14689-1:2003, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description.*

BS EN ISO 22475-1:2006, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution.* **[A]**

[A] BS EN ISO 22476-3:2005, *Geotechnical investigation and testing — Field testing — Part 3: Standard penetration test.* **[A]**

4 Safety

This Code of Practice describes procedures for site investigations and all involve some risk to safety unless an appropriate safety plan has been prepared and implemented. Safety is considered in **9.4**.

Elsewhere, safety is only mentioned where a special reminder has been considered necessary, e.g. work in contaminated ground. However, it is emphasized that safety is of paramount importance for every activity in site investigation.

[A] ^{A)} BS 22475-2:2010 and BS 22475-3:2010 are in preparation. **[A]**

Section 1. Preliminary considerations

5 Primary objectives

Investigation of the site is an essential preliminary to the construction of all civil engineering and building works and the objects in making such investigations are as follows.

- a) **Suitability.** To assess the general suitability of the site and environs for the proposed works including, where applicable, the implications of any previous use or contamination of the site.
- b) **Design.** To enable an adequate and economic design to be prepared, including the design of temporary works.
- c) **Construction.** To plan the best method of construction; to foresee and provide against difficulties and delays that may arise during construction due to ground, groundwater and other local conditions; in appropriate cases, to explore sources of indigenous materials for use in construction (see 10.4); and to select sites for the disposal of waste or surplus materials.
- d) **Effect of changes.** To determine the changes that may arise in the ground and environmental conditions, either naturally or as a result of the works, and the effect of such changes on the works, on adjacent works, and on the environment in general.
- e) **Choice of site.** Where alternatives exist, to advise on the relative suitability of different sites, or different parts of the same site.
- f) **Existing works.** Unless the contrary can be demonstrated, it should be assumed that site investigations are necessary in reporting upon the existing works (see 10.3), and for investigating cases where failure has occurred (see 10.2).

The ground is naturally variable and often the nature of these variations is not known in advance. A site investigation is a process of continuous exploration and interpretation, with the scope of the investigation requiring regular amendment in the light of the data being obtained. In order to evaluate properly the nature of the ground and the groundwater and so to achieve the objects of the site investigation, it is essential that the work be planned, undertaken and supervised by personnel who have appropriate qualifications, skills and experience in geotechnical work (see clause 17). If this is not done, the results and conclusions of an investigation may be inadequate or even misleading and result in a considerable over-run of time and expenditure when the proposed works are under construction [1] [2].

6 Procedure

6.1 Extent and sequence

6.1.1 General

The extent of the investigation depends primarily upon the magnitude and nature of the proposed works and the nature of the site. The former use of a site, and the presence of contamination of the ground or groundwater can also have a significant impact on the extent of the investigation.

A site investigation should proceed in stages as follows:

- Stage 1 Desk study and site reconnaissance.
- Stage 2 Detailed investigation for design including ground investigation, topographic and hydrographic surveying and any special studies.
- Stage 3 Construction review, including any follow-up investigations during construction, and the appraisal of performances.

Stage 1 should be undertaken at the start of every investigation. The desk study should include consideration of the possible existence of contaminated ground, where additional site safety procedures need to be established in advance of any intrusive investigation. It should also include environmental and ecological considerations, which might impose constraints on the execution of Stage 2. As far as possible, the assembly of the desk study information should be complete before the ground investigation (Stage 2) begins.

A preliminary ground investigation may often be desirable to determine the extent and nature of the main ground investigation. The extent of the ground investigation is discussed in clause 12.

The costs of a site investigation are low in relation to the overall cost of a project and may be further reduced by intelligent forward planning. Discussion at an early stage with a geotechnical advisor or appropriate specialist can help to formulate an efficient and economic plan.

6.1.2 Adjacent property

In view of the possibility that the construction of new works may affect adjacent property or interests, it is important that investigations for new works should consider all factors that may affect adjacent land or existing works and that, where possible and expedient, records of ground levels, groundwater levels and relevant particulars of adjacent properties should be made before, during and after the construction of the new works. Where damage of existing structures is a possibility, adequate photographic records should be obtained. This is particularly important where existing structures are defective.

6.2 Desk study

It is essential to carry out a desk study as the first stage of a site investigation. The primary objectives of the desk study are to evaluate the ground conditions based upon existing information, and to plan the scope of the subsequent stages of investigations. Annex A indicates the kinds of information that may routinely be required. Where there is a choice of site, information obtained from this study may well influence such choice. Much information may already be available about a site in existing records. A summary of the most important sources of information is given in annex B, and a more detailed catalogue is given elsewhere [3].

Information based on local experience, including earlier uses of the site, may be available from local authorities and local or regional statutory undertakings (see clause 7). Occasionally, it is possible to obtain the results of previous ground investigations carried out on or near the site. Excavations on or near the site may have been made in the recent past by such authorities or with their knowledge. Information may also be available from local industry and others. Copies of old maps are often available in public libraries and local museums. Papers and local projects presented to professional bodies and local societies and technical journals may be other sources of information. Local oral tradition, although of variable reliability, may sometimes give a lead. Helpful information may be obtained from aerial photographs (see clause 8 and B.6). For sources of information about previous industrial uses, see annex E.

6.3 Site reconnaissance

At an early stage, a thorough visual examination should be made of the site. The extent to which ground adjacent to the site should also be examined is, in general, a matter of judgement (see 6.1.2). Annex C gives a summary of the procedure for site reconnaissance and the main points to be routinely considered. This procedure may need to be extended or modified, depending upon the particular circumstances of the site.

Nearby railway or road cuttings can reveal soil and rock types and their stability characteristics, as can old pits and quarries. Similarly, there may be embankments, buildings or other structures in the vicinity that have a settlement history because of the presence of compressible or unstable soils. Other important evidence that might be obtained from an inspection is the presence of current or old mine workings (see annex E) or other underground excavations, such as old cellars, tunnels or sewers. The behaviour of structures similar to those planned also provides useful information, as does the absence of such structures, for example, a vacant site in the midst of otherwise intensive development may be significant. The type and abundance of

vegetation on a site should be noted and can provide important information on chemical contamination of the ground, or the presence of soil gases (see annex F).

For instances of earlier uses of the site that may affect new construction works, see clause 7.

6.4 Detailed examination and special studies (see also annex D)

For most projects, the design and planning of construction requires a detailed examination of the site and its surroundings. Such requirements may necessitate a detailed land survey (see D.1), or an investigation of liability to flooding. The investigation of ground conditions is dealt with in other sections in this code, e.g. section 2. Other requirements may entail studies of special subjects such as hydrography (see D.4); climate (see D.5); sources of materials (see D.7); disposal of waste materials (see D.8); for other environmental and ecological considerations.

Where mining and quarrying, whether past, present or prospective, is likely to be a factor affecting the site, reference should be made to annex E.1. Where contamination of the ground or the presence of soil gases is possible, reference should be made to annex F. Effects of tunnelling, where this is a possibility, should be considered.

6.5 Construction and performance appraisal

Construction and performance appraisals are discussed in clause 18.

7 Earlier uses and state of site

7.1 General

If a site has been used for other purposes in the past, this can have a major effect on present intended use. A careful visual inspection of a site and the vegetation it sustains may reveal clues suggesting interference with the natural subsoil conditions at some time in the past. Examples are given in 7.2 to 7.7.

The former uses of the site can sometimes be discovered by a study of old Ordnance Survey and earlier maps. In some cases, the forerunners of local authorities commissioned the making of maps of their areas long before Ordnance maps were produced, and these maps were often drawn using the most meticulous detail. Former occupiers of the site may also be able to provide detailed maps indicating the layout of facilities.

In the marine environment where topographic changes may occur more rapidly, references to early Admiralty charts and other charts may indicate earlier configurations, see B.3.1.

7.2 Underground mining

Annex E gives details of the procedure that should be followed for enquiries and the subsequent site investigation for an area where underground mining has been or is currently being carried out, or is envisaged.

7.3 Opencast mining

The extraction of coal by opencast methods has been carried on extensively since the late 1930s and details of the availability of records are given in annex E. Other minerals have also been extracted by opencast methods.

7.4 Quarry operations

The quarrying of materials such as stone, chalk, sand, gravel and clay has been carried out since ancient times and, over the years, many excavations have been back-filled and then put to some other use. Many such sites have subsequently been used for waste disposal (see 7.5 and annex F).

7.5 Waste tips and landfills

The site may have been used for the tipping of mining waste, industrial waste, domestic refuse, chemical waste and miscellaneous refuse. Such sites require special consideration before any intrusive investigation is carried out to ensure the safety of site investigation workers and protection of the environment. Frequently, harmful chemicals and toxic or explosive gases may be present. Consultation with the Environment Agency in England and Wales and the Scottish Environmental Protection Agency in Scotland and Waste Regulation Authority is essential during the planning stage of investigations in such sites. See also annex F.

7.6 Industrial sites

In many parts of the country, there are sites where heavy industries once existed. Often no visible signs remain of the buildings and other structures, but below ground level, for example, there may be foundations including piles and sheet piled walls, engine beds, pits and chambers, often of massive construction, which can be major obstacles to redevelopment. The ground may still be affected by extremes of temperature from installations such as cold-storage plants, high-temperature kilns and furnaces. The ground is also frequently contaminated by spilled chemicals, leaking sumps and drains, the spreading or burial of waste, or the importation of contaminated fill. Historic aerial photography can be very useful in identifying the locations of physical obstructions and potential chemical contamination (see clause 8).

7.7 Other earlier use

Redevelopment of urban areas may involve running into disused tunnels and encountering obstacles such as cesspits, sewers, wells, cellars, drains and communication passages.. It is essential that site investigations in such areas cover both the physical obstacles and the potential contamination of the ground.

7.8 Ancient monuments

If it becomes apparent during the desk study that any ancient monument or site of archaeological interest is likely to be affected by the investigation or the subsequent works, the matter should be referred to the Chief Inspector of Ancient Monuments.

7.9 Ecology

Ecological issues need to be carefully considered, because they could impose significant constraints on both the execution of the site investigation and on the future development of the site. A variety of plants, animals and habitats is specially protected by law e.g. The Conservation (National habitats etc.) Regulations 1994.

8 Aerial photographs and satellite imagery

8.1 General

Aerial photographs and satellite imagery can be used both in the preparation and revision of maps and plans and for the interpretation of site features or earlier uses of a site. They are particularly useful for mapping large, undeveloped sites, notably for such projects as dams, power stations, and highways, although they can also be used for mapping smaller sites.

During the desk study stage they can assist in the identification of geological and geomorphological features on or in relation to a site, and in the interpretation of earlier uses of the site. [4], [5] Although a non-specialist can often extract a substantial amount of relevant information from satellite imagery, trained interpreters are necessary if full information is to be obtained [6] Interpreters should be carefully briefed on the requirements of the interpretation. A considerable database of aerial photography has been available since the 1940s, particularly in urban areas, and existing sources should be checked (see B.6) before special photography is commissioned, which could prove to be very expensive and unnecessary.

8.2 Topographical mapping

Accurate, contoured maps can be produced from aerial photographs by a competent survey organization that normally carries out ground control. This is done by placing markers on the ground that can be identified from the air and also measured in plan and level on the ground.

The scale of photography should be properly related to the project. Normally, photography is available at the various scales considered appropriate for level map or plan making. The scales 1:500, 1:1 000, and 1:2 500 are most appropriate for investigations of limited areas, whereas scales of 1:5 000 to 1:20 000 are more appropriate to regional studies. Although much map revision of urban areas is carried out by the Ordnance Survey using aerial survey, specially commissioned surveys are not likely to be justifiable for small urban sites.

Orthophotomaps, unlike conventional vertical photographs, are true to scale. They consist of rectified (true to scale) photographs overprinted with contours and grid, and for some purposes provide an alternative to a conventional map or plan; they may be of particular value to major site investigations.

8.3 Identification of features

Aerial photographs can often be used to identify such features of engineering significance as geological lineaments, for example, strata boundaries, faults, soil and rock types, landforms, drainage patterns and unstable ground, including areas of mining disturbance and swallow holes. They are particularly useful in the study of extended sites where ground visibility is limited by obstructions or where access is difficult. Significant features should be checked on the ground whenever possible. Although photographs are best studied stereoscopically, much data can be obtained from single photographs. Additional information may be gained by the study of aerial photographs taken at different times when the direction or nature of light differs, or when soil and vegetation has undergone seasonal changes.

8.4 Earlier uses of sites

Inspection of historic aerial photography can yield valuable information of previous construction and earthworks on a site, and is an essential part of the desk study of former industrial, quarrying and waste tip sites. The RAF carried out extensive photography in the early 1940s and many areas have been subject to repeated photography by commercial sources over the past 50 years. Annex B gives details of sources of historic aerial photography, and annex F describes particular features of importance to be noted on potentially contaminated sites.

8.5 Sophisticated techniques

Natural colour does have particular advantages. Multispectral techniques providing simultaneous images in selective wave bands, including the infra-red, are also available. One example of the uses of infra-red photography is to identify vegetation “distress” caused by landfill gas, chemical contamination, water deficiency or heat. The use of false colour to enhance such features as vegetation is possible when selective wave bands have been used [4]. It is stressed that the more sophisticated, and costly, systems require more highly trained interpreters if the full value of such systems is to be realized. It should be appreciated that rapid advances are being made in the use of sensor systems, in both the conventional airborne field and using earth satellite imagery.

Section 2. Ground investigations

9 Introduction

9.1 Objectives

For new works, the objectives of ground investigations are to obtain reliable information to produce an economic and safe design, to assess any hazards (physical or chemical) associated with the ground, and to meet tender and construction requirements. The investigation should be designed to verify and expand information previously collected.

The objectives of ground investigations related to defects or failures of existing works (see **10.2**) or to the safety of existing works (see **10.3**), are directly related to the particular problems involved. The requirements for investigation of materials for construction purposes are discussed in **10.4**.

An understanding of the geology of the site is a fundamental requirement in the planning and interpretation of ground investigations. In some cases, where the geology is relatively straightforward and the engineering problems are not complex, sufficient geological information may have been provided by the desk study, subject to confirmation by trial pits or boreholes or both. In other cases, it may be necessary to undertake geological mapping, which is discussed in clause **11**.

Of primary importance is the establishment of the soil profile or soil and rock profile, and the groundwater condition. The profile should be obtained by close visual inspection and systematic description of the ground using the methods and terminology given in section 2. Provided the profile is supplemented by limited in-situ or laboratory testing, in many cases this suffices. In others, it is necessary to determine the engineering properties of the soils and rocks in detail. The extent of the ground investigation is discussed in clause **12**. Where appropriate the geometry and nature of discontinuities should be established (see **14.10**).

The investigation should cover all ground in which significant temporary or permanent changes may occur as a result of the works. These changes include: changes in stress and associated strain; changes in moisture content and associated volume changes; changes in groundwater level and flow pattern; and changes in properties of the ground, such as strength and compressibility. Materials placed in the ground may deteriorate, especially in landfill and contaminated former industrial sites. It is therefore necessary to provide information from which an estimate of the corrosivity of the ground can be made (see clause **15**).

In certain districts, special measures need to be taken to locate underground cavities, such as old mine workings or swallow holes, which may collapse and cause damage to structures. Other hazards may arise on account of earlier uses of the site (see clause **7**).

9.2 Planning and control

Before commencing the ground investigation, all relevant information collected from the sources discussed in section 1 should be considered, in order to form a preliminary view of the ground conditions and the engineering problems that may be involved.

This assists in planning the amount and types of ground investigation required.

A ground investigation should be conducted as an operation of discovery. Planning should be flexible so that the work can be varied as necessary in the light of fresh information. On many occasions, especially on large or extended sites, a preliminary investigation is necessary in order that the main investigation may be planned to best advantage. The main investigation obtains the bulk of the information required, but it may be necessary to carry out supplementary investigations after the main work to gather more detailed information related to specific matters.

The ground investigation should be completed before the works are finally designed. It is therefore important that sufficient time for ground investigation, including reporting and interpretation, is allowed in the overall programme for any scheme. Should changes in the project occur after completion of the main investigation, additional ground investigation may be required. If so, the programme should be adjusted to allow for this.

Sometimes conditions necessitate additional investigation after the works commence. In tunnelling, for example, probing ahead of the face may be required to give warning of hazards or changes in ground conditions. The properties of the ground and also the groundwater levels may vary with the seasons. In planning the investigation, consideration should be given to predicting the ground conditions at other times of the year.

The imposition (for reasons of cost and time) of limitations on the amount of ground investigation to be undertaken may result in insufficient information being obtained to enable the works to be designed, tendered for and constructed adequately, economically and on time. Additional investigations carried out at a later stage may prove more costly and result in delays.

It is essential that there be adequate direction and supervision of the work by a competent person who has appropriate knowledge, training and experience and the authority to decide on variations to the ground investigation when required (see clauses **5** and **17**).

Guidance on planning a site investigation is found in [7] and a suitable specification in [8].

9.3 Quality management

This involves the construction and implementation of a managerial plan, designed to ensure that the results of the site investigation are submitted within the required standards for accuracy and presentation, as defined in the specification.

Depending on the objectives, the amount and types of investigation can vary from the very simple, e.g. boring, to establish the level of an easily recognized rock-head, to the highly complex, involving sophisticated techniques for boring, sampling and testing.

The quality management plan consists of a series of written procedures covering some or all of the following components of a site investigation:

- a) equipment: standard of maintenance, frequency of checks on performance, frequency of calibrations;
- b) testing: procedures including checking of observations and calculations;
- c) personnel: all personnel should have qualifications, training and experience appropriate to their duties;
- d) audits to check that the quality management plan is being fully implemented: depending on circumstances, these may be done by internal or external auditors.

Many organizations and personnel already have some form of quality accreditation from external authorities. Examples include:

- 1) Accreditation for Quality Assurance, QA: this certifies that an organization has quality management systems in operation which satisfy the requirements of BS EN ISO 9000 series, in respect of those parts appropriate to site investigations.
- 2) UKAS: this certifies that an organization carries out tests strictly in accordance with the appropriate British Standard or International Standard, e.g. BS 1377, *Methods of test for soils for civil engineering purposes*.
- 3) Personnel are usually accredited in terms of vocational, academic or professional qualifications together with suitable specialist experience or training. The British Drilling Association operates a scheme for the accreditation of site investigation drillers.

Guidelines on quality management of site investigations are given in [7].

9.4 Safety

Safety is relevant to all aspects of site investigation. This code cannot attempt to address all the very important and wide ranging aspects of safety, including procedures to be followed and precautions to be taken on site. It is only in this section that reference is made to general safety requirements; the guidance is not repeated in the other sections describing specific activities.

The Health and Safety at Work etc. Act 1974 [9] established formal rules for the management of safety and defined clearly the responsibilities of organizations, employers and employees. Within the umbrella of this Act there exists a framework of Regulations (see [9] to [18]), Approved Codes of Practice, Codes of Practice, Guidance Notes and other published information which define the requirement for safety on sites where investigation and construction work is being carried out.

The complexity and volume of EC directives and safety regulations make it difficult to communicate all the changes relating to safety in the work place. Safety directions are constantly under preparation. The most recent of the Regulations also have an Approved Code of Practice issued by the Health and Safety Executive and reference should be made to these Codes of Practices.

Other documents relating to safety in investigation work may be found in the Bibliography ([19] to [23]). A combination of badly managed events often results in death and injury. Safety can always be improved by raising awareness of the dangers, provided that there is the management will to adopt a "Safety culture".

All employers of five or more persons have a statutory duty to prepare and revise as necessary a written safety policy and communicate this to all employees.

Under the Management of Health and Safety Regulations 1992, [12] firms employing similar numbers of employees (five or more) are required to implement a formal approach to safety. This is normally undertaken through a Safety Management System, which requires induction, risk assessments, method statements, consultation and audit.

The Construction (Design and Management) Regulations 1994, [16] effective from 31 March 1995, cover notification of the project, impose duties on all clients, contractors and employees, create additional duty holders of Planning Supervisor and Principal Contractor, require that a Site Safety plan is prepared before construction (and investigation) work can proceed and that all work is carried out to the safety plan or its subsequent revisions. The CDM Regulations apply to a construction project at a particular location and to all contracts that may be awarded as part of that project. They are designed to provide a continuous and integrated system for the avoidance, reduction and management of health and safety risks from conception to commissioning and handover of the finished project.

Most ground investigations, geotechnical advice and design and other associated work falls within the CDM Regulations even though they often form part of the concept, feasibility, design and planning stages, as well as being required to be undertaken on some occasions during the construction phase. Ground investigation is included in the listed definitions of construction work [11] and in the

follows that the construction phase for any project may well commence with the ground investigation fieldwork. The project is notifiable if the construction phase is longer than 30 days or involves more than 500 person days of construction work.

It is essential that reference is made to regulation 3 to determine whether all or any of the regulations apply to any proposed investigation work. Projects that fall outside the full scope of the Regulations may include:

- a) where the project is not notifiable and involves no more than four persons at work at any one time;
- b) where the Local Authority is the enforcing authority for health and safety purposes [12] [13].

Where CDM Regulations do not apply, other Health and Safety Regulations still apply to the employers, employees and self employed carrying out construction work.

The Control of Substances Hazardous to Health Regulations 1988, cover the protection of people at work who may be exposed to health risks arising from hazardous substances.

In particular employers are required to:

- assess the hazard potential of all substances and work processes and record them in writing;
- identify how exposure is controlled;
- explain how any control measures are monitored;
- identify health surveillance needs;
- establish a record keeping programme;
- arrange for suitable training.

When investigating sites there are usually two potential sources of hazardous substances: those that exist on site (contaminated land); and those purchased by the contractor to enable the works to be carried out (cement, bentonite, fuels etc.). In the case of a potentially contaminated site the initial safety assessment for a potentially hazardous site should list the likely substances to be encountered. The assessment provides the basis of the site specific Safety Plan which includes the requirements for personal protective equipment (PPE).

In the case of purchased materials it is the responsibility of the contractor to consider each individual site and to prepare a “notification of use and assessment” for each hazardous substance. It is important to include on the sheet the procedures to be adopted to control the hazardous substance. Where products such as cement, bentonite, fuel etc. are used daily on various investigation sites, these substances may be dealt with by using general assessment sheets prepared in the Head Office, provided that they are retained on site and all site staff and operatives are aware of the existence of these assessments.

When work is being carried out on premises controlled by public authorities or large commercial or utility organizations, such as those in the railways, water, oil and gas industries, compliance is required with the organizations’ own regulations, which include the established precautions relating to their particular business and its hazards.

Certain risks are attached to working on investigation sites, not least of which are road traffic accidents, which occur not only on site, but also to employees travelling long distances. The advice in the booklet *Safer Road Works Ahead* [24] should be followed when signing roads, except those on motorways and high speed dual carriageways with hard shoulders. Detailed traffic management procedures for major trunk roads and motorways are outlined in the *Traffic Signs Manual* [25]. Attention is also drawn to The New Roads and Street Works Act, 1991 [26] and The Street Works (Qualification of Supervisors and Operatives) Regulations, 1992 [27].

Risks associated with particular circumstances or hazards should also be assessed and provision made for safe working in the site safety plan. These include underground and overhead services, underground ducts and tunnels, work over and adjacent to water, geophysical surveys, diving services, work underground, work on contaminated land [28], abseiling and the use of equipment containing radioactive sources. All these types of work should be undertaken in accordance with current practices and the existing appropriate Regulations.

10 Types of ground investigation

10.1 Sites for new works

Investigations for new works differ from the other types of investigation mentioned in clause 9, in that they are usually wider in scope; this is because they are required to yield information to assist in selecting the most suitable location for the works. For instance, when an excavation has to be carried out, a knowledge of the subsurface strata and groundwater conditions should indicate, for example:

- a) whether removal of the material is difficult;
- b) whether the side of the excavation is stable if unsupported or requires support (see BS 6031);
- c) whether groundwater conditions necessitate special precautions such as groundwater or other geotechnical processes;
- d) whether the nature of the excavated material will change;
- e) whether any of the soil or groundwater is contaminated, therefore requiring special controls on excavation, movement, disposal, and additional safety measures;
- f) whether environmental or ecological considerations might impose any constraints on the scope of the new works.

On the design side, it is necessary to assess such considerations as bearing capacity and settlement of foundations, stability of slopes in embankments and cuttings, earth pressures on supporting structures, and the effect of any chemically aggressive or hazardous ground conditions. For the design of new works, it is important that the range of conditions, including least favourable conditions, should be known. This entails not only a study of the degree of variability in the strata over the area of the site, but also an appreciation of the possible injurious effects of groundwater variation and weather conditions on the properties of the various strata. Where works require excavations into or within rock, the orientation and nature of discontinuities in the rock may be the most important factor.

10.2 Defects or failures of existing works

The investigation of a site where a failure has occurred is often necessary to establish the cause of the failure and to obtain the information required for the design of remedial measures.

Observations and measurements of the structure to determine the mode or mechanism of failure are first needed and these often suggest the origin of the trouble, or at least indicate whether the ground conditions were partly or wholly responsible. If this is the case, ground investigation is required to ascertain the condition of the strata and the groundwater conditions, both as they exist in-situ and as they existed before the works were constructed. Each problem needs to be considered individually. Indications of the probable cause of a failure often result in detailed attention being directed to a particular aspect or to a particular stratum of soil.

In the case of slope failure, or where such failure is considered imminent, it is common practice to monitor movements on the surface and underground. This is achieved by conventional survey methods and by instruments such as slip indicators, tilt meters, inclinometers etc. Automatic data recorders and warning systems may be used to monitor potentially unstable conditions. These techniques are fully described in BS 6031.

An investigation to determine the causes of a failure may be much more detailed than an investigation for new works.

10.3 Safety of existing works

10.3.1 Effect of new works upon existing works

Existing works close to, or even at a distance from, the proposed site may need to be investigated, to decide whether they are likely to be affected by changes in the ground and groundwater conditions brought about by the new works.

10.3.2 Kinds of effects

Existing structures may be affected by changed conditions such as the following:

- a) excavations or demolitions in the immediate vicinity, which may cause a reduction in support to the structure, either by general ground deformation or by slope instability;
- b) mining or tunnelling operations in the neighbourhood, which may cause deformations and subsidence; the effect of tension and compression on drainage and on ground deformation should not be overlooked;
- c) stresses that the new structure may impose on the foundation strata below adjacent structures or upon earthworks and supporting structures;
- d) vibrations and ground movement resulting from traffic, vibratory compaction, piling or blasting in the immediate vicinity;
- e) lowering of the general groundwater level by pumping from wells which causes an increase in the effective stress in the subsoil affected, and can lead to excessive settlement of adjacent structures; also, if wells do not have an adequate filter, the leaching of fines from the subsoil can easily result in excessive settlement of structures at a considerable distance from the well;
- f) shrinkage or swelling of clay soils due to weather, transpiration of trees and shrubs, and heat from furnaces;
- g) soil movements associated with freezing, which may occur naturally or artificially;
- h) impeded drainage, which may result in a rise in the groundwater level; this can cause softening of cohesive strata and a reduction of bearing capacity of permeable strata, as well as giving rise to increased pore pressures affecting the stability of slopes and retaining walls; swelling may result in ground heave;
- i) alteration in stream flow of a waterway, which may cause undercutting of banks or scouring of foundations of walls, bridges and piers, and may be due to works carried out some distance away;
- j) siltation of the approaches of harbour works or the changing of navigation channel alignments;
- k) disturbance of contaminated ground, which may allow aggressive leachates or noxious gases to migrate through the ground.

10.3.3 Procedure

Given problems of this kind, it is important to first establish what changes are likely to occur. Knowledge of the subsurface strata needs to be determined from the ground investigation and samples need to be tested and examined to assess the effect that the changed conditions are likely to have on these strata. In some cases, it may be necessary to carry out a detailed analysis to estimate the effect of the changed conditions on the safety of the existing works.

10.4 Material for construction purposes

Investigations of sites are sometimes required:

- a) to assess the suitability and quantities of material that become available from excavations or dredgings for construction work, e.g. whether spoil from cuts in roads and railway works is suitable for fills in other places;
- b) to find suitable material for specific purposes, e.g. borrow pits for earthworks, aggregate for concrete and road construction (see BS 882);
- c) to assess the chemical characteristics of ground that may need to be removed for environmental reasons;
- d) to locate suitable disposal sites for excess spoil and dredged materials.

In works such as railways and roads, a prior knowledge of the strata on the line of the route may influence design, e.g. by suggesting deeper cuts at places where the material is particularly suitable for fill construction, or a reduction of cuts in unsuitable material. It may be possible to assess the suitability of the material by visual inspection alone and in such cases the main task is to explore the extent of the material and to estimate the amount available. In other cases, the suitability of the material may not be evident and then it will be necessary to carry out tests to determine what steps are required to make the best use of it (see [29]). Published and unpublished records of the Institute of Geological Sciences and the British Geological survey are particularly recommended for investigations of this kind (see B.2).

11 Geological mapping for ground investigation

Information concerning the geological survey maps is given in B.2. If this is insufficiently detailed for a particular investigation, it may be necessary to carry out additional geological mapping. Nevertheless, even when the maps are considered to be sufficiently detailed, a walkover survey should still be undertaken where possible. Methods used for geological mapping [30] [31] are equally suitable for ground investigation purposes, and may be supplemented by geophysical investigations (see clause 35) and aerial photographs (see clause 8). The object of geological mapping is the elucidation of the character, distribution, sequence and structure of the soils and rocks underlying the area. Interpretation of the geological conditions at the site may therefore require the mapping of a larger area. An understanding of geomorphological features may be valuable in interpreting the nature and distribution of soils and rocks. Hydrogeological conditions and man-made features should be recorded.

Natural exposures and artificial exposures, such as quarries and cuttings beyond the site may provide data on the material and mass characteristics of soils and rocks, including, for example, the orientation, frequency and character of discontinuities, weathering profiles, and the nature of the junction between superficial and solid formations. Such information should be used as a guide only to conditions likely to be present at the site. Extrapolation of data should be avoided as a general rule. Interpolation should be made with care; geological deposits may vary laterally and very important geological structures such as faults and other major discontinuities may have only a restricted extent.

It may be expedient to investigate local conditions at an early stage of the mapping, using mechanically excavated shallow pits and trenches. The walls of excavations and, where appropriate, the floor should be mapped using a large scale and samples taken before backfilling takes place.

As the construction work proceeds, the actual geological conditions exposed in the various excavations should be logged so that the previous geological reports can be revised as necessary.

Further information and examples of engineering geological mapping are given elsewhere (see [32] and [33]).

12 Extent of the ground investigation

12.1 General

The extent of the ground investigation is determined by the character and variability of the ground and groundwater, the type of project and the amount and quality of existing information. It is important that the general character and variability of the ground be established before deciding on the basic principles of the design of the works. It may be that the desk study of existing information will provide sufficient high quality data for a preliminary design to be started with confidence.

A range of “methods” is used to carry out ground investigations. These include intrusive methods such as excavations, boreholes and probing (see section 2), and geophysical surveying (see clause 35).

The factors determining the selection of a particular method are discussed in clauses 13 and 14, and in section 2. In general, the recommendations in 12.2 to 12.7 apply irrespective of the method adopted, and the term “exploration point” is used to describe a position where the ground is to be explored by any particular “method”.

Each combination of project and site is likely to be unique, and the following general points should therefore be considered as guidance in planning the ground investigation and not as a set of rules to be applied rigidly in every case.



Certain methods of investigation are more suitable than others on contaminated land. Also the density and layout of exploration points will need to recognize the location and depth of potential contamination on a site. Annex F provides further guidance on these matters.

12.2 Character and variability of the ground

The greater the natural variability of the ground, the greater the extent of the ground investigation required to obtain an indication of the character of the ground. The depth of exploration is usually determined by the nature of the works projected, but it may be necessary to explore to greater depths at a number of points to establish the overall geological structure. The technical development of the project should be kept under continuous review since decisions on the design influence the extent of the investigation.

It is important to realize that the detailed geology of a site can be no more than inferred from aerial photography, from surface outcrops and from subsurface information at the positions of the exploration points. The possibility remains that significant undetected variations or discontinuities can exist, including lateral or vertical variations within a given stratum. Even an intensive investigation can only reduce uncertainties; a complete excavation is the only way to reveal the true nature of the ground. The use of angled drill holes can in certain cases greatly assist interpreting variations between vertical boreholes. In some circumstances, additional information between investigation points can be obtained by geophysical methods (see clause 35).

12.3 Nature of the project

The investigation should yield sufficient data on which to base an adequate and economical design of the project. It should, in addition, be sufficient to be able to decide which of the various possible methods of construction would be desirable and, where appropriate, to suggest sources of construction materials. The lateral and vertical extent of the investigation should cover all ground that may be significantly affected by the new works or their construction. Two typical examples are the zone of stressed ground beneath the bottom of a group of piles and an adjacent slope, the stability of which may be decreased by the works.

12.4 Preliminary investigation

Depending on the results of the desk study, and the size and complexity of the project, it may be advisable to carry out the investigation in stages. The initial stage might involve widely spaced boreholes, probing, or trial pits designed to establish the general geological conditions, the suitability of different methods of investigation, the groundwater conditions, or an indication of the degree of chemical contamination. This preliminary investigation assists in producing an effective programme for the detailed investigation.

12.5 Location

The points of exploration, e.g. boreholes, soundings, pits, should be so located that a general geological view of the whole site can be obtained providing details of the engineering properties of the soils and rocks and of groundwater conditions. More detailed information should be obtained at positions of important structures and earthworks, at points of special engineering difficulty or importance and where ground conditions are complicated, e.g. suspected buried valleys and old slipped areas. In the absence of other criteria, a regular array of exploration points may be used in the initial design of an investigation. However, sufficiently close supervision and flexibility (in the contract) should be provided to allow amendments to be made to this pattern as the work proceeds. Sometimes it is not possible to locate structures until much of the ground investigation data has been obtained. In such cases, the programme of work should be modified accordingly.

When investigating tunnels and shafts, boreholes should be offset so as not to interfere with subsequent construction. For other structures, the need to offset boreholes and trial excavations from critical points should be considered. In most cases, boreholes should be carefully backfilled, concreted or grouted up. Trial excavations should be outside proposed foundation areas.

For highways, it is important that some exploration points are arranged at offsets to the centre-line of the proposed road, so that lateral variation in ground conditions can be revealed and material obtained to test suitability for use as fill material.

It is essential that the locations and ground levels for all exploration points be established, if necessary by survey.

12.6 Spacing

Although no hard and fast rules can be laid down, a relatively close spacing between points of exploration, e.g. 10 m to 30 m, are often appropriate for structures. For structures small in plan area, exploration should be made at a minimum of three points, unless other reliable information is available in the immediate vicinity.

Where a structure consists of a number of adjacent units, one exploration point per unit may suffice. Certain engineering works, such as dams, tunnels and major excavations, are particularly sensitive to geological conditions, and the spacing and location of exploration points should be related more closely to the detailed geology of the area than is usual for other works.

12.7 Depth of exploration

12.7.1 General

The depth of exploration depends on how new building work significantly affects the ground and groundwater, or is affected by them. Normally exploration should be undertaken below all deposits that may be unsuitable for foundations purposes, e.g. made ground and weak compressible soils, including weak strata overlain by a layer of higher bearing capacity. The exploration should go through compressible cohesive soils likely to contribute significantly to the settlement of the proposed works, normally to a depth where stress increases cease to be significant, or deeper. If rock is found, a penetration of at least 3 m in more than one borehole may be required to establish whether bedrock or a boulder has been encountered, unless prior knowledge of the local geology obviates this. Three metres may be an insufficient penetration into rock in areas where the rocks have a massive structure (see clause 44) or where large, apparently undisturbed sedimentary masses underlain by till may occur as rafts in till deposits. No guidance can be given in such cases, but where doubt arises, consideration should be given to drilling a deeper hole, or making an in-situ examination in an excavation. More specific recommendations are given in 12.7.2 to 12.7.8.

It is not always necessary that every exploration should be taken to the depths recommended in 12.7.2 to 12.7.8. In many instances, it is adequate if one or more boreholes are taken to those depths in the early stages of the field work to establish the general ground profile, and then the remainder sunk a little higher to explore more thoroughly the zone near the surface which the initial exploration had shown to be most relevant to the problem in hand.

12.7.2 Foundations for structures

For these, the depth of exploration should be at least one and a half times the width of the loaded area, unless the imposed stress change becomes insignificant when compared with the strength and stiffness of the ground at a lesser depth, e.g. in strong rock. For foundations near the surface, the loaded area is considered as either:

- a) the area of an individual footing; or
- b) the plan area of the structures, where the spacing of foundation footings is less than about three times the breadth, or where the floor loading is significant; or
- c) the area of a foundation raft.

In each case, the depth should be measured below the base of the footing or raft.

Where piled foundations are considered a possibility, a preliminary analysis of the possible lengths of different types and sizes of pile should be made using the desk study information. In addition, the following factors should be taken into account when planning the depth of exploration.

- 1) Pile groups stress the ground below the pile points to a greater depth than will an individual isolated pile. The depth of exploration should be sufficient to identify any weak strata beneath the pile points, which might affect the bearing capacity of the pile groups.
 - 2) Made ground, and weak compressible soils seldom contribute to the shaft resistance of a pile and may add down drag to the load on it. The whole pile load, possibly with the addition of down drag, has to be borne by the stronger strata lying below the weak materials.
 - 3) In the case of end-bearing piles in strong rock, boreholes should be of sufficient depth to establish conclusively the presence of rock head. The rock should then be further explored, usually by means of rotary drilling, to such a depth that the engineer directing the investigation is satisfied that there is no possibility of weaker strata occurring lower down, which could affect the performance of the piles.
 - 4) Pile-supported rafts on clays are often used solely to reduce settlement. In these cases, the depth of exploration is governed by the need to examine all strata that could contribute significantly to the settlement. A commonly used approximation in settlement calculations for piled rafts is to assume that the whole of the load is carried on an imaginary raft situated at a depth below the underside of the real raft equal to two-thirds of the pile length. The size of this imaginary raft is determined by assuming a spread of load of 4:1 (vertical:horizontal) outwards from the edge at underside of pile cap level of the rectangle containing the piles. In theory, the depth of exploration should be one-and-a-half times the width of this imaginary raft below its base.
- In practice, on many occasions, this would lead to an excessive and unnecessary depth of exploration and the engineer directing the investigation should terminate the exploration once relatively incompressible strata have been reached, provided that the depth of exploration is sufficient to prove the strata well below the toes of the piles. Similar considerations apply to groups of end bearing piles in coarse grained soils, except that in this case the imaginary raft should be assumed to be at the pile toe level, with an area extent the same as the pile group.
- 5) In chalk and other weak rocks, the exploration should be taken to the base of the weathered materials and to a sufficient depth into the unweathered rock to prove its continuity.

Based on the information of the probable ground profile obtained from the desk study, the general guidance given in 1) to 5) and the assessment of the types of pile likely to be considered, the engineer directing the investigation should determine the depth of exploration and be ready during the course of the field work to modify this depth as appears to be necessary. In any event, exploration should at some points be taken below the depth of which it is considered likely that the longest piles penetrate.

It should be noted that if any structure is likely to be affected by subsidence due to mining or any other causes, greater exploration depths than those recommended in this clause may be required so that basic geological data can be obtained.

12.7.3 Embankments

For embankments, the depth of the exploration should be sufficient to check possible shear failure through the foundation strata and to assess the likely amount of any settlement due to compressible strata. In the case of water-retaining embankments, investigation should explore all strata through which piping could be initiated or significant seepage occur.

12.7.4 Cuttings, quarries and opencast mines

For cuttings, quarries and opencast mines, the depth of exploration should be sufficient to permit assessment of the stability of the future slopes; this may require proving the full depth of any relatively weak strata. Groundwater conditions, including the possibility of artesian water, should also be determined.

12.7.5 Roads and airfields

For roads and airfields, the depth of exploration should be sufficient to determine the strength and frost susceptibility of possible subgrades and the drainage conditions. Exploration to a depth 2 m to 3 m below the proposed formation level is probably sufficient in most cases. A greater depth may be needed where a road is to pass over a shrinkable subgrade through a heavily vegetated area.

12.7.6 Pipelines

For small, shallow pipelines, it is frequently sufficient to take exploration to 1 m below the invert level. For deeper pipelines the depth of exploration should be sufficient to enable dewatering and to allow any likely difficulties in excavating trenches and supporting the pipelines to be investigated. This means that a depth of at least 1 m to 2 m below the invert level may be advisable. Large pipelines, especially those in ground of low bearing capacity, require special consideration.

12.7.7 Maritime works

For maritime works, the possible effects described in 12.7.2 and 12.7.3 should be considered as well as the effects of tidal variations.

12.7.8 Tunnels

For tunnels, it is important to take the exploration to an adequate depth below the proposed invert level, both because changes in design may result in the lowering of the level of the tunnel, and because the zone of influence of the tunnel may be extended by the nature of the ground at a greater depth. It is also necessary to take some of the boreholes to a depth sufficient to establish the overall geological structure (note also 12.5 on the location of the boreholes).

12.8 Contaminated ground

When establishing the extent of the site investigation for developments on ground that has been contaminated by former use the design of remedial ground treatment and the geotechnical design of foundations and services need to be taken into account. The type, spacing and depth of investigation points are determined by the objectives of the investigation, as well as the prevailing geological conditions, the nature and extent of the contamination, and the proposed end use. Further guidance on the design of site investigation on contaminated ground is given in annex F.

13 General considerations in the selection of methods of ground investigation

13.1 Introduction

Although the character of the ground, the objectives and technical requirements are the most important aspects in the selection of methods of ground investigation, selection may also be influenced by the character of the site, the availability of equipment and personnel, and the cost of the methods.

13.2 Site considerations

The topography, nature of the ground surface, surface water, and the existence of buildings or other structures, may cause problems of access to the locations for exploratory holes, as well as probing, in-situ testing, etc. or interfere with geophysical methods. For example, if the ground surface is soft, it can be traversed only by very light equipment. Where this would not be effective, access roads for heavier equipment are required. On very steeply sloping open sites, it may be necessary to construct an access road and lower the equipment down the slope or haul it up. Where the working position is on steeply sloping ground, it is necessary to form a horizontal working area by excavation or the use of a staging. Gaining access to sites covered by water also presents special problems (see clause 16). On sites that are obstructed by buildings and other structures, it may be necessary to demolish walls to gain access. Alternatively, it may be possible to lift the equipment over obstructions using a crane or to use special equipment that can be dismantled and manhandled through the building and used inside.

confined space. Investigations inside existing buildings are usually carried out with cut-down rigs, portable drive sampling equipment or hand excavation. In such cases, the depth of such investigation is usually restricted.

Environmental and ecological conditions also need to be taken into account since these may impose constraints on both the locations and on the equipment that can be used.

Certain methods of boring and of field testing require a supply of water. There may be legal restrictions on obtaining water for drilling purposes. In the United Kingdom this may involve the prior publication of notices in order to obtain a licence to abstract. The Water Resources Act 1963 [34] controls permissions to take water from any natural source. On a site where water is not available, it is necessary to arrange for a temporary supply to be provided. This usually involves pumping through pipelines or transporting the water in bowsers. On sites where the provision of water presents a major problem, it may be necessary to use alternative methods of investigation; for example, with rotary drilling an air flush could be considered instead of water flush, see 20.7.

In built-up areas the avoidance of noise nuisance, the limitation of the working area, and the enclosure of the works by hoardings or safety barriers can restrict the methods and progress of the investigation. Surface obstruction and buried services may also interfere with geophysical survey methods as well as restrict intrusive investigation.

A2 13.3 Sampling considerations

The appropriate techniques and methods for sampling and groundwater measurement should be selected from BS EN ISO 22475-1:2006, 5.2. **A2**

14 The effect of ground conditions on the selection of methods of ground investigation

14.1 Introduction

A2 The factors involved in the choice of the most suitable procedures for boring (including drilling), sampling, probing, tests in boreholes and field tests, as determined by the character of the ground, are considered in 14.2 to 14.10. Further detailed information may be found in BS EN 1997-2:2007, Section 3 and BS EN ISO 22475-1:2006, Clause 5. Frequent reference is made to classes of sample quality; these are defined in 22.2. **A2**

The determination of the groundwater conditions is a most important part of a ground investigation. It usually involves the installation of piezometers and the performance of field testing in piezometers or boreholes (see clauses 22, 23 and 27). In general the investigation of the groundwater conditions does not govern the choice of the method of exploration. Where the ground is contaminated, however, specific investigations are usually required to define the chemical constituents of the groundwater at various

depths across the site, as well as to examine the hydraulic characteristics of the ground and the direction of flow (see annex F).

The presence of chemical contamination, or of hazardous soil gases, is a significant factor in the selection of the method of investigation, or in the conduct of the work. It is vital for the investigation to be carried out under strict health and safety guidelines, in order to prevent the creation of contaminants and their migration pathways and in order to provide reliable samples for chemical analysis.

14.2 Non-cohesive soils containing boulders, cobbles or gravel

Within the limits of cost, the best method for investigating this type of ground is by means of a dry excavation (see 20.1 and 20.2). If it is necessary to investigate the ground below the groundwater table, dewatering is required to obtain a dry excavation. The excavation permits the structure of the ground to be inspected, class 4 samples to be obtained, and field tests to be used to measure the in-situ density, strength and deformation characteristics (see clauses 31 and 32).

When boring, there may be difficulty in advancing the boreholes and consequently in obtaining samples of adequate quality. Normally, the most suitable method of boring is with light cable percussion (see 20.5) using the shell and by supporting the sides of the borehole with casing. Pieces that are too large to enter the shell need to be broken up by the chisel, which is often a slow process. To reduce the use of the chisel, it is advantageous to use the largest size of boring equipment that is available. Generally, the 200 mm to 250 mm sizes are suitable for gravel, and larger sizes in the range 300 mm to 450 mm may give faster progress on cobbles. Boring in soils containing boulders calls for the alternate use of the chisel and the shell, and can be a very slow operation. Other methods of boring that use high-powered machines may sometimes be used to obtain a faster rate of progress than is obtained by light cable percussion. Both methods require some technique to support the sides of the borehole, and there may be an appreciable cost from wear of the tools.

None of the sampling methods described in 22.4 to 22.7 is suitable for this type of ground. Disturbed samples taken from the shell are only class 5 (grading incomplete) because the fine fraction has been washed out and the coarse fragments may have been broken up by the use of the chisel.

Borehole tests can be used to obtain an indication of the properties of the ground. The standard penetration test (see 24.2), with the 60° cone replacing the cutting shoe, gives some indication of the relative density in gravel. Occasional high values that are unrepresentative of the true relative density are obtained when the penetrometer encounters coarse gravel. In ground containing cobbles or boulders, the standard penetration test gives an increasing proportion of unrealistically high results.

The borehole permeability test (see 24.4), may give a reasonable indication of permeability, and the results can also be used to give a guide to the proportion of fine particles in the soil. A more reliable assessment of permeability is obtained from a pumping test (see clause 27). The static cone penetration test (see 26.3) has limitations where there is a significant content of boulders or cobbles. It is also limited because of the inability of the cone to penetrate dense gravel. Dynamic probing (see 26.2) may give useful results provided the density is not too high.

14.3 Sand

Boreholes in sand are usually sunk by the light cable percussion method using a shell. This requires sufficient water in the borehole to cover the shell, as it is necessary to add water in dry ground. The addition of water to the borehole (so that the shell can be used) renders the moisture content of samples unrepresentative of the stratum. Below the water table, some sands tend to “blow” up the borehole, therefore loosening the ground below the bottom of it. Keeping the borehole full of water, and using an undersized shell carefully can reduce the tendency to blow, but may not completely eliminate it. Disturbed samples taken with the shell are likely to be deficient in fines owing to the action of water, and are therefore only class 5. Samples suitable for particle size distribution, class 4 are usually obtained using the split barrel standard penetration test sampler (see 22.4.5). Larger class 4 samples can usually be obtained by using the 100 mm open-tube sampling equipment with two or three tubes coupled together and with a core catcher fitted above the cutting shoe (see 22.4.4).

The action of forcing a sampler into sand tends to cause a change in volume, even if the area ratio is small (see 22.4.1.2c)), and hence the density of the sample may not be representative of the stratum. In some cases, a piston sampler is effective (see 22.5); this should produce class 2 samples or, where the sand is loose or very dense, class 3 samples.

However, in both cases the moisture content of the samples may be unrepresentative of the stratum.

In shallow investigations above the water table, excavations or hand augering (see 20.4) may be used.

A guide to the relative density of sands is obtained by the standard penetration test. However, the results can easily be invalidated if, as previously discussed, sand is loosened below the water table. Where it is important that the relative density should not be underestimated, for example when a driven pile project is being investigated, the relative density should be assessed by the static cone penetration test (see 26.3).

Approximate values of the strength and compressibility parameters can be estimated on an empirical basis from the results of the standard penetration test or, preferably, from the results of the static cone penetration test. Pressuremeter tests are also useful. A more direct determination requires the use of plate tests carried out in a dry excavation (see 25.6 and clause 31).

Permeability may be assessed from borehole permeability tests (see 25.4) or by pumping tests (see clause 27).

14.4 Silt

Silt is a difficult material to sample and test, and in considering methods, it is sometimes necessary to distinguish between finer grained, cohesive silts and coarse silts, which approach fine sand in behaviour. Boreholes in silt are usually sunk by the light cable percussion method using the shell. The shell sample may be deficient in fines owing to the action of the water and therefore only class 5. Above the water table, it may be possible to use the clay cutter and recover samples of class 3 or 4. Silt is usually sufficiently cohesive to allow the recovery of samples using the 100 mm open-tube sampler. Because of the relatively low permeability, these samples usually permit a reliable determination of moisture content, even when water has been added to the borehole. Silts are often sensitive to disturbance during sampling, and hence samples taken with the 100 mm open-tube sampler are usually only class 3. In low or medium density silt, class 2 samples can be obtained using a thin-walled piston sampler (see 22.5).

In preliminary investigations, the standard penetration test is used to obtain an indication of the relative density and is usually alternated with the recovery of 100 mm open-tube samples. Blowing and disturbance caused by the borehole tools can lead to the standard penetration test giving erroneously low results. As with sand, a more reliable result can be obtained using the static cone penetration test (see 26.3).

14.5 Normally consolidated and lightly overconsolidated clay

Boreholes in clay are usually sunk by the light cable percussion method using the clay cutter where boreholes are dry. Where the borehole contains water, it may be necessary to use the shell.

Disturbed samples obtained with the clay cutter are class 4. Disturbed samples recovered with the shell are class 4 provided that lumps of intact clay can be recovered. Samples taken with an open-tube sampler suffer disturbance, the degree of disturbance increasing with the sensitivity of the clay to remoulding, and with the depth at which the sample is taken; such samples are therefore class 2 or 3. Class 1 samples can usually be obtained by using a thin-walled piston sampler. It should be noted that clays that exhibit permeable fabric may require a water head in the borehole as for sands.

The vane test (see 25.3) is useful for the measurement of the undrained shear strength of normally consolidated or lightly overconsolidated clays. Conventional oedometer tests have severe limitations in respect of determination of rate of settlement (see clause 39, which deals with tests on soils, in particular Table 10 under “Soil deformation tests”). To overcome this difficulty, such tests can be used in conjunction with in-situ constant head permeability measurements. Alternatively, large diameter piston samples should be obtained, either 150 mm or 250 mm diameter, depending on the soil fabric, so that hydraulic odometer tests can be conducted in the laboratory. Probing may be used to determine the thickness of superficial soft clays and peats.

The static cone penetration test can be used to provide continuous in-situ shear strength profiles.

14.6 Overconsolidated clays

Boreholes in overconsolidated clays are usually sunk by the light cable percussion method. Alternatively, they can be sunk using continuous flight augers, with solid or hollow stems although this can lead to difficulties if granular materials are also encountered. Rotary core drilling can also be used in overconsolidated clays, but considerable care is required to avoid change of moisture content and disturbance by the drilling fluid.

A2 Samples of clays in the firm to stiff consistency range taken with a 100 mm thick-walled open-tube sampler (OS-TK/W) usually suffer significant material disturbance, and will not produce samples better than class 2. With very stiff and hard clays there is significant disturbance. Thin-wall samplers (OS-T/W) pushed statically into the ground can produce class 1 samples. **A2** Where the nature of the problem warrants greater accuracy, the assessment of strength and undrained deformation characteristics requires plate tests in large diameter boreholes, although these can give erroneous results below the water table (see 25.6).

Standard penetration tests can give a useful indication of shear strength (see 25.2).

There may be a significant amount of disturbance in laminated clays, particularly if there is no water head in the boreholes. In addition, samples of laminated clays soften through migration of porewater from the more permeable laminations into the cohesive laminations.

Piston samples, including large diameter samples up to 250 mm diameter can also be obtained in overconsolidated clays in the lower part of their strength range.

14.7 Clay containing gravel, cobbles or boulders

Within the limits of cost, the best method of investigating clay containing gravel, cobbles or boulders is by a dry excavation. The excavation enables the structure of the ground to be inspected, class 3 samples to be obtained, and field tests for the determination of the in-situ density, strength and undrained deformation characteristics to be carried out.

When using borehole methods of investigation, this type of ground presents difficulties in both advancing the boreholes and recovering samples of adequate quality.

Using the light cable percussion method, it is often necessary to resort to alternate use of the chisel and shell. Disturbed samples recovered by the shell are class 5 and give a very poor guide to the character of the ground, because the coarse particles are broken up by the chisel and much of the fine matrix is washed out. It may be possible to recover samples of the clay matrix using the 100 mm open-tube sampler fitted with a strengthened cutting shoe, but the sampler frequently cannot be driven past the coarser particles. **A2** Generally, the samples are of limited length, have been disturbed by coarse particles, and are only class 4 or 5. **A2**

An alternative borehole method, for use when the clay matrix is stiff or hard, is rotary core drilling (see 20.7). The core recovery increases with core size. In general, the core size should not be less than about 70 mm diameter (H size) and better results are obtained with cores of about 100 mm diameter or larger. Considerable care and expertise is required in the operation of the drill. The core samples give an indication of the structure of the ground, but the moisture content might be altered by the use of the drill flush.

The standard penetration test (see 24.2) is useful in these soils to give a rough indication of strength, which may be adequate in some problems. Pressuremeter tests can also be useful (see 24.7).

14.8 Filled ground

Filled ground can consist of selected materials placed and compacted in a controlled manner and generally known as “fill”. Alternatively, it can consist of replaced natural ground, waste soils, demolition rubble or other materials of various origins, laid with little or no supervision and generally known as “made ground”. In the latter case the quality and consistency of the material, and the method of placement and compaction affects its uniformity. Normally, there is little or no control of the fill and the major problem in planning the ground investigation is to assess the variation in character and quality across the site. Often the variation is random.

Conventional methods of boring, sampling and in-situ testing, as appropriate to the character of the ground, can give information on the thickness and properties of the fill at the particular locations of the boreholes or in-situ test. It is essential to ensure that boreholes are always fully cased through uncontrolled fill to avoid contamination of the natural groundwater and underlying strata. Pits and trenches are particularly useful for investigating the nature and variability of made ground (see clause 20).

In combustible fills, temperature measurements should be carried out as a routine part of the investigation. It should be noted that on waste tips, burning materials below ground may give rise to toxic or flammable gas from the borehole. Tip fires may also create voids, which may collapse under the weight of an investigation rig. Lagoons within waste tips may be areas of very soft ground.

Further guidance on the investigation of colliery waste tips is given in annex E. Particular guidance on the investigation of landfill sites and contaminated land is given in annex F.

14.9 Rock

Boreholes can be sunk in some weaker and weathered rocks by the light cable percussion method, using the clay cutter, shell or chisel, as appropriate to the character of the rock. Disturbed samples from the drill tools are class 5 if recovered by the shell, and class 4 or 5 if recovered by the clay cutter. In many weak rocks, driven samples can be recovered using the 100 mm diameter sampler fitted with a strengthened cutting shoe. Driving the sampler usually causes severe disturbance; often the sample is shattered, making it very difficult, if not impossible, to identify the natural structure of the rock. The samples are often in the range class 3 to 5. Light cable percussion boring in rock gives results of very limited value, and at best provides a general lithological profile. In many cases, as for example when rock is overlain by boulders, the method cannot identify the interface between soil and rock with any certainty. In such cases, the identity and character of the rock should be confirmed by drilling or excavations. Rotary core drilling with diamond or tungsten carbide bits is normally used in rock strata (see 20.7). In weathered weak rock and in harder rocks that are closely bedded, jointed, or affected by faulting, there may be difficulty in recovering cores of satisfactory quality. The use of larger-sized equipment producing cores of about 100 mm diameter or more and the proper selection of barrel and bit type, helps to improve the core recovery. Where weathered rock occurs at shallow depth, pits are probably the most effective means of investigation, because block samples can be obtained from these for laboratory testing.

Soft infilling of rock discontinuities can sometimes be lost by erosion by the flush water, and air flush drilling may be desirable. Rotary core drilling usually produces samples, which may permit an investigation of the character and engineering properties of the intact rock material and which may give some indication of the frequency of discontinuities but not their orientation. The use of borehole periscopes, impression packers, cameras and television cameras may be useful in this connection. In many cases, the sample disturbance associated with rotary drilling causes any infilling in the discontinuities to be lost and hence the rotary core samples give little or no indication of the character of the infilling. In-situ permeability by packer testing (see 24.5) may give a useful indication.

There are many possible combinations of drilling methods, tools, and core barrel and bit designs in rotary core drilling. Because the brevity of most site investigations does not allow much experiment to achieve the best results, particular attention should be paid to the best method of sampling rock.

In a ground investigation using light cable percussion boring or rotary core drilling, an indication of the properties of the rock mass can best be obtained from tests in boreholes. For certain of such tests, however, it is necessary to take into account the probable effects of disturbance of the ground by the boring process. The standard penetration test (see 25.2) can give a rough indication of the variation of strength and compressibility in weak rock. The permeability test (see 25.4) or the packer or Lugeon test (see 25.5) may give a measure of the mass permeability, which in turn can give an indication of the presence of open joints and other water bearing discontinuities. Where applicable, the plate test (see 25.5) and dilatometers such as the pressuremeter (see 25.7) can be used to investigate deformation properties and possibly also the strength.

The best method for determining the properties of a rock mass, including the orientation of discontinuities, is visual in-situ inspection, and field tests carried out in excavations, shafts, or headings (see 20.1, 20.2 and 20.3).

14.10 Discontinuities

In most rocks, the mass properties depend largely on the geometry and nature of the discontinuities. This can require the engineering properties to be measured in the plane of the discontinuities along specific orientations determined by the anticipated directions of the stresses to be applied. The control by discontinuities over the strength and deformation characteristics of a ground mass is less obvious in soils than in rock, but may be equally important.

No satisfactory drilling or boring techniques are available that ensure the core recovered can be oriented over the full depth penetrated. In soils, the discontinuities are often destroyed by the drilling and therefore overlooked. Where discontinuities are important to the engineering problems involved, in-situ exposures of discontinuities are necessary to obtain data on their orientation and nature. After initial investigations using interpretation of aerial photographs, surface outcrop logging and the drilling of vertical and inclined oriented holes, it may be necessary to undertake full surface exposure, large diameter boreholes, trenches, pits or adits to allow visual inspection around and within the undisturbed ground mass, and measurement of the relevant discontinuity data. In some projects, suitable exposures may be provided in excavations necessitated by the permanent works. The extraction or in-situ preparation of orientated test samples can be carried out in these excavations together with oriented large scale tests. The orientation of the excavations controls their intersection with the discontinuities and, consequently, the discontinuity data that can be obtained. Normally, three orthogonal exposures are required to define fully the spatial distribution of the discontinuities. The extent of the excavations is governed by the spacing between discontinuities and the size of the works (see 44.4.3).

15 Aggressive ground conditions

15.1 Introduction

In certain localities, groundwater, soil and rock may contain constituents in amounts sufficient to cause damage to Portland cement concrete, particularly thin members. The constituents principally concerned are sulfates, which are most common in clay soils, and acidic waters, which are found in or derived from peaty soils and from the breakdown of pyrites in many other rocks.

Some types of ground have a corrosive action on metals, particularly on cast iron, owing to electrolytic or other chemical or bacteriological agencies. In industrial areas, corrosive action may arise from industrial waste products that have been dumped on the site, from contaminated materials brought onto the site as fill, or from liquid sources such as leaking tanks, sumps and chemical drains. In river and maritime works, the possible corrosive action of fresh water, sea water and other saline waters and of trade effluents may also require investigation. In a marine environment, the most severe corrosion is found in the zone that is occasionally wetted. This effect is increased in waters with a high tidal range. In estuarine situations, there may be an adverse condition because of alternation of water of different salinities. Disturbed soils are often more aggressive than undisturbed soils.

15.2 Investigation of potential deterioration of concrete

Laboratory tests to assess the aggressiveness of the ground and groundwater against Portland cement concrete include determination of pH value and sulfate content (see clause 39, which deals with tests on soils and its corresponding Table 10, in particular "Chemical and electro-chemical tests"). [35]

15.3 Investigation of potential corrosion of metals

The likelihood of corrosive ground conditions can be assessed from geophysical testing (see 35.5), from in-situ measurement of redox potential and electrical conductivity (see BS 1377:1990), and from laboratory tests on undisturbed soil specimens and groundwater samples. The samples should be placed in air-sealed containers immediately after sampling (see clause 39, which deals with tests on soils and its corresponding Table 10, in particular "Soil corrosivity tests"). (See also [35].) For specimens for bacteriological tests, the containers should be sterilized. When designing a testing programme it is important to model the correct conditions. Disturbance to the ground and the use of imported backfill materials can have a significant impact on the evaluation. Local enquiry is desirable to ascertain whether corrosion of metals has previously occurred.

15.4 Industrial causes of aggressive ground

Many types of industry are known to cause contamination of the ground through the disposal of solid and liquid wastes, and through the inevitable leaks and spills of chemicals. A very wide range of substances may be present in the ground, and often occur in localized concentrations. Some chemicals, such as acids, are highly aggressive to both concrete and metal in underground structures. Other substances such as solvents attack epoxy cements, and even low concentrations of phenols permeate plastic water mains and taint the supply.

A thorough investigation of potential chemical contamination is necessary as an essential part of any site investigation on a former industrial site. Guidance on the planning and execution of such an investigation is given in annex F.

16 Ground investigations over water

16.1 Introduction

Site investigations conducted over water are more expensive and time consuming than comparable investigations conducted on land, and there may be a temptation to economize by reducing the scope of the investigation. The extent of the requirement for ground investigations should be realistically assessed, since economies in this direction can turn out to be false. Geophysical surveys are extensively used at the planning stage to provide additional geological information for the ground beneath the construction site and the positioning of the investigation boreholes (see 35.4).

The sinking of boreholes below water presents special difficulties particularly with regard to rotary diamond core drilling. Working platforms can be fixed, floating or heave compensated. A conductor pipe is usually suspended from the platform to protect the flexible investigation string from the force of currents. Percussion boring and rotary drilling techniques, both conventional and wireline, may be employed. Geophysical logging techniques are often employed to augment the information obtained from the borehole programme (see 35.5).

Increasing use is being made of a variety of penetration testing techniques. In some cases, it may be feasible to lower specially designed boring, drilling or penetration testing equipment to the water bottom to be operated by remote control or by a diver. With remote control, operation is restricted to a single continuous operation. Penetration depths vary from less than 5 m for some devices, to 20 m or more for others.

Overwater work is always subject to a risk of delay because of unsuitable weather. For any given weather condition, the amount of delay depends on the type and size of the installation. In general, the larger the staging or floating craft, the smaller the risk of delay due to weather but, on the other hand, the greater the operating costs. When planning an overwater investigation, it is important that a realistic allowance is made for the possible cost of weather delays. The scope of the work, including the methods of boring, sampling and in-situ testing, requires careful consideration depending on the particular difficulties of the site. When working over water it is essential that due consideration be given to health and safety requirements, navigational warnings, and the regulations of governmental departments and other authorities.

16.2 Stages and platforms

Where stable working platforms are available or can be provided, such as oil drilling platforms and jetties or purpose-built scaffold stages and drilling towers, it is normally possible to use conventional dry-land site investigation boring equipment and conventional methods of sampling and in-situ testing. When working from existing structures, it may be necessary to construct a cantilever platform over the water on which to mount the boring rig. When boring close to the shore in relatively shallow water, it may be most convenient to construct a scaffold or other tower at the borehole location, in which case some means of transporting the boring equipment to the tower is needed. Some towers are so constructed that they can be moved from one borehole location to another without having to be dismantled.

Jack-up platforms and special craft fitted with spud legs can be floated into position and then jacked out of the water to stand on their legs. These fulfil the requirement for a fixed working platform and provide manoeuvrability.

The design of all staging, towers and platforms should take into account the capability of the sea-bed strata to withstand the foundation loads. The design should also include the effects of the fluctuating water levels due to tides, waves and swell conditions and it is essential that such constructions be sufficiently strong for the boring operations to resist waves, tidal flow, other currents and floating debris.

16.3 Floating craft

The type of floating craft suitable as a boring vessel depends on the anchor holding properties of the sea bed; the likely weather conditions; the depth of water; the strength of currents; whether the water is sheltered or open; and whether accommodation is required on board for personnel. In inland water, a small anchored barge may suffice, but in less sheltered waters a barge should be of substantial size, and anchors are required to be correspondingly heavy. In offshore conditions, a ship is often employed, and it may then be possible to accommodate the personnel on board, with a consequent saving in auxiliary supply vessels.

An auxiliary vessel is required to handle the moorings if a barge is used for the work, but in certain cases a ship may be able to lay and pick up its own moorings. Normally, four or six point moorings are required and anchors should have the best holding capacity feasible for the expected ground conditions. In water depths greater than about 80 m conventional moorings are difficult, and the use of vessels that can be maintained in position by computer-controlled thrusting devices, i.e. dynamically positioned, should be considered.

In order to achieve high quality coring it is necessary to maintain constant pressure between the drill bit and the bottom of the hole. For shallow water investigations coring is usually carried out using an hydraulic power swivel suspended in the drilling mast. For the deeper waters, particularly with swells, special techniques of heave compensation are required. Because of the special equipment employed when boring from floating craft, and also the movement of the working platform, the types of sample to be recovered and in-situ tests to be performed require particular consideration.

16.4 Inter-tidal working

Sinking boreholes between high and low tide levels may be achieved using scaffold stagings or platforms (see 16.2), by using flat-bottomed pontoons or shallow draft jack-up rigs or by moving boring rigs to the location during periods permitted by the tides.

16.5 Setting-out and locating borehole positions

Modern positioning systems, such as the Global Positioning System (GPS) and the Differential Global Positioning System (DGPS) are now commonly used, because they are simple to operate, provide accurate surveying data and eliminate unnecessary risks to personnel in terms of health and safety.

Close inshore, it is often possible to set out boreholes satisfactorily by using sextant observations to features onshore or by lining in from previously placed shore markers. Where necessary theodolite observations can be taken from land based stations. Further offshore, it is necessary to use electronic methods of position fixing. Electronic methods are also advantageous in bad visibility conditions.

16.6 Determination of reduced level of bed and strata boundaries

Reduced levels are usually transferred to a boring vessel from shore by setting up a tide gauge close inshore; this is read at frequent intervals throughout the tidal cycles and readings of water depth are taken at the same time on the boring vessel. Corrections may be necessary to allow for tidal variations when the tide gauge reading and the one from the vessel vary significantly. Some methods of heave compensation on the drilling vessel automatically make this correction. The depth of water can be difficult to determine where the seabed is very soft and reduced levels of strata boundaries would then become less accurate.

17 Personnel for ground investigation

17.1 Introduction

In view of the importance of ground investigation as a fundamental preliminary to the proper design and the efficient and economical construction of all civil engineering and building works, it is essential that personnel involved in the investigation should have appropriate qualifications, skills and specialist experience and that they should be familiar with the purpose of the investigation. A guide to the qualifications required for the various levels of seniority is given in [7].

17.2 Direction, planning and execution

For most projects, the client appoints a principal technical adviser who has direct responsibility to the client for the design, planning and construction of the project. This adviser is usually a chartered engineer or architect who probably does not have specialist expertise in geotechnics and/or geology.

A geotechnical adviser should be appointed who is directly responsible to the principal technical adviser for the planning, direction, execution and supervision of the ground investigation. It is suggested (see [7]) that the geotechnical adviser should have a first degree in engineering or engineering geology, preferably a postgraduate degree of at least MSc level in a geotechnical topic, should have achieved the qualification of chartered engineer or chartered geologist and have considerable practical experience in geotechnics.

The geotechnical adviser should determine the extent and adequacy of the investigation, direct the investigation both in the field and in the laboratory, and finally assess the results in relation to the design of the proposed works. He may delegate part of these duties to geotechnical specialists who are on his staff or who act as consultants or contractors.

The person responsible to the geotechnical adviser for the execution of the ground investigation may be on the staff of the geotechnical adviser, or may be a geotechnical consultant or contractor. The person should be a suitably qualified geotechnical specialist, geotechnical engineer, or engineering geologist as required by the character and scope of the ground investigation. Details of the required qualifications for each of these proposed designations are given in [7]. As a minimum, all require a first degree, together with some further experience, which would eventually lead to the designation of Geotechnical Adviser (see 17.1). In particular, the person should have had experience in carrying out ground investigation and in the interpretation of the results.

17.3 Supervision in the field

The supervision of the work in the field should be either the full-time or the part-time responsibility (depending on the size of the investigation) of a suitably qualified and experienced geotechnical engineer or engineering geologist. This person may be assisted by:

- a) assistant geotechnical engineers or engineering geologists;
- b) field engineers and senior field technicians who are skilled in the work described in 17.7 and who are competent to supervise such work by others, and in addition may be required to supervise work described in 17.8.1 and 17.8.2;
- c) drilling supervisors who are skilled in the work described in 17.8.1 and who are competent to supervise such work by others, and to supervise the work described in 17.8.2.

17.4 The logging of excavations and boreholes and the describing of soils and rocks

The [A2] qualified operator, who is commonly the lead [A2] driller, should normally be responsible for recording the information obtained from the borehole as it arises (see 17.8.1 and clause 41); this should include a measured record of strata, with simple soil and rock descriptions. Subsequently, detailed engineering descriptions of all the soil and rock samples obtained (see section 6) should be made by a suitably qualified and experienced geotechnical engineer or engineering geologist. For more extensive investigations, it is preferable to do this on site, and proper facilities should be provided. For smaller investigations, the description may be made in the laboratory. (The incorporation of these engineering descriptions in the borehole logs form part of the report preparation).

For rotary cored boreholes, it may sometimes be necessary to have the full-time attendance on site of an engineering geologist so that the rock cores may be logged and described in their fresh condition as the work proceeds. Where trial pits and other exploratory excavations are required and where existing natural or man-made exposures of the ground are involved, the detailed recording of the soils and rocks, their stratification, structure and fabric should be made by a suitably qualified and experienced geotechnical engineer or engineering geologist.

17.5 Laboratory work

The testing of soil and rock samples should be carried out in a laboratory approved by the engineer, under the control of a suitably qualified and experienced supervisor (see 36.4). Laboratory technicians should have received training and have skill and experience in the type of test they are conducting.

17.6 Interpretation

The preparation of the report, including the factual information obtained and the engineering interpretation of it, is described in section 7. This work should be prepared by suitably qualified and experienced geotechnical engineers or engineering geologists and the engineering interpretation should be made by the geotechnical specialist, geotechnical engineer or engineering geologist directing the investigation under the supervision of the geotechnical adviser (see 17.2). Except where the geology is simple, the geological aspects should be reviewed by a suitably qualified and experienced engineering geologist.

17.7 Field technicians

Field technicians who carry out special sampling and testing in boreholes, piezometer installations and probing (described in section 3) and field tests (described in section 4) should have received training and have skill and experience in the work.

17.8 Operatives

17.8.1 Lead driller and driller

The lead driller in charge of an individual drilling rig should be skilled in the practice of exploration of the ground by means of boreholes, simple sampling and testing, making groundwater observations in boreholes, and properly recording the information obtained. In the UK, all boring and drilling operatives, including lead drillers employed on the contract should hold a valid and current audit card of competence applicable to the work and the specific drilling operation on which they are engaged, such as issued by the British Drilling Association Ltd. under its BDA Audit, or an equivalent body. They should also hold Construction Skills Certification Scheme (CSCS) blue skilled (Land Drilling) cards.

NOTE The lead driller needs to meet the competency requirements for "qualified operator" in BS 22475-2:2010.

Drillers who are support operatives should hold an appropriate, valid and current audit card of competence and CSCS card. 

17.8.2 Operators of excavating plant

Operators of excavating plant should be skilled and experienced in its safe use for digging trial pits and trenches. Any timbering or other support required in excavations should be installed by skilled operatives.

18 Review during construction

18.1 Introduction

There is an inherent difficulty in forecasting ground conditions from ground investigations carried out before the works are started because, no matter how intensive the investigation and whatever methods are used, only a small proportion of the ground is examined.

18.2 Purpose

The primary purpose of the review during construction is to determine, in the light of the conditions newly revealed, to what extent conclusions drawn from the ground investigation are required to be revised, if at all. The maximum benefit is obtained when the review is directed by the geotechnical advisor (see 17.2).

In some cases, additional information is found which may necessitate amendment of the design or the construction procedures. As a result, in certain cases it may be appropriate to initiate a site procedure in the early stages of the contract, so that correct and agreed records are kept during the duration of the contract by both the engineer and the contractor.

The purpose of the records is to:

- a) check the adequacy of the design;
- b) check the safety of the works during construction and to assess the adequacy of temporary works;
- c) check the findings of the ground investigation and to provide feedback so that these findings may be reassessed;
- d) check initial assumptions about ground conditions related to construction methods, which may include groundwater;
- e) provide agreed information about ground conditions in the event of dispute;
- f) check the suitability of proposed instrument installations;
- g) enable the best use to be made of excavated materials;
- h) reassess the initial choice of construction plant and equipment.

18.3 Information required

18.3.1 Soil and rock

Accurate engineering descriptions of all strata encountered below ground level should be made in accordance with section 6. The soil profile revealed on site should be recorded and compared with that anticipated from the ground investigation. The descriptions should be made by a geotechnical engineer or engineering geologist competent in geotechnics. It is advantageous to arrange for the site to be inspected by the organization that carried out the site investigations, particularly if conditions appear to differ significantly from those described in the ground investigation.

18.3.2 Water

It is most important to record accurately all information about the groundwater obtained during construction, so that this may be compared with information recorded during the investigation. The information should include the flow and static conditions in all excavations, any seepage from slopes, any seasonal variations, any tidal variations in excavations or tunnels near the sea or estuaries, suspect or known artesian conditions, the effect of weather conditions on groundwater, and any unforeseen seepage under or from water-retaining structures. The effect of groundwater lowering should also be recorded in observation holes to determine the extent of the cone of depression.

18.4 Instrumentation (see also 33.2)

On many types of structures, such as earth dams, embankments on soft ground, some large buildings with underground construction, excavations and tunnels, it is prudent to consider regular observations by means of instrumentation in order to check that construction works can proceed safely. Such observations include measurement of pore pressure, seepage, earth pressure, settlement and lateral movements. The instrumentation may be usefully continued after construction in order to observe the performance of the project. This is particularly necessary in the case of earth dams for maintaining a safe structure under varying conditions, and in other cases for gaining valuable data for future design.

Section 3. Field investigations

19 Introduction

There is considerable variety in ground investigations and normally a combination of methods is employed to cover the technical requirements and the range of ground conditions that are encountered. The factors involved in the selection of methods are discussed in section 2. The collection and recording of data to be obtained is discussed in section 7. In-situ tests that are carried out in boreholes as part of a borehole investigation are described in clause 25. Other in-situ tests for which a borehole either is unnecessary or is only an incidental part of the test procedure are described in section 4.

In planning ground investigations, particular attention should be paid to the safety of personnel and the public at all stages of the investigation. Certain methods present special safety problems, and recommendations are given in the relevant clauses. Other methods involve normal safety precautions appropriate to site or laboratory work. Since backfilled pits and boreholes might interfere with subsequent construction, they should be sited and backfilled with care. It is essential that the precise location of every excavation, boring and probing is properly recorded during the execution of the fieldwork. It is equally essential that the ground levels of these locations be established and recorded. The records should be such that the locations and levels can be readily incorporated into the report on the investigations (see 12.5 and 47.2.8).

Should it appear during the course of ground exploration that buried structures or artefacts of archaeological interest have been encountered, the matter should be reported to the Chief Inspector of Ancient Monuments.

20 Excavations and boreholes

20.1 Shallow trial pits

Shallow trial pits are usually dug using an hydraulic back-hoe excavator, preferably mounted on a tractor for ease of mobility. This expedient is used in ground that can temporarily stand unsupported and in suitable conditions. For practical reasons, the maximum depth of excavation is 4 m to 5 m. Where personnel are required to enter pits, it is essential that the sides are safe or made safe, particularly from sudden collapse, by supporting the sides. Ideally, the support system should consist of purpose-made metal frames that can be quickly inserted and extracted. Alternatively, it may be possible to excavate the sides to a safe profile by means of a series of benches [36]. Entry by personnel into unsupported pits deeper than 1.2 m is not allowed for health and safety reasons. The safety aspect is discussed more fully in BS 6031.

By providing access for taking samples and carrying out in-situ tests, shallow trial pits permit the in-situ condition of the ground to be examined in detail both laterally and vertically; they also provide a means of determining the orientation of discontinuities in the ground. The field record should include a plan giving the location and orientation of the pit with details of which face(s) was logged, and a dimensioned section of each side and the floor (see [36]). Whenever possible, the record should include photographs. Further details of reporting are given in 47.2.6.6. Shallow trial pits can readily be extended into trenches in order to trace any particular feature, and in suitable ground this method is very efficient and economical.

Shallow pits without side support can be used for making a rapid check on the condition of the ground. It may be unsafe for personnel to enter a pit but, working from ground surface, the technician can prepare a visual log of the strata and take disturbed samples using the excavator bucket. Tube samplers can be driven into the floor of the pit, using a jarring link and drill rods, and then extracted by the excavator. In-situ testing, such as the vane shear strength test, can also be carried out. Pits that are unsupported may collapse soon after being dug, so any logging, sampling and in-situ testing should be carried out immediately after the pit has been dug. It is advisable to backfill pits as soon as possible after logging, sampling and testing have been completed, since open pits can be a hazard to the general public. There can be advantages though in leaving pits fenced, shored and open (at least overnight and possibly up to 7 days), as this can allow the excavated surface to partially dry, exposing fissures and fabric better than immediately after excavation. Recommendations on backfilling are given in 20.9. Any pits that have to be left open and unattended should be securely fenced off.

20.2 Deep trial pits and shafts

Deep trial pits and shafts are normally constructed by hand excavation using traditional methods for supporting the sides. In suitable ground conditions, shafts approximately one metre in diameter can be bored using large power-driven augers. Temporary liners are used to support the sides in unstable ground, and to provide the necessary protection for personnel working in the shafts. When making inspections, however, it is necessary to expose as much of the ground as possible, and considerable judgement and experience is required, since the excessive use of liners can lead to delay and to additional danger as a result of the build-up of water pressure behind the liners. Suitable ground conditions are those that can be bored with a minimum use of temporary liners and in these conditions augered shafts provide a fast and economical expedient for inspection, sampling and

testing in-situ. For many types of ground excavations below the water table present serious problems both in maintaining a dry investigation and in stabilizing the sides. For such circumstances, the water table may be the maximum depth for which this method is feasible.

Working in a deep shaft is dangerous unless the appropriate safety precautions are strictly followed and these are discussed in BS 8008. Attention should be given to the possible occurrence of injurious or combustible gases or of oxygen deficiencies, and the correct inspections and precautions established (see clause 19 and annex F). Oxygen-consuming engines that emit toxic exhaust fumes, such as petrol-driven pump motors, should not be employed in shafts. The safety precautions to be followed and the safety measures to be adopted when human entry into the shaft is envisaged are covered in BS 8008:1996.

20.3 Headings (adits)

Headings are driven from the bottom of shafts or laterally into sloping ground and can be used for the in-situ examination of the strata, existing foundations and other underground constructions, as well as for carrying out special sampling and in-situ testing. One important use of headings is in the inspection of abutments of dams. In soil and many types of rock, the sides and roof of the heading require support.

Driving a heading below the water table presents a major construction problem in strata that are not naturally self-supporting during the period required to erect support elements. Below the water table, it is probable that headings are only an economical means of ground investigation in rock and stiff impermeable clay.

20.4 Hand auger boring

The hand auger boring method uses light hand-operated equipment. The auger and drill rods are usually lifted out of the borehole without the aid of a tripod, and no borehole casing is used. Boreholes up to 200 mm diameter may be made in suitable ground conditions to a depth of about 5 m. The method can be used in self-supporting strata without hard obstructions or gravel-sized particles. Hand auger boreholes can be used to obtain disturbed samples, small open-tube samples and for groundwater observations.

20.5 Light cable percussion boring

Light cable percussion boring is an adaptation of standard well-boring methods, and normally uses a mobile rig specially designed for ground investigation work. For most investigations, the rig has a winch of 1 tonne to 2 tonne capacity, which is driven by a diesel engine and a derrick of about 6 m in height. With many types of rig, the legs of the derrick fold down to form a simple trailer that can be towed by a light vehicle. The clay cutter is used

in cohesive soil in a damp or dry borehole. The shell is used in cohesionless soils and requires there to be sufficient water in the bottom of the borehole to cover the shell (about 2.5 m). It is therefore necessary to add water to a borehole in order to bore through dry cohesionless strata that require the use of the shell.

The above methods may conflict with the geotechnical objects of the investigation, which may require the borehole to be drilled either in a dry condition or with the water level in the borehole maintained at or above the natural groundwater level. In such cases it may be necessary to adopt a less efficient method of boring with the cable percussion rig, e.g. boring a stiff clay under water might require the use of the chisel and shell, or to adopt a different method of drilling such as mechanical augering.

Light cable percussion boring is suitable for soil and weak rock. The sizes of borehole casings and tools are usually 150 mm and 200 mm. For special projects 250 mm and 300 mm are available. This gives a maximum borehole depth of about 60 m in suitable strata. This type of rig may have an hydraulic power take-off to drive a rotary drilling attachment for coring rock. The drill tools, which are worked on a wire rope using the clutch of the winch for the percussive action, consist of the clay cutter for dry cohesive soils, the shell or baler, for cohesionless soils and the chisel for breaking up rock and other hard layers. The clay cutter and shell bring up disturbed material, which is usually sufficiently representative to permit identification of the strata.

20.6 Mechanical augers

Mechanical augers for ground investigations normally use a continuous-flight auger with a hollow stem and these are suitable for augering in cohesive soils. When augering, the hollow stem is closed at its lower end by a plug, which may be removed so that the sampler can be lowered down through the stem and driven into the soil below the auger bit. The use of hollow-stemmed augers in cohesionless soils often presents practical problems because it may be difficult to prevent material from flowing into the hollow stem on removal of the plug. When rock is encountered, boring can be extended by core-drilling through the hollow stem. Typically, augers with hollow stems of approximately 75 mm and 125 mm diameter produce boreholes of about 150 mm and 250 mm diameter respectively, to a depth of 30 m to 50 m. Continuous-flight augering requires considerable mechanical power and weight so that the machine is therefore usually mounted on a heavy vehicle. The debris from drilling is brought to the surface by auger flights and gives only a very rough indication of the levels and character of the strata. A precise intermittent identification of the strata may be obtained from drive samples taken through the hollow stem of the auger.

In self-supporting strata, solid rods and a suitable auger tool can be used, the auger tool being drawn up to the ground surface each time it has to be emptied. Drive sampling and testing can be carried out in the borehole.

20.7 Rotary open hole drilling and rotary core drilling

20.7.1 Introduction

Rotary drilling methods, in which the drill bit is rotated on the bottom of the borehole, are used to drill rocks and sometimes soils for investigation purposes. The drilling fluid, which is passed from the surface through hollow drill rods to the face of the bit, cools and lubricates the bit, transports drill cuttings to the ground surface and, when using particular types of drilling fluids, stabilizes the borehole. Drilling fluids are commonly clean water, air, or a mixture of both. In some cases mud, polymers or foam are used to maintain or assist borehole stability, aid the transport of drill cuttings to the surface and maximize core recovery, particularly in superficial deposits and weak rock formations. It is essential that the cleaning and recirculation of the drill fluid is arranged so that the cuttings transported from the bottom of the borehole are not recirculated and that the condition of the drill fluid is maintained to achieve its objectives.

There are two basic types of rotary drilling: open hole (or full hole) drilling, where the drill bit cuts all the material within the diameter of the borehole; and core drilling, where an annular bit, fixed to the bottom of the outer rotating tube of a core barrel, cuts a core, which is recovered within the innermost tube of the core barrel assembly and brought to the surface for examination and testing. Rotary drilling for ground investigation is usually core drilling.

When open hole drilling or coring, temporary casing is normally used to support unstable ground or to seal off fissures or voids, which cause excessive loss of drilling fluid. Drilling fluid additives or cement grouting may sometimes be satisfactory alternatives.

The rotary drilling rig should be well maintained and should be capable both of controlling rotational speed and providing axial load and torque to suit the nature and hardness of the material penetrated, the diameter of the core barrel and drill string, drilling fluid and flushing system, weight of drill string and installation of temporary casing(s).

Drilling is in part an art, and its success is dependent upon good practice and the skill of the lead driller, particularly when coring partially cemented, fractured, weathered and weak rocks or superficial deposits. Good drillers have had adequate training, together with considerable experience.

NOTE Further guidance on drillers is given in 17.8.1 and in BS 22475-2:2010 and BS 22475-3:2010.

20.7.2 Open hole drilling

This technique is sometimes used in soils and weak rocks as a rapid and economical means of making holes in the ground for the purpose of taking soil samples, for carrying out in-situ tests, for installing instruments etc. The technique may also be used to probe for voids such as mine workings, solution cavities etc. While drilling, the only samples recovered are the drill cuttings returned in the drill fluid. These constitute very low quality samples and it is usually difficult to detect a change in strata, unless there is a strong contrast in properties such as colour or hardness. Where such contrast prevails, open hole drilling can be used as a probing technique. The use of suitable instrumentation, in order to record the progress of the drilling rig can considerably enhance the results obtained (see [37]).

20.7.3 Rotary core drilling

This is normally carried out using conventional or wireline double or triple tube core barrels (a triple tube system may be simulated by a double barrel fitted with a semi-rigid plastic liner) fitted with diamond or tungsten tipped core bits. Specifications of all the major components found in core barrels, rods and casings may be found in BS EN ISO 22475-1:2006. The objective of core drilling is to achieve optimum core recovery and core quality consistent with cost. The choice of drill and compatible in-hole and surface equipment, their condition and suitability for the work anticipated, are all most important if the objective is to be achieved. Detailed guidance on the selection of core bits for particular formations or the suitability of various techniques in different types of soil and rock are beyond the scope of this document and advice should be sought from a drilling specialist.

NOTE General guidance on the available techniques and their suitability to various ground conditions is given in BS EN ISO 22475-1:2006.

The conventional double tube core barrel consists of two concentric barrels. The outer is rotated by the drill rods and, at its lower end, carries the coring bit. The inner barrel is mounted on a swivel so that it does not rotate during the drilling process. The core, cut by the coring bit, passes up into the inner barrel and, at the end of the coring run, the core barrel assembly is lifted to the surface by raising and removing each drill rod individually. This becomes increasingly time consuming as the borehole becomes deeper. The core is prevented from dropping out of the core barrel by a core catcher made of spring steel and located just above the core bit. The drill fluid flows down through the annulus between the inner and outer barrels on its way to the core bit. The core itself is only in contact with the drill fluid as it passes through the core bit.

A2 Table deleted. **A2**

With triple tube core barrels, the non-rotating inner barrel contains a removable sample tube or liner. At the end of each coring run this liner, together with the core it contains, is extracted and stored in a core box. It should be recognized, however, that the provision of such liners, which may be made from a variety of materials and take the form of split tubes, seamless tubes or rigid and semi-rigid plastic liners, does not in itself increase core recovery, but is much more likely to preserve the core in an intact condition, thus enabling the logging geologist to extract more information than would otherwise be the case. Triple tube barrels can be purpose designed, but more commonly conventional double tube barrels can be modified to take an inner semi-rigid plastic liner and thus act as a triple tube core barrel.

Wireline core barrels are rotated from the surface by drill rods, which are normally of the same diameter as the outer core barrel. The core is brought to the surface within the inner core barrel on a small diameter wire rope or line attached to an “overshot” recovery tool. Larger diameter wireline systems are particularly suitable where superficial and weak deposits are anticipated, as any vibration created from the drilling action on the surface is minimized due to the close fitting nature of the rods within the borehole. The smaller wireline sizes do not show this characteristic and are normally used for hard rock drilling at speed. The borehole wall is constantly supported during the drilling process and when recovering the inner core barrel to the surface, which makes core retrieval quicker and improves production. The main disadvantage with large diameter wireline drilling in weak materials is that it is necessary to remove the string to change the drill bit. In unstable holes not supported by drilling mud or in gravels, collapse of the hole may occur and redrilling of the collapsed material is then necessary.

A2 Detailed information relating to core barrel sizes and the core sizes they produce is listed in BS EN 22475-1:2006, Annex C. When a double core barrel is fitted with an additional plastic liner to simulate a triple barrel, the core diameters in BS EN 22475-1:2006, Annex C reduce, because different core bits are required to accommodate the liner. **A2**

A very wide range of coring bits is available and the type which gives the best results in any given ground conditions may have to be determined by trial. It should be recognized that the factors affecting bit selection for optimum rate of drilling may be different from those that determine quality of core. Thin-walled bits produce fewer cuttings, which permits the use of a lower flushing rate with diminished disturbance. On the other hand, thin-walled bits normally do not provide for face

discharge of the flushing fluid and some disturbance may occur as the fluid passes between the inside of the bit and the core, although this may be obviated by the use of protruding or retractor type core barrels. Stepped bits offer advantages of drilling rates and quality in some circumstances; they also tend to produce straighter holes. For strong abrasive rocks diamond quality and matrix selection are important considerations.

Careful selection of the flushing medium, which is compatible with the ancillary surface and in-hole equipment employed, and which is suitable for the anticipated geological conditions to be drilled, is very important. Water and air are the simplest and most commonly used. Drilling muds consisting of water with clay or bentonite, water with an additive such as sodium chloride, foam, polymer mixtures and air/water mist are also used as flushing media. Polymer mixtures and water with additives have an advantage over water and air in that the cuttings may be removed at a lower flushing velocity, thereby reducing disturbance and washing out at the cutting bit or within the borehole in weak or uncemented formations. Using air as the flushing medium may be more advantageous in some geological formations or where limitations are imposed on the use of other fluids in respect of aquifer or groundwater contamination. Whereas water and polymer may tend to increase the natural moisture content of the core though, the use of air may tend to reduce it. In some formations air may fracture weak formations and create paths of weakness, possibly causing leakage of the air flush and a permanent change to groundwater paths.

20.7.4 Core extrusion and preservation

After the recovery of the core barrel to the surface, every effort should be made in handling to ensure that the recovered core is maintained in a condition as near as possible to its natural state until it is finally stored. It is at this stage that the expense and effort to recover high quality cores can be negated by careless or inappropriate handling. Except in relatively strong and massive rocks, core is almost inevitably disturbed if it is removed from the barrel, held in a vertical position and then placed into the core box. When using a double tube core barrel the core should be extruded with the tube in a horizontal position by using a purpose-made core extruder. Extruders should be of the piston type, preferably mechanically activated, since water or air pressure type extruders can lead to water contact with the core, impulse stressing of the core and uncontrolled explosive ejection of the core from the barrel. It should be noted that in weak, weathered or fractured rocks and superficial deposits extrusion can lead to core disturbance, however carefully it is done.

A2 It is recognized that core may be recovered from a variety of material types. The majority of core may however be obtained within fine soils of variable strength and in rocks in various states of weathering and also having variable strength. Some core may be obtained by using double tube core drilling and some by triple tube core drilling. Either of these systems may include the use of a semi rigid plastic liner.

Irrespective of the material type or presence of a core liner system, the core should be extruded from the core barrel in the same direction as it entered the barrel. Core should be carefully extruded into core boxes having receiving channels appropriate to the diameter of the core.

It is important to note that the sampling category cannot be improved once coring has taken place.

Unless stated to the contrary for individual investigations, it should be assumed that all core obtained will be required to conform to sampling category A as defined in BS EN ISO 22475-1:2006. This may be achieved by the use of appropriate core bit, core barrel and flushing medium. Cores recovered may be divided into:

a) Cores not sensitive to moisture content change:

Category A status may be maintained by either the use of sealed core liner or by immediately wrapping all extruded core with suitable impermeable material, e.g. cling film, plastic sheeting.

b) Cores sensitive to moisture change: Category A status should be maintained by sealing the core immediately with the use of moisture sealing material, e.g. cheesecloth soaked in wax, waxed sealed tubes.

Where the core is to be sub-sampled for specific laboratory testing, this should be done immediately after the core has been extruded into the core box. When core liner has been used this may be done by cutting both the liner and core in two places in order to remove the sample.

The sub-sample's category A status should be maintained as described in b). Each sample should be clearly labelled. The sample should be placed in an appropriate container that will protect the sample during transport. **A2**

It is usual to preserve all core obtained from the borehole for the period of the main works contract to which the core drilling relates. This is conveniently achieved with wooden or plastic core boxes, usually between 1 m and 1.5 m in length and divided longitudinally to hold a number of rows of core. The box should be of such depth and the compartments of such width that there is minimal movement of the cores when the box is closed [38]. The box should be fitted with stout carrying handles, a hinged lid and strong fasteners and should be designed so that two persons can lift the box when it

is full of core. In removing the core from the barrel and placing in the box, great care should be taken to ensure that the core is not turned end for end but lies in its correct natural sequence with the shallowest core to the top left hand corner, the top being considered adjacent to the hinged section. Core retained in the core catcher box shall also be placed in the core box at the correct relative depth. Depths below ground surface should be indicated in indelible marker on small spacers of core diameter size that are inserted in the core box between cores from successive runs. Where there is failure to recover core, or where specimens of recovered core are removed from the box for other purposes, this should be indicated by spacing blocks of appropriate length. Both the lid and the box should be marked to show the site location, borehole number, range of depth of the core within the box, in addition to the number of the box in the total sequence of boxes in the borehole. Core box marking should be such as to facilitate subsequent photography which, if required should be carried out as soon as practicable after recovery of the core and before description, sampling and testing. A graduated scale running parallel to the core axis, for the full length of the core box should be included in photographs. The core should fill at least 50 % of the photograph frame and care should be taken to ensure that the core is in sharp focus with good even lighting (this may well require some form of artificial lighting). When using colour photography, a suitable colour standard indicator should be included in each photograph.

20.8 Wash boring and other methods

20.8.1 Wash boring

Wash boring is best suited to sands, silts and clays and is normally carried out using 65 mm borehole tools and borehole casing. Wash boring has been widely used in North America, but not often in Britain. The drill rig consists of a simple winch and tripod. The ground at the bottom of the borehole is broken up by the percussive action of a chisel bit, and washed up to the surface by water that is pumped down the hollow drill rods. In collapsing ground, casing is driven down to support the sides of the borehole, or drilling mud may be used. The fragments of soil brought to the surface by the wash return are not representative of the character and consistency of the strata that are being penetrated. These properties are determined by carrying out standard penetration tests at the top of each stratum and at frequent intervals of depth (see 22.4.5 and 25.2). Open-tube samples or piston samples can be taken in cohesive strata. This method can be extended in sands and silts to holes up to 150 mm in diameter but its use in gravels is impractical and should be avoided.

20.8.2 Other methods of boring

There are many methods of boring, which have been developed mostly to obtain maximum penetration speed, e.g. rotary percussive drilling for blast holes and grouting. When such boreholes are sunk for site investigations, limited information about ground conditions may be obtained, provided that the boreholes are drilled under controlled conditions: rate of penetration should be measured, drilling characteristics should be observed, and samples should be taken of the drilling flushings (see [37] and [39]).

20.9 Backfilling excavations and boreholes

Poorly-compacted backfill causes settlement at the ground surface and can act as a path for groundwater. The latter effect can cause very serious inconvenience if the backfilled excavations or boreholes are on the site of future deep excavations, tunnels or water-retaining structures. It could also lead to the future pollution of an aquifer. For boreholes in dry ground, it may be possible to use compacted soil as a backfill, although the procedure is often unsuccessful in preventing the flow of water. The best procedure is to refill the borehole with a cement-based grout introduced at the lowest point by means of a tremie pipe. Cement alone does not necessarily seal a borehole, on account of shrinkage, and it is often preferable to use a cement and bentonite grout, mixed with no more water than is necessary to permit the grout to flow or to be pumped. The addition of an expanding agent may be necessary. The need and specification for the grout is project dependent. ^[A2] The backfill material should be of lower permeability than the surrounding ground (see BS EN ISO 22475-1:2006, 5.5). ^[A2]

It is possible to compact the backfill of excavations by means of the excavator bucket or other mechanical means. In special cases, weak concrete or a specified granular fill may be required.

21 Frequency of sampling and testing in boreholes

21.1 General principles

The frequency of sampling and testing in a borehole depends on the information that is already available about the ground conditions and the technical objectives of the investigation. In general, the field work covers three aspects, each of which may require a different sampling and testing programme and may also require phasing of operations. These aspects are as follows:

- a) the determination of the character and structure of all the strata and the ground water conditions;
- b) the determination of the properties of the various strata whose locations have been determined in a), using techniques for sampling and testing that are normally available in routine ground investigations;

- c) the use of special techniques of sampling and testing in strata where the normally available techniques have given, or may be expected to give, unsatisfactory results.

21.2 Determination of character and structure of the strata

In areas where suitable information about the ground conditions has been built up from the results of previous investigations, it may be possible to omit this aspect. Without this information, it is necessary to determine, so far as is practicably possible, the location, character and structure of each stratum. Some of the strata may be quite thin, and continuous sampling to the depth of the borehole may be required in order that the necessary information may be obtained.

In fine cohesive soil, and some silty sand, consecutive drive samples can be obtained using the 100 mm diameter sampler, or similar. In soft clay and sand the barrels of the sampler can be coupled together to form a sampler 1.0 m in length and, if necessary, the core catcher should be used to help retain the samples. Special sampling equipment is available for taking long continuous samples in soft clay, loose silt, and loose silty sand (see 22.6).

In coarse non-cohesive soil, such as gravel, it is necessary to take disturbed samples from the drill tools (see 22.3), together with any split barrel standard penetration test samples at about 1 m intervals (although in gravels it is likely that the solid cone is used) (see 22.4.5).

In rock, continuous rotary core sampling (see 22.8) should be undertaken and, if the core recovery is poor, disturbed samples should be taken from the return drill fluid to provide some information about the nature of the material in the sample. Where a run with the rotary core barrel results in poor core recovery, it may be useful to try to recover a small drive sample using the split barrel standard penetration test sampler.

Some of the samples obtained by drive sampling or rotary coring, which are not required for undisturbed tests, may usefully be split along their longitudinal axis and carefully examined and described first in their fresh condition and then again later in a semi-dried state when the fabric is more readily identified. Where highly variable ground conditions are expected, it may be advantageous initially to sink one or more boreholes by rotary core sampling or by cable tool boring with continuous tube sampling. The cores or tube samples can then be examined to give guidance for sampling at selected depths in boreholes subsequently sunk close to the initial boreholes.

Ground water conditions are determined from the water levels in the boreholes, from the identification of water bearing strata and from observations in piezometers set at the appropriate depths (see clause 23).

21.3 The determination of strata properties using equipment normally available for sampling and testing

After the strata whose properties are likely to be relevant to the technical objectives of the investigation have been identified, the properties of the strata are assessed using techniques that are normally available or special techniques such as those given in **21.5**. The programme of sampling and testing can be varied to suit the requirements of a particular investigation and the drilling equipment that is in use. The following is a programme suitable for general use where the borehole is being sunk through soil, either using a light cable percussion boring rig together with the general purpose 100 mm diameter sampler and the standard penetration test equipment; or, alternatively, through rock by rotary core drilling, producing cores of approximately 55 mm or 70 mm diameter.

a) Sand and gravel

At the top of each new stratum, and thereafter at 1 m intervals of depth, a standard penetration test should be carried out; if the soil is suitable a split barrel sampler should be used.

At the top of each new stratum and thereafter at 1.5 m interval of depth, a disturbed sample should be obtained from the drill tools.

b) Cohesive soil

At the top of each new stratum and thereafter at 1.5 m intervals of depth, a 100 mm sample should be obtained.

If with the 100 mm sampler there is inadequate recovery or the sampler cannot be driven, this should immediately be followed by a standard penetration test using a split barrel sampler.

At each metre of depth, a disturbed sample should be obtained from the drill tools.

c) Rock

Continuous rotary core sampling should be used.

In cases where the core recovery is poor and the rock is weak, the split barrel standard penetration test sampler should be used after each core run in an attempt to recover a small sample of the rock. Depending on the rock type, it may also be useful to take a disturbed sample from the drill fluid return, and thereafter at 1 m intervals of depth.

Notwithstanding the procedures outlined above, the object in rotary core drilling is to obtain full core recovery (see **20.7**).

21.4 Double-hole sampling

In this method, a borehole is sunk to ascertain the full sequence of strata. A second borehole is sunk adjacent to the first, but at least 1 m from it to avoid the disturbed zone; samples are then taken at predetermined levels. The following variation of this method is useful where it is difficult to determine the change from superficial deposits or weathered

rock to relatively unweathered rock, or where it is difficult to decide when to change over from cable-tool boring to rotary drilling. The first borehole is sunk using cable-tool boring and driven tube sampling to the depth beyond which the method ceases to be practicable. The second borehole is then sunk using rotary coring from the highest practicable level. This may obviate loss of sample or loss of core arising from a change of method at an inappropriate level.

21.5 Special techniques of sampling and testing

Special techniques of sampling and testing include the following techniques.

Type of ground	Special techniques
sand	sand samplers
soft sensitive clay	borehole or penetration vane test; thin-walled open or piston sampler; continuous soil sampler; large diameter samplers
hard stony clay	plate bearing test; pressuremeter; rotary core sampling
rock	rotary core drilling using larger core sizes than recommended in 21.3 .

Some of the equipment is fragile, and easily damaged if used in unsuitable ground. It should preferably be used only where it is known that ground conditions are suitable.

Using a special sampling technique, the frequency of sampling in sand and in soft sensitive clay is normally determined by similar considerations to those in **21.3**. If, however, the stratum requiring the use of a special sampling technique is of limited thickness, it may be advisable to take samples at smaller intervals of depth to obtain a sufficient quantity of sample material. Rotary core samples in hard stony clay or rock are usually taken continuously.

In the borehole vane test, only the small volume of clay that is rotated by the vane is tested, and individual results can show a considerable scatter. For this reason, vane tests should be carried out as frequently as possible. The vertical interval is determined by the depth at which the test is carried out below the bottom of the borehole; this interval is usually 500 mm. Closer spacing can be obtained using the penetration vane apparatus.

Where a series of plate tests is required at increasing depths, the minimum spacing is determined by the depth to which the soil has been stressed by the test. A vertical interval of not less than four times the borehole diameter is usually adequate.

22 Sampling the ground

22.1 General principles

The selection of sampling technique depends on the quality of the sample that is required and the character of the ground, particularly the extent to which it is disturbed by the sampling process. It should also be borne in mind that the behaviour of the ground in mass is often dictated by the presence of weaknesses and discontinuities. It is therefore possible to obtain a good sample of material that may be unrepresentative of the mass. In choosing a sampling method, it should be made clear whether it is the mass properties or the intact material properties of the ground that are to be determined (see 14.10).

There are the following main techniques for obtaining samples (see [40]):

- a) taking disturbed samples from the drill tools or from excavating equipment in the course of boring or excavation (see 22.3);
- b) drive sampling, in which a tube or split tube sampler having a sharp cutting edge at its lower end is forced into the ground, either by a static thrust or by dynamic impact (see 22.4 to 22.7);
- c) rotary sampling, in which a tube with a cutter at its lower end is rotated into the ground, thereby producing a core sample (see 22.8);
- d) taking block samples specially cut by hand from a trial pit, shaft or heading (see 22.9).

Samples obtained by techniques b), c) and d) are often of sufficient quality to enable the ground structure within the sample to be examined. The quality of such samples can vary considerably, depending on the technique and the ground conditions, and most exhibit some degree of disturbance. A method for classifying the quality of the sample is given in 22.2, Table 2. Clauses 22.3 to 22.9 describe the various sampling techniques and give an indication of the sample qualities that can be expected. Intact samples obtained by techniques b), c) and d) are usually taken in a vertical direction, but specially orientated samples may be required to investigate particular features.

When taking samples for chemical testing and in particular, on potentially contaminated sites, additional care is needed to avoid cross-contamination and chemical or biological reactions, which may affect the result. The risks of cross-contamination are reduced by:

- 1) using dry drilling or air flush methods for progressing the boreholes;
- 2) using casing to isolate upper layers of soil and groundwater;
- 3) ensuring that all sampling and boring equipment are clean;
- 4) implementing strict sample handling protocols.

A detailed consideration of investigations on potentially contaminated sites is given in annex F. Any sample of ground that might be contaminated by substances hazardous to health should have a warning to that effect on the sample label so that personnel can follow appropriate safety procedures (see 36.1).

22.2 Sample quality

The sampling procedure should be selected on the basis of the quality of the sample that is required, and is assessed largely by the suitability of the sample for appropriate laboratory tests [42] (see also BS EN 1997-2:2007, Section 3 and BS EN ISO 22475-1:2006) [42]. Table 2 shows a classification for soil samples developed in Germany. A useful basis for classifying samples in terms of quality is provided in [41].

Table 2 — Quality classification for soil samples

Quality	Properties that can be reliably determined
Class 1	Classification, moisture content, density, strength, deformation and consolidation characteristics
Class 2	Classification, moisture content, density
Class 3	Classification, moisture content
Class 4	Classification
Class 5	None (sequence of strata only)

In general, Classes 1, 2 and 3 are achieved with tube samplers, rotary coring or block samples [see 22.1b), c) and d)]. Such are often known as intact samples. Samples from the drill tools [see 22.1a)] are class 4 or 5. Laboratory classification tests are relevant only to soils, but the quality classification may usefully be applied to rock samples in respect of other properties. Laboratory testing of samples is discussed in section 5.

Whichever sampling methods are used, it is sometimes only possible to obtain samples with some degree of disturbance, i.e. class 2 at best. The results of any strength or compressibility tests carried out on such samples should be treated with caution.

A further consideration in the selection of procedures for taking class 1 samples is the size of the sample. This is determined largely by the structure of the ground, which for soil is often referred to as “the fabric” [42]. Where the ground contains discontinuities of random orientation, e.g. in a clay fill, the sample diameter, or width, should be as large as possible in relation to the spacing of discontinuities. Alternatively, where the ground contains strongly orientated discontinuities, e.g. in jointed rock, it may be necessary to take samples that have been specially oriented. For fine soils that are homogeneous and isotropic, samples as small as 35 mm in diameter may be used.

Table 3 — Mass of soil sample required for various laboratory tests

Purpose of sample	Soil	Mass of sample required kg
Soil identification, including Atterberg limits; sieve analysis; moisture content and sulfate content tests	Clay, silt, sand	1
	Fine and medium gravel	5
	Coarse gravel	30
Compaction tests	ALL	25–60
Comprehensive examination of construction materials, including soil stabilization	Clay, silt, sand	100
	Fine and medium gravel	130
	Coarse gravel	160

general use, samples 100 mm in diameter are preferred because the results of laboratory tests may be more representative of the ground mass. In special cases, samples of 150 mm and 250 mm in diameter or block samples of larger size are used [42].

Precise details of the mass of sample required for each test specimen can be found in the relevant parts of BS 1377:1990 and BS 1924, with more general guidance in BS 1377-1:1990, Table 5. Where the approximate number of tests is known, it is a simple matter to estimate the total amount of soil that has to be obtained. Where the programme of laboratory tests is uncertain, Table 3 gives some guidance on the amount of soil that should be obtained for each series of tests. Where in-situ materials are being considered, details of the size of sample required are given in BS 812-1.

22.3 Disturbed samples from boring tools or from excavating equipment

The quality of the sample depends on the technique used for sinking the borehole or excavation and on whether the ground is dry or wet. When disturbed samples are taken from below water in a borehole or excavation, there is a danger that the samples obtained may not be truly representative of the deposit. This is particularly the case with non-cohesive soils containing fines, which tend to be washed out of the tool. This can be partly overcome by placing the whole contents of the tool into a tank and allowing the fines to settle before decanting the water.

The following classes of sample can normally be expected from the various methods of boring and sampling:

Class 3: disturbed samples from dry excavations and from dry boreholes sunk either by a clay cutter using cable percussion equipment or by an auger.

Class 4: disturbed samples obtained in cohesive soil from excavations, or from boreholes sunk either by a clay cutter using cable percussion equipment, or by an auger, in conditions where water is present.

Class 5: disturbed samples in non-cohesive soil from wet excavations or from any borehole sunk by a shell using cable percussion equipment or from any borehole sunk by a method in which the drill debris is flushed out of the borehole, e.g. rotary, wash boring.

The mass of sample required for various purposes is determined by the character of the ground and the tests that are to be undertaken. A guide to the mass of soil sample required for various purposes is given in Table 3. Care should be taken that the sample is representative of only the stratum from which it comes, and has not been contaminated by other strata.

22.4 Open-tube samples

22.4.1 Principles of design

NOTE BS EN ISO 22475-1:2006, 6.4.2.1, 6.4.2.5 and particularly 6.4.2.6 identify two categories of open tube (OS) samples. These are thin-wall (type OS-T/W) and thick-wall (type OS-TK/W) open tube samples. Details of dimensions, applicability, and sample categories and quality are given in BS EN ISO 22475-1:2006, Table 3 and Table 4. 

22.4.1.1 General

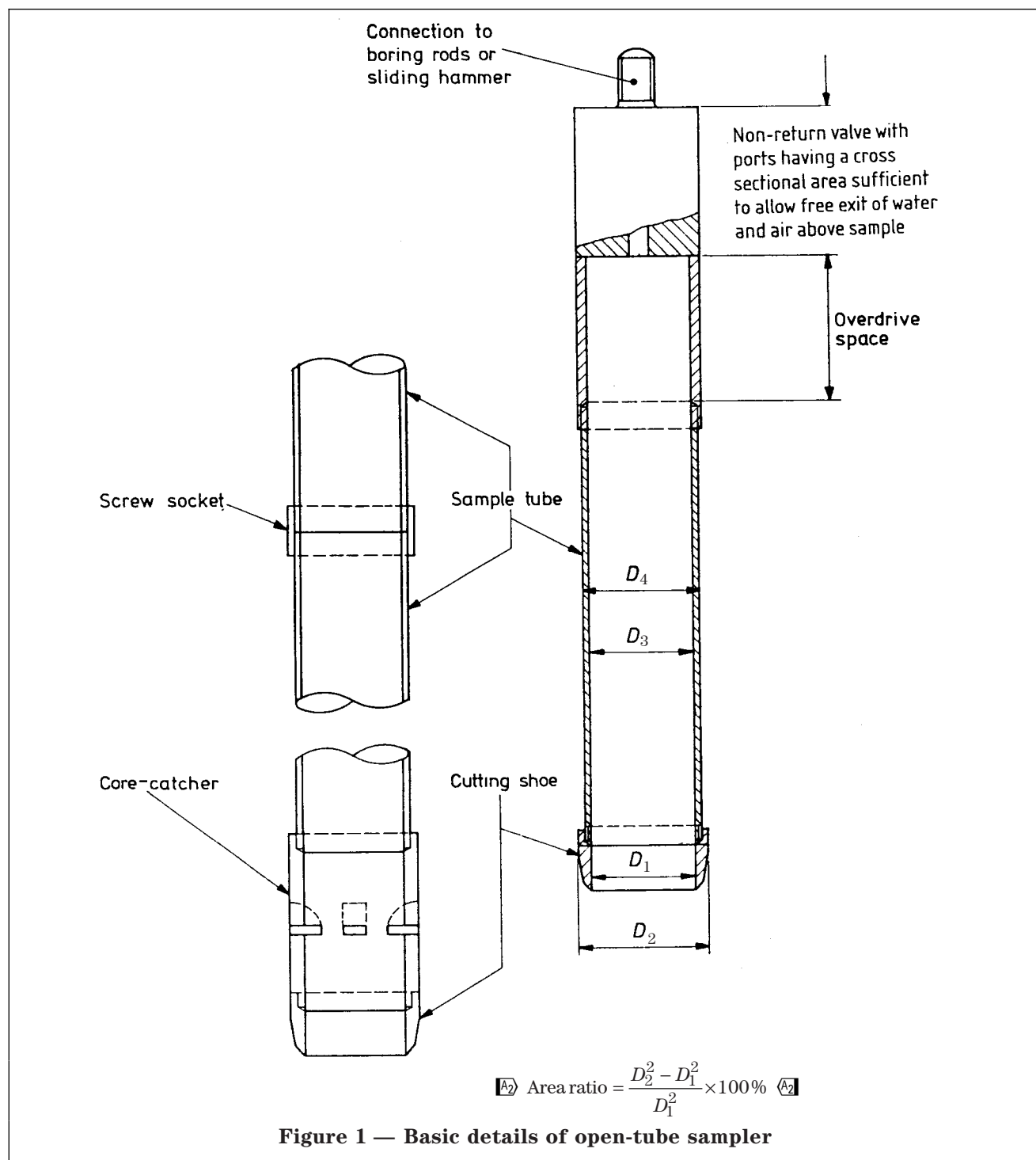
 Open-tube samplers consist essentially of a tube that is open and made sharp at one end and fitted at the other end with means for attachment to the drill rods. A non-return valve permits the escape of air or water as the sample enters the tube, and assists in retaining the sample when the tool is withdrawn from the ground. Figure 1 shows the basic details of an open tube sampler (OS-TK/W) suitable for general use, which has a single sample tube and simple cutting shoe. The use of sockets and core catcher is discussed in 22.4.4. An alternative sampler incorporates a detachable inner liner.

The fundamental requirement of a sampling tool is that it should cause as little remoulding and disturbance as possible when forced into the ground. Three features of the design control the degree of disturbance: the cutting shoe, the inside wall friction and the non-return valve. The sampling procedure (see 22.4.2), is also an important factor in controlling sample disturbance. 

22.4.1.2 The cutting shoe

 The cutting shoe, if used, should normally be of a design similar to that shown in Figure 1 and should embody the following features:

a) *Inside clearance.* The internal diameter of the cutting shoe, D_1 , should be slightly less than that of the sample tube, D_3 ; to give inside clearance this is typically 1 % of the diameter for OS-TK/W but should be less than 0.5 % for OS-T/W. This allows 



A2 for slight elastic expansion of the sample as it enters the tube, reduces frictional drag from the inside wall of the tube and helps to retain the sample. A large inside clearance should be avoided since it would permit the sample to expand, thereby increasing the disturbance.

b) *Outside clearance.* The outside diameter of the cutting shoe should be kept to a minimum, without being less than the outside diameter of the sampler.

c) *Area ratio.* The area ratio represents the volume of soil displaced by the sampler in proportion to the volume of the sample (see Figure 1). It should

be kept as small as possible consistent with the strength requirements of the sample tube. The area ratio is about 30 % for the general purpose 100 mm diameter sampler (OS-TK/W), and up to about 15 % for a thin-walled sampler (OS-T/W). Some special samplers have a large outside diameter D_4 , relative to the internal diameter D_1 , e.g. in order to accommodate a loose inner liner. The sampling disturbance is reduced by using a cutting shoe that has a long outside taper and is considerably less than that which would be expected from the calculated area ratio. **A2**

22.4.1.3 Wall friction

This can be reduced by a suitable inside clearance and by a clean, smooth finish to the inside of the tube.

 *Figure deleted* 

22.4.1.4 Non-return valve

The non-return valve should have a large orifice to allow air and water to escape quickly and easily when driving the sampler, and to assist in retention of the sample when removing the sampler from the borehole.

22.4.2 Sampling procedure

Before a sample is taken, the bottom of the borehole or surface of the excavation or heading should be cleared of loose or disturbed material as far as possible. Some or all of any such loose or disturbed material that is left normally passes into the overdrive space of the sampler.

Below the water table, certain types of laminated soils occurring below the bottom of the borehole or excavation may be disturbed if the natural water pressure in the laminations exceeds the pressure imposed by the water within the borehole or excavation. To reduce this effect, it is necessary to keep the level of the borehole water above the groundwater level appropriate to the location of the sample.

The sampler can be driven into the ground by dynamic means, using a drop weight or sliding hammer, or by a continuous static thrust, using an hydraulic jack or pulley block and tackle

 (see BS EN ISO 22475-1:2006).  The driving effort for each sample may be recorded as an indication of the consistency of the ground.

The distance that the tool is driven should be checked and recorded because, if driven too far, the soil is compressed in the sampler. A sampling head with an “overdrive” space (see Figure 1) allows the sample tube to be completely filled without risk of damaging the sample. After driving, the sampler is steadily withdrawn. The length of sample that is recovered should be recorded, compared with the distance that the tool was driven, and any discrepancy investigated. For example, if the length of the sample is less than the distance driven, the sample may have experienced some compression or, alternatively, the sample tool may have permitted the sample to slip out as the tool was being withdrawn.

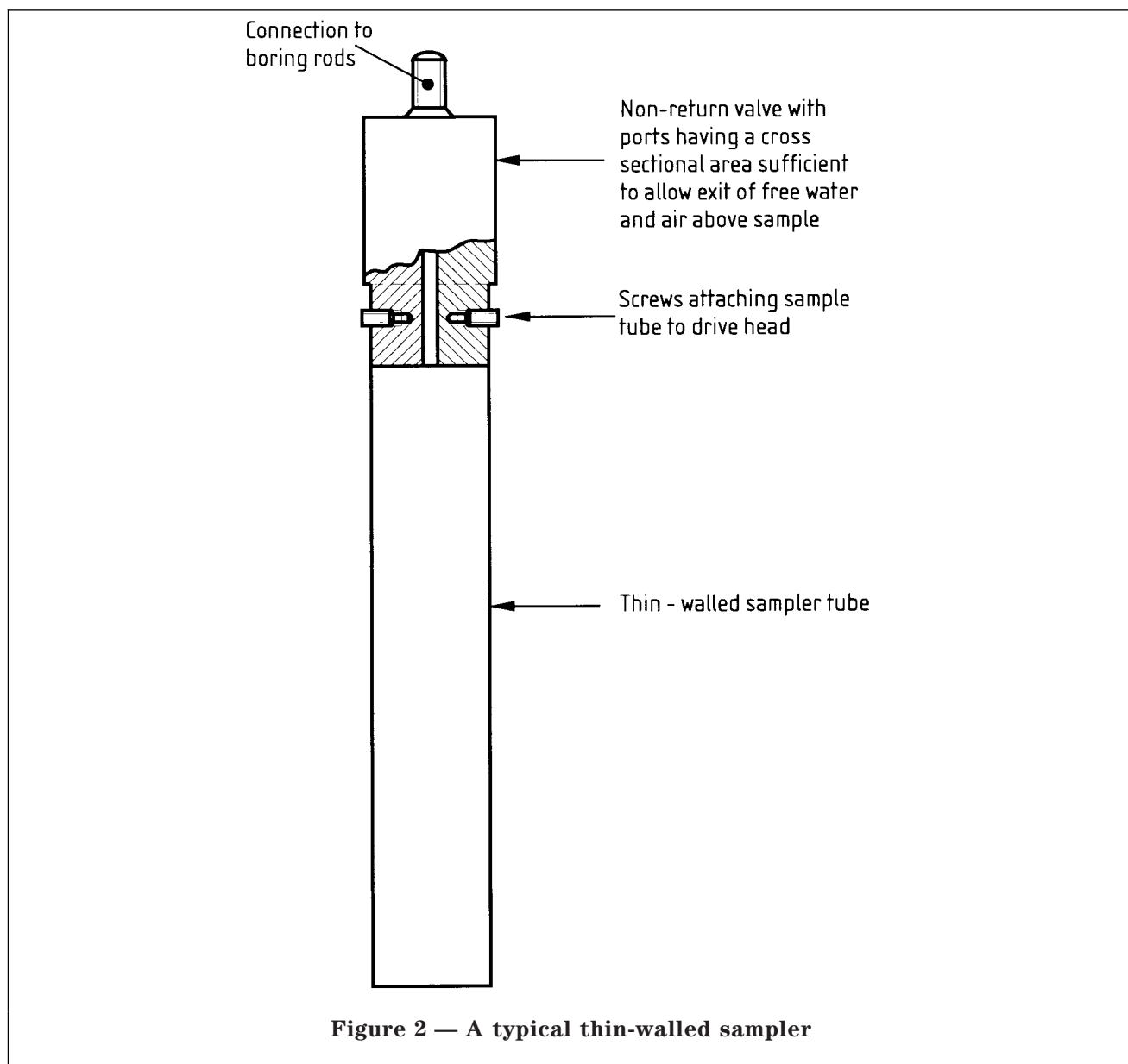
22.4.3 Thin-walled samplers (Type OS-T/W)

 Thin-walled samplers consist of a thin-walled steel tube whose lower end is shaped to form a cutting edge with an area ratio of less than 15 % and a taper angle of less than 5°, with or without a small inside clearance. Area ratios up to 25 % and taper angles of between 5° and 15° may only be used if it can be demonstrated that the sample quality class is not affected. They are pushed into the soil by continuous static thrust from hydraulic jacks or pulley block and tackle. These samplers are usually only suitable for fine soils up to a firm to stiff consistency, and free from large particles, although samples have been successfully obtained from very stiff soils. They normally give class 1 samples of all fine soils, including sensitive clays, provided that sinking the borehole has not disturbed the soil. Samples between 70 mm and 120 mm in diameter are usually obtained and samples up to 250 mm in diameter are sometimes obtained for special purposes. It is to be noted that disturbance at the base of the borehole occurs in weak soil below a certain depth because of stress relief. Piston samples penetrating well below the base of the borehole are therefore preferable (see 22.5). A typical thin-walled sampler is illustrated in Figure 2. 

22.4.4 General purpose 100 mm diameter (U100) open-tube sampler (type OS-TK/W)

The 100 mm diameter open-tube sampler is the standard sampler for routine use with cable percussion boring and is usually driven into the ground using a sliding hammer or drop weight. It can be used in all fine soils and in weak rock, such as chalk and weathered Mercia Mudstone. In fine soils of stiff or lower consistency, the standard open tube sampler (see Figure 1) may sometimes give class 2 samples but, more often, class 3 samples. In brittle or closely fissured materials, such as certain weak rocks and very stiff clays, and also in stony materials, the sampler gives class 3 samples; this is because sampling disturbs these materials, reducing the sample quality to class 3, or class 4 if water has been added to the borehole.

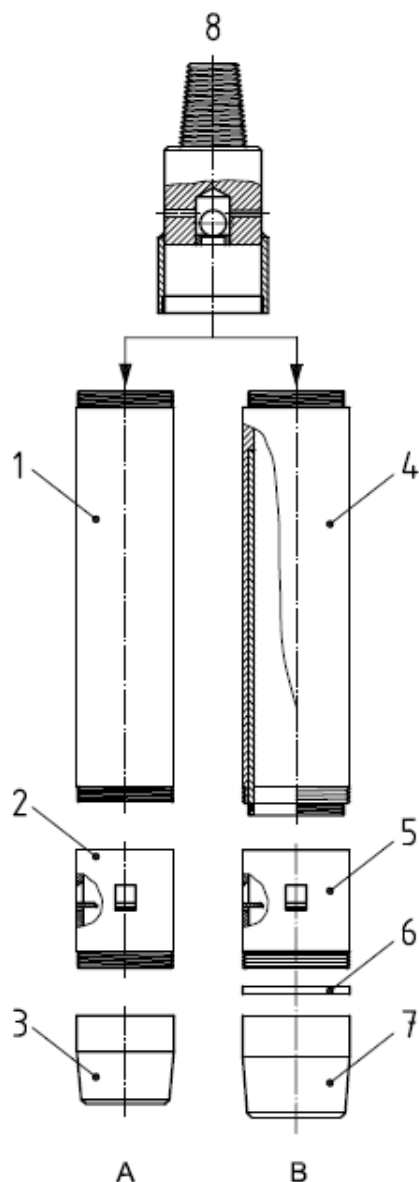
The sampler is illustrated in Figure 1 and Figure 3, and consists of a rigid steel or alloy sample barrel, about 450 mm in length, with a screw-on cutting shoe and drive head. The area ratio should not normally exceed 30 %, but the use of a liner system increases the area ratio up to 50 % and reduces the sample qualities referred to above by one or more classes. Sample barrels can be coupled together with screw sockets to form a longer sampler. Two or three standard barrels coupled together are often used for sampling soft clays, although the increased length of the sample tube may lead to increased disturbance. 



[A2] In soils of low cohesion, such as silt and silty fine sand, the sample may fall out when the tool is withdrawn from the ground. Sample recovery can be improved by inserting a core catcher between the cutting edge and the sample barrel, as shown in Figure 1 and Figure 3.

Smaller samplers of about 50 mm or 75 mm diameter can be used if use of the 100 mm sampler is precluded by the borehole size. The smaller samplers are of similar design, except that the cutting edge may not be detachable. **[A2]**

A2



A) Standard system B) Plastic liner system

Key

- | | |
|---|---|
| 1 Sample tube (cadmium-plated steel or aluminium) | 5 Core catcher (optional) |
| 2 Core catcher (optional) | 6 Spacing ring |
| 3 Cutting shoe (plain or serrated edge) | 7 Cutting shoe (plain or serrated edge) |
| 4 Steel body tube (enclosing plastic liner) | 8 U100 drive head (bell housing) |

Figure 3 – U100 sampler

A2

A2 22.4.5 Split-barrel standard penetration test sampler (type S-SPT)

The split-barrel sampler is used in the standard penetration test and is described in BS EN ISO 22476-3. It takes samples 35 mm in diameter and has an area ratio of about 100 %. It is used to recover small samples, particularly under conditions which prevent the use of the general purpose 100 mm sampler, and gives class 4 samples (see also 25.2). **A2**

22.5 Stationary piston sampler

A2 NOTE BS EN ISO 22475-1:2006, 6.4.2.1, 6.4.2.5 and particularly 6.4.2.7 identify two categories of piston (PS) samples. These are thin-wall (type PS-T/W) and thick-wall (type PS-TK/W) piston samples. Details of dimensions, applicability, and sample categories and quality are given in BS EN ISO 22475-1:2006, Table 3 and Table 4.

22.5.1 Thin-walled stationary piston sampler (type PS-T/W)

The thin-walled stationary piston sampler consists of a thin-walled sharpened sample tube containing a close-fitting sliding piston, which is slightly coned at its lower face. The sample tube is fitted to the drive head, which is connected to hollow drill rods. The piston is fixed to separate rods, which pass through a sliding joint in the drive head and up inside the hollow rods. Clamping devices, operated at ground level, enable the piston and sample tube to be locked together or the piston to be held stationary while the sample tube is driven down. Figure 4 shows the basic details of a stationary piston sampler. The sample diameter is normally 75 mm or 100 mm, but samplers up to 250 mm diameter are used for special soil conditions. Typically, for the smaller diameter holes, samples up to 1 m long can be taken.

Initially, the piston is locked to the lower end of the sample tube to prevent water or slurry from entering the sampler. In soft clay, with the piston in this position, the sampler can be pushed below the bottom of the borehole. When the sample depth is reached, the piston is held stationary and the sample tube is pushed or pulled down by a static thrust until the drive head encounters the upper face of the piston. An automatic clamp in the drive head prevents the piston from dropping down and extruding the sample while the sampler is withdrawn. Hydraulically operated piston samplers are also available. **A2**

The sampler is normally used in low strength fine soils and gives class 1 samples in silt and clay, including sensitive clay. Its ability to take samples below the disturbed zone and to hold them during recovery gives an advantage over the thin-walled sampler described in 22.4.3. Although normally used in soft clays, special piston samplers have been designed for use in stiff clays [42].

22.5.2 Other stationary piston samplers

Variations on the piston sampling method are also available, for example, as used with cone penetrometer systems. These samples are pushed into the ground with a cone locked in front of the sample cutting tube. At the desired depth a fishing tool is lowered down the tube string. By pulling the fishing tool the cone and piston are unlocked and held stationary. The sample cutting mouth with the rest of the assembly goes further into the soil and so the sample is taken. The sample is packed in a nylon stocking that is connected to the piston. The stocking acts as a friction reducer between the sample and the sample tube. Samples can be taken from any depth within the capacity of the penetrometer unit used. Typically samples are 1 m long and 35 mm to 65 mm in diameter.

22.6 Continuous soil sampling

22.6.1 General

Continuous soil sampling can produce samples up to 30 m in length in soils such as fine alluvial deposits. This is of particular value for identifying the soil fabric [42] and gives results superior to those that can be obtained by consecutive drive sampling. The Swedish system [43] takes samples 68 mm in diameter using steel foils to eliminate inside friction between the sample and the tube wall. The Delft system, which uses lighter equipment and offers two sizes of sample, is described more fully in 22.6.2.

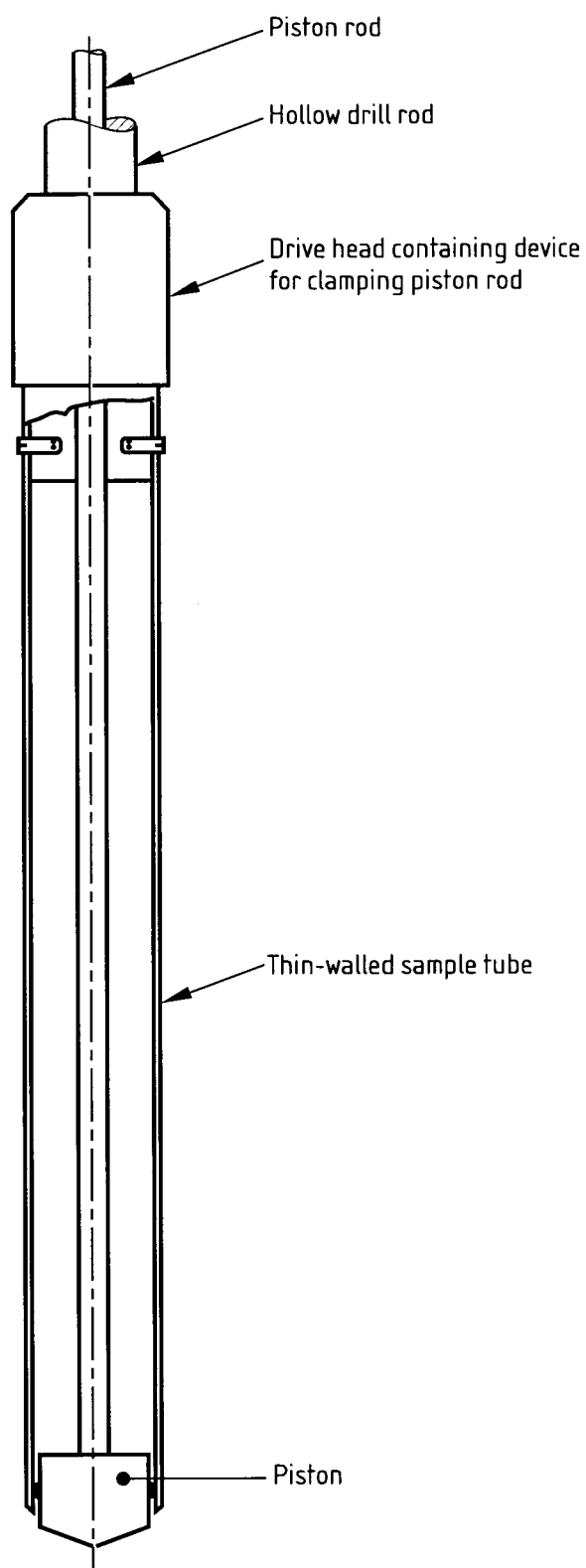


Figure 4 — Basic details of piston sampler